Bridge Deck Preservation Tool (BDPT)

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Objective of the BDPT

How do we balance rehab needs with preventive maintenance?

What are our "preventive maintenance needs" anyway?

We can't do everything…how do we choose?

Good decision-making requires good information.

The objective is to create a tool that will supply

cost, service life, and risk (uncertainty) information

so bridge owners can choose good bridge deck maintenance strategies.

Focus on the deck permits more detail & accuracy than current network- or bridge-level systems.

Bridge Deck Preservation Tool (BDPT)

- Bridge Deck Preservation Portal - Phase I (ElBatanouny et al. 2020)
  - Project led by Iowa DOT & FHWA, but ME, WA, OR, and NC DOTs also on TAC
  - Objective: to develop a framework for a BDPP to aid engineers in choosing an *optimal preservation strategy* for *a given bridge deck* based on calculated *cost, service life, and risk/uncertainty*
  - 5 modules (User Inputs, Selection of Maintenance Actions, Algorithms, Optimization, Output)

Project Scope

- Bridge Deck Preservation Tool - Phase II (Implementation)
  - Pooled fund study TPF-5(474) with IA, IN, MN, MO, NM, TX DOTs and FHWA

To develop

a fully-functional, cloud-based Bridge Deck Preservation Tool (BDPT)

hosted on the FHWA LTBP InfoBridge web portal.

1. Finalize BDPT framework *(Tier 1)*
2. Incorporate final BDPT into InfoBridge *(Tier 2)*
3. Promote use of the BDPT *(Tier 3)*

BDPT Overview

Applicability of BDPT

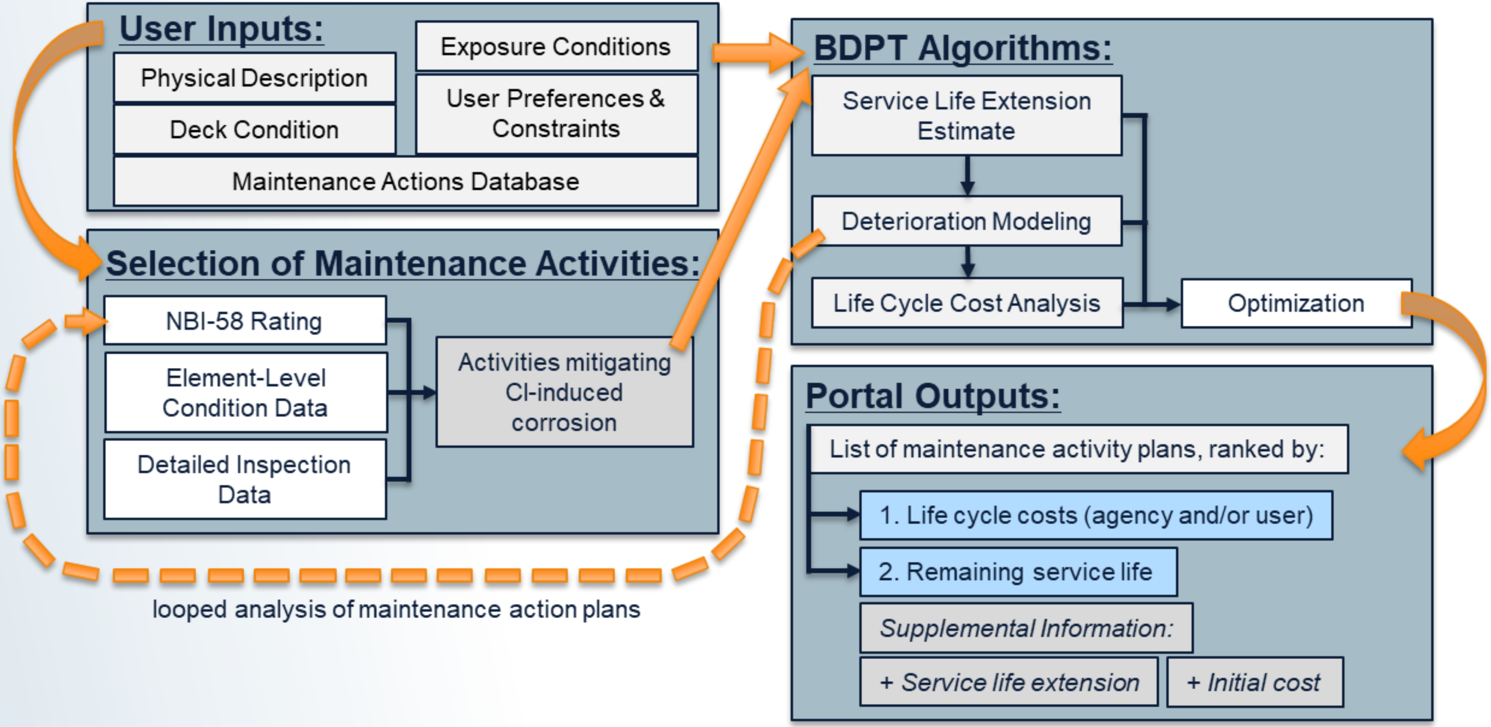
When it can be applied:

- Project- or asset-level analysis
- Concrete bridge decks
- Min. to max. amount of condition info known
  - *NBI-58, NBE, in-depth*
- Governing deterioration mechanism is [Cl^-]-induced corrosion of deck topside
- Selection between preventive maintenance options for decks with NBI-58 ≥ 5

When it should NOT be applied:

- Network-level analysis
- Steel & timber decks
  - *Catalog alternatives*
- [Cl^-]-induced corrosion of deck underside requires repairs
- Other concrete degradation mechanisms govern deterioration (e.g., abrasion, ASR)
- Structural capacity is in question
- Selection between rehabilitation, replacement, and/or deferred replacement

BDPT Framework



User Inputs & Database

- Describing current conditions (of the deck and the region)
- Setting the parameters of the analysis

User Inputs

- Physical Description (from InfoBridge or user input)
  - Deck Age
  - Deck Construction Material
  - Deck Area
- Bridge Deck Conditions
  - NBI general condition
  - Element level
  - Detailed inspection data
- Exposure Conditions
  - Climate
  - Chloride exposure
  - Traffic
- User Preferences
  - When to apply maintenance
  - Action versus plan
  - LCCA parameters
  - Optimization weights

Deck Conditions: Detailed Inspection Data

Inspection Technique:	Requested Information:	Possible Responses:
Crack Mapping	Typical crack widths	Hairline, OR Greater than hairline
	Crack density (ft/ft^2)	Numeric
Delamination Survey	Total delaminated area (%)	Numeric
HCP Survey	Deck area likely to be corroding (%)	Numeric
Chloride Testing	Is the chloride concentration at the depth of the reinforcing steel sufficiently elevated such that corrosion is a risk?	Yes, OR No

- Crack widths:
  - Guidance for definition of "hairline" (< 0.012 to 0.015 inches) but up to user/agency
  - User's interpretation if "typical" or "maximum" appropriate
- Chloride test results:
  - Sampling, testing, and interpretation of chloride results is complex
  - User must judge extent of chloride concentration and risk of corrosion initiation

Maintenance Actions Database (defaults)

- Background database with default values for cost and service life. Default replacement cost is $100/square foot

Maintenance Action	Default Agency Costs		Default User Costs	
	Unit Cost	Unit	Cost	Unit
Applying a Penetrating Sealer	1.4	$/square foot	(empty)	$
Crack-Chasing	5	$/linear foot	(empty)	$
Applying a Floodcoat	3	$/square foot	(empty)	$
Applying a Thin Polymer Overlay	8	$/square foot	(empty)	$
Applying a HMA Overlay with a Waterproofing Membrane	10	$/square foot	(empty)	$
Applying a Modified Asphalt Overlay	15	$/square foot	(empty)	$
Applying a Rigid Cementitious Overlay	20	$/square foot	(empty)	$
Applying an LMC Overlay	16	$/square foot	(empty)	$
Applying a PPC Overlay	15	$/square foot	(empty)	$
Applying a UHPC Overlay	56	$/square foot	(empty)	$

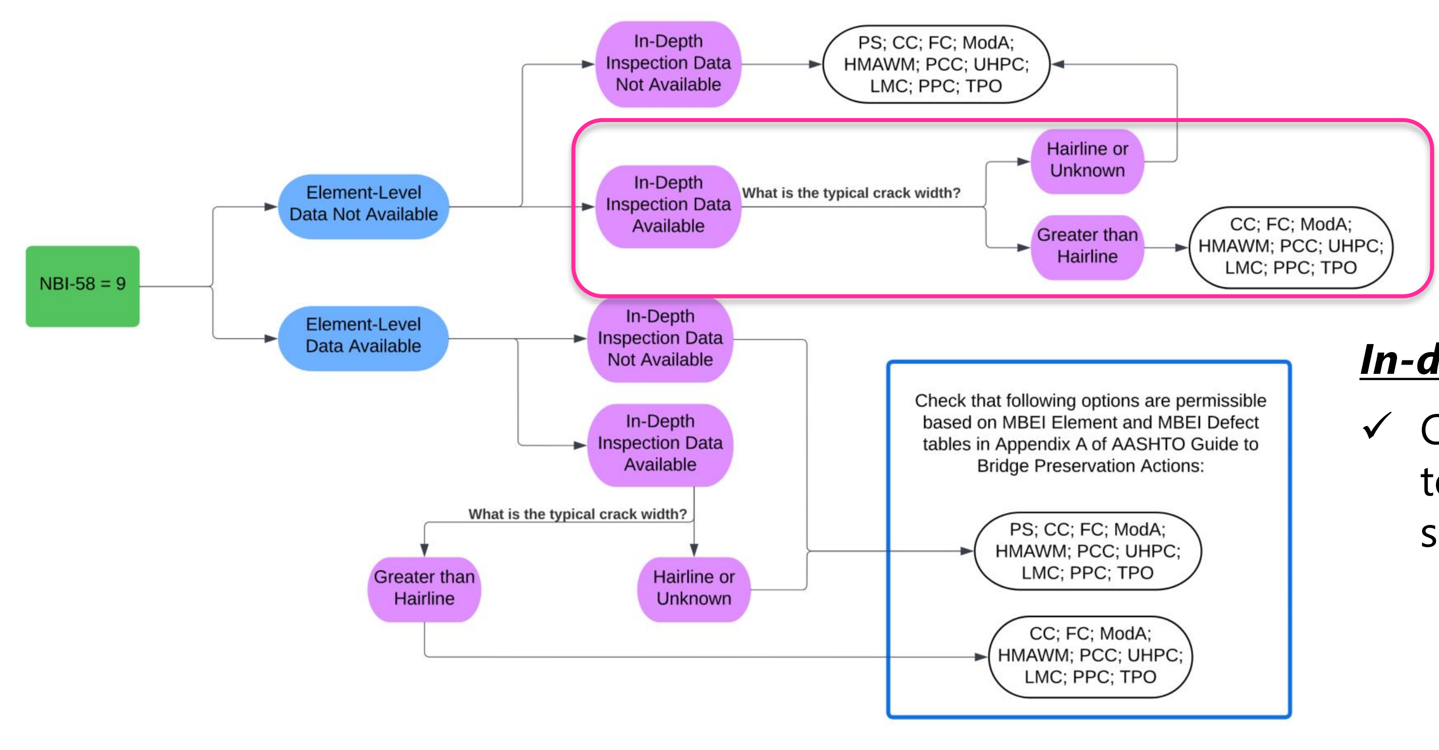
Filters & Thresholds Module

- Selecting appropriate maintenance options for analysis

Exclusion Filters

- Non-Condition Based
  - Material incompatibilities, smooth riding surface
  - Not enough info to get cost estimate (crack density for crack chasing)
- Condition Based
  - Removed if NBI-58 is 5 or 6:
    - Applying a penetrating sealer
    - Crack-chasing
    - Applying a floodcoat
    - Applying a thin polymer overlay

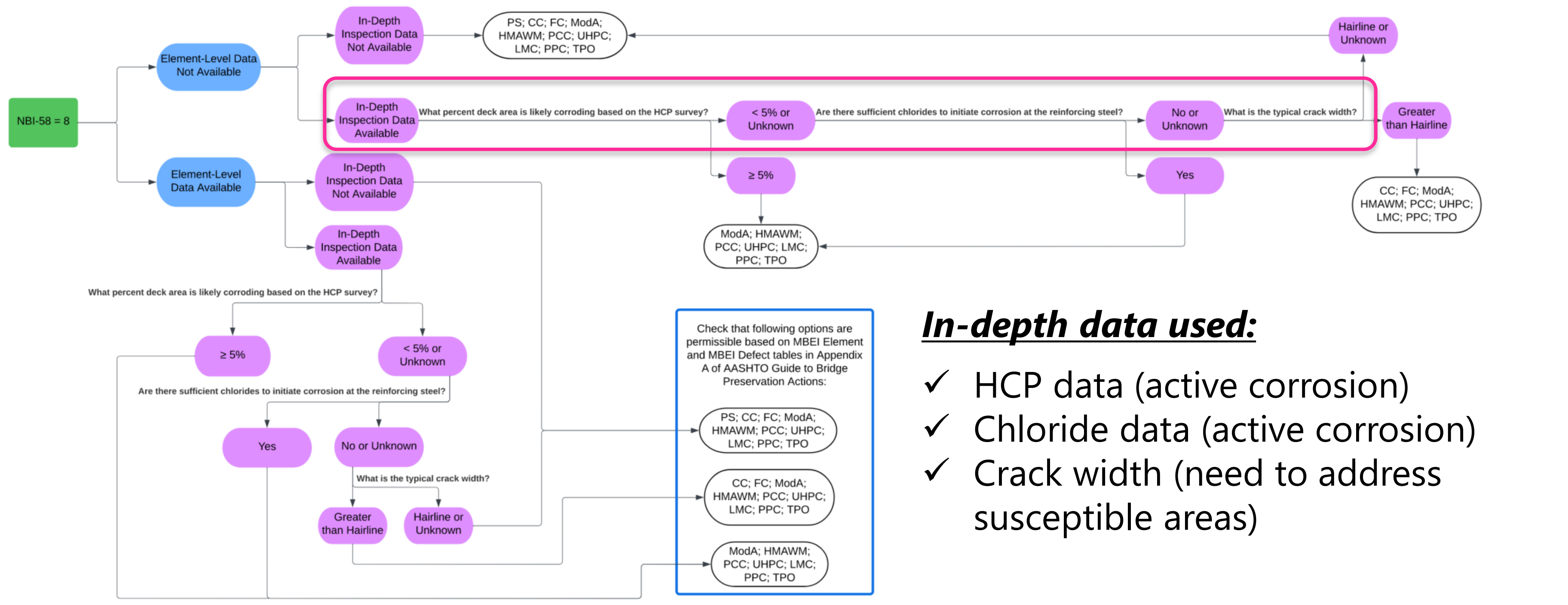
Decision Tree: NBI-58 of 9



In-depth data used:

- ✓ Crack width (need to address susceptible areas)

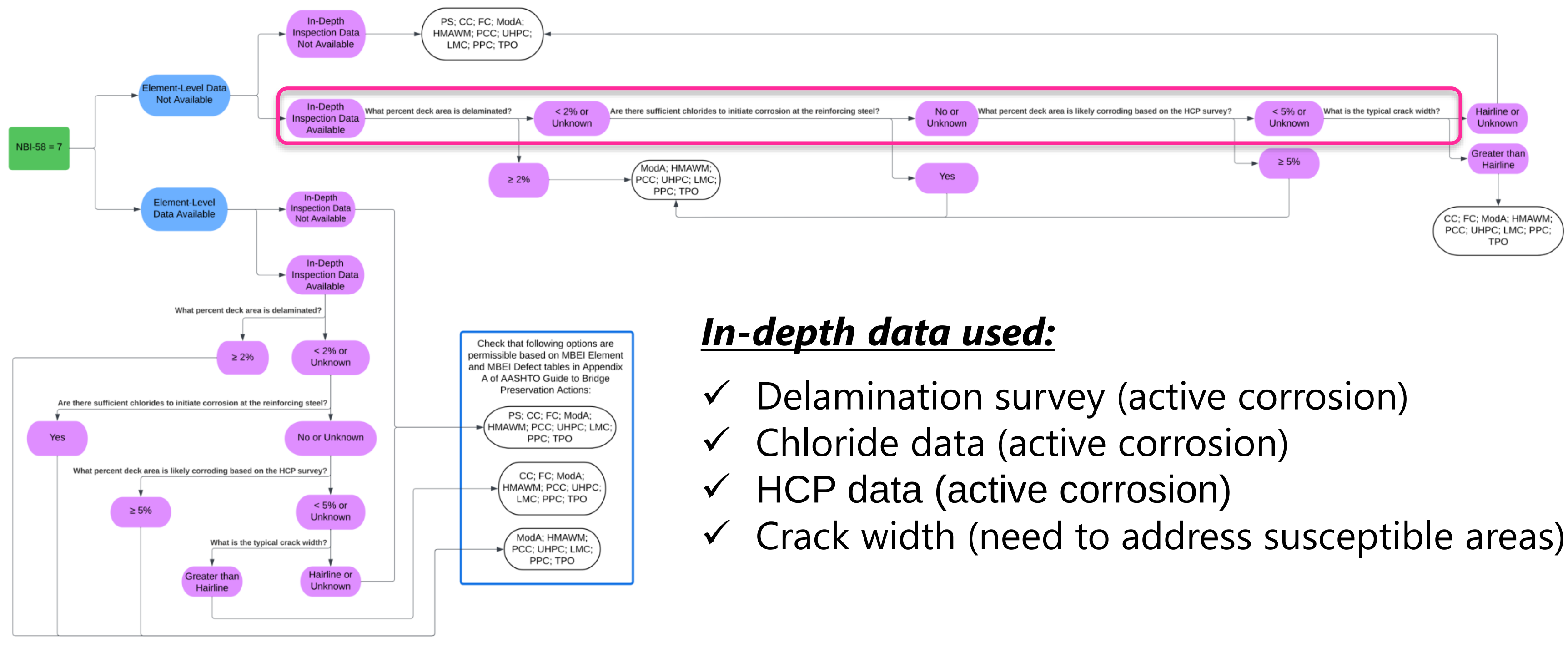
Decision Tree: NBI-58 of 8



In-depth data used:

- ✓ HCP data (active corrosion)
- ✓ Chloride data (active corrosion)
- ✓ Crack width (need to address susceptible areas)

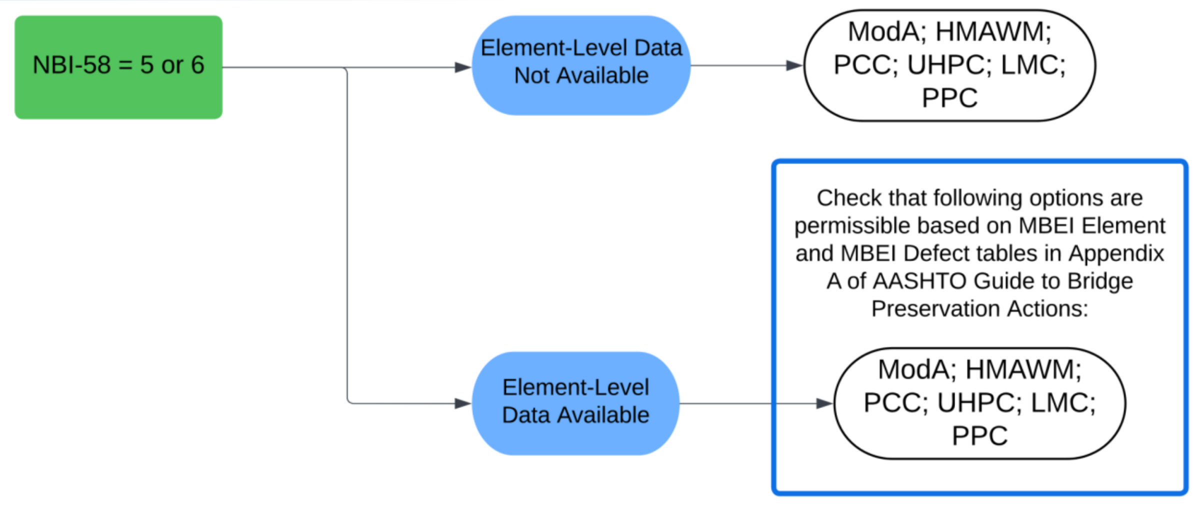
Decision Tree: NBI-58 of 7



In-depth data used:

- ✓ Delamination survey (active corrosion)
- ✓ Chloride data (active corrosion)
- ✓ HCP data (active corrosion)
- ✓ Crack width (need to address susceptible areas)

Decision Tree: NBI-58 of 5 or 6



- Assume [Cl-]-induced corrosion is present → no need for detailed inspection data

F&T Module Output

- ☑ Applying a penetrating sealer
- ☑ Crack-chasing
- ☑ Applying a floodcoat
- ☑ Applying a thin polymer overlay
- ☑ Applying an HMA overlay with a waterproofing membrane
- ☑ Applying a modified asphalt overlay
- ☑ Applying a rigid cementitious overlay
- ☑ Applying an LMC overlay
- ☑ Applying a PPC overlay
- ☑ Applying a UHPC overlay

SLEE, DM, & LCCA Algorithms

- Estimating service life benefits
- Extending deck service life
- Calculating life-cycle cost

Purpose of SLEE & DM Algorithms

- Service Life Extension Estimate (SLEE) Algorithm:
  - ~~Estimates service life extensions offered to the deck by the maintenance actions~~ Unless user gave estimate; then SLEE Algorithm not needed
- Deterioration Model (DM) Algorithm:
  - Updates deterioration model/forecasted conditions to reflect maintenance
    - Assume no condition improvement, but slowed deterioration rates
- Results from both algorithms are used to calculate life-cycle cost

SLEE Algorithm

$$SLEE_{deck} \approx SLE_{ma} = max\{SL_{upb} * f_{pec} * f_{Cl-} * f_{ADTT} * f_{FT} * f_{CR}, SL_{lob}\} * f_{bar}$$

$SLEE_{deck}$ = service life extension estimate experienced by deck
SLE_{ma} = service life estimate of the maintenance action
SL_{upb} = upper bound considered for the service life extension
SL_{lob} = lower bound considered for the service life extension

f_{pec} = reduction factor for pre-existing condition of the deck

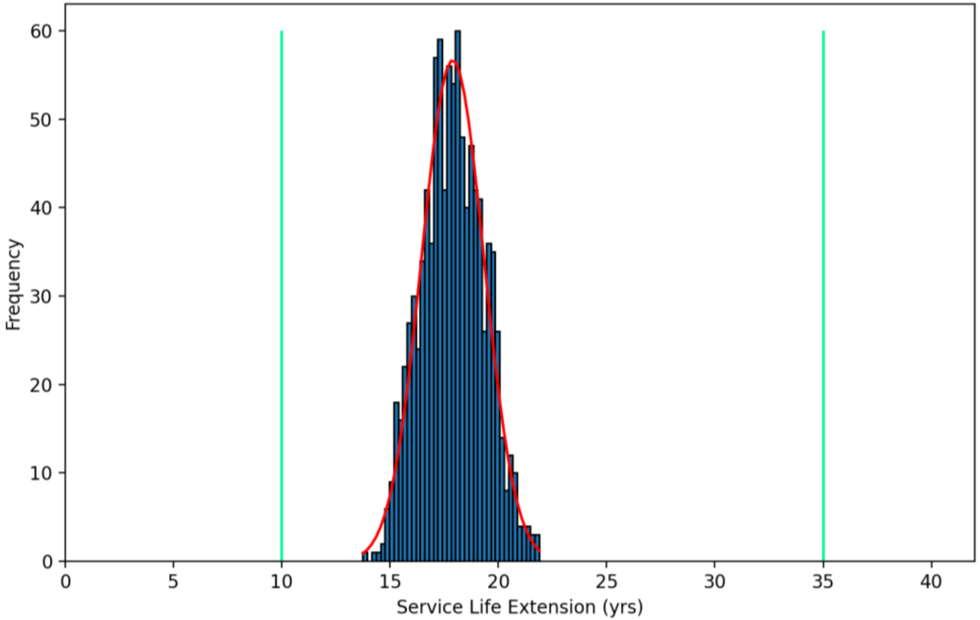
f_{Cl-} = reduction factor for severity of chloride exposure
f_{ADTT} = reduction factor for traffic exposure
f_{FT} = reduction factor for freeze-thaw cycling
f_{CR} = reduction factor for contractor experience & construction challenge

f_{bar} = "augmentation" factor for corrosion-resistant rebar

Probabilistic SLEE

- SLEE represented by a distribution rather than an exact number
- Monte Carlo simulation
  - Probabilistic inputs give probabilistic outputs

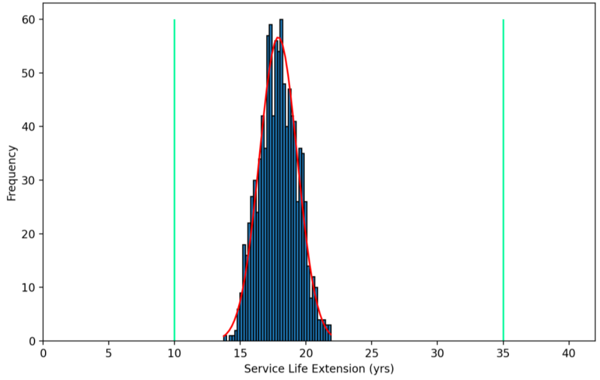
SLEE for Rigid Cementitious Overlay
High [Cl-], Low CR, PEC of 6



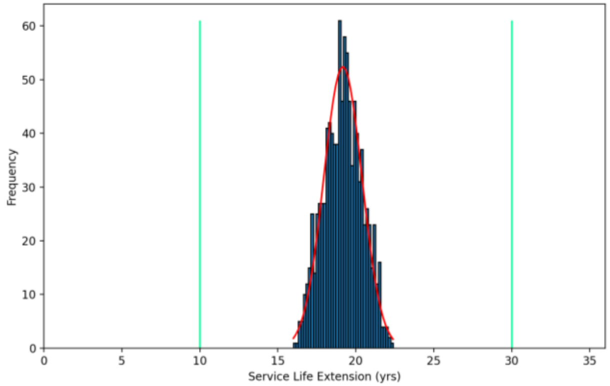
SLEE Output

- [ ] Applying a penetrating sealer
- [ ] Crack-chasing
- [ ] Applying a floodcoat
- [ ] Applying a thin polymer overlay
- [ ] Applying an HMA overlay with a waterproofing membrane
- [ ] Applying a modified asphalt overlay
- [x] Applying a rigid cementitious overlay
- [ ] Applying an LMC overlay
- [x] Applying a PPC overlay
- [ ] Applying a UHPC overlay

SLEE for Rigid Cementitious Overlay (High [Cl-], Low CR, PEC of 6)

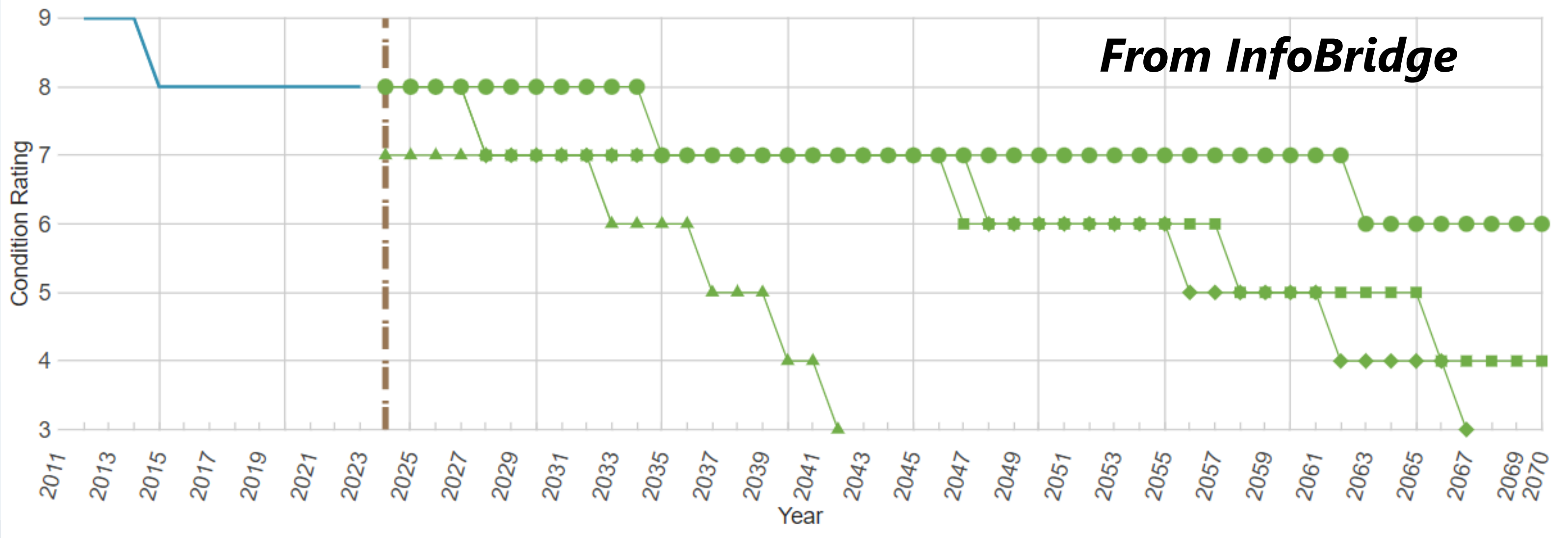


SLEE for PPC Overlay (High CR, PEC of 6)

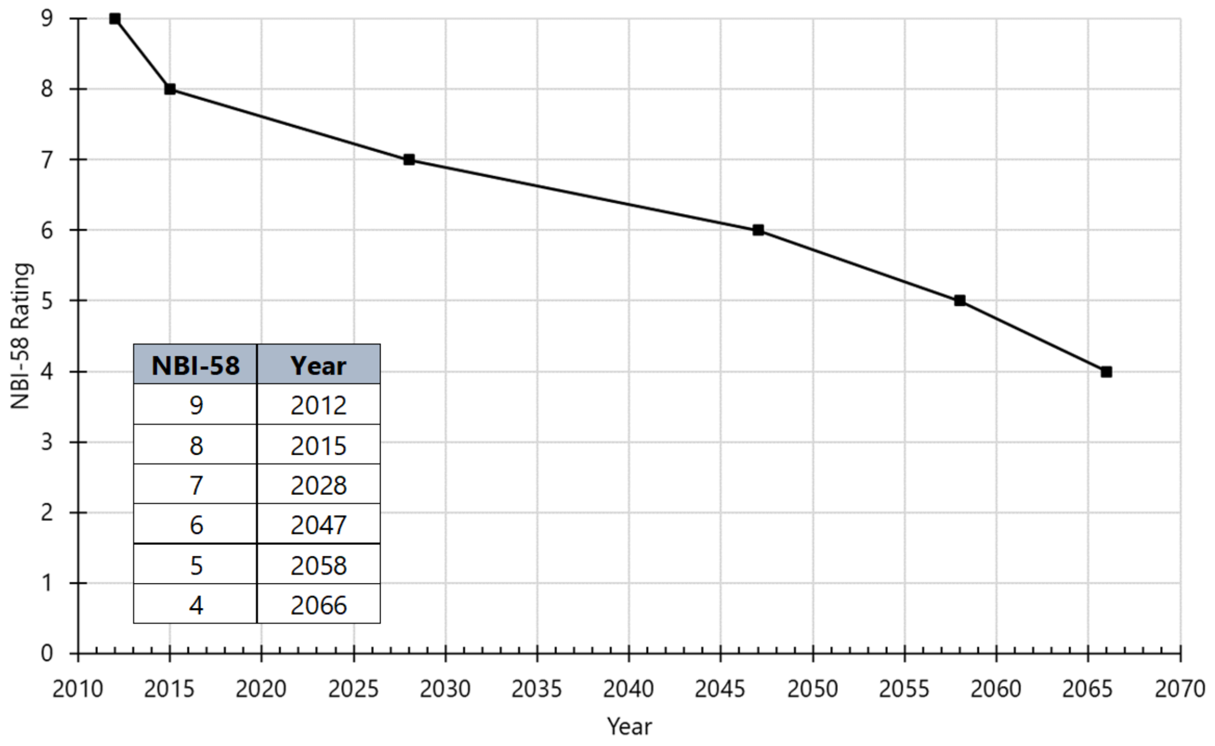


DM Algorithm

1. Deterioration model of "unmaintained" bridge deck (from User Inputs)
2. Adjust to reflect preventive maintenance
   - Assuming only deterioration rate is affected



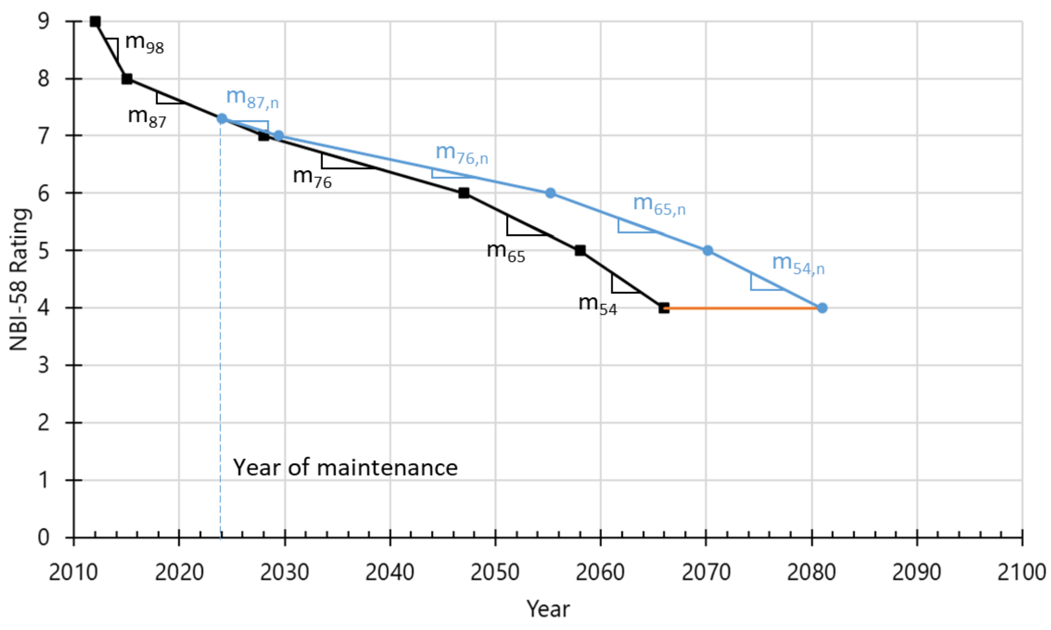
DM Algorithm: Model for Unmaintained Deck



NBI-58	Year
9	2012
8	2015
7	2028
6	2047
5	2058
4	2066

Interpreted by BDPT

DM Algorithm: Calculating Slowed Rates



1. Add SLEE to end of deck life.
2. Calculate adjustment ratio.
3. Draw DM of maintained deck using adjusted deterioration rates.

$$m_{ij,n} = \frac{m_{adj}}{m_{net}} m_{ij}$$

DM Algorithm Outputs

- Remaining service life of maintained deck
  - Expressed using 10th, 50th, and 90th percentiles of the SLEE

Used in LCCA

Slowed Deterioration Rate:

- Visual DM that is output to user
- Forecasted NBI-58 at end of life of maintenance action

Only needed if analyzing MAPs

LCCA Overview

- Defined cash flow:
  - Agency costs
    - Maintenance, rehabilitation costs
    - Replacement costs
    - Salvage value
  - User costs
    - E.g., travel delays

- Analysis period to make options comparable
- Future values discounted to present value:

$$PV = FV_n * \frac{1}{(1+r)^n}$$

n = age
r = discount rate

Activity/Maintenance Profile

Analyzing Maintenance Action Plans (MAPs)

- AUTO-GENERATION OF MAPS AND ANALYSIS OF THEIR SERVICE LIFE BENEFITS,

OR

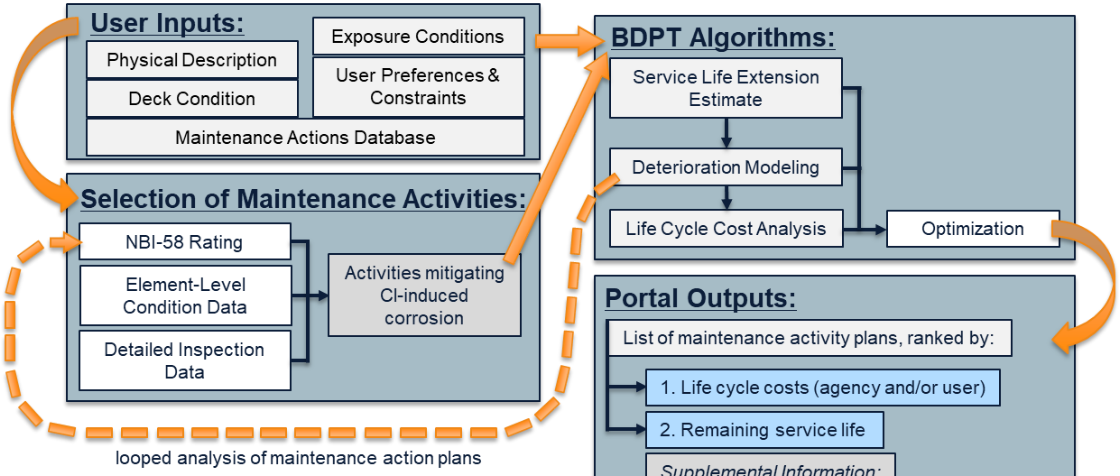
- ANALYSIS OF SERVICE LIFE BENEFITS OF USER-DEFINED MAPS

Auto-MAPs: The MAP Loop

Assumption:

Next maintenance action occurs at end of life of previous maintenance action.

1. F&T Module relies on NBI forecasted by DM Algorithm.
2. SLEE Algorithm:
   - Relies on F&T Module to select next maintenance actions to analyze.
   - Relies on forecasted NBI.
3. DM Algorithm relies on SLEE.



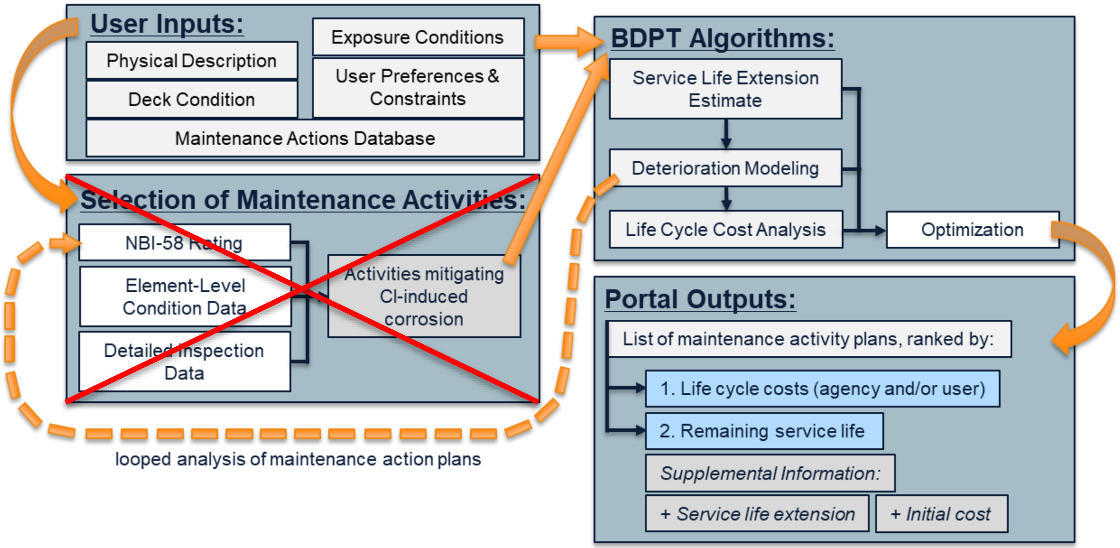
Note: Full life cycle must be characterized before conducting LCCA.

User-Defined MAPs: Sequence Only

Same assumption:

Next maintenance action occurs at end of life of previous maintenance action.

1. ~~F&T Module relies on NBI forecasted by DM Algorithm.~~
2. SLEE Algorithm:
   - ~~Relies on F&T Module to select next maintenance actions to analyze.~~
   - Relies on forecasted NBI.
3. DM Algorithm relies on SLEE.

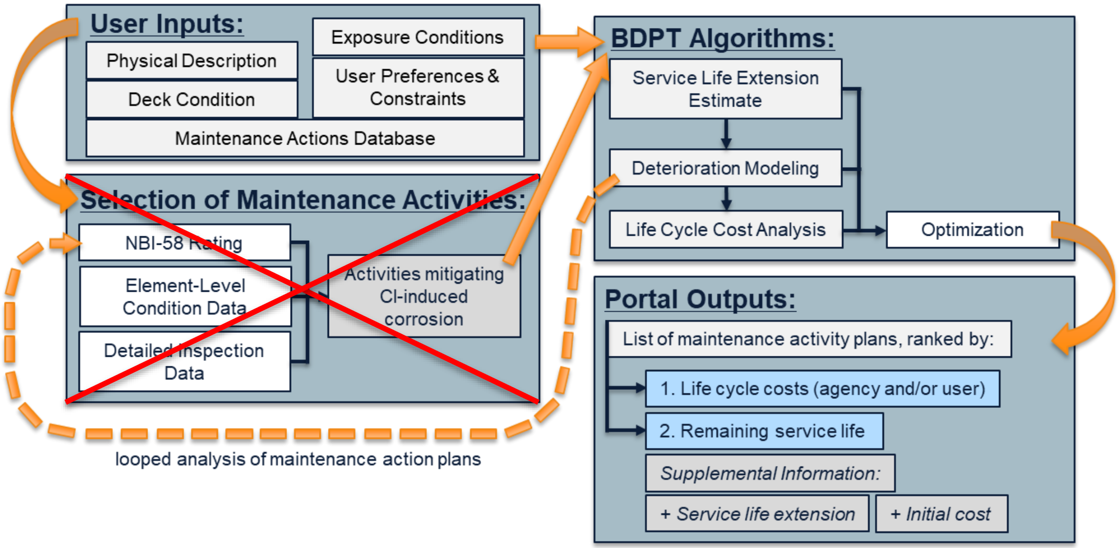


User-Defined MAPs: Sequence & Timing

~~**Same assumption:**~~

~~Next maintenance action occurs at end of life of previous maintenance action.~~

1. ~~F&T Module relies on NBI forecasted by DM Algorithm.~~
2. SLEE Algorithm:
   - ~~Relies on F&T Module to select next maintenance actions to analyze.~~
   - Relies on forecasted NBI.
3. DM Algorithm relies on SLEE.



Optimization Module & BDPT Outputs

- Ranking maintenance options based on service life benefits and costs

Optimization Module

- Linear Weighted Sum Method
  - Minimize agency life cycle costs
  - Maximize remaining service life of the deck
  - Minimize user life cycle costs

$$maximize\ Z_i = W_{LCCa}\left({}^{1}/_{S_{LCCa,i}}\right) + W_{LCCu}\left({}^{1}/_{S_{LCCu,i}}\right) + W_{RSL}S_{RSL,i}$$

Scaled values:

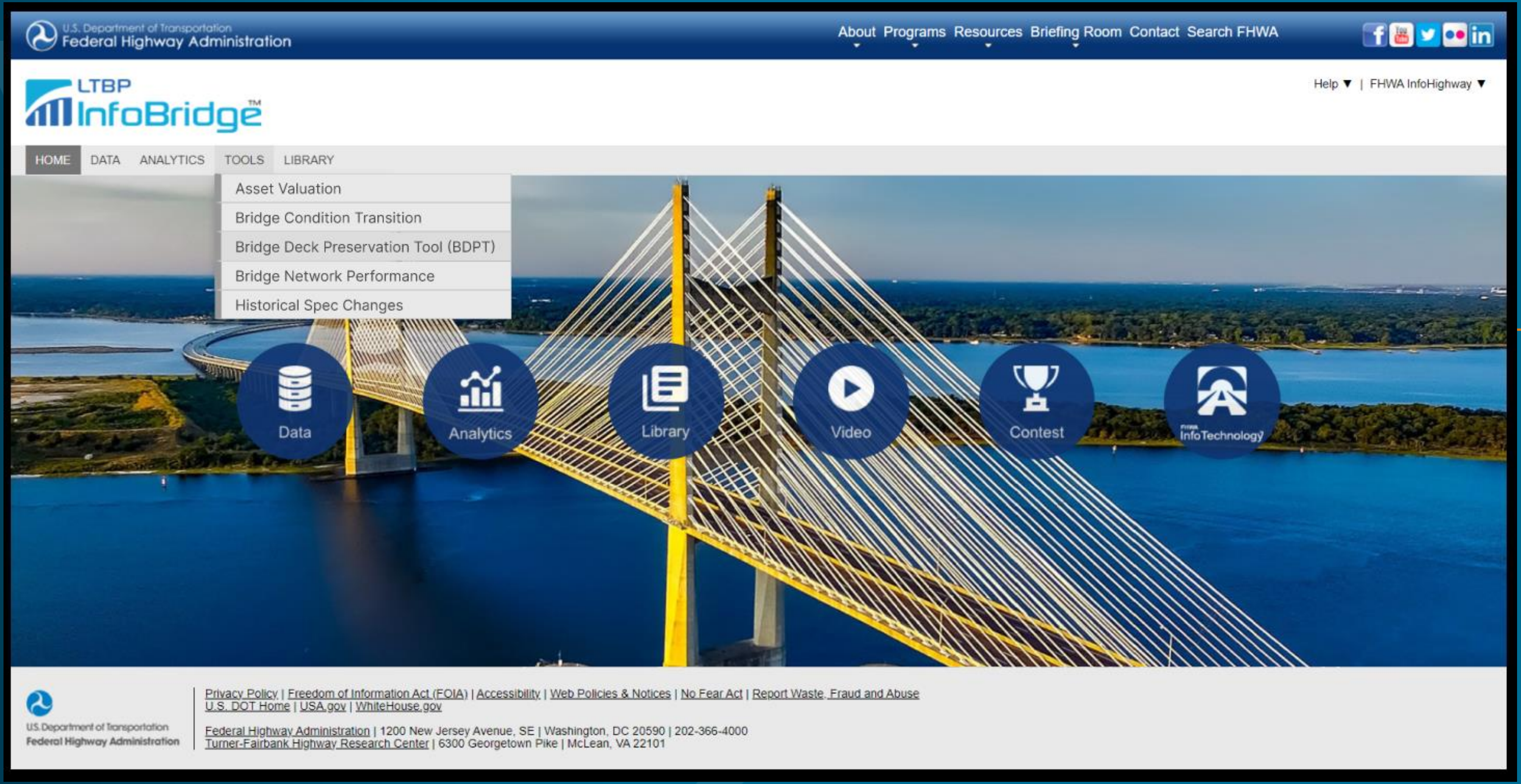
$$S_{LCCa,i} = \frac{LCCa_i}{max\{LCCa_1, LCCa_2, \dots, LCCa_N\}}$$

$$S_{RSL,i} = \frac{RSL_i}{max\{RSL_1, RSL_2, \dots, RSLu_N\}}$$

BDPT Outputs:

Ranked list of maintenance options, with:

- Initial cost
- Agency life cycle cost
- User life cycle cost (if analyzed)
- Remaining service life of deck before replacement
- Service life extension
- Plot of deterioration model for maintained deck, assuming slowed deterioration rates
- Z-value (objective function)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Questions?

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