Allocation of Bridge Deck Preservation Budget Using Optimization

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Overview

1. General concept of optimization process.
3. Implement single objective optimization using two different scenarios. (Using two different objectives in optimization)
4. Introduction to multi-objective optimization.
Optimization

- Compares deterioration of bridge deck with improvements along with associated costs to meet the objectives.
- Determines what percentage of the budget should be allocated for specific preservation actions.
- Optimization performed at a network level.
- Specific bridges are to be selected at the project level based on result of budget allocation.
Components needed in optimization

1. BMS models - Deterioration models, Improvement models, and Cost models.
2. What are the objectives for optimization? (Objective Function)
3. What are the constraints in optimization?
4. Economic factors. (Inflation rate, Discount factor, etc.)
Optimization for Budget Allocation

Improvement Model

Deterioration Model

7  Repair  6  Minor Rehab  5  Major Rehab  4  Rehab / Replace  3  Replace

BRIDGE PROGRAM
WYOMING DEPARTMENT OF TRANSPORTATION
## Improvement Strategy

<table>
<thead>
<tr>
<th>NBI Rating before MR&amp;R</th>
<th>MR&amp;R Action</th>
<th>Cost (Probability of cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Do nothing</td>
<td>$0.0</td>
</tr>
<tr>
<td>6</td>
<td>REPAIR</td>
<td>$9.2 (μ)</td>
</tr>
<tr>
<td>5</td>
<td>REHAB</td>
<td>$20.5 (μ)</td>
</tr>
<tr>
<td>4</td>
<td>REHAB</td>
<td>$25.0 (70%)</td>
</tr>
<tr>
<td>3</td>
<td>REHAB/REPLACE</td>
<td>$57.6 (30%)</td>
</tr>
<tr>
<td>2</td>
<td>REPLACE</td>
<td>$63.8 (μ)</td>
</tr>
<tr>
<td>1</td>
<td>REPLACE</td>
<td>$63.8 (μ)</td>
</tr>
</tbody>
</table>
Results of Optimization

P stands for pure deck without rehabilitation history and R stands for rehabilitated deck.
Deterioration Model

- WYDOT uses historical NBI deck condition rating data for deterioration modeling.
- Rather than producing deterministic modeling, probable duration model that remains in each of NBI condition ratings are used.
- Markov chain deterioration model are formed from probable duration models.
- Two different deterioration models are produced for bridge decks without / with rehabilitation history.
Probable durations (Do nothing)
Probable durations after REHAB

Duration Model for NBI rating

- NBI 58 = 7
- NBI 58 = 6
- NBI 58 = 5
- NBI 58 = 4
- NBI 58 = 3

NBI deck condition rating vs. Time in years
Deterioration Models

![Graph showing deterioration models over time]

- **Pure deterioration**
- **Deterioration after rehabilitation**

**Axes:**
- **Y-axis:** NBIDeck Condition Rating
- **X-axis:** Age in years

**Legend:**
- Green line and markers: Pure deterioration
- Orange line and markers: Deterioration after rehabilitation
Cost Models

- Estimate costs associated with typical preservation actions.
- Developed by analyzing historical rehabilitation and new construction cost data.
- Developed by a probabilistic approach due to variability and uncertainty in estimation of costs.
- Continually being evaluated, refined and updated as necessary.
Probable Cost Model

![Graph showing probability distributions for different cost models. The x-axis represents Total Unit Cost in $/SF, and the y-axis represents Probability density. The graph includes curves for Repair, Minor REHAB, Major REHAB, and Replace.]
Improvement Models

- Simulate the effects of preservation actions in terms of increase in NBI condition rating at network level.
- Developed by analyzing historical rehabilitation data.
  - NBI condition ratings are compared prior to and after application of preservation actions.
- In the form of Markov chain model.
- Continually being evaluated, refined and updated as necessary.
## Improvement Model

<table>
<thead>
<tr>
<th>NBI</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td>36%</td>
<td>64%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>53%</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>49%</td>
<td>38%</td>
<td>13%</td>
</tr>
<tr>
<td>3</td>
<td>30%</td>
<td>70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Objectives and Constraints

Single Objective Optimization

Minimizing structural deficiency / Annual budget

Manipulating variables - Allocation fund on various preservation actions.

Achievable structural deficiency / Annual budget.

Annual budget / Target structural deficiency.
Optimization-Scenario 1

- **Objective Function** - Minimizing Structural Deficiency (SD%)
- **Constraint** - Annual budget of 20 million dollars
- **Planning horizon** - 10 years.
- **Agency Policy** - Replace the deck for condition rating equal to or less than 2 prior to other actions.
- **Achieve the as minimum as possible structural deficiency with allowable maximum annual budget using agency policy.**
Structural Deficiency – Scenario 1

Total budget of 200 million dollars

Structural deficiency in % by deck area

Year

2016 2018 2020 2022 2024 2026
NPRM Measure - Scenario 1

Total budget of 200 million dollars

- **Good**
- **Fair**
- **Poor**

Year:
- 2016
- 2018
- 2020
- 2022
- 2024
- 2026

NPRM in %:
- 0
- 20
- 40
- 60
- 80
- 100
Budget Allocation – 1st Year

P stands for pure deck without rehabilitation history and R stands for rehabilitated deck.
Budget Allocation – 10th Year

P stands for pure deck without rehabilitation history and R stands for rehabilitated deck.
Structural Deficiency vs. Year

![Graph showing decreasing structural deficiency from 2016 to 2026.](image)
NPRM Measure for Scenario 1
Optimization-Scenario 2

- **Objective Function** - Minimizing annual budget.
- **Constraint** - Achieve structural deficiency of 6% within 3 years and then maintain on 6%.
- **Planning horizon** - 10 years.
- **Agency Policy** - Replace the deck for condition rating equal to or less than 2 prior to other actions.
- **Spend** as minimum as possible annual budget to achieve the target structural deficiency using agency policy.
Structural deficiency - Scenario 2

Total budget of 164.34 million dollars

Year
2016 2018 2020 2022 2024 2026

Structural deficiency in % by deck area
0 2 4 6 8 10 12

WYOMING DEPARTMENT OF TRANSPORTATION
Required annual budget

Total budget of 164.34 million dollars
NPRM Measure – Scenario 2

Total budget of 164.34 million dollars

- Good
- Fair
- Poor
Budget Allocation – 1\textsuperscript{st} Year

P stands for pure deck without rehabilitation history and R stands for rehabilitated deck
Budget Allocation – 10th Year

P stands for pure deck without rehabilitation history and R stands for rehabilitated deck.
Considerations

- The single objective optimization produces the focused result to the its objective function.
- There is only one optimal solution point at each year. Therefore there is no trade-off analysis.
- Balanced solution point is necessary to satisfy the multiple objectives in certain level at the same time.
- Number of objective functions can be more than 2.
- There are multiple solution points which satisfy optimality condition.
Multi-Objective Optimization

Multi-Objective Optimization

By manipulating variables $x = \{x_7, \ldots, x_1\}$

Single Objective Optimization

Objective function, $f_1$

By manipulating variables, $x_i$

Utopia Point

Minimized Point

Annual Budget, $f_1$
1\textsuperscript{st} Year multi-objective optimization

1 Year Pareto Frontier

SD in %

MR&R Budget in million dollars
Thank you...