Introduction

This Infrastructure Week Webinar will Examine the Historical Life Cycle Costs of Steel and Concrete Bridges in Pennsylvania.
Background

Past work in Bridges – Michael Barker

**Education:**
Masters at Purdue in Concrete & PhD at Minnesota in Steel Bridge Research

At U of Missouri & U of Wyoming:
Concrete & Steel Bridge Rating Research
Steel Bridge AASHTO Design Provisions
Concrete & Steel Bridge Field Testing
Concrete Bridge FRP Strengthening
Concrete & Steel Bridge Serviceability Research
Work with Counties and County Built Bridges

Disclaimer

This work was supported by the steel industry
SMDI, NSBA & AGA

As a sabbatical project at the University of Wyoming

**BUT**..... This study was not influenced by the Steel Industry

I am First and Foremost a Bridge Engineer

And

This is a **Systematic & Honest** study of Life Cycle Costs for a database of Steel & Concrete bridges in Pennsylvania
Why the Study?

As owners replace their bridge infrastructure, the question of Life Service and Life Cycle Costs routinely comes up between concrete and steel bridge options.

This is especially true for typical and short span bridge replacement projects.

The bridge industry does not have a good answer:
   Both steel and concrete bridge advocates claim an advantage.
   Anecdotal information is not convincing.

Study Objective

Examine Historical Life Service (Performance and Maintenance) and Agency Life Cycle Costs (True Agency Costs for a Bridge) of Steel and Concrete Bridges in Pennsylvania

Also, Questions Remain Within Material Type

   Different PC Concrete Bridge Types
   Steel Bridge Construction Techniques & Coatings
   Deck System & Rebar
Life Cycle Cost Data Collection

Start with a Comprehensive Inventory of Bridges

Initial Costs & Date Built
Maintenance Costs and Date Performed
End of Service Date – End of Life Model

Issues:

- Availability of Historical Data
- Large Amount of Time & Resources to Collect Data

PennDOT Stepped Up to Participate
**PennDOT Database Development**

**Criteria to Develop LCC Bridge Database**

Modern typical bridge structures
- Precast I-Beam, Box Adjacent, and Box Spread bridges
- Steel Rolled Shape and Welded Plate Girder bridges

Bridges built between 1960 and 2010

Bridges with complete and accurate department maintenance records
- Consider any maintenance cost that is equal to or greater than $0.25/ft²

Bridges with known initial costs

Bridges with complete and accurate external contractor maintenance and rehabilitation

Initial cost limitation to bridges with initial cost less than $500/ft² and greater than $100/ft²

Note: Total Recorded Initial and Maintenance Costs Used

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**PennDOT Database Development**

All Bridges in PennDOT Inventory = 25,403
Number of Type Bridges in Inventory = 8,466
Number of Types Built 1960-2010 = 6,587

Bridges that Meet All Criteria

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges that Meet All criteria</th>
<th>Percentage of 1960 – 2010 database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>14.9%</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>230</td>
<td>22.6%</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>27.8%</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>26.5%</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>29.8%</td>
</tr>
<tr>
<td>Total</td>
<td>1705</td>
<td>25.9%</td>
</tr>
</tbody>
</table>
**NEEDED Notes on Limitations**

Database Contains Only 25.9% of Eligible 1960 - 2010 Bridges

Large Percentage of Bridges Not Included

Bridges Removed Due To:
- Unknown Dates and/or Costs of Department Maintenance
- Unknown Dates and/or Costs of Contractor Maintenance

Therefore,
- Database is “Skewed” Towards Bridges with Lower Amounts of Maintenance

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**NEEDED Notes on Limitations**

The Systematic Nature of the Study Used

- Total 1960-2010 PennDOT Database Average Deterioration Rates Based on Condition Ratings

The Study Does Not Predict Any Future Maintenance

Therefore,

*Results, Comparisons & Conclusions Must Be Taken In Context to the Database and the Database Limitations*
PennDOT Database Bridge Life Model

Bridge Life Model uses Average Deterioration Rates of Total PennDOT Inventory

Assume Bridge Replacement at Condition Rating = 3

Table 9: Average Deterioration Rates

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges 1960 - 2010</th>
<th>Deterioration Rate (Condition Rating Loss/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>550</td>
<td>-0.07114</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>1017</td>
<td>-0.08144</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>1440</td>
<td>-0.08125</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>2196</td>
<td>-0.07988</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>1384</td>
<td>-0.08383</td>
</tr>
</tbody>
</table>

All are “similar” with None “Way Out” of Balance

Agency Life Cycle Costs – An Example

Precast Spread Box-Beam Bridge

BrKey: 30570
Bridge Type: P/S, Box Beam (Spread)
County: Shuylkill
Location: 0.75 mi. N of Exit 107(33)
Year Built: 1969
Spans: 3
Length: 176 ft
Deck Area: 7621 ft²
Super Cond Rating: 5

Average Precast Box Beam – Spread bridge deterioration rate = -0.07988

Remaining Life = \( \frac{3 - 5}{-0.07988} = 25 \) years

Bridge Life = 2014 + 25 - 1969 = 70 years
**Life Cycle Costs**

**Example Bridge Costs**

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Year</th>
<th>Cost (Dollars)</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost</td>
<td>1969</td>
<td>$141,475 ($18.56/ft²)</td>
<td>Bridge Construction</td>
</tr>
<tr>
<td>External Contract</td>
<td>1988</td>
<td>$58,401 ($7.66/ft²)</td>
<td>Latex Overlay</td>
</tr>
<tr>
<td>Maintenance 1</td>
<td>2009</td>
<td>$18,911 ($0.25/ft²)</td>
<td>Repair Concrete Deck</td>
</tr>
<tr>
<td>Maintenance 2</td>
<td>2013</td>
<td>$25,100 ($0.33/ft²)</td>
<td>Repair Concrete Deck</td>
</tr>
</tbody>
</table>

Transform the costs to constant 2014 dollars using Construction Cost Indices:

- **Initial Cost:** Year = 0, Cost = $18.56/ft²(9806/1269) = $143.45/ft²
- **External Contract:** Year = 19, Cost = $7.66/ft²(9806/4519) = $16.63/ft²
- **Maintenance 1:** Year = 40, Cost = $0.25/ft²(9806/8570) = $0.28/ft²
- **Maintenance 2:** Year = 44, Cost = $0.33/ft²(9806/9547) = $0.34/ft²

**Present Value Cost for 1 Cycle**

\[PVC = 143.45 + 16.63(1.023)^{-19} + 0.28(1.023)^{-40} + 0.34(1.023)^{-44} = 154.49/ft^2\]
**Life Cycle Costs**

Example Bridge Life Cycle

OMB Circular A-94 2011 30 yr Discount Rate = 2.3%

![Graph showing various costs over time]

Present Value Cost for 1 Cycle

\[ PVC = 143.45 + 16.63(1.023)^{-19} + 0.28(1.023)^{-40} + 0.34(1.023)^{-44} = \$154.49/\text{ft}^2 \]

Perpetual Present Value Cost

\[ PPVC = 154.49 \left( \frac{(1 + 0.023)^{70}}{(1 + 0.023)^{70} - 1} \right) = 1.256(154.49) = \$193.97/\text{ft}^2 \]

With PPVC, Can Compare Bridges Directly

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**Life Cycle Cost Analyses**

The Steel Plate Girder Bridge Data Base

<table>
<thead>
<tr>
<th>General Information</th>
<th>Maintenance &amp; Contract Work</th>
<th>Initial &amp; LCC</th>
</tr>
</thead>
</table>

The full history of the bridge
Location, year built, spans, length, area, geometry, materials
Department and contractor maintenance performed
Initial, perpetual present value, and future maintenance costs
Life Cycle Cost Analyses

Additional Bridges Removed Based on PPVC

To Consider “Typical” Bridges, Keep Bridges with PPVC within +/- 1 Standard Deviation of Overall Average

Bridges in the Life Cycle Cost Analyses

Table 13: Final Life Cycle Cost Database

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges in Table 11 Database</th>
<th>Number of Bridges in LCC Study Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>54</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>230</td>
<td>144</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>282</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>397</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>309</td>
</tr>
<tr>
<td></td>
<td>1705</td>
<td>1186</td>
</tr>
</tbody>
</table>

LCC Study

Analysis and Variables Examined

Bridge Life
PPVC
  Number of Spans
  Bridge Length
PVC Future Costs
  Department Maintenance
  External Contracts
Type of Steel Bridge (curved & straight, fracture critical)
Steel Protection (painted, weathering & galvanized)
Bridge Life

Table 10: Final LCC Database that Meets All Criteria

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges in Final LCC Database</th>
<th>Average Year Built</th>
<th>Average Bridge Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>1981</td>
<td>81.3</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>230</td>
<td>1977</td>
<td>79.2</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>1985</td>
<td>74.0</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>1984</td>
<td>79.9</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>1984</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Steel Rolled Precast Box - Spread

All are “similar” with None “Way Out” of Balance

Bridge Life

CDF for Bridge Life

- Probability Bridge Lasts >75 yrs
  - Steel Rolled 73.0%
  - Steel Plate 62.7%
  - Conc Box Adjacent 45.6%
  - Conc Box Spread 65.0%
  - Conc I Beam 44.3%
Perpetual Present Value Cost – All Bridges

Table 14: Life Cycle Cost Results Using Total Database

<table>
<thead>
<tr>
<th></th>
<th># Bridges</th>
<th>PPVC</th>
<th>Initial Cost</th>
<th>Future Cost</th>
<th>Avg Length</th>
<th>Avg # Spans</th>
<th>Avg Year Built</th>
<th>Avg Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>54</td>
<td>$232.78</td>
<td>$194.78</td>
<td>$0.42</td>
<td>166</td>
<td>2.19</td>
<td>1980</td>
<td>82</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>144</td>
<td>$273.71</td>
<td>$226.10</td>
<td>$0.21</td>
<td>406</td>
<td>4.07</td>
<td>1976</td>
<td>80</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>282</td>
<td>$278.30</td>
<td>$223.74</td>
<td>$0.96</td>
<td>89</td>
<td>1.31</td>
<td>1987</td>
<td>74</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>397</td>
<td>$256.11</td>
<td>$210.65</td>
<td>$2.06</td>
<td>89</td>
<td>1.56</td>
<td>1986</td>
<td>79</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>309</td>
<td>$217.50</td>
<td>$174.10</td>
<td>$0.20</td>
<td>212</td>
<td>2.43</td>
<td>1985</td>
<td>73</td>
</tr>
</tbody>
</table>

All are “similar” with None “Way Out” of Balance

Perpetual Present Value Cost – All Bridges

CDF for Bridge Cost
Perpetual Present Value Cost – Length<140 ft

Table 20: Life Cycle Cost Results for Span Length maximum = 140 ft

<table>
<thead>
<tr>
<th># Bridges</th>
<th>PPVC Initial Cost</th>
<th>Future Cost</th>
<th>Avg Length</th>
<th>Avg # Spans</th>
<th>Avg Year Built</th>
<th>Avg Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>27 $266.24</td>
<td>$222.08</td>
<td>$0.16</td>
<td>84</td>
<td>1.26</td>
<td>1978</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>18 $313.26</td>
<td>$257.19</td>
<td>$0.29</td>
<td>119</td>
<td>1.00</td>
<td>1977</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>240 $292.38</td>
<td>$235.03</td>
<td>$0.95</td>
<td>69</td>
<td>1.09</td>
<td>1987</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>325 $272.20</td>
<td>$225.14</td>
<td>$2.16</td>
<td>64</td>
<td>1.23</td>
<td>1986</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>98 $281.64</td>
<td>$231.20</td>
<td>$0.05</td>
<td>104</td>
<td>1.08</td>
<td>1987</td>
</tr>
</tbody>
</table>

Future Costs

Future Costs Compared to Initial Costs

Table 22: Life Cycle Costs and PPVC/Initial Cost for Total Database

<table>
<thead>
<tr>
<th># Bridges</th>
<th>PPVC Initial Cost</th>
<th>Future Cost</th>
<th>Avg Life</th>
<th>PPVC/Initial Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>54 $232.78</td>
<td>$194.78</td>
<td>82</td>
<td>1.20</td>
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<tr>
<td>Steel I Girder</td>
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<tr>
<td>P/S Box - Adjacent</td>
<td>282 $278.30</td>
<td>$223.74</td>
<td>74</td>
<td>1.24</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>397 $256.11</td>
<td>$210.65</td>
<td>79</td>
<td>1.22</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>309 $217.50</td>
<td>$174.10</td>
<td>73</td>
<td>1.25</td>
</tr>
</tbody>
</table>

All are “similar” with None “Way Out” of Balance
Which Type of Bridge is Best?

Steel Rolled Beam

Precast Box Adjacent

Steel Plate Girder

Precast I Beam

Precast Box Spread

Which Type of Bridge is Best?

All are “similar” with None “Way Out” of Balance

Overall Average PPVC = $252.40/ft²

Bridge Type Range within 14%

Standard Deviations Range

$48.02/ft² - $65.60/ft²

Any One Type of Bridge May Be Most Economical for a Given Bridge Project

There is No One Type of Bridge That Clearly Beats the Others
Summary

The report examines the Initial Costs, Life Cycle Costs, and Future Costs of the Bridges in the PennDOT Database

The database is limited to bridges that met the Criteria – It is Not as Comprehensive as Desired and Results must be Taken In Context of the Database and the Database Limitations

PennDOT expended resources to collect the required data and now have information on the Life Cycle Costs of their bridges. A template of what is required and how to handle the data has been developed. Other owners may be interested in the performance of their bridge inventories.

Possible Benefits of Life Cycle Cost Analyses

Concrete and Steel Bridges

Different Types of Concrete and Steel Bridges

Others Superstructure Issues:
  Rebar – Black, Epoxy, Galvanized & Stainless
  Decks – Joints, Integral abutments & Overlays
  Protective Systems – Paint, Weathering, Galvanizing
  Maintenance Programs – Washing, Clearing & Touch-Ups
  Service Programs – Salting, Cinders & Sanding
PennDOT Database Conclusions

Typical Concrete and Steel Bridges are Competitive on Initial Cost, Future Costs, Life Cycle Costs and Bridge Life

For any Given Bridge Project, Concrete or Steel Bridge Types May Be the Most Economical

Owners Should Consider Both Steel and Concrete Alternatives for Individual Bridge Projects

Closing

Thank You to PennDOT professionals, especially Tom Macioce, Bridge Engineer, and Katherine Schopman, Civil Engineer, for their participation.

Thanks to SMDI, NSBA and AGA for supporting the work.

Report currently under final review with the American Iron & Steel Institute, Steel Market Development Institute

The opinions, findings and conclusions in this work are not necessarily those of SMDI, NSBA or the AGA