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

Bob McCullouch

SPR-4225 • Report Number: FHWA/IN/JTRP-2017/22 • DOI: 10.5703/1288284316631
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
December 2017
Table of Contents

Introduction ..................................................................................................................................................... 1
Benefit-Cost Analysis Methodology ............................................................................................................. 1
Benefit-Cost Analysis Results ....................................................................................................................... 2
Summary ...................................................................................................................................................... 6
Appendix ..................................................................................................................................................... 7
  Individual Project Analysis .......................................................................................................................... 11
    SPR-2938: Materials Characterization for the AASHTO New Design Guide ........................................ 11
    SPR-3403: Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening
    Requirements.............................................................................................................................................. 14
    SPR-3418: Quantifications of Benefits of Subsurface Drainage............................................................... 16
    SPR-3506: Concrete Pavement Joint Deterioration................................................................................. 19
    SPR-3510: Subbase Requirements for Utilizing Unsealed Joints in PCCP .............................................. 22
    SPR-3617: Bridge Preservation Treatments and Best Practices.............................................................. 24
    SPR-3624: Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to
    Improve Hot-Mix Asphalt Durability........................................................................................................... 26
    SPR-3636: LRFD of Bridge Foundations Accounting for Pile Group-Soil Interaction........................... 29
    SPR-3705: Performance Assessment of Road Barriers in Indiana............................................................ 32
    SPR-3830: Evaluation of Alternative Intersections and Interchanges.................................................... 35

List of Tables

Table 1. Quantitative Benefits Projects List .................................................................................................. 2
Table 2. Quantitative Projects Five Year Cash Flows.................................................................................. 4
Table 3. Complete Research Project List – FY 2016.................................................................................... 7
Introduction

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

Benefit-Cost Analysis Methodology

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

The ROI analysis included the following savings components:

- **Agency savings and costs.** This was based on research findings, engineering judgment/estimates from INDOT BO (business owner) and SME (subject matter experts), available data, and projected use of the new product/process.

- **Road User Costs (RUC) Savings.** RUC includes value of time (VOT), and vehicle operating costs (VOC). RUC unit values will be obtained from current INDOT standards which INDOT provided.

- **Safety Costs (SC) Savings.** Safety costs (SC) can include a before and after evaluation or engineering judgement from BO/SMEs to calculate the reduction in crashes (e.g. property damage, fatalities, etc.). SC unit values will be obtained from current INDOT standards which INDOT provided.

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

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

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

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

- **Quantitative** - Implementation produces benefits that are measureable and quantifiable. Each of these projects has an individual analysis performed and is included in the Appendix. The analysis or impact period is the time benefits were calculated.

- **Qualitative** - Implementation is successful and benefits occur, but cannot be quantified with certainty due to data not being available or easily discoverable. Examples of qualitative benefits could include a specification revision, a proof-of-concept study, a synthesis study that produces a summary of options and best practices, manuals or guidelines, or where cost comparison data is unavailable.

- **Not Successfully Implemented** - For various reasons the project outcomes could not be currently implemented. Common reasons are management, logistical, technical, or legal issues.

Individual Project Analysis

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

<table>
<thead>
<tr>
<th>No</th>
<th>FY 16 Completed &amp; Implemented SPR Projects</th>
<th>Project Cost ($1000)</th>
<th>TITLE</th>
<th>Benefit Type</th>
<th>Analysis Period</th>
<th>NPV Project Benefit ($1000) 2016$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2938</td>
<td>$150</td>
<td>Materials Characterization for the AASHTO New Design Guide</td>
<td>Agency Savings</td>
<td>5 Years</td>
<td>$33,137</td>
</tr>
<tr>
<td>2</td>
<td>3403</td>
<td>$250</td>
<td>Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements</td>
<td>Agency Savings</td>
<td>5 Years</td>
<td>$5,643</td>
</tr>
<tr>
<td>3</td>
<td>3418</td>
<td>$97</td>
<td>Quantifications of Benefits of Subsurface Drainage</td>
<td>Agency Savings</td>
<td>5 Years</td>
<td>$4,174</td>
</tr>
<tr>
<td>4</td>
<td>3506</td>
<td>$240</td>
<td>Concrete Pavement Joint Deterioration</td>
<td>Agency Savings</td>
<td>5 Years</td>
<td>$544</td>
</tr>
</tbody>
</table>
Eight of the projects have a five-year analysis period. On these projects the annual benefits were based on planned installed quantities that resulted in immediate savings, such as construction cost savings. Project 3617 analysis period is based on the expected bridge life of 75 years, because the recommended maintenance program starts after construction and is in place throughout the life of the bridge. Project 3705 has a 24-year analysis period because it uses barrier quantities estimated in the 5-year work plan and maintenance and user safety costs calculated during the 20-year barrier life.

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

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

<table>
<thead>
<tr>
<th>Project Description</th>
<th>FY2016</th>
<th>FY2017</th>
<th>FY2018</th>
<th>FY2019</th>
<th>FY2020</th>
<th>FY2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>2938 - Annual Benefit (5 year impact)*</td>
<td>0</td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-150,000</td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
</tr>
<tr>
<td>Net benefit</td>
<td>-150,000</td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>33,137,617</strong></td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
</tr>
<tr>
<td>3403 - Annual Benefit (5 year impact)*</td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-250,000</td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
</tr>
<tr>
<td>Net benefit</td>
<td>-250,000</td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>5,642,615</strong></td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
</tr>
<tr>
<td>3418 - Annual Benefit (5 year impact)*</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-97,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td></td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-97,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td></td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>4,174,290</strong></td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
</tr>
<tr>
<td>3506 - Annual Benefits (5 year impact)*</td>
<td>0</td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-240,000</td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-240,000</td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>544,632</strong></td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td>3510 - Annual Benefit (5 year impact)*</td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-100,000</td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-100,000</td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>6,772,236</strong></td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
</tr>
<tr>
<td>3617 - Benefit, 75 year life (1)</td>
<td>-100,000</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-100,000</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td></td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-100,000</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td></td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>11,481,000</strong></td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
<td>390,627</td>
</tr>
<tr>
<td>3624 - Annual Benefit (5 year impact)*</td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-204,000</td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-204,000</td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>7,531,690</strong></td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
</tr>
<tr>
<td>3636 - Annual Benefit (5 year impact)*</td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
<td></td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-416,000</td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
</tr>
<tr>
<td>Net Benefit</td>
<td>-416,000</td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
</tr>
<tr>
<td><strong>NPV FY 2016</strong></td>
<td><strong>7,199,826</strong></td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
</tr>
<tr>
<td>3705 - 24 year life (2)</td>
<td>FY2016</td>
<td>FY2017</td>
<td>FY2018</td>
<td>FY2019</td>
<td>FY2020</td>
<td>FY2021</td>
</tr>
<tr>
<td>Research and Implementation cost</td>
<td>-150,000</td>
<td>-120,000</td>
<td>-247,200</td>
<td>-381,924</td>
<td>-524,509</td>
<td>-675,305</td>
</tr>
<tr>
<td>Barrier Cost - INDOT 5 Year program*</td>
<td>-4,800,000</td>
<td>-4,944,000</td>
<td>-5,092,320</td>
<td>-5,245,090</td>
<td>-5,402,442</td>
<td>-5,559,733</td>
</tr>
<tr>
<td>Annual Maintenance Cost</td>
<td>-4,800,000</td>
<td>-4,944,000</td>
<td>-5,092,320</td>
<td>-5,245,090</td>
<td>-5,402,442</td>
<td>-5,559,733</td>
</tr>
</tbody>
</table>
Eight of the ten projects, with quantifiable benefits, resulted in agency savings, while two other projects resulted in a reduced road user cost (RUC). A summary of these agency cost savings and RUC are described below:

- **2938** – New pavement design procedure reduces asphalt pavement thickness on mainline pavements by 1.5” and concrete pavements greater than 12” thick by 1.5”. The savings are lower pavement material costs.
- **3403** - Allows for a reduction in cement values for concrete pavements and an earlier opening date to traffic. Savings are lower concrete pavement costs.
- **3418** - A proper subsurface drainage layer below heavily traffic areas can improve pavement life. Benefit is longer pavement life in these areas.
- **3506** – A new concrete pavement joint design for transverse joints reduces material and construction costs.
- **3510** – Revising concrete pavement joint detail results in construction cost savings.
- **3617** – A new bridge deck maintenance program reduces lifecycle costs in its maintenance and upkeep.
- **3624** – Changing asphalt pavement mix design increases pavement life and reduces pavement lifecycle costs of asphalt pavements.
- **3636** – A new pile driving formula results in higher pile capacities, lower pile quantities and lower pile costs.
- 3705 - Installing median cable barrier systems is more cost-effective than other barrier options due to lower maintenance and user safety costs.
- 3830 project benefits are classified as Road User Costs (RUC) as the Double Diamond Interchange option reduces travel time through the intersection.

**Summary**

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

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

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

<table>
<thead>
<tr>
<th>No</th>
<th>FY 16 Completed &amp; Implemented SPR Projects</th>
<th>Project Title</th>
<th>Project Cost ($ 1000)</th>
<th>Quantitative Benefits, Qualitative Benefits or Not Successfully Implemented</th>
<th>Project Benefits ($1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2938</td>
<td>Materials Characterization for the AASHTO New Design Guide</td>
<td>$150</td>
<td></td>
<td>33137</td>
</tr>
<tr>
<td>2</td>
<td>3403</td>
<td>Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements</td>
<td>$250</td>
<td></td>
<td>5643</td>
</tr>
<tr>
<td>3</td>
<td>3418</td>
<td>Quantification of Benefits of Subsurface Drainage</td>
<td>$97</td>
<td></td>
<td>4174</td>
</tr>
<tr>
<td>4</td>
<td>3425</td>
<td>Improved Methods of Bridge Maintenance and Inspection</td>
<td>$75</td>
<td>Not Successfully Implemented</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>3506</td>
<td>Concrete Pavement Joint Deterioration</td>
<td>$240</td>
<td></td>
<td>757</td>
</tr>
<tr>
<td>6</td>
<td>3510</td>
<td>Subbase Requirements for Utilizing Unsealed Joints in PCCP</td>
<td>$100</td>
<td></td>
<td>6772</td>
</tr>
<tr>
<td>7</td>
<td>3512</td>
<td>Performance Evaluation of Deployed Cathodic Protection</td>
<td>$100</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>3523</td>
<td>Evaluation of Sealers and Waterproofers for Extending the Life Cycle of Concrete</td>
<td>$150</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>3533</td>
<td>Performance Evaluation of Crack Sealing and Filling Materials with Pavement Preservation Treatments</td>
<td>$118</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>3615</td>
<td>Active Corridor Management</td>
<td>$500</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>3617</td>
<td>Bridge Preservation Treatments and Best Practices</td>
<td>$100</td>
<td></td>
<td>11581</td>
</tr>
<tr>
<td>12</td>
<td>3624</td>
<td>Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability</td>
<td>$204</td>
<td>7531</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>-------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3626</td>
<td>Enhanced Treatment Selection for Reflective Joint Cracking in Composite Pavements</td>
<td>$169</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>14</td>
<td>3630</td>
<td>Efficient Load Rating an Quantification of Life-Cycle Damage of Indiana Bridges for Overweight Loads</td>
<td>$173</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>15</td>
<td>3636</td>
<td>LRFD of Bridge Foundations Accounting for Pile Group-Soil Interaction</td>
<td>$416</td>
<td>7199</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>3704</td>
<td>Indiana State Highway Cost Allocation and Revenue Attribution Study / Estimation of Travel by Out-of-State Vehicles on Indiana Highways</td>
<td>$375</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>3705</td>
<td>Performance Assessment of Road Barriers in Indiana</td>
<td>$150</td>
<td>273714</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>3706</td>
<td>Laser Mobile Mapping Standards and Applications in Transportation</td>
<td>$234</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>19</td>
<td>3707</td>
<td>A Synthesis Study on Collecting, Managing, and Sharing Road Construction Asset Data</td>
<td>$145</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>20</td>
<td>3716</td>
<td>Relating Design Storm Events to Ordinary High Water Marks in Indiana</td>
<td>$125</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>21</td>
<td>3717</td>
<td>Streambank Stabilization Alternatives to Riprap</td>
<td>$108</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>22</td>
<td>3726</td>
<td>Upgrading RoadHAT - Collision Diagram Builder and HSM Elements</td>
<td>$165</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td>23</td>
<td>3751</td>
<td>Evaluation of the Microstructural Characteristics of Soil Treated with Cement Kiln Dust (CKD) and Used as a Subgrade at US 24</td>
<td>$33</td>
<td></td>
<td>Qualitative Benefits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Development of a Geographic Winter-Weather Severity Index for the Assessment of Maintenance Performance</td>
<td>$175</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>------------------------------------------------------</td>
<td>-------</td>
<td>---------------------</td>
<td>----</td>
</tr>
<tr>
<td>24</td>
<td>3800</td>
<td>Development of Standardized Component Based Equipment Specifications and Transition Plan Into a Predictive Maintenance Strategy.</td>
<td>$115</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>3802</td>
<td>Long Term Pavement Performance Indicators for Failed Materials</td>
<td>$140</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>26</td>
<td>3805</td>
<td>Verification of the Enhanced Integrated Climatic Module Soil Subgrade Input Parameters in the MEPDG</td>
<td>$132</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>27</td>
<td>3806</td>
<td>Analysis of the MSCR Asphalt Binder Test and Specifications for Use in Indiana</td>
<td>$210</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>3810</td>
<td>Performance of Warranted Asphalt Pavements: Smoothness and Performance of Indiana Warranted Asphalt Pavements</td>
<td>$120</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>29</td>
<td>3813</td>
<td>Element Level Bridge Inspection - Benefits and Use of Data for Bridge Management</td>
<td>$69</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td>3819</td>
<td>Models to Support Bridge Management</td>
<td>$125</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>31</td>
<td>3828</td>
<td>Estimation and Prediction of Statewide Annual VMT by Vehicle Class and Highway Category</td>
<td>$100</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>32</td>
<td>3829</td>
<td>Evaluation of Alternative Intersections and Interchanges</td>
<td>$235</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>3830</td>
<td>INDOT-JTRP Project/Program Implementation Improvement</td>
<td>$102</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Description</td>
<td>Cost</td>
<td>Benefits</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>---------------------------</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>3859</td>
<td>Culvert Inspection and Data Management</td>
<td>$25</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>3863</td>
<td>Use of Tablets and Apps to Enhance Construction Inspection Practices</td>
<td>$165</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>37</td>
<td>3864</td>
<td>Performance of Deicing Salts and Deicing Salt Cocktails</td>
<td>$85</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>38</td>
<td>3901</td>
<td>Synthesis Study: Best Practices for Maximizing Driver Attention to Work Zone Warning Signs (End of Queue Warning Devices)</td>
<td>$45</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>3907</td>
<td>Simplified Construction Scheduling for Field Personnel</td>
<td>$85</td>
<td>Not Successfully Implemented</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>3908</td>
<td>Algorithm and Software for Proactive Pothole Repair</td>
<td>$78</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
<tr>
<td>41</td>
<td>3941</td>
<td>Storm Water Pollution and Best Management Practice Guidance for Indiana</td>
<td>$36</td>
<td>Not Successfully Implemented</td>
<td>0</td>
</tr>
<tr>
<td>42</td>
<td>3944</td>
<td>Pre-Contract Scoping Processes – Synthesis of Best Practices</td>
<td>$46</td>
<td>Qualitative Benefits</td>
<td>0</td>
</tr>
</tbody>
</table>
Individual Project Analysis

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

Introduction

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

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

Analysis

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

Calculations

Savings calculations are broken into concrete and asphalt pavements.

Concrete

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

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

\[
1,500,000 \text{ SY} \times 9 \text{ SF/SY} \times 1.5”/12” = 1,687,500 \text{ cubic feet (CF) of concrete reduced} = 1,687,500/27 = 62,500 \text{ CY of concrete materials saved. Labor and equipment costs are minimally affected by less material quantity since the area (SY) of pavement does not change.}
\]
Annual concrete material saving = 62,500 CY x $85/CY = $5,312,500

Asphalt

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

Forecasted estimated mainline lane miles of asphalt pavement.

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
<td>33</td>
<td>28</td>
<td>19</td>
</tr>
</tbody>
</table>

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

Base Course Material Savings per Year

Base course weighs 100#/SY/in.

**CY 2017**
Pavement area = 237 lane miles x 5,280 ft./mile x 12’ (lane width) x 1 SY/9SF = 1,668,480 SY
Weight savings = 1,668,480 SY x 1.5” (thickness reduction) x 100#/SY/in. x 1 ton/2000 # = 125,136 tons
Cost savings = 125,136 tons x $50/ton = $6,256,800

**CY 2018**
Pavement area = 80 lane miles x 5,280 ft./mile x 12’ (lane width) x 1 SY/9SF = 563,200 SY
Weight savings = 563,200 SY x 1.5” (thickness reduction) x 100#/SY/in. x 1 ton/2000 # = 42,240 tons
Cost savings = 42,240 tons x $50/ton = $2,112,000

**CY 2019**
Pavement area = 33 lane miles x 5,280 x 12’ x 1 SY/9SF = 232,320 SY
Weight savings = 232,320 x 1.5” x 100#/SY/in. x 1 ton/2000# = 17,424 tons
Cost Savings = 17,424 tons x $50/ton = $871,200

**CY 2020**
Pavement area = 28 lane miles x 5,280 x 12’ x 1/9 = 197,120 SY
Weight savings = 197,120 x 1.5” x 100#/SY/in. x 1 ton/2000# = 14,784 tons
Cost Savings = 14,784 tons x $50/ton = $739,200

**CY 2021**
Pavement area = 19 lane miles x 5,280 x 12’ x 1/9 = 133,760 SY
Weight savings = 133,760 x 1.5” x 100 x 1/2000 = 10,032 tons

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

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-150,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
<td></td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-150,000</td>
<td>11,569,300</td>
<td>7,424,500</td>
<td>6,183,700</td>
<td>6,051,700</td>
<td>5,814,100</td>
</tr>
<tr>
<td>NPV</td>
<td>$33,137,617.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>221</td>
</tr>
</tbody>
</table>

**Summary**

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

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

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

**References**

1. Pavement Cost Study by John Weaver, INDOT Statewide Asset Management Engineer, April 2017.
3. Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association.
4. Quantities provided by John Weaver and Andrew Pangallo, INDOT Field Engineer, apangallo@indot.in.gov.
SPR-3403: Removing Obstacles for Pavement Cost Reduction by Examining Early Age Opening Requirements

Introduction

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

Analysis

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

Calculations

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

Potential Savings

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

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-250,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td></td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-250,000</td>
<td>1,248,750</td>
<td>1,286,213</td>
<td>1,324,799</td>
<td>1,364,543</td>
<td>1,405,479</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td>5,642,614.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>23</td>
</tr>
</tbody>
</table>

¹ This savings calculation does not account for potential long-term performance impacts or other factors that may influence the decision to use lower-strength concrete.
Summary

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

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

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

References

1 Cost, project, and estimated quantity data were provided by Mike Byers, Indiana Ready Mix Concrete Association and Tommy Nantung, INDOT Division of Research.
SPR-3418: Quantifications of Benefits of Subsurface Drainage

Introduction

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

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

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

Analysis

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

Calculations

The cost analysis is based on the following:

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

MESAL data was provided by the INDOT GIS section. Below is a map showing where these segments occur in the state.
These heavy traffic segments total to 5,600 lane miles.

Using the lower unit cost of $40,000 per lane mile, the following analysis is based on 120 lane miles to be reconstructed over the next 5 years, according to the Next Level Roads Program. An average lane mile of 1/5 per year, 120 x 1/5 = 24 is used.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-97,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td></td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-97,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
<td>960,000</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$4,174,290.19</td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>43</td>
</tr>
</tbody>
</table>

**Summary**

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

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

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

**References**


2. MESAL data provided by Kevin Munro, Statewide GIS Asset Manager, INDOT.
SPR-3506: Concrete Pavement Joint Deterioration

Introduction

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

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

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

Analysis

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

Calculations

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

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

SY – square yard, SYS – square yards

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

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

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

   Longitudinal joint bars
   
   #6 @ 3’ = 4 bars x $2.12 = $8.48/panel - $8.48/20 SY = $0.43/SY to cost of pavement
**Estimated Savings:**

Comparing bar options

#7 (old standard) vs. #6 (new standard) - $0.54 - $0.43 = $0.11/SY

#6 (old standard) vs. #6 (new standard) - $0.64 - $0.43 = $0.21/SY

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

Estimated cost saving range in 2017 is:

$0.11 x 1,500,000 SYS = $165,000 (#7 vs. #6)

$0.21 x 1,500,000 SYS = $315,000 (#6 vs. #6)

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

**Example project impact**

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

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

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

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

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

Following is the benefit cost analysis for the next five-year work plan.
### Project Benefits and Costs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-240,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017 Installation</td>
<td></td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-240,000</td>
<td>165,000</td>
<td>169,950</td>
<td>175,049</td>
<td>180,300</td>
<td>185,709</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td>$544,631.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

### Summary

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

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

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

### References

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

2. Tommy Nantung, Manager for Pavement, Materials, and Construction Research, Indiana Department of Transportation, Division of Research and Development.
SPR-3510: Subbase Requirements for Utilizing Unsealed Joints in PCCP

Introduction

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

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

Analysis

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

Calculations

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

Potential Savings

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

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

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

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-100,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
<td></td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-100,000</td>
<td>1,457,533</td>
<td>1,501,259</td>
<td>1,546,297</td>
<td>1,592,686</td>
<td>1,640,466</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td>$6,772,235.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td>68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary

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

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

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

References

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

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

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

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

Analysis

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

Calculations

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

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

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

- Estimated annual savings = $80.63 - $43.30 = $37.33/SF
- $37/SF during the 75-year deck life is used in the calculations.
Since future deck quantities are difficult to estimate, an average of past year new bridge deck quantities is used in the calculations.\(^1\) In the years 2013-2017 there were a considerable number of new bridges built on the new I-69 segments, US 31, SR 25 (Hoosier Heartland), I-65 southern Indiana, and the Ohio River bridges. With the increased funding provided in the last two legislative sessions through HB 1001 and 1002, new bridges will be constructed, but likely not at the same level experienced in the 2013-2017 time period. Since the Ohio river bridges have very large decks and are not built every year, their quantities were not included. Deck quantities for the I-69 bridges were removed as well. This produces a conservative cost savings number.

- Average annual deck area for new bridges (2013-2017) = 313,000 SF
- Average cost savings for a new bridge (75-year life) using option 2 maintenance plan is:
  \[313,000 \text{ SF} \times $37.33/\text{SF} = $11,581,000 \text{ (one year of new bridges constructed)}\]
- NPV Benefits (75 years) = $11,581,000
  
  Convert to annual benefits for 75 years = $11,581,000 (A/P @ 3%)
  
  Annual cash flow benefit = $11,581,000 \times 0.03373 = $390,627, annual cash flow, see table
- Benefit cost ratio = $11,581,000 / $100,000 = 115.81

**Summary**

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

- Research cost of $100,000.

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

**References**


2. Bridge deck quantities provided by Jaffar G. Golkhajeh, Bridge Asset Management Office, Division of Bridges, INDOT. Email: jgolkhajeh@indot.in.gov. Bridges where deck or superstructure were replaced, deck areas came from SPMS. Existing bridges which were replaced or built on new alignments came from the Bridge Inspection Application System (BIAS).
SPR- 3624: Optimizing Laboratory Mixture Design as it Relates to Field Compaction in order to Improve Hot-Mix Asphalt Durability

Introduction

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

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

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

Analysis

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

Calculations

Asphalt pavement life in Indiana is currently 15-20 years. Using a twenty-year life with an estimated increase life of 12 percent (conservative) an extra 2.5 years is expected to be gained from this new mix design. Using bid quantities, the area cost of asphalt pavement for a twenty-year period was calculated. Using mainline pavement quantities, used in the SPR-2938 project analysis, the following table indicates asphalt pavement lane miles for 2017 (actual) and 2018 – 2021 (estimated).
<table>
<thead>
<tr>
<th>2017 (actual)</th>
<th>2018 (est.)</th>
<th>2019 (est.)</th>
<th>2020 (est.)</th>
<th>2021 (est.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>237 lane miles</td>
<td>80 lane miles</td>
<td>33 lane miles</td>
<td>28 lane miles</td>
<td>19 lane miles</td>
</tr>
</tbody>
</table>

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

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

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

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

Estimated new pavement value for each year is calculated.

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

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

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-204,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
<td></td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-204,000</td>
<td>5,005,440</td>
<td>1,689,600</td>
<td>696,960</td>
<td>591,360</td>
<td>401,280</td>
</tr>
<tr>
<td>NPV</td>
<td>$7,531,690.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>37</td>
</tr>
</tbody>
</table>

**Summary**

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

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

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

**References**


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

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

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

**Analysis**

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

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

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

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

Calculations

Between 2008 to 2014, there have been 1,196,956 linear feet of piles installed on INDOT projects at a
total cost of $56,941,969 which corresponds to a unit cost of $47.57 per foot. Based on the test piles
driven on these six contracts which is 336 ft. and the load capacities between the current driven
analysis method and the Purdue method is 1845 kips to 2230 kips, or a 17% savings in pile driving costs.
Using the total pile cost between CY 2008-2014, the 17% savings is, $56,941,969 x .17 = $ 9,680,134.
This is over a 6-year period, or an annual savings $1,613,355.
The financial analysis used a present worth approach for a five-year period with expected capital cost and inflation of 3%. The five-year period coincides with an INDOT proposed 5-year work plan which estimates expected bridge quantities. Estimated bridge quantities are estimated at the quantities experienced during the 2008 to 2014 time period. Benefits are expected to accrue after the 5-year period but are not calculated as bridge quantities may vary.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-416,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
<td></td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-416,000</td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td>1,613,355</td>
<td>1,661,756</td>
<td>1,711,608</td>
<td>1,762,957</td>
<td>1,815,845</td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>

**Summary**

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

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

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

**References**


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

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

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

Analysis

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

Calculations

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

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

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

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

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

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

- $120,000 * 40 (miles) adjusted for inflation

### Annual maintenance cost

\[ \text{Annual maintenance cost} = 3,000 \times (\text{total installed cable barrier during the 5-year plan}) \text{ adjusted for inflation} \]

### Annual benefit

\[ \text{Annual benefit} = 80,000 \times 40 \text{ (miles)} \text{ adjusted for inflation} \]

### Summary

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

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

### Table

<table>
<thead>
<tr>
<th>Project Description</th>
<th>FY2026</th>
<th>FY2027</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research cost</td>
<td>-150,000</td>
<td></td>
</tr>
<tr>
<td>Barrier cost - 5 Year program (a)</td>
<td>-4,380,000</td>
<td></td>
</tr>
<tr>
<td>Annual Maintenance cost (b)</td>
<td>-320,000</td>
<td>-247,000</td>
</tr>
<tr>
<td>Annual Benefit 2016 installation (c)</td>
<td>3,200,000</td>
<td>3,200,000</td>
</tr>
<tr>
<td>Annual Benefit 2017 installation</td>
<td>3,396,766</td>
<td>3,396,766</td>
</tr>
<tr>
<td>Annual Benefit 2018 installation</td>
<td>3,494,880</td>
<td>3,494,880</td>
</tr>
<tr>
<td>Annual Benefit 2019 installation</td>
<td>3,494,760</td>
<td>3,494,760</td>
</tr>
<tr>
<td>Annual Benefit 2020 installation</td>
<td>3,600,440</td>
<td>3,510,440</td>
</tr>
<tr>
<td>Net Benefit cost</td>
<td>-4,810,000</td>
<td>-3,640,000</td>
</tr>
</tbody>
</table>

(a) Barrier cost = $120,000 * 40 (miles) adjusted for inflation

(b) Annual maintenance cost = $3,000 * (total installed cable barrier during the 5-year plan) adjusted for inflation

(c) Annual benefit = $80,000 * 40 (miles) adjusted for inflation

<table>
<thead>
<tr>
<th>Project Description</th>
<th>FY 2028</th>
<th>FY 2029</th>
<th>FY 2030</th>
<th>FY 2031</th>
<th>FY 2032</th>
<th>FY 2033</th>
<th>FY 2034</th>
<th>FY 2035</th>
<th>FY 2036</th>
<th>FY 2037</th>
<th>FY 2038</th>
<th>FY 2039</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrier cost - 5 Year program (a)</td>
<td>-355,457</td>
<td>-691,250</td>
<td>-307,054</td>
<td>-394,780</td>
<td>-982,824</td>
<td>-391,793</td>
<td>-1,621,486</td>
<td>-1,052,004</td>
<td>-1,003,667</td>
<td>-1,116,177</td>
<td>-1,496,862</td>
<td>-1,184,152</td>
</tr>
<tr>
<td>Annual Benefit 2016 installation (c)</td>
<td>4,562,435</td>
<td>4,689,308</td>
<td>4,691,147</td>
<td>4,585,430</td>
<td>5,135,091</td>
<td>5,293,112</td>
<td>5,447,786</td>
<td>5,511,219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit 2017 installation</td>
<td>4,652,435</td>
<td>4,689,308</td>
<td>4,691,147</td>
<td>4,585,430</td>
<td>5,135,091</td>
<td>5,293,112</td>
<td>5,447,786</td>
<td>5,511,219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit 2018 installation</td>
<td>4,652,435</td>
<td>4,689,308</td>
<td>4,691,147</td>
<td>4,585,430</td>
<td>5,135,091</td>
<td>5,293,112</td>
<td>5,447,786</td>
<td>5,511,219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit 2019 installation</td>
<td>4,652,435</td>
<td>4,689,308</td>
<td>4,691,147</td>
<td>4,585,430</td>
<td>5,135,091</td>
<td>5,293,112</td>
<td>5,447,786</td>
<td>5,511,219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit 2020 installation</td>
<td>4,562,435</td>
<td>4,689,308</td>
<td>4,691,147</td>
<td>4,585,430</td>
<td>5,135,091</td>
<td>5,293,112</td>
<td>5,447,786</td>
<td>5,511,219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NPV 273,714,281

Benefit Cost Ratio 1825
• Estimated maintenance cost $3,000 (2016$) per mile.
• 20-year service life.
• 3% cost of capital and inflation.
• NPV of future costs and benefits brought to 2016$.

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

References

1 Provided by Brad Steckler, INDOT Director of Traffic Engineering, INDOT unit cost
2 Provided by Brad Steckler, verified by Todd Shields (INDOT Maintenance Field Support Manager) and unit costs from 4 other state DOT agencies.
**SPR-3830: Evaluation of Alternative Intersections and Interchanges**

**Introduction**

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

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

**SPUI**

I-465 and Emerson Avenue in Indianapolis

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

Analysis

Two DDI intersections were cited in the study. A DDI in Salt Lake City, Utah signals timing was studied and with proper timing scheme traffic green time improved from 53% to 92%. The second was I69 and DuPont Road in Allen County. At this interchange signal timing optimization was performed using Bluetooth vehicle sensors. The optimization improved intersection travel times so that user costs were estimated to save $564,000 annually. This number was calculated based on a methodology developed by the Texas Transportation Institute (TTI) located at Texas A&M University. TTI derived a cost of congestion equation which is determined by computing the average delay for a section and multiplying it by the expected traffic volume and the value of time. Added to the congestion cost is the CO₂ emission cost. Combining the congestion and emission costs is the user cost. AADT values for these calculations is provided by INDOT.

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

Calculations

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

2 additional DDI interchanges added each year for years 2018-2021. Cost savings for each year by using the DDI option over the SPUI configuration is shown below.
2018 – $564,000 x (3 (previous)+2) = $2,820,000
2019 - $564,000 x (5 (previous) + 2) = $3,948,000
2020 - $564,000 x (7 (previous) +2) = $5,076,000
2021 - $564,000 x (9 (previous) +2) = $6,204,000

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Cost</td>
<td>-235,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Benefit</td>
<td></td>
<td>1,692,000</td>
<td>2,820,000</td>
<td>3,948,000</td>
<td>5,076,000</td>
<td>6,204,000</td>
</tr>
<tr>
<td>Net Benefit-Cost</td>
<td>-235,000</td>
<td>1,692,000</td>
<td>2,820,000</td>
<td>3,948,000</td>
<td>5,076,000</td>
<td>6,204,000</td>
</tr>
<tr>
<td>NPV</td>
<td></td>
<td>$17,029,517.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefits Cost Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>

Summary

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

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

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

References

   [http://dx.doi.org/10.5703/1288284316012](http://dx.doi.org/10.5703/1288284316012)


3. Phone Interview, Jim Sturdevant, 10/20/17 and 12/6/17.
About the Joint Transportation Research Program (JTRP)

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

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

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

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

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is: