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OHIO DEPARTMENT OF TRANSPORTATION

A NOVEL COST AND CONDITION BASED INDEX FOR ASSESSMENT OF BRIDGES

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Outline

- Introduction
- Overview of OBCI
  - Features of OBCI
  - Framework of OBCI
  - $OBCI_{min}$ & $OBCI_{current}$
- Calculations of cost terms in OBCI
- Case Study 1: Detailed analysis of OBCI for one bridge
  - Element-, component-, and bridge-level $OBCI_{min}$ & $OBCI_{current}$
  - Assisting in decision-making
  - Capability of OBCI in reflecting serviceability parameters in the index
- Summary and Conclusions

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Introduction

- Bridges are key components in transportation systems that support mobility in the nation.
- They are diverse in **type**, **configuration** and **age**, and are exposed to various **environmental** and **traffic conditions**.
- These factors pose a **major challenge** for **performance evaluation** and **management** of bridges.
- Furthermore, each state is responsible for managing **a large number of bridges**, while its **budget** is **limited**.
- **Bridge indices** are then used for the management of such large assets.

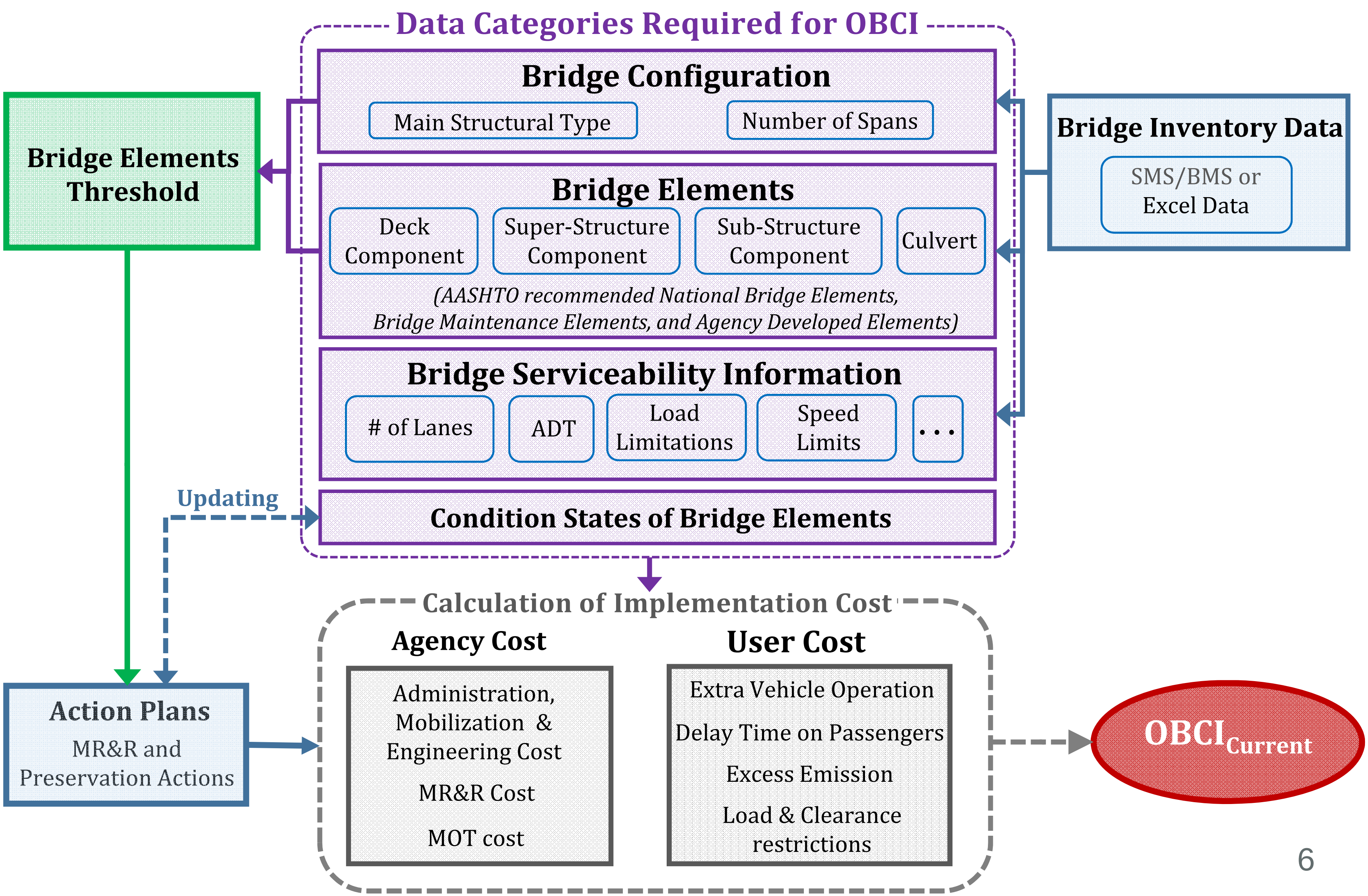
Overview of OBCI
: Features of OBCI

OBCI has the following features

- Evaluates bridge conditions at **element**-, **component-, bridge**-, and **network-**levels.
- Reflects objectively **negative effects of defects**, and **positive impacts of improving actions** in the index.
- Represents the **needs** of bridges to reach a **target state**.
  - For objectivity, needs are expressed in terms of **cost** as a **unified measure**; removes biasness from weight factors.
  - For comprehensiveness, needs account for **all direct** and **indirect consequences** for **agencies and users.**
- Is based on the recent **AASHTO condition-state** rating system.

Overview of OBCI
: Features of OBCI

- To assure **minimum level of safety and serviceability**, state DOTs set up target conditions **at components-, bridges-levels**:
  - E.g. Ohio defines 15% as the maximum allowable percentage for the area of its bridge decks with NBI general appraisal ratings less than 5.
- In line with AASHTO condition-states, **at element-level**, we have defined the following minimum condition-state thresholds:
  - The percentage of NBE, defects and primary elements of ADE in condition-states 3 should be less than 2%, while no quantities of these elements should be in condition-state 4.
  - The percentage of BME and non-primary ADE in condition-state 3 and 4 should be less than 10%.


Data Categories Required for OBCI
Bridge Configuration
Main Structural Type
Number of Spans
Bridge Elements
Deck Component
Super-Structure Component
Sub-Structure Component
Culvert
(AASHTO recommended National Bridge Elements, Bridge Maintenance Elements, and Agency Developed Elements)
Bridge Serviceability Information
# of Lanes
ADT
Load Limitations
Speed Limits
. . .
Condition States of Bridge Elements
Bridge Elements Threshold
Bridge Inventory Data
SMS/BMS or Excel Data
Updating
Action Plans
MR&R and Preservation Actions
Calculation of Implementation Cost
Agency Cost
Administration, Mobilization & Engineering Cost
MR&R Cost
MOT cost
User Cost
Extra Vehicle Operation
Delay Time on Passengers
Excess Emission
Load & Clearance restrictions
OBCI Current

Overview of OBCI
: Formulation of $OBCI_{min}$

- In $OBCI_{min}$ the target is: all elements of the system **reach** their **minimum thresholds**.

Need to meet min thresholds for that system in the worst condition

$$OBCI_{min} = 1 - \frac{\sum need\ to\ meet\ min\ thresholds(\$)}{replacement\ cost(\$)}$$

- The need is the imposed costs on users and agencies because of MR&R actions to make all elements reach their minimum thresholds.

- An ideal $\boldsymbol{OBCI_{min}}$ should be equal to **1**;
  - All elements are in condition-states **above their minimum thresholds** and thus the bridge is **structurally/operationally acceptable**.

Overview of OBCI
: *Formulation of* $OBCI_{min}$

- As a particular case, for element-level, $\boldsymbol{OBCI_{min}}$ is defined as follows:

The cost to bring the element to the minimum threshold

If below the threshold, the required cost to repair portions of element in CS3 and CS4.

Element−Level cost

$$OBCI_{min} = 1 - \frac{\left(MOT_E^{min} + AEM_E^{min} + MR\&R_E^{min}\right) + \left(LCR_E^{min} + DVE_E^{min}\right)}{\left(MOT_E^{rep} + AEM_E^{rep} + MR\&R_E^{rep}\right) + \left(LCR_E^{rep} + DVE_E^{rep}\right)}$$

Replacement cost

- *MOT=Agency cost of Maintenance Of Traffic*
- *AEM=Agency cost of Administration, Engineering and Mobilization*
- *MR&R =Agency cost of applying Maintenance, Repair and Rehabilitation*
- *LCR=User cost from Load and Clearance Restrictions*
- *DVE=User cost from delay time, vehicle operation, and excess emission*

Overview of OBCI

: Formulation of $OBCI_{current}$

- In $OBCI_{current}$ the target is: all elements of the system **meet their like-new state**:
    - Portions of the element in **CS3 and CS4**, should be **repaired** to be improved to at least CS2.
    - Portions of the element in **CS2** should be **maintained** to stay in CS2.

The cost to bring the element to the like−new state

Element−Level cost

$$OBCI_{current} = 1 - \frac{(MOT_E^1 + AEM_E^1 + MR\&R_E^1) + (LCR_E^1 + DVE_E^1)}{(MOT_E^{rep} + AEM_E^{rep} + MR\&R_E^{rep}) + (LCR_E^{rep} + DVE_E^{rep})}$$

Replacement cost

Cost Terms in OBCIs

: MR&R Costs

- MR&R costs are calculated at element-level, depending on:
  - Material and type of elements.
  - The current condition-state of the elements.
  - The target condition-state of the elements.

Element	Condition Before	Condition After 1		Condition After 2		Condition After 3		Condition After 4	
Floorbeams /Steel	1	Do nothing	0.00						
		Surface clean	17.15						
	2	Replace unit	275.06	Do nothing	0.00				
				Power tool clean and paint	22.40				
				Replace paint system	98.00				
	3	Replace unit	275.06	Power tool clean and paint	44.80	Do nothing	0.00		
				Replace paint system	98.00				
				Major Rehab	222.79				
	4	Replace unit	275.06					Do nothing	0.00

- For component-level MR&R costs: **reduction factor** of **0.80** is considered.
- For bridge-level MR&R costs: **reduction factor** of **0.90** is considered.

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Cost Terms in OBCIs
: MOT Costs

- MOT costs are calculated based on:
  - Ohio reported costs per hour for crew, equipment, and police.
    - $260/hour, with 60% for workers, and 40% for equipment.
    - $65/hour for law enforcement.
  - Logical considerations for the times and conditions that crew, equipment, and police are in the work site.
    - On average, laborers work 8 hours/day.
    - Law enforcement is present only on weekdays when more than 40% of the road is closed.

$$MOT_l^t = \left(8 \times T_l^{t'} \times \$260 + 8 \times T_l^{t'} \times F^{N_{Cl}} \times \$65 + 16 \times T_l^{t'} \times 0.4 \times \$260\right) + \left(2 \times \left\lfloor \frac{T_l^{t'}}{7} \right\rfloor \times 24 \times 0.4 \times \$260\right)$$

Cost incurred in working hours

Duartion

Equipment cost incurred during other times in the working days

Equipment cost incurred on

Cost Terms in OBCIs

: Work Duration

- A primary input to the calculation of MOT, DVE and LCR costs is the duration of MR&R actions.

- Correct identification of these values is important to arrive at accurate OBCI.

- For automation of estimating element-level durations of work plans:

  1) Elements are categorized based on their cost units and materials.

  2) For each category, a formula is developed that calculates the duration as a function of the quantity of element, and the type of action, i.e. repair or replacement.

Number of bearing devices to repair

$$T_e^{repair} = RF \times \left(N_e \times 1 \frac{day}{each} \right) \geq 1day$$

Reduction Factor

$$\frac{1}{\left(1 + \frac{N_e}{100} \times 3\right)} \geq \frac{1}{4}$$

Cost Terms in OBCIs
: DVE Costs

- DVE cost is systematically calculated as follows:

$$DVE_i^t = T_i^t \times (t_{ij}^{D/R} - t_{ij}^{O}) \times [(ADT - ADTT) \times \rho_C + ADTT \times \rho_T]$$

Extra time spent by drivers

unit user cost for cars

unit user cost for trucks

$$= t_{ij}^{F} \times \left[1 + \alpha \left(\frac{f_{ij}}{f_{ij}^{c}}\right)^{\beta}\right] + \sum_{b \epsilon ij} s_{b,ij} \times t_{b,ij}^{d} \times \left[1 + \alpha \left(\frac{s_{b,ij}.f_{ij}}{f_{b,ij}^{c}}\right)^{\beta}\right] - t_{ij}^{O} \times \left[1 + \alpha \left(\frac{f_{ij}}{f_{ij}^{c}}\right)^{\beta}\right]$$

Passing time for drivers taking the partially/complete closed bridge

Extra passing time for drivers taking the detour

Passing time when the bridge is fully open

- It uses serviceability data form **inventory documents**, including: ADT, ADTT, detour length, number of lanes on the bridge, number of traffic directions.
- It is based on **logical assumptions** and **considerations** for other required parameters, such as $\boldsymbol{s_{b,ij}}$.

Cost Terms in OBCIs
: DVE Costs

- DVE cost is systematically calculated as follows:

$$DVE_i^t = T_i^t \times (t_{ij}^{D/R} - t_{ij}^O) \times [(ADT - ADTT) \times \rho_C + ADTT \times \rho_T]$$

Extra time spent by drivers

unit user cost for cars

unit user cost for trucks

$$= t_{ij}^F \times \left[1 + \alpha \left(\frac{f_{ij}}{f_{ij}^c}\right)^\beta\right] + \sum_{b \epsilon ij} s_{b,ij} \times t_{b,ij}^d \times \left[1 + \alpha \left(\frac{s_{b,ij}.f_{ij}}{f_{b,ij}^c}\right)^\beta\right] - t_{ij}^O \times \left[1 + \alpha \left(\frac{f_{ij}}{f_{ij}^c}\right)^\beta\right]$$

Passing time for drivers taking the partially/complete closed bridge

Extra passing time for drivers taking the detour

Passing time when the bridge is fully open

- o DVE cost is sensitive to **number of closed lanes**, since this parameter determines the ratio of vehicles taking detour, $\boldsymbol{s_{b,ij}}$.
- o An **optimization procedure** is developed to identify this factor, by:
  - Finding the scenario for the number of closed lanes that minimizes the incurred costs of MOT and DVE.

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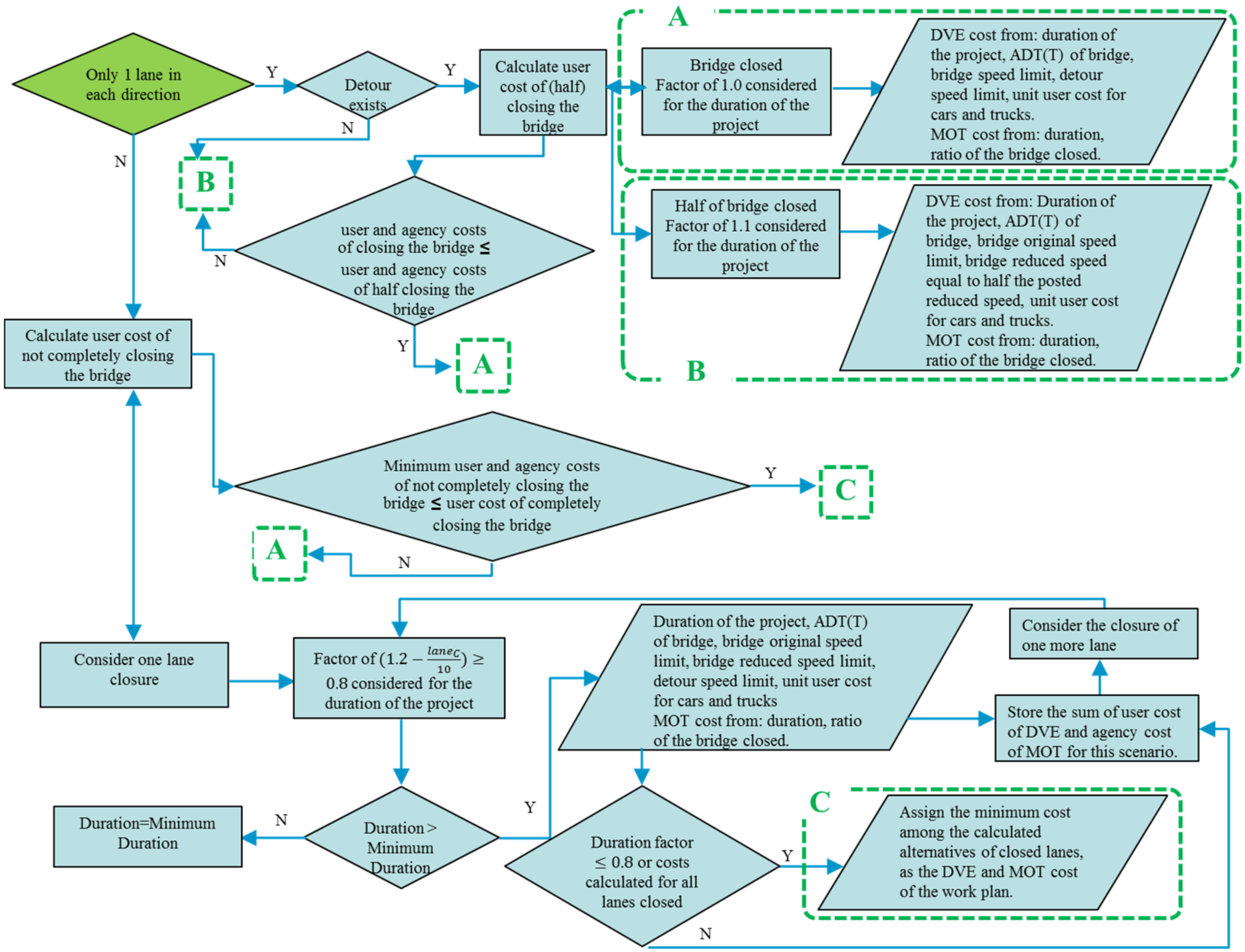
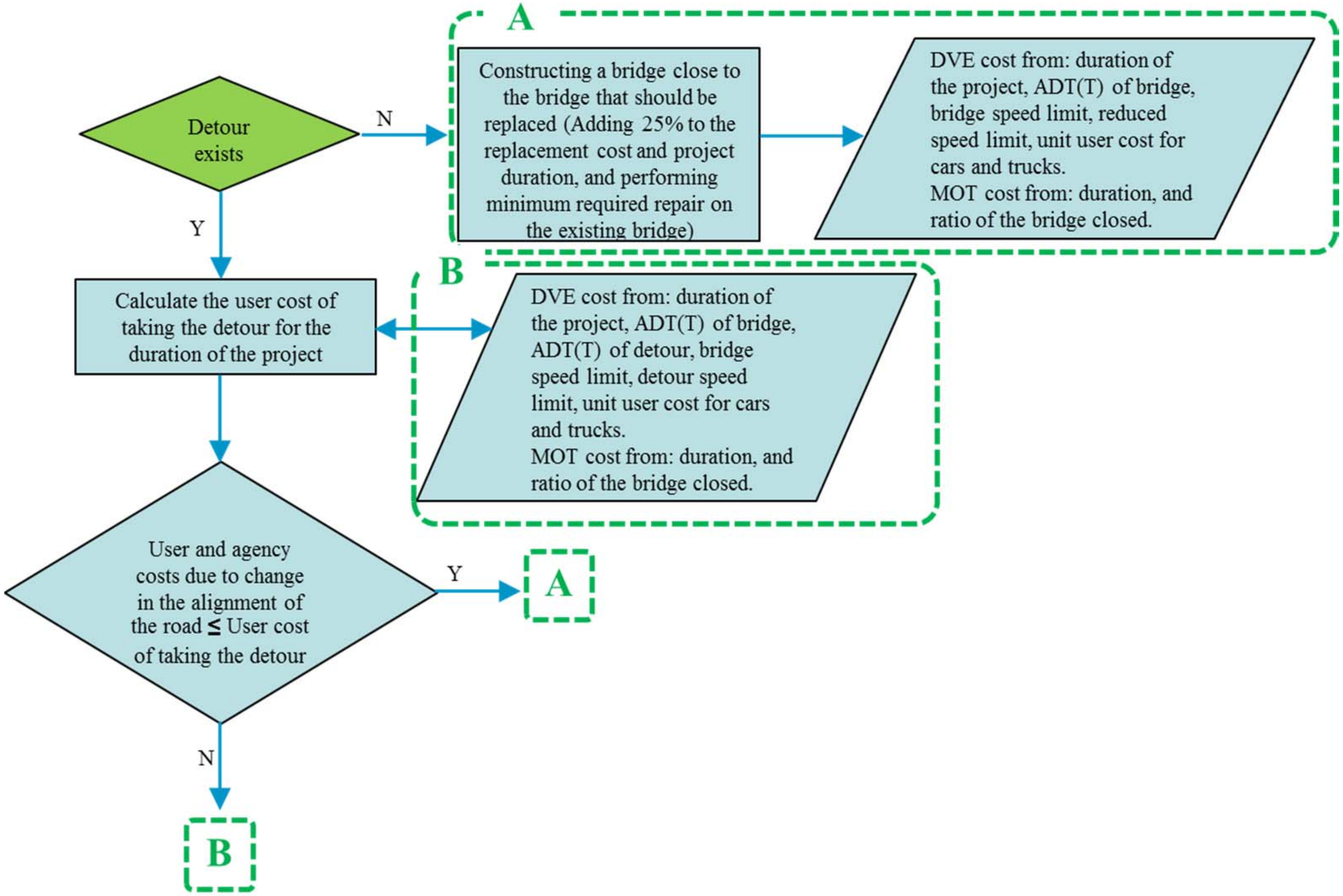
Cost Terms in OBCIs
: Calculation of MOT and DVE Costs

- The flowchart for the calculation of optimized MOT and DVE costs for **repair** work plans is presented here:



Cost Terms in OBCIs
: Calculation of MOT and DVE Costs

- The flowchart for the calculation of optimized MOT and DVE costs for **replacement** work plans is shown here:



Cost Terms in OBCIs
: LCR and AEM Costs

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- LCR cost can be calculated in the same way as DVE cost:

$$LCR_l^t = T_l^t \times (t_{ij}^{D/R} - t_{ij}^{O}) \times [ADTT^R \times \rho_T]$$

Extra time spent by drivers

percentage of restricted trucks that should take the available detour

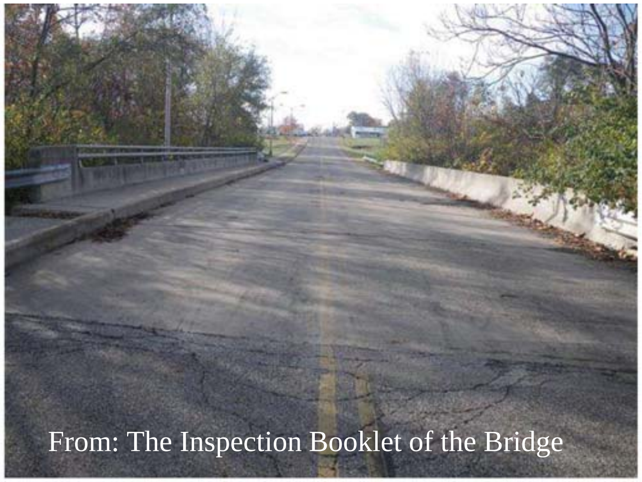
- AEM cost is calculated as follows:

$$AEM_l^t = \beta \times (MOT_l^t + MR\&R_l^t)$$

Overhead factor=0.25

Evaluation of OBCI for: Case Study 1

- For the demonstration of OBCI, a bridge in Ohio is selected:
  - A two way, two lane bridge with three main spans and nine continuous prestressed box beams, passing over a river.
  - It has a low ADT of 50, and is on a path with no detour.
  - Element-level inspection data is available for this bridge.



From: The Inspection Booklet of the Bridge

Evaluation of OBCI for: Case Study 1

Component	Element	Unit	QTY	Condition-State			
				CS1	CS2	CS3	CS4
Approach Items	Approach Wearing Surface	Each	2	0	2	0	0
	Approach Slab	SF	810	146.5	405	202.5	56
	Embankment	Each	4	0	0	0	4
	Guardrail	Each	4	4	0	0	0
Deck Items	Floor/Slab	SF	3795	3783	4	8	0
	Wearing Surface	SF	2970	1140	1140	540	150
	Curb/Sidewalk/Walkway	LF	110	105	5	0	0
	Railing	LF	220	180	30	10	0
	Drainage	Each	2	0	0	2	0
	Expansion Joint	LF	69	14	15	40	0
Superstructure Items	Alignment	Each	3	3	0	0	0
	Beams/Girders	LF	990	987	1	2	0
	Bearing Device	Each	72	72	0	0	0
Substructure Items	Abutment Walls	LF	70.06	61.1	9	0	0
	Pier Caps	LF	70.1	69.1	0	1	0
	Pier Columns/Bents	Each	4	4	0	0	0
	Wingwalls	Each	4	4	0	0	0
	Scour	Each	4	4	0	0	0
	Slope Protection	Each	2	2	0	0	0
Channel Items	Alignment	LF	200	200	0	0	0
	Protection	LF	200	200	0	0	0
	Hydraulic Opening	EA	4	4	0	0	0
Sign Items	Utilities	LF	220	220	0	0	0

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Evaluation of OBCI for: Case Study 1

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	0.78	0.950	0.56	0.57	0.895
	Approach Slab	0.62			0.42		
	Embankment	0.00			0.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	0.90		0.98	0.82	
	Wearing Surface	0.76			0.58		
	Curb/Sidewalk/Walkway	1.00			0.87		
	Railing	0.93			0.86		
	Drainage	0.56			0.56		
	Expansion Joint	0.70			0.70		
Superstructure Items	Beams/Girders	1.00	1.00		0.96	0.99	
	Bearing Device	1.00			1.00		
Substructure Items	Abutment Walls	1.00	1.00		0.97	0.99	
	Pier Caps	1.00			0.97		
	Pier Columns/Bents	1.00			1.00		
	Wingwalls	1.00			1.00		
	Slope Protection	1.00			0.90		
Channel Items	Alignment	1.00	1.00		1.00	1.00	
	Protection	1.00			1.00		
	Hydraulic Opening	1.00			1.00		
Sign Items	Utilities	1.00	1.00		1.00	1.00	

Evaluation of OBCI for: Case Study 1

Work Plan	Description	Agency cost of the work plan	Duration (days)	$OBCI_{current}$	BHI
0	Condition of the bridge after inspection	-	-	**0.895**	0.944
A	Perform minimum required repair on elements with $\mathbf{OBCI_{min}}$<1	$130,810	9	**0.928**	0.961
B	Improve approach elements to like-new, and perform minimum required repair on other elements with $\mathbf{OBCI_{min}}$<1	$212,800	12	**0.951**	0.961
C	Improve deck elements to like-new, and perform minimum required repair on other elements with $\mathbf{OBCI_{min}}$<1	$233,620	13	**0.966**	0.961

- Deck and approach components have the lowest OBCI (the only components with $\mathbf{OBCI_{min}}$<1). MR&R work plans are suggested for these components.
- Generally, more effective and costly improving actions result in more increase in OBCI.
- However, BHI:
  - Just improves by 1.8%, even after costly work plans B and C.
  - Is not sensitive to maintenance actions that keep the portions in CS2.

Evaluation of OBCI for: Case Study 1

- A sensitivity analysis is performed to show the ability of OBCI in reflecting the effect of variations in serviceability parameters such as ADT.

	ADT			
	Original ADT of the bridge (50)	25% of the capacity	50% of the capacity	75% of the capacity
$\mathbf{OBCI}_{Current}$-**Before** Work Plan A*	**0.90**	**0.85**	**0.78**	**0.51**
$\mathbf{OBCI}_{Current}$-**After** Work Plan A*	**0.93**	**0.89**	**0.86**	**0.63**

* Work Plan A: Perform minimum required repair on elements with $\mathbf{OBCI}_{\mathbf{min}}$<1

- OBCI is sensitive to the ADT value, which directly affects the user cost.
- As the ADT values increase, the advert consequences of maintaining/repairing actions on users become more significant compared to agency costs; therefore OBCI decreases.

Summary and Conclusion

- OBCI is a cost-based index that evaluates bridge performance at different levels of **element-**, **component-**, and **bridge-levels.**
- $OBCI_{min}$ is calculated based on **cost incurred** to reach the **minimum safe and serviceable** state of the system.
- $OBCI_{current}$ is calculated based on **cost incurred** to reach the **like-new** state of the system.
- Results show, as expected, the more severe the condition state of an element/component, the lower the corresponding values of OBCI.
- OBCI is shown to be helpful in **decision-making** among various work plan alternatives.

Summary and Conclusion

- Unlike BHI, OBCI is shown to be fully capable of reflecting the impact of **defects** as well as **condition enhancements** achieved by improving actions.
- In addition to agency costs, OBCI reflects the impact of user cost due to repair actions in the performance of bridges.
- OBCI **objectively** calculates a **comprehensive list of consequences**, yet it is **practical**, since:
  - For each bridge, it only requires **inventory appraisal document**, and **inspection report**.

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Thank You!

Outline

- Various indexes have been developed for different purposes. Some of these metrics include:
  - NBI rating, GA rating, SD, FO, Sufficiency rating, Vulnerability rating, BHI, BPI, … .
- These indexes are mostly developed through **subjective weight factors**, or do not consider **all consequences.**
- Thus, in collaboration with ODOT, an objective, comprehensive and practical performance measure, is developed .
- The index is called **Ohio Bridge Condition Index (OBCI)**.

Evaluation of OBCI for: Case Study 2

Inventory Bridge No.	Bridge Type	Year Built	No. of Spans	No. of lanes	Length (FT)	ADT	Detour length
Bridge 2	CONCRETE/ SLAB/CONTINUOUS	1963	3	2	79.5	28,620	1
Bridge 3	STEEL/BEAM/ CONTINUOUS	1973	2	8	113.8	139,740	1
Bridge 4	STEEL/BEAM/SIMPLE	1973	1	8	120.7	139,740	1
Bridge 5	STEEL/BEAM/ CONTINUOUS	1973	3	2	132.3	31,970	1
Bridge 6	STEEL/BEAM/ CONTINUOUS	1968	3	3	178.0	30,795	1
Bridge 7	STEEL/CULVERT/ FILLED	1971	1	4	88.0	31,000	4
Bridge 8	PRESTRESSED CONCRETE/BOX BEAM/SIMPLE	1967	16	2	805.8	3,511	0

Evaluation of OBCI for: Case Study 2

- As a general trend, while not always true, elements/components/bridges with more severe condition-states, have lower OBCI values.
- OBCI of an element does not necessarily become 0 if the condition-state of all portions of that element is 4:
  - This is because the action of improving to condition 2 exists and its cost is less than the replacement cost (e.g. the backwall element of Bridge 6).
- The value of OBCI changes with the variation of user cost. This cost depends on factors such as:
  - ADT, availability of detours and the duration of the work plans.
- $OBCI_{min}$ and $OBCI_{current}$ are not only directly proportional to the severity of the condition-states if:
  - Contribution of user cost is at the same level or more than that of MR&R costs.

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Evaluation of OBCI for: Bridge 2

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	0.10	0.57	**0.84**	0.10	0.44	**0.54**
	Approach Slabs	1.00			0.51		
	Embankment	1.00			1.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	0.98		0.95	0.92	
	Edge of Floor/Slab	0.58			0.17		
	Wearing Surface	1.00			0.96		
	Railing	1.00			1.00		
	Drainage	1.00			0.72		
	Expansion Joint	1.00			1.00		
Superstructure Items	Slab	1.00	1.00		0.95	0.95	
Substructure Items	Abutment Walls	0.91	0.99		0.78	0.80	
	Pier Caps	1.00			1.00		
	Pier Columns/Bents	1.00			0.76		
	Wingwalls	1.00			1.00		
	Scour	1.00			1.00		
	Slope Protection	1.00			1.00		
Channel Items	Alignment	1.00	1.00		1.00	1.00	
	Hydraulic Opening	1.00			1.00		

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Evaluation of OBCI for: Bridge 3

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	1.00	0.995	0.44	0.69	0.85
	Approach Slabs	1.00			0.99		
	Embankment	1.00			1.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	0.995		0.99	0.99	
	Edge of Floor/Slab	1.00			0.80		
	Wearing Surface	1.00			0.99		
	Median	1.00			1.00		
	Railing	1.00			0.88		
	Expansion Joint	0.82			0.82		
Superstructure Items	Beams/Girders	1.00	1.00		1.00	0.89	
	Diaphragm/X-Frames	1.00			1.00		
	Bearing Devices	1.00			0.76		
	Prot. Coating System	1.00			0.52		
Substructure Items	Abutment Walls	1.00	0.996		0.98	0.99	
	Pier Caps	0.96			0.96		
	Pier Columns/Bents	1.00			1.00		
	Backwalls	1.00			0.96		
	Wingwalls	1.00			1.00		
Sign Items	Signs	1.00	1.00		1.00	1.00	
	Sign Supports	1.00			1.00		
	Utilities	1.00			1.00		

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Evaluation of OBCI for: Bridge 4

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	1.00	**0.97**	1.00	0.99	**0.91**
	Approach Slabs	1.00			0.99		
	Embankment	1.00			1.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	0.99		0.996	0.99	
	Edge of Floor/Slab	1.00			1.00		
	Wearing Surface	1.00			0.99		
	Median	1.00			1.00		
	Railing	1.00			1.00		
	Expansion Joint	0.81			0.81		
Superstructure Items	Beams/Girders	1.00	0.98		0.98	0.86	
	Diaphragm/X-Frames	1.00			0.97		
	Bearing Devices	0.88			0.64		
	Prot. Coating System	1.00			0.52		
Substructure Items	Abutment Walls	0.97	0.98		0.95	0.97	
	Backwalls	0.97			0.95		
	Wingwalls	1.00			1.00		
Sign Items	Utilities	0.12	0.12		0.12	0.12	

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Evaluation of OBCI for: Bridge 5

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Deck Items	Floor/Slab	1.00	0.97	**0.97**	0.95	0.92	**0.83**
	Edge of Floor/Slab	1.00			1.00		
	Wearing Surface	0.93			0.88		
	Median	1.00			1.00		
	Railing	1.00			0.90		
Superstructure Items	Beams/Girders	0.96	0.99		0.69	0.75	
	Diaphragm/X-Frames	1.00			0.75		
	Bearing Devices	1.00			1.00		
	Prot. Coating System	1.00			0.59		
Substructure Items	Abutment Walls	1.00	1.00		1.00	1.00	
	Pier Caps	1.00			1.00		
	Pier Columns/Bents	1.00			1.00		
	Backwalls	1.00			1.00		
	Wingwalls	1.00			1.00		
	Slope Protection	1.00			1.00		

Evaluation of OBCI for: Bridge 6

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	0.70	**0.85**	1.00	0.53	**0.80**
	Approach Slabs	0.56			0.32		
	Embankment	1.00			1.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	1.00		0.97	0.98	
	Edge of Floor/Slab	1.00			0.88		
	Wearing Surface	1.00			1.00		
	Railing	1.00			1.00		
	Expansion Joint	1.00			1.00		
Superstructure Items	Beams/Girders	0.98	0.86		0.98	0.83	
	Diaphragm/X-Frames	0.84			0.84		
	Bearing Devices	0.59			0.59		
	Prot. Coating System	1.00			0.78		
Substructure Items	Abutment Walls	1.00	0.73		1.00	0.73	
	Pier Walls	1.00			1.00		
	Pier Caps	1.00			1.00		
	Backwalls	0.13			0.13		
	Slope Protection	1.00			1.00		

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Evaluation of OBCI for: Bridge 7

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	1.00	**0.84**	1.00	1.00	**0.79**
	Embankment	1.00			1.00		
Culvert Items	General	0.79	0.89		0.73	0.85	
	Alignment	1.00			1.00		
	Shape	1.00			1.00		
	Seams	0.49			0.49		
	Headwall/Endwall	1.00			0.50		
	Scour	1.00			1.00		
Channel Items	Alignment	1.00	1.00		1.00	1.00	
	Protection	1.00			1.00		
	Hydraulic Opening	1.00			1.00		

Evaluation of OBCI for: Bridge 8

Components	Elements	$OBCI_{min}$			$OBCI_{current}$		
		Element	Comp.	Bridge	Element	Comp.	Bridge
Approach Items	Approach Wearing Surface	1.00	1.00	**0.99**	1.00	0.96	**0.97**
	Approach Slabs	1.00			0.93		
	Embankment	1.00			1.00		
	Guardrail	1.00			1.00		
Deck Items	Floor/Slab	1.00	1.00		0.99	0.98	
	Wearing Surface	1.00			0.998		
	Railing	1.00			0.86		
	Drainage	1.00			1.00		
	Expansion Joint	1.00			1.00		
Superstructure Items	Beams/Girders	1.00	1.00		0.96	0.997	
	Bearing Devices	1.00			1.00		
Substructure Items	Abutment Walls	1.00	0.96		0.97	0.94	
	Pier Walls	1.00			0.97		
	Pier Caps	0.94			0.92		
	Wingwalls	1.00			1.00		
Sign Items	Utilities	1.00	1.00		1.00	1.00	

- OBCI is also applied for an optimal budget allocation project for a network consisting of the eight case study bridges.

- A numerical algorithm with:
  - The objective of maximizing network-level OBCI after performing an MR&R work plan.
  - In the presence of budget limitation.

$$\max \sum_{B=1}^{M_n^*} \sum_{j=1}^{2^{M_B^*}} (AC_{B,j} + UC_{B,j}) \times x_{B,j}$$

$$Subject\ to: \begin{cases} \sum_{\mathrm{B}=1}^{M_n^*} \sum_{j=1}^{2^{M_B^*}} AC_{B,j} \times x_{B,j} \le Budget \\ x_{B,j} \in \{0,1\} \\ \sum_{j=1}^{2^{M_B^*}} x_{B,j} = 1 \ \ for\ each\ B = 1 \dots M_n^* \end{cases}$$

Current progress and future applications

Budget Limit of $400,000-$410,000

Inventory Bridge No.	Required money to improve all elements above min thresholds		Recommended actions for bridge components	Before optimal work plan		After optimal work plan	
	Value	Percentage		Current	Min	Current	Min
Bridge 1	0	0.00	${}^{0}_{\mathrm{Appr}}, C^{0}_{\mathrm{Deck}}, C^{0}_{\mathrm{Supr}}, C^{0}_{\mathrm{Subs}}, C^{0}_{\mathrm{Chanl}}, C^{0}_{\mathrm{Sig}}$	0.89	0.95	0.89	0.95
Bridge 2	0	0.00	$C^{0}_{\mathrm{Appr}}, C^{\mathrm{min}}_{\mathrm{Deck}}, C^{0}_{\mathrm{Supr}}, C^{\mathrm{min}}_{\mathrm{Subs}}, C^{0}_{\mathrm{Chanl}}$	0.76	0.89	0.76	0.89
Bridge 3	21,845	5.36	$C^{0}_{\mathrm{Appr}}, C^{\mathrm{min}}_{\mathrm{Deck}}, C^{0}_{\mathrm{Supr}}, C^{\mathrm{min}}_{\mathrm{Subs}}, C^{0}_{\mathrm{Sign}}$	0.81	0.99	0.82	1.00
Bridge 4	118,853	29.17	$C^{0}_{\mathrm{Appr}}, C^{\mathrm{min}}_{\mathrm{Deck}}, C^{\mathrm{min}}_{\mathrm{Supr}}, C^{\mathrm{min}}_{\mathrm{Subs}}, C^{\mathrm{like-new}}_{\mathrm{Sign}}$	0.88	0.96	0.92	1.00
Bridge 5	43,364	10.64	$C^{\mathrm{min}}_{\mathrm{Deck}}, C^{0}_{\mathrm{Supr}}, C^{0}_{\mathrm{Subs}}$	0.84	0.98	0.85	0.99
Bridge 6	223,352	54.82	$C^{0}_{\mathrm{Appr}}, C^{0}_{\mathrm{Deck}}, C^{\mathrm{min}}_{\mathrm{Supr}}, C^{0}_{\mathrm{Subs}}$	0.79	0.86	0.85	0.93
Bridge 7	0	0.00	$C^{0}_{\mathrm{Appr}}, C^{0}_{\mathrm{Culvert}}, C^{0}_{\mathrm{Chanl}}$	0.79	0.85	0.79	0.85
Bridge 8	0	0.00	$C^{0}_{\mathrm{Appr}}, C^{0}_{\mathrm{Deck}}, C^{0}_{\mathrm{Supr}}, C^{0}_{\mathrm{Subs}}, C^{0}_{\mathrm{Sign}}$	0.95	0.99	0.95	0.99
Sum of Bridges	**407,415**	**100**	**-**	**0.854**	**0.966**	**0.872**	**0.986**

Note: Appr=Approach component, Deck=Deck component, Supr=Superstructure component, Subs=Substructure component, Chanl=Channel component,Sign=Sign component.

- As a future step, OBCI can be combined with Weibull-Markovian processes to assist agencies with long-term preservation decision-making.