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 2017

Bob McCullouch

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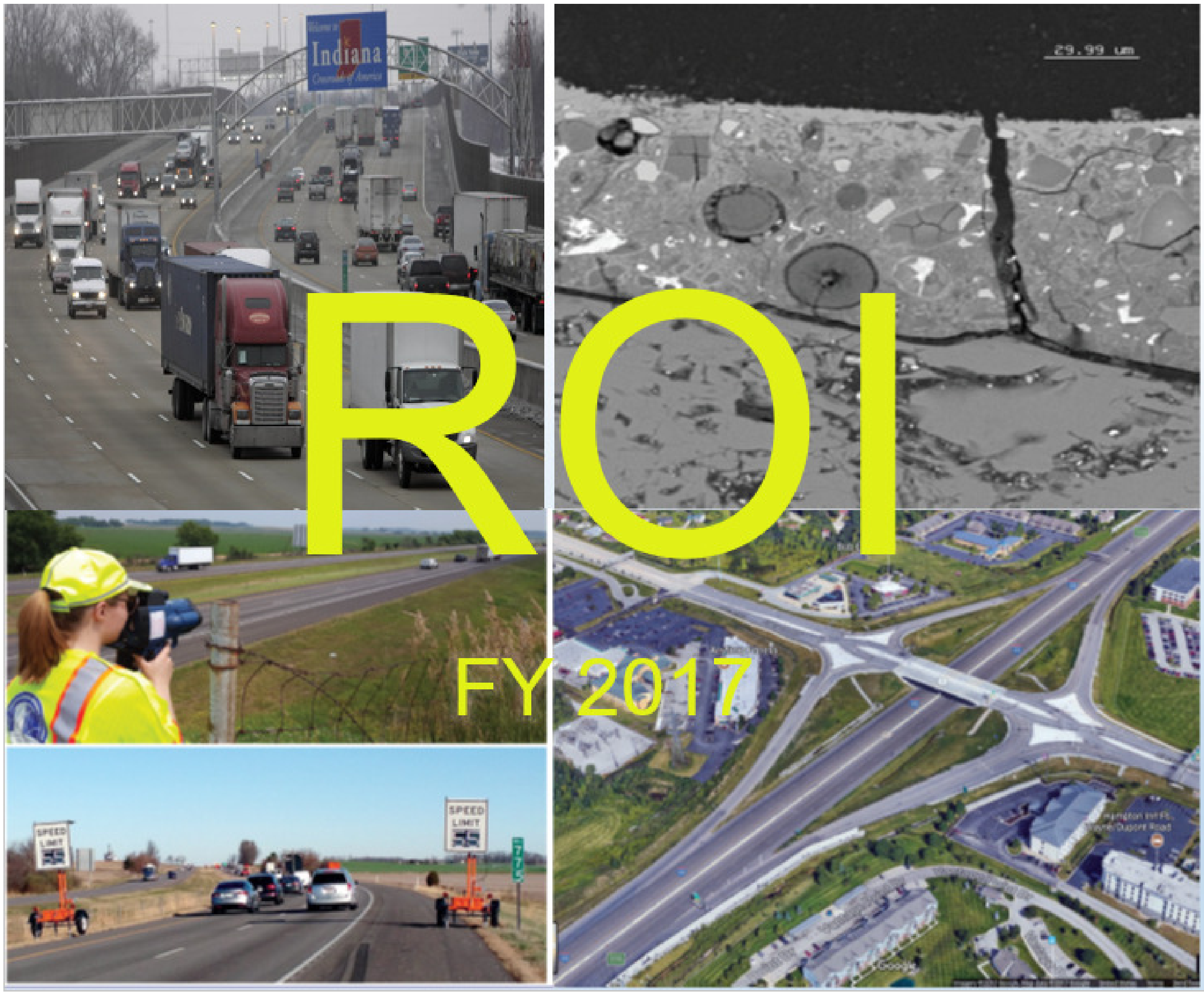
INDOT Research Program Benefit Cost Analysis – Return on Investment

For Projects completed in FY 2017

(SPR – 4225)



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

Bob McCullouch PE, Ph.D.

School of Civil Engineering

Purdue University

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Table of Contents

List of Tables

Introduction

The Governor's Office requested an annual financial analysis of the INDOT Research Program to determine the return on the research investment (ROI). The current financial analysis is for research projects that completed in FY 2017. 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 2017 analysis is completed in calendar 2018. The ROI analysis will supplement the annual IMPACT report (qualitative and quantitative benefits) 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 into a rolling 5-year average.

While the quantitative benefit cost analysis (BCA) was rigorous, results are limited to projects where benefits and costs could be quantified. Qualitative benefits are highlighted in the companion annual IMPACT report (https://www.in.gov/indot/2404.htm)

The agency savings generally would be expected to be used to select other construction projects (or other activities) that would otherwise have to be deferred to later years. Frequently, research projects that have the likelihood of saving large amounts of dollars in initial or long term maintenance costs, which essentially allows us INDOT fund other projects more fully or sooner.

Benefit-Cost Analysis Methodology

All FY 2017 completed projects were reviewed to determine if they were a viable candidate for BCA. Selection was based on 1) can the costs and benefits be quantified on outcomes that impact INDOT operations, 2) what are the implementation costs, and 3) what is the expected impact time period?

The ROI analysis included the following savings components:

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

Accrued Benefits will be the combination of **Agency savings, RUC cost savings,** and **SC savings**. 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 only 3866 reported RUC and SC savings. A separate B/C ratio is calculated for Agency Savings and Safety/RUC Savings. Safety and RUC savings are often related, these savings were combined into the same category.

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. A five-year analysis period was used on one of the projects, a seven-year period on another, and a 14 and 20 year period on two others. 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 2017 dollars by combining costs and benefit cash flows. Individual project analyses are included in the Appendix. Backup documentation describing calculations and analysis for qualifying projects will be kept by the INDOT Research 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 ROI to create a rolling average over time. The rolling average will accumulate up to a maximum of the five recent years, with FY 2016 being the first year.

Benefit-Cost Analysis Results

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

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

Individual Project Analysis

Table 1 is the list of the six projects where benefits (NPV 2017$ - NPV of future cash flows in 2017 dollars) could be quantified and their individual analysis is found in the Appendix. Table 4, in the Appendix, is a complete list of all 24 projects completed in FY 2017.

Two of the projects have a five-year analysis period. On these projects the annual benefits were based on planned installed quantities that resulted in immediate savings, such as construction cost savings.

Project 3310 analysis period is based on the expected time to longitudinal joint rehabilitation in concrete pavements, which based on current project data, is currently occurring every 20 years. Project 3833 has a 14 - year analysis period which is the expected life of LED lighting fixtures. Project 3866 has a seven-year analysis period because INDOT Traffic Engineering has estimated the number of diamond interchanges to be built during this time period.

Table 1. Quantitative Benefits Project List

No	FY 16 Completed & Implemented SPR Projects	Project Cost ($1000)	TITLE	Benefit Type	Analysis Period	NPV Project Benefit ($1000) 2017$
1	3310	$202	Investigation of Use of Slag Aggregate and Slag Cements in Concrete Pavement to Reduce Their Maintenance Costs	Agency Savings	20 Years	$51,310
2	3811	$250	Moisture Strength Constructability Guidelines for Subgrade Foundation Soils Found in Indiana	Agency Savings	5 Years	$242
3	3818	$153	Cost Benefit Analysis and Implementation of NDT Testing of INDOT Bridge Decks	Agency Savings	5 Years	$99,999
4	3833	$136	Site Selection for New Lighting Technologies	Agency Savings	14 Years	$10,390
5	3866	$160	Performance of Alternative Diamond Interchange Forms	Agency Savings RUC Savings	7 Years	$27,747 (Agency) $11,247 (RUC)

Total Benefits $200,935,000
Agency Benefits $189,688,000
Road User Benefits $ 11,247,000

Agency Savings

The total quantifiable savings from the five projects resulting in agency savings, during their analysis or impact period, was calculated at $189,688,000 (in 2017$). The total research program cost in FY 2017 was $3,944,000. Therefore, the agency savings BCA for FY 2017 is: **$189,688,000 /$4,124,000 = 46,** or 46 dollars in agency savings for every research dollar expended.

Safety/RUC Savings

The total quantifiable savings from the one project (3866) resulting in safety/RUC savings, during the analysis or impact period was calculated at $11,247,000 (in 2017$). The total research program cost in FY 2017 was $4,124,000. Therefore, the safety/RUC savings BCA for FY 2017 is: **$11,247,000/$4,124,000 = 3**, or 3 dollars in safety/RUC savings to our customers for every research dollar expended.

A table for each savings category was created, five projects cash flows classified as Agency Savings (Table 2) and one project (3866) produced Agency and RUC Savings (Table 3). A condensed version of the tables are shown. The expanded version of each table is included in the Appendix with the project write-ups.

Table 2. Agency Savings Projects

Project Description	**FY2017**	**FY2018**	**FY2019**	**FY2020**	**FY2021**
3310 – Annual Benefit (20 Year impact)* 1.	312,500	321,875	331,531	341,477	351,722
Research and Implementation cost	-202,000	0	0	0	0
Net Benefit	110,500	321,875	331,531	341,477	351,722
NPV FY 2017	**51,310,085**				
3811- Annual Benefit (5 year impact)*	100,000	103,000	106,090	109,273	112,551
Research and Implementation cost	-250,000				
Net Benefit	-150,000	103,000	106,090	109,273	112,551
NPV FY 2017	**242,718**				
3818 - Annual Benefit (5 year impact)*	51,000,000	59,000,000	94,000,000	127,000,000	26,000,000
Research and Implementation cost	1,077,000	-951,720	-980,272	-1,009,680	-1,039,970
Net Benefit	49,923,000	58,048,280	93,019,728	125,990,320	24,960,030
NPV FY 2017	**99,999,000**				
3833 – Annual Benefit from INDOT Construction Contract T-40681-A 2.	**0**	**0**	837,468	1,108,832	888,470
Research and Implementation Cost	**-315,000**				
Net Benefit	-315,000	0	837,468	1,108,832	888,470
NPV FY 2017	**10,930,916**				
3866- Annual Benefit (7 Year impact) ** 3.	300,000	8,300,000	6,400,000	7, 700,000	2,100,000
Research and Implementation Cost	**-153,000**				
Net Benefit	147,000	8,300,000	6,400,000	7,700,000	2,100,000
NPV 2017	**27,747,000**				
NPV Total 2017	**$189,688,000**				
Research Program Cost	$4,124,000				
Benefit Cost Ratio - ROI	**46**				
Report Date	12/31/2018				

* Based on INDOT 5 Year Work Program ** Based on 7 Year projection					
1. The first 5 years of the 20-year cash flows are shown. See supplementary file for the additional cash flows.					
2. The first 5 years of the 14-year cash flows are shown. See supplementary file for the additional cash flows.					
3. The first 5 years of the 7-year cash flows are shown. See supplementary file for additional cash flows.					

Table 3. Safety/RUC Savings Project - 3866

Project Benefits and Costs $	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research Cost	-153,000						
Annual User Cost Benefit	2,100,000	2,500,000	1,600,000	3,300,000	700,000	0	1,200,000
Net Benefit-Cost	1,947,000	2,500,000	1,600,000	3,300,000	700,000	0	1,200,000
NPV 2017	$11,247,000						
Research Program Costs	**$4,124,000**						
Benefit Cost Ratio - ROI	**3**						

As previously noted, five projects produce quantifiable benefits that result in agency savings. One project also produces road user cost (RUC) savings. A summary of these cost savings are described below.

- **3310** – New concrete mix design that includes slag cement and fly ash as a partial replacement for Portland cement improves the durability of concrete pavements in the presence of deicers and freeze thaw cycles. This increased durability will eliminate one joint repair project during the life of a concrete pavement.
- **3811** - Change orders caused by excessive soil moisture during construction projects increase construction costs for INDOT and cause unexpected delays. To alleviate these problems and minimize change order costs associated with having unexpectedly high soil moisture conditions at the time of construction, a methodology was developed to allow INDOT engineers to estimate in situ soil moisture conditions early in the design phases of projects.
- **3818**– Nondestructive testing (NDT) methods have been used by other state departments of transportations resulting in more accurate condition assessments to base bridge deck repair and replacement decisions on. This project evaluated the NDT approach and performed a cost-benefit analysis of various NDT methods; and estimated the cost for establishing and operating an internal NDT work group, and comparing it to using an external NDT consulting service.
- **3833** – This project determined the impact of changing INDOT roadway lighting fixtures from high-pressure sodium (HPS) lamps to light emitting diodes lamps.
- **3866** – This study developed guidelines for screening and evaluating options for alternative diamond interchanges. The guidelines provide a fair comparison procedure during the preliminary planning and conceptual design stages and are used to determine the best

interchange form based on initial construction cost, traffic operations improvement, and user travel time savings.

Summary

The aggregate benefit is significant, resulting in more than $200 million in savings over the projected service lives (in 2017$). The aggregate benefit combines expected agency savings and expected savings for users of the INDOT network. Direct agency savings of over $189 million is a return of $46 for every $1 spent in research. For users, the return is 3 to 1 through lower user costs. The basis for the numbers used in the BCA came from INDOT personnel, Industry Associations, and researchers. These are described in detail in the individual analyses in the Appendix.

A ROI of 46 to 1 is considered a significant agency return on research investment, which is indicative of other State DOT Research Programs. While the ROI is significant, a review of the individual project analysis shows a conservative approach was taken in any assumption made and in the calculations, and actual savings may be higher. This analysis indicates that INDOT is receiving a significant return on its research investment which will continue to grow due to recently passed legislation (HB 1002), authorizing more funding for construction, re-construction, and preservation, as more projects will be impacted.

For the 19 projects completed in FY 2017, quantifiable benefits could not be calculated, however other qualitative benefits resulted that brought significant value to the Department and are highlighted in the annual IMPACT report. Five of the projects were quantified and described herein. A complete listing of all research projects completed in FY 2017 is shown in Table 4 in the Appendix.

Rolling Average BCA

Annual BCA provide an assessment of INDOT's investment in Research on an annual basis. For the last two years, 2016 and 2017, the investment indicates positive returns during the life of individual projects implemented. The majority of the projects in the last two years, 48 out of 66 total research projects benefits are not quantifiable due to the unavailability of quantifiable data, but provide documented qualitative benefits. 13 projects where benefits were quantified, produced significant agency savings and 3 projects produced significant road user cost savings. For the combined years of 2016 and 2017 the Agency and Road User BCA are:

BCA (2016 and 2017) Agency Savings = $266,149,000/$10,388,000 = 25 to 1

BCA (2016 and 2017) User Savings = $301,990,799/$10,388,000 = 29 to 1

BCA Rolling Average – 2016-2017

Year	Research Investment	Agency Savings	User Savings
2016	$6,264,000	$76,481,000	$290,743,799
2017	$4,124,000	$189,668,000	$11,247,000
Totals	$10,388,000	$266,149,000	$301,990,799

Appendix

Table 4. – Complete Research Project List – FY 2017

No	FY 17 Completed & Implemented SPR Projects	Project Title	Project Cost ($ 1000)	Quantitative Benefits, Qualitative Benefits or Not Successfully Implemented	Project Benefits ($1000)
1	3310	Investigation of Use of Slag Aggregate and Slag Cements in Concrete Pavement to Reduce Their Maintenance Costs	$202	Quantitative	51,310
2	3319	Assessment of the Performance of MSE Abutment Walls in Indiana	$185	Qualitative Benefits	0
3	3320	Development of a Cost Effective Bridge Preservation and Rehabilitation Program	$341	Qualitative Benefits	0
4	3702	Strategies for Grouping of Transportation Projects	$170	Qualitative Benefits	0
5	3714	Guardrails for Use on Historic Bridges	$300	Qualitative Benefits	0
6	3728	Sulfates in Indiana Substrates	$90	Qualitative Benefits	0
7	3801	Using Field Electrical Conductivity Measurements for Scheduling Chip Seal Spreading/Sweeping Operation	$150	Qualitative Benefits	0
8	3811	Moisture-Strength-Constructability Guidelines for Subgrade Foundation Soils Found in Indiana	$250	Quantitative	242
9	3814	Ecologically-aware Design of Waterway-encapsulating Structures	$116	Qualitative Benefits	0
10	3818	Cost Benefit Analysis and Implementation of NDT Testing of INDOT Bridge Decks	$153	Quantitative	99,999

11	3823	INDOT-JTRP LPA Process Improvement	$300	Qualitative Benefits	0
12	3831	Safety Data Acquisition and Management (Data Portal and Tscan)	$400	Qualitative Benefits	0
13	3833	Site Selection for New Lighting Technologies	$315	Quantitative	10,930
14	3853	CAI/S-BRITE Pad/Site Development Project	$460	Qualitative Benefits	0
15	3858	A Mobile Concrete Laboratory to Support Testing in 2014 on Internal Curing and High Early Strength Patches	$110	Qualitative Benefits	0
16	3866	Performance of Alternative Diamond Interchange Forms	$160	Quantitative	$27,747 (Agency) $11,247 (RUC)
17	3900	Variable Speed Limit Feasibility Study	$90	Qualitative Benefits	0
18	3940	Chemical Modification of Uniform Soils and Soils with High/Low Plasticity Index	$130	Qualitative Benefits	0
19	3946	Improving Energy Efficiency of Facilities	$50	Qualitative Benefits	0
20	3947	Precast Slab Pilot Implementation	$10	Qualitative Benefits	0
21	3948	Pre-Contract Scoping Processes Value Stream Mapping	$49	Qualitative Benefits	0
22	4000	Mechanic/Maintenance Training and Certification Program	$77	Qualitative Benefits	0

23	**4152**	**Pavement Density Demonstration Project**	**$7**	**Qualitative Benefits**	**0**
24	**4159**	**Evaluation of alternative LiDAR platforms and sensors for Asset Management**	**$9**	**Qualitative Benefits**	**0**
			$4,124		

Total 2017 Research spending is $4,124,000.

Individual Project Analysis

SPR-3310: Investigation of Use of Slag Aggregates and Slag Cements in Concrete Pavements to Reduce Maintenance Cost

Introduction

This study evaluated the use of ground granulated blast furnace slag (GGBFS) called slag cement as a replacement for cement and its long-term effect on concrete pavements. Based on laboratory tests using GGBFS/slag cement and fly ash together as a partial replacement for Portland cement, these materials improved concrete strength while increasing concrete durability in the presence of deicers and freeze thaw cycles. Damage typically occurs at the pavement longitudinal joint making joint repairs more frequent which will be minimized through this approach.

By using a combination of GGBFS/slag cement and fly ash, savings in concrete materials and increased pavement durability occurs. The increased durability indicates that for a typical concrete pavement life (50 years) one joint repair can be avoided. The benefit cost analysis is based on initial material savings and increased joint durability.

One outcome of this project was the development of a unique special provision for Section 501 adopted in January 2017 that allows for the use of GGBFS.

Analysis

Based on past concrete pavement quantities and current estimates an average of 1.5 million SYD of concrete pavement is estimated to be placed annually in the five-year INDOT work plan. Estimated savings comes from initial material savings and long-term maintenance savings.

Calculations

Annual Material savings – average pavement thickness is 12"

1,500,000 SY[1] (Estimated concrete pavement) x (12"/36") = 500,000 CY

500# cement/CY x 500,000 CY = 125,000 tons of cement required

@25% fly ash replacement for cement = 125,000 x .25 = 31,250 tons fly ash

@75% cement = 125,000 x .75 = 93,750 tons of cement

Estimated that slag cement will replace fly ash at a 50% rate – 31,250/2 = 15,625 tons[1]

Cement cost is approximately $125 a ton[1]

Slag cement cost is $100-$110/ton[1]

Fly ash cost is $65-$80 a ton[1]

Calculate savings by using slag cement over regular cement, initial cost savings –

Slag cement average cost is an average of $105/ton

Cost savings = $125 - $105 = $20/ton

Annual estimated material cost savings = $20/ton x 15,625 tons = $312,500

Longitudinal Joint Repair Savings- During pavement life

Based on current joint repair contracts this avoidance will occur at year 20 in the pavement life, so cost savings will be calculated at that point in time and brought back to a 2017$ net present value.

Contract R 41350 (I-465 on the southwest side of Indianapolis) was bid in August 2018. Concrete joint repair was a work item and there were three bidders. The lowest bid for joint repair was $38[2] per square foot and using a one-foot wide trench, the linear cost translates to $38 per linear foot. This cost can be eliminated in year 20 of the pavement. To determine this savings the 20-year unit cost is increased due to inflation at a 3% annual rate. The estimated 20 year unit cost = $38 (F/P, 3%) = $38*1.8061 = $68 LF.

For 1,500,000 SYD of pavement and assuming a 24 ft. wide pavement, the linear foot of longitudinal joint is:

1,500,000 SYD x 9 SF/SYD = 13,500,000 SF / 24 FT (pavement width) = 562,500 LFT of longitudinal joint. Concrete joint repair contracts indicate that not 100 % of the joint needs to be repaired, it varies between 50% – 75% of the total joint. Using the lower percentage produces a conservative repair cost saving.

The longitudinal joint repair cost, at year 20 is 562,500 LFT * (50% replacement rate) X $68/LFT = $19,125,000.

3310 - 20 year life													
	FY2017	**FY2018**	**FY2019**	**FY2020**	**FY2021**	**FY2022**	**FY2023**	**FY 2024**	**FY 2025**	**FY 2026**	**FY 2027**	**FY 2027**	**FY 2028**
Research and Implementation cost	-202,000												
Material Savings	312,500	321,875	331,531	341,477	351,722								
Maintenance Benefit - 2017 pavement		0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Benefit - 2018 pavement		0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Benefit - 2019 pavement			0	0	0	0	0	0	0	0	0	0	0
Maintenance Benefit - 2020 pavement				0	0	0	0	0	0	0	0	0	0
Maintenance Benefit - 2021 pavement						0	0	0	0	0	0	0	0
Net Benefit-Cost	110,500	321,875	331,531	341,477	351,722	0	0	0	0	0	0	0	0

FY 2029	**FY 2030**	**FY 2031**	**FY 2032**	**FY 2033**	**FY 2034**	**FY 2035**	**FY 2036**	**FY 2037**	**FY2038**	**FY2039**	**FY2040**
0	0	0	0	0	0	0	19,125,000				
0	0	0	0	0	0	0	0	19,125,000			
0	0	0	0	0	0	0	0	0	19,125,000		
0	0	0	0	0	0	0	0	0	0	19,125,000	
0	0	0	0	0	0	0	0	0	0	0	19,125,000
0	0	0	0	0	0	0	19,125,000	19,125,000	19,125,000	19,125,000	19,125,000

NPV 2017	$51,310,085
Benefit Cost Ratio	254

Summary

The benefit cost ratio for this project is 254 to 1. The number is based on the following:

- Research cost of $202,000.
- 5 Year work program scheduling pavement estimates were used at 1.5 million SYD per year.
- Concrete joint repair cost is based on 2018 unit bid cost.
- 3% cost of capital
- 3% annual inflation rate
- NPV of future costs and benefits brought to 2017$.

This analysis is only for this project's cost to execute research and implement. In the summary report an overall 2018 benefit cost analysis is based on total program costs.

References

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

[2] INDOT bid tab, August 8, 2018, Contract ID: R-41350-A.

SPR-3811: Moisture-Strength-Constructability Guidelines for Subgrade Foundation Soils Found in Indiana

Introduction

Construction activities become difficult when the soil moisture content is excessive, especially in fine-grained soils. Change orders caused by excessive soil moisture during construction projects increase construction costs for INDOT and cause unexpected delays. To alleviate these problems and minimize change order costs associated with having unexpectedly high soil moisture conditions at the time of construction, a methodology was developed to allow INDOT engineers to estimate in situ soil moisture conditions early in the design phases of projects.

The soil moisture prediction methodology is based on results from soil moisture flow simulations carried out using the HYDRUS-1D software. The results obtained from initial soil moisture flow simulations were validated using field measurements from six test sites located in Indiana where soil property data was available and continuous in situ soil moisture measurements at multiple depths were available for up to 3 years (2011-2014). Agreement was found between moisture content measurements and predictions. After validation of the developed moisture prediction methodology, ten-year moisture content simulations using HYDRUS 1D were performed for typical profiles in each county in Indiana using input weather data from the climate database, groundwater data from Department of Natural Resources (DNR) database and soil properties from Indiana Geological Survey (IGS), INDOT and the Soil Survey Geographic (SSURGO) databases. Yearly results from these ten-year soil moisture flow simulations were then overlapped to ascertain how the profiles of the in situ soil moisture content within the depth of interest varied monthly within this period of time, in each county. Using these results, constructability criteria was developed that is based on determining how the in situ soil moisture content deviates from the optimum soil moisture content obtained from standard Proctor compaction tests. This criteria is to be used to determine expected soil moisture levels at the design phase that can eliminate costly geotechnical change orders.

Analysis

To determine the frequency and magnitude of wet subgrades or high soil moisture conditions and their impact on INDOT construction projects and associated costs; a list of geotechnical change orders was obtained from INDOT Geotechnical Services.[1] Returned was a list of all geotechnical change orders for the years 2014-2017. From these change orders; those that were connected to high moisture content were analyzed to determine relevance and are summarized in the following table.

Date	Change Order #	Cost	Problem
September 2017	B-31498	$42,062	Failed proof rolling due to wet subgrade
June 2017	R -37250	$7,335	Subsurface remediation required due to wet subgrade.
September 2016	R-33582	$140,183	Weak subgrade soils preventing pavement stability
2016	R-35411	$31,227	Subgrade pumping and not compactable.
2016	R-35968	$19,527	Subgrade too soft for compaction due to unforeseen wet conditions.
2015	R-34078	$22,898	Encountered quick sand and unstable soils due to high water table.
2015	RS-34356	$1,616	Soft and wet shoulder material.
2014	B-29487	$36,150	Unstable subbase due to moisture conditions.
2014	R-33562	$90,936	Wet sandy soils encountered requiring additional subgrade treatment and geogrid.

Total Change Orders = $391,934

During 2014-2017, a four-year time period there were nine change orders costing $391,934 caused by high moisture conditions. This is an average of approximately two per year at an average cost of $391,934/4yrs. = $97,983. For B/C calculation purposes $97,983 a year will be the estimated cost savings by using the subgrade moisture guidelines developed in this project which are extended over a five-year work plan period.[1]

Calculations

Project Benefits and Costs	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Research Cost	-250,000				
Estimated Annual Change Order Savings	97,983	100,922	103,950	107,069	110,281
Net Benefit-Cost	-152,017	100,922	103,950	107,069	110,281
NPV	232,927				
Benefits Cost Ratio	1				

Summary

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

- Research cost of $250,000.
- 5 Year work program.
- 3% cost of capital
- 3% annual inflation rate
- NPV of future costs and benefits (change order avoidance) brought to 2017$.

This analysis is only for this project's cost to execute research and implement. In the summary report an overall 2018 benefit cost analysis is based on total program costs.

References

[1]Nayyar Zia Siddiki MS PE, Geotechnical Services Section

Ganju, E., Rahman, S., Prezzi, M., Salgado, R., & Siddiki, N. (2016). *Moisture-strength-constructability guidelines for subgrade foundation soils found in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/27). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284316354

SPR-3818: Cost Benefit Analysis and Implementation of NDT Testing of INDOT Bridge Decks

Introduction

INDOT is required to inspect bridges every two years and has typically used visual based inspection methods to evaluate the health of bridge decks. This method does not always accurately portray deck health or possible damage that can lead INDOT to schedule deck repairs based on age in-lieu of more definitive condition ratings. Nondestructive testing (NDT) methods have been used by other state departments of transportations resulting in more accurate condition assessments to base repair and replacement decisions on. This project evaluated the NDT approach and performed cost-benefit analysis of various NDT methods with the current INDOT program; and estimated the cost for establishing and operating an internal NDT work group, and comparing it to using an external NDT consulting service.

NDT technologies evaluated were: Infrared thermography (IR), Chloride ion penetration (CIP), Half-cell potential, ground coupled GPR, Air-launched horn GPR, and impact echo with the IR, CIP, and GPR the least expensive and used in the cost analysis.

Analysis

ROI analysis is based on comparing the current INDOT program scheduling of inspecting and repairing bridge decks to using NDT inspection and repair based on condition results. INDOT deck repair program is a schedule of repairs at designated age levels. For example one schedule is: overlay at 20 years; deck replacement at 40 years; overlay at 60 years; and replace bridge at 80 years.

The INDOT program schedule (can result in) taking bridges out of service at the same time , earlier , or later than using an NDT based program. A better average condition may exist through the current INDOT program, however at a potentially higher cost because more actions could be performed that could be reduced if repair decisions are based on NDT outcomes.

A network (total INDOT bridge inventory) cost based simulation using engineering economic principles of net present cost (NPC) and equivalent uniform annual cost (EUAC) was performed for four different bridge deck repair schedules. The lowest cost schedule is the one described above and shown in the below table on an annual cost basis.

Calculations

	EUAC ($)
Current INDOT Bridge Deck Inspection and Repair Program	**203 Million**
NDT Inspection and Condition Based Repair	**136 Million**

NDT inspections provide more accurate and reliable condition reports, and better life-cycle costs which can prevent unnecessary repairs and lower deck repair costs during the bridge life. The simulated cost analysis shows an expected annual savings of 33% (1-(136/203)).[2]

Potential Savings

- Improved deck quality assessment
- Lower bridge lifecycle deck costs

Since INDOT does not have, an NDT inspection program, an initial and annual investment cost will occur. Initial costs include NDT equipment, a van, inspection, data analyst personnel, and their training. Annual costs is comprised of personnel, equipment maintenance, travel, and maintenance of traffic costs. The equivalent uniform annual cost for the initial investment and annual maintenance cost for an NDT program was calculated to be $924,000.[2]

The current five year work plan for bridge deck repair is shown in the below table. Estimated savings are based on the simulated EUAC cost analysis performed by using an NDT inspection program.

	2017	2018	2019	2020	2021
Estimated cost[1]	$155 M	$179 M	$287M	$387M	$81M
Estimated Savings (33%)	$51M	$59M	$94M	$127M	$26M

Below is the benefit cost analysis for a five-year work plan.[1] The analysis is based on a known five-year work plan (2017-2022) and an NDT inspection program was used to determine deck repairs and not based on age-based repairs, which is the current INDOT policy.

Project Benefits and Costs($)	**FY 2017**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**
Research Cost	-153,000				
Annual NDT cost	-924,000	-951,720	-980,272	-1,009,680	-1,039,970
Annual Benefit	51,000,000	59,000,000	94,000,000	127,000,000	26,000,000
Net Benefit-Cost	49,923,000	58,048,280	93,019,728	125,990,320	24,960,030
NPV	99,999,000				
Benefits Cost Ratio	654				

Summary

INDOT can realize significant cost savings by implementing an NDT based bridge deck inspection program. The calculated savings are significant, but it indicates that INDOT should adopt an NDT inspection program as soon as possible after making an investment to either establish an internal program or outsource to a private company. The study calculated a break-even point of $0.22 per square foot for a consultant to be competitive with an internal INDOT based program.

The benefit cost ratio for this project is 654 to 1. This number is based on the following:

- Research cost of $153,000.
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2017$.

This analysis is only for this project's cost to execute research and implement. In the summary report an overall 2018 benefit cost analysis is based on total program costs.

References

[1] Estimated annual bridge deck costs provided by Adam Post, INDOT Bridge Asset Manager.

[2] Taylor, B. R., Qiao, Y., Bowman, M. D., & Labi, S. (2016). *The economic impact of implementing nondestructive testing of reinforced concrete bridge decks in Indiana* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP- 2016/20). West Lafayette, IN: Purdue University. https://doi.org /10.5703/1288284316343

Professor Mark Bowman (PI) phone conversation, September 25, 2018.

SPR-3613: Cost and Energy Efficient Roadway Lighting
SPR-3833: Safety and Cost Performance of Intersection Lighting
SPR-4153: INDOT Highway Lighting Support Services

Introduction

SPR-3613 examined the viability of new, solid state lighting technologies for the state highway system, determining whether adequate light levels could be obtained and confirming manufacturers' claims on the energy efficiency of their models. Findings of this project included: 1) at least some if not all of the solid state models examined did provide adequate light levels- average maintained illumination, ratio of average to minimum and 2) solid state models do use significantly less energy- in some cases less than half of their High Pressure Sodium counterpart.

SPR-3833 investigated and analyzed the effect of lighting on intersection accidents and crashes. Crash data from a ten-year period (2004 – 2013) shows that Indiana has a higher number of crashes in the unlit intersections than neighboring states (73% to 38%) and the nation (73% to 34%). Field light tests were performed at fourteen intersections producing maintenance recommendations and cost data. One outcome was the development of crash modification factors to be used to perform a justification analysis to determine the need for an intersection lighting project. To assist in determining this need an excel worksheet was created that performs a life cycle cost analysis for an intersection lighting project. The study also assessed the in-service performance of new lighting technologies and developed an economic methodology to compare these technologies from a life cycle cost perspective. The benefit cost analysis is based on this economic methodology and a current INDOT lighting retrofit contract.

Through extensive field demonstrations started under SPR-3613 and continued through SPR-3833, INDOT found that most of the solid state models worked reliably- this was another concern of the agency when first approached about the new technology.

SPR-4153 is an active project which provides for bench testing of solid state luminaires at the Purdue Office of Energy Efficiency and Reliability, Northwest campus. This testing is of models that have been formally submitted for INDOT Approved Materials List. Successful completion of the bench test is a prerequisite for a model to be placed on the list and in turn a model must be on the list for it to be used on a contract. To date 26 models have been or are currently being tested.

Analysis

INDOT Construction Contract T-40681-A, let May 10, 2018, repaired and replaced lighting fixtures in the Greenfield District.[1] Contract amount was $5.3 million with work to be completed by June, 2019. Of the $5.3 million contract total $5.1 million was spent on the luminaires and work associated with converting to solid state.

The number light fixtures included in this contract relative to function are:

2,315 of High Lumen Roadway
1,822 of High Mast Lighting
1,324 Low Lumen Roadway
695 Underpass Lighting

A total of 6,156 highway light fixtures are being replaced. This is approximately 40% the number of INDOT light fixtures state-wide.

The final report for SPR-3833[2] included a life cycle cost analysis (LCCA) of a lighting retrofit project which is what the above contract is. The LCCA compared existing light fixtures that INDOT uses, high-pressure sodium (HPS) lamps with new technology options, light emitting diodes (LED). HPS lamps consume more energy and have a shorter life span when compared to LED lamps. Basic assumptions used in the calculations were:[3]

- Existing HPS fixtures have their lamps replaced every three years and LED options lamps last longer, replaced every five years.
- Annual operating time for lamps is 4380 hours
- Indiana electricity price is $0.10/kWh.

Final report Table 7.8[2] shows the result of the EUAC analysis results, this is for the life of the fixture, 25 years.[3]

Lamp Type	EUAC	EUAC Savings
HPS 250W – High wattage	$354.25	-----
LED 168W – High wattage	$343.10	$11.15
LED 80W – Low wattage	$277.99	$76.26

Calculations

To estimate the impact of the research implementation through statewide upgrade to LED some adjustments need to be made to the assumptions used on the EUAC calculations in SPR-3833:

- Service life of the new solid state luminaire should be estimated at 14 years this equates to the design year for the light level calculations. Presumably after 14 years INDOT will have to modernize again as light output will have diminished below acceptable levels by that time.
- While existing HPS fixtures are re-lamped every three years LEDs are not replaced but the lenses/refractors have to be cleaned approximately every 5 years- cleaning can be estimated at $50 per cleaning per luminaire.[3]

The following energy consumptions are from the LED luminaire models selected by the winning bidder for T-40681:

High Mast: reducing from 1104 W from HPS to 646 W for LED
High Lumen: reduce from 468 W (HPS) to 251 W (LED)
Low Lumen: reduce from 305 W (HPS) to 194 W (LED)
Underpass: reduce from 183 W (HPS) to 125 W (LED)

Potential Savings

- Reduced crashes resulting in Safety benefits for users,
- Decision tool for technology choice on intersection lighting.
- Annual savings from reduced electrical consumption and longer life light sources.

Below is the benefit cost analysis for implementing research results into one lighting contract. The calculations are based on electricity savings and the cost of cleaning the LED fixtures every 5 years.[3]

Annual electricity Cost Savings	Based on $0.10/kWh and 4380 hours of use annually					
	HPS Wattage	LED Wattage	Difference	# Fixtures	Annual Electricity Cost savings	
High Mast	1104	646	458	1822	$365,500	
High Lumen	468	251	217	2315	$220,031	
Low Lumen	305	194	111	1324	$64,370	
Underpass	183	125	58	695	$17,656	
			Total fixtures	6156	$667,558	Total savings all fixtures

LED fixtures require cleaning every five years with estimated cost[3] at $75 (future) each, making the total cost = $75 * 6156 (# of fixtures) = $461,700. The next page shows the cash flow analysis for a 14-year period which is assumed the life of the lighting system (fixture).

Annual maintenance costs[3] are different for the HPS and LED lights. Annual maintenance costs for HPS fixtures is $60 each. Annual maintenance cost for LED fixtures are $50 for high mast and $25 for the remaining fixtures. Maintenance cost savings calculation is shown in the below table.

	High Mast	Roadway
# fixtures	1822	4334
HPS Maintenance cost /fixture	$60	$60
LED Maintenance cost/fixture	$50	$25
Maintenance cost savings	$10	$35
annual savings	$18,220	$151,690
Total annual savings	$169,910	

Another cost savings is bulb replacement. HPS bulbs are replaced every three years at a cost of $40 [3] each while LED bulbs are not replaced. Bulb and maintenance cost savings are included in the 14-year analysis period.

14 year LED fixture life																
	FY 2017	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**FY 2025**	**FY 2026**	**FY 2027**	**FY 2027**	**FY 2028**	**FY 2029**	**FY 2030**	**FY 2031**
Research and Implementation cost	-315,000															
5 Year cleaning cost							-461,700					-461,700				
HPS Bulb replacement cost savings				246,240			246,240			246,240			246,240			246,240
Maintenance Cost Savings			169,910	175,007	180,258	185,665	191,235	196,972	202,881	208,968	215,237	221,694	228,345	235,195	242,251	249,519
Electricity Cost savings		0	667,558	687,585	708,212	729,459	751,342	773,883	797,099	821,012	845,643	871,012	897,142	924,056	951,778	980,331
Net Benefit-Cost	-315,000	0	837,468	1,108,832	888,470	915,124	727,118	970,855	999,981	1,276,220	1,060,879	631,006	1,371,727	1,159,252	951,778	1,476,090

NPV 2017	$10,930,916
Benefit Cost Ratio	35

This benefit cost calculation is based on the one contract previously described. This contract represents approximately 40% the state-wide existing fixture inventory, so the calculated benefits can be multiplied by 2.5 to determine potential statewide impact of research implementation.

Summary

The benefit cost ratio for this set of projects is 35 to 1. This number is based on the following:

- Total research cost of $315,000 ($54,000 for SPR-3613, $125,000 for SPR 3833, $135,000 for SPR 4153)
- 3% cost of capital and inflation.
- NPV of future costs and benefits for a 14-year life of light fixtures brought to 2017$.

Improved roadway lighting has improved safety benefits for users which is not included in the benefit analysis. The calculated benefit is an expected agency benefit.

The JTRP research directly influenced and enabled that technology retrofit of INDOT lighting in Greenfield District, essentially from HPS to LED, for the purpose of reducing power cost and improving lighting quality.

Additionally, the research included bench testing all candidate lamp models, allowing INDOT to build an "approved products list" for future work. The research produced information to rewrite INDOT's Design Manual relative to use of emerging highway lighting technologies.

All future lighting contracts will benefit directly from this research.

This analysis is only for this project's cost to execute research and implement. In the summary report an overall 2018 benefit cost analysis is based on total program costs.

References

[1] Brad Steckler, INDOT Director of Traffic Engineering

[2] Zhao, G., Li, S., & Jiang, Y. (2016). *Safety and cost performance of intersection lighting* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/17). West Lafayette, IN: Purdue University. http://dx.doi.org /10.5703/1288284316340.

[3] Lalit Garg, PE, Senior Engineer of Signing and Lighting and Dave Boruff, PE, Manager of Traffic Administration Office.

SPR-3866 – Performance of Alternative Diamond Interchange Forms

Introduction

This study developed guidelines for screening and evaluating options for alternative diamond interchanges. The guidelines provide a fair comparison procedure during the preliminary planning and conceptual design stages and are used to determine the best interchange form based on initial construction cost, traffic operations improvement, and user travel time savings.

Analysis

Thirty-six diamond interchanges are planned within a 7-year program/analysis period (2017-2023) that could be plausibly considered as having benefited from the research project.[1] The frequency of 36 over 7 years compares with historical counts for new or modified/modernized service interchanges dating back to fiscal year 2007, at about seven annually.[1] Traffic safety was not evaluated as a benefit relative to diamond performance, even though it is.

Calculations

Benefits calculated are savings in interchange construction costs and road user costs. User travel time is not a direct benefit to the agency so its effect on the return on investment will be separated from agency construction cost savings. The below table was developed by Brad Steckler, INDOT Director of Traffic Engineering for the purpose of this report.[1]

Fiscal Year of Construction Letting	# of Diamond Interchanges	Initial Capital Construction Investment Agency Benefit (2017$)	Service Life User Travel Time Benefit (2017$)	Sum of Agency & User Benefits (2017$)
2017	5	$300,000	$2,100,000	$2,400,000
2018	9	$8,300,000	$2,500,000	$10,800,000
2019	5	$6,400,000	$1,600,000	$8,000,000
2020	9	$7,700,000	$3,300,000	$11,000,000
2021	2	$2,100,000	$700,000	$2,800,000
2022	0	None are planned	0	0
2023	6	$2,000,000	$1,200,000	$3,100,000
Total 2017--2023	**36**	**$26,700,000**	**$11,400,000**	**$38,100,000**
Annual Average 2017--2023	**5**	**$4,500,000**	**$1,900,000**	**$6,400,000**

All the costs and benefits are discounted to 2017 dollars. The annual average savings for the seven year period (2017- 2023) is based on an average of five interchange projects per year.

Potential Savings

- Lower construction costs
- Reduced user travel time through the interchange
- Reduced crashes resulting in safety benefits (not included in the analysis)

Below is the benefit cost analysis for a seven-year work plan provided by INDOT Traffic Engineering.

Estimated Interchange Construction Cost Savings[1]

Project Benefits and Costs $	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research Cost	-153,000						
Annual Construction Cost Benefit	300,000	8,300,000	6,400,000	7,700,000	2,100,000	0	3,100,000
Net Benefit-Cost	147,000	8,300,000	6,400,000	7,700,000	2,100,000	0	3,100,000
NPV	27,747,000						
Agency Benefits Cost Ratio	181						

Estimated User Cost Benefit[1]

Project Benefits and Costs $	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research Cost	-153,000						
Annual User Cost Benefit	2,100,000	2,500,000	1,600,000	3,300,000	700,000	0	1,200,000
Net Benefit-Cost	1,947,000	2,500,000	1,600,000	3,300,000	700,000	0	1,200,000
NPV	11,247,000						
User Benefits Cost Ratio	74						

Summary

The Agency benefit cost ratio for this project is 181 to 1. The estimated user benefit due to reduced travel time is 74 to 1. These numbers are based on the following:

- Research cost of $153,000.
- User travel cost savings is $12/hr. for passenger cars and $25/hr. for commercial vehicles.[1]
- 3% cost of capital and inflation.
- NPV of future costs and benefits brought to 2017$.

Benefits from this research investment will continue into the future and return benefits many times over.

This analysis is only for this project's cost to execute research and implement. In the summary report an overall 2018 benefit cost analysis is based on total program costs.

References

[1] Brad Steckler, INDOT Director of Traffic Engineering

Tarko, A. P., Romero, M. A., & Sultana, A. (2017). *Performance of alternative diamond interchange forms: Volume 1— Research report* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2017 /01). West Lafayette, IN: Purdue University. https://doi.org /10.5703/1288284316385

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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

About This Report

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