Review of Methods Utilized in Estimating Bridge Health Indices

Zachary Hamida Doctorant
James-A. Goulet Professeur

Polytechnique Montréal, Canada
Département des génies civil, géologique et des mines

June 30, 2020

Transports, Mobilité durable et Électrification des transports Québec Partenaire

Outline

Context & Objectives

Evaluating Bridge Health

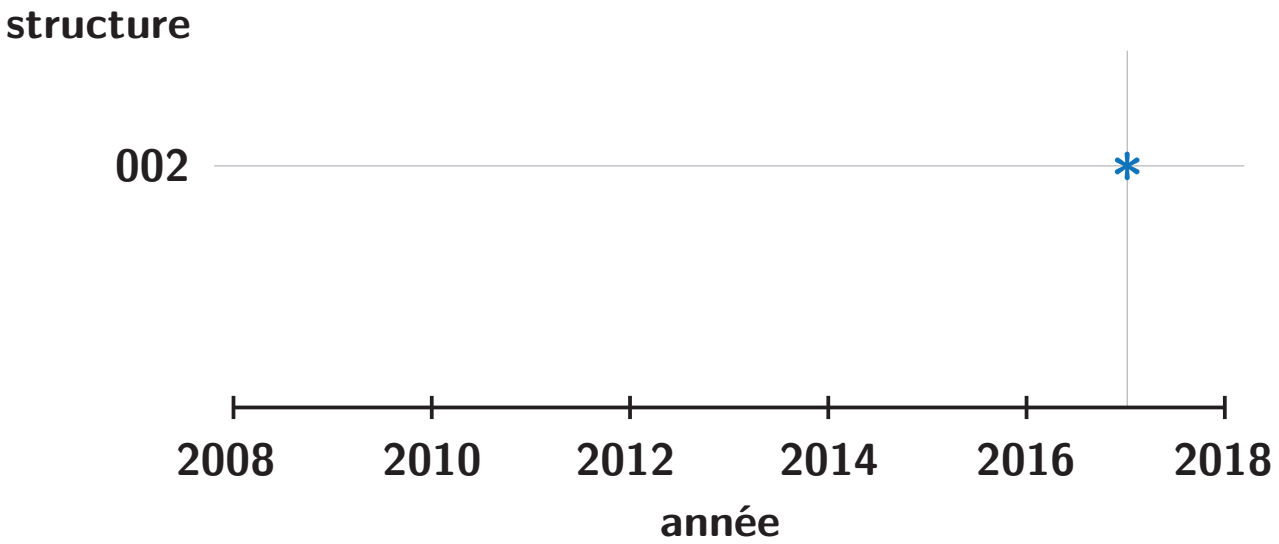
Existing Information & Estimation Method

Next Steps

Database of Visual Inspections

Year: 2017
Structure: #002

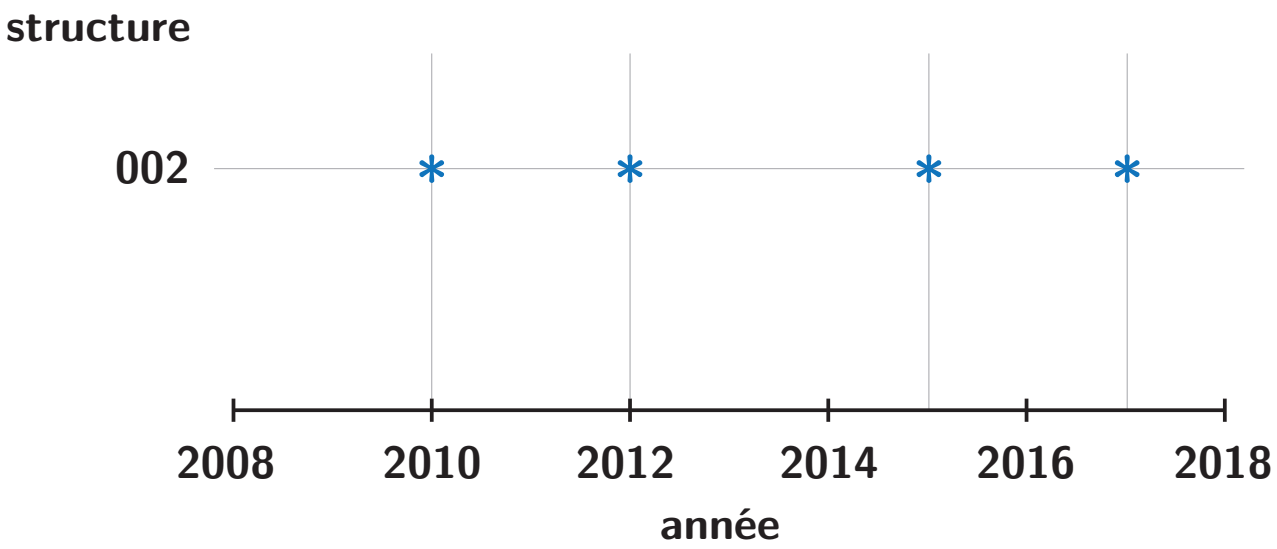
Database of Visual Inspections



Year: 2017
Structure: #002

$\mathbf{b}_{002}$: {type, material, DJMA, Location,. . . }

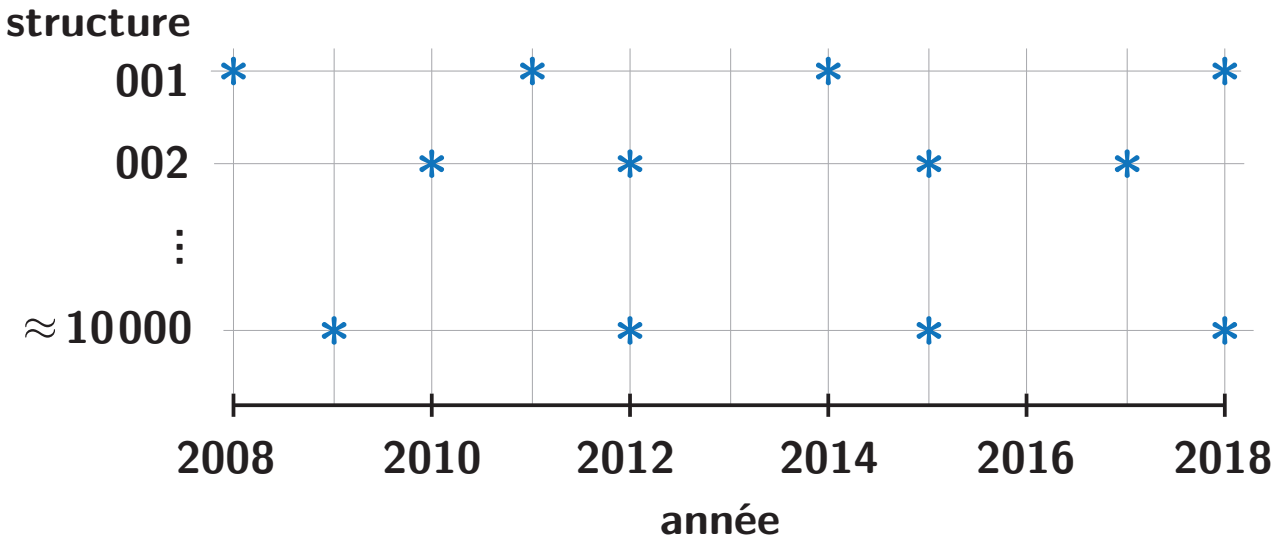
Database of Visual Inspections



Year: 2017
Structure: #002

$\mathbf{b}_{002}$: {type, material, DJMA, Location,. . . }

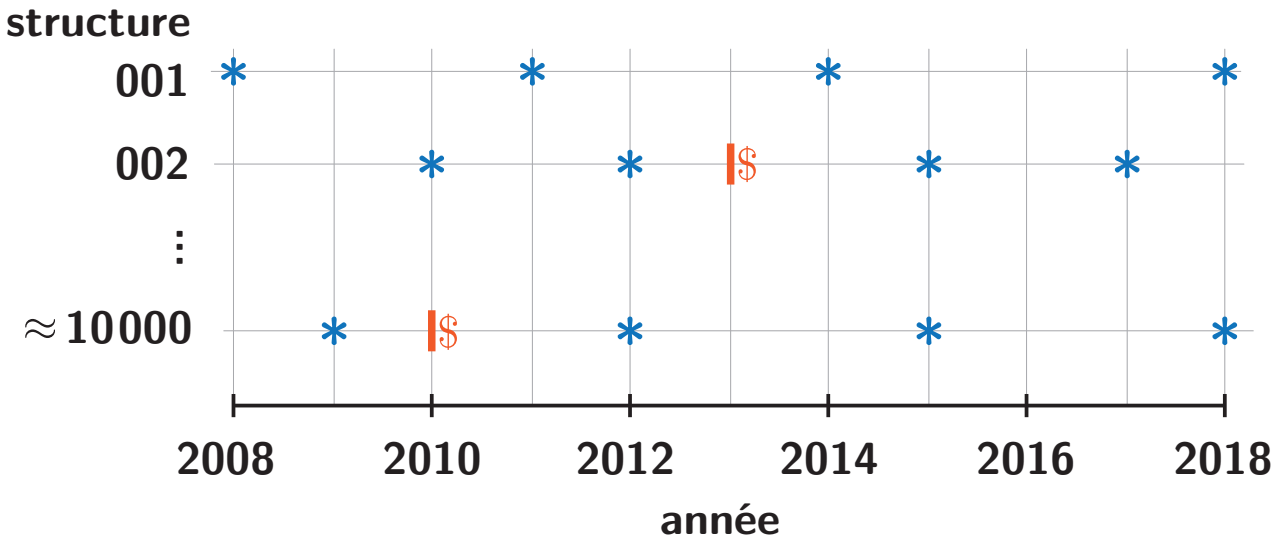
Database of Visual Inspections



Year: 2017
Structure: #002

$\mathbf{b}_{002}$: {type, material, DJMA, Location,. . . }

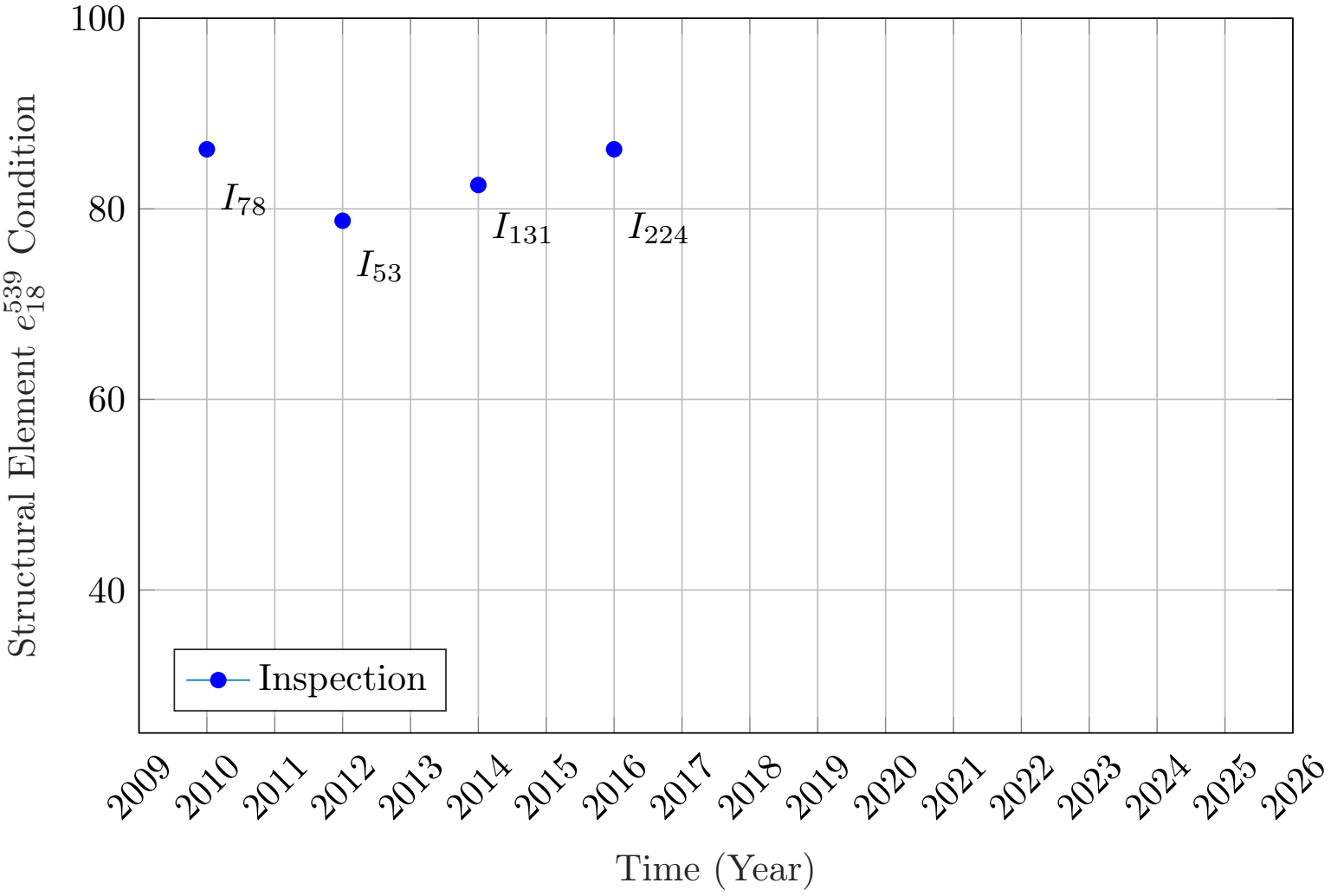
Database of Visual Inspections



Year: 2017
Structure: #002

$\mathbf{b}_{002}$: {type, material, DJMA, Location,. . . }

Example: Series of Inspections on Structural Element



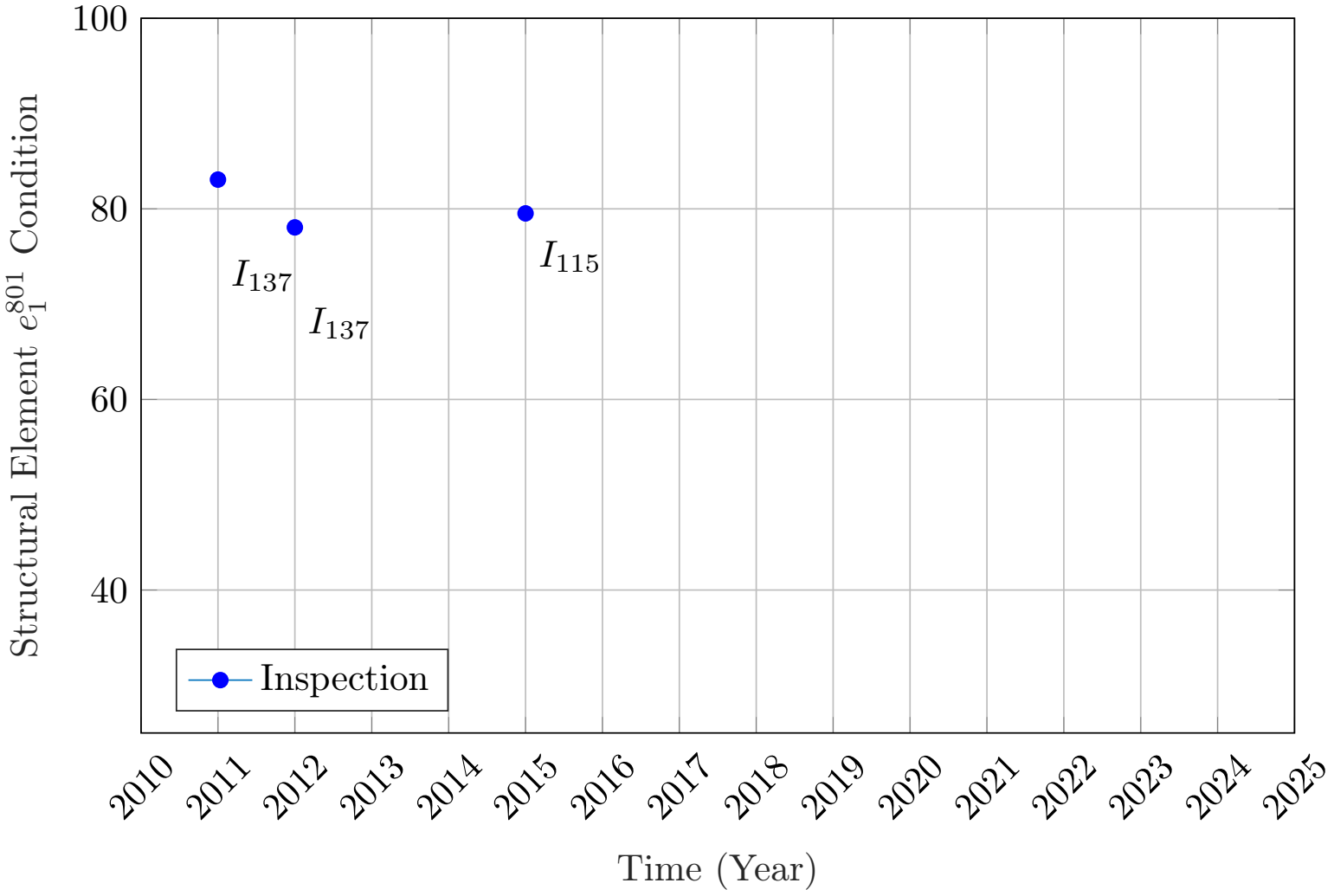
Objectives

- **Model the deterioration** behaviour based on the data from network of bridges.

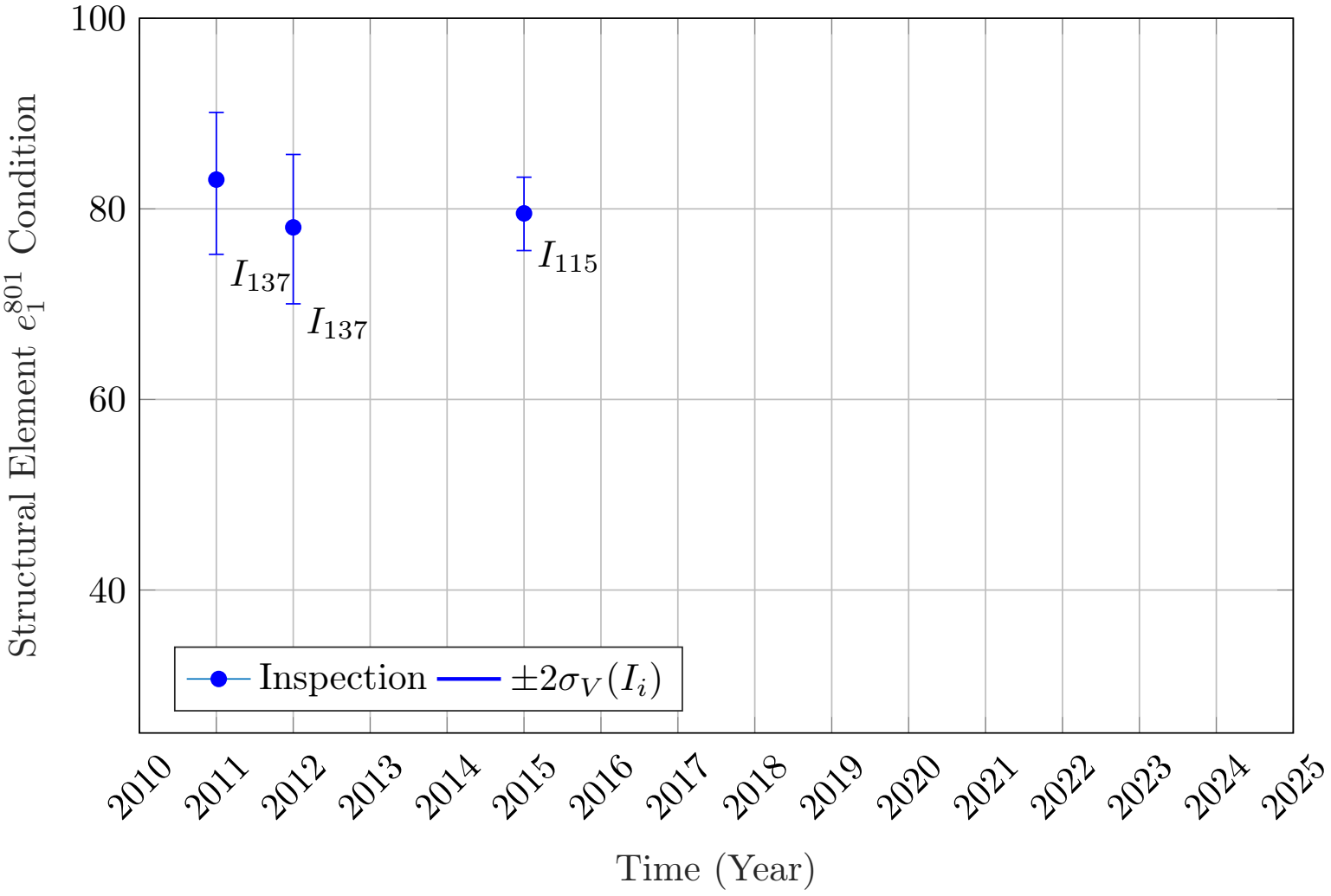
Objectives

- **Model the deterioration** behaviour based on the data from network of bridges.
- Quantify the **effect of interventions** on structural elements.

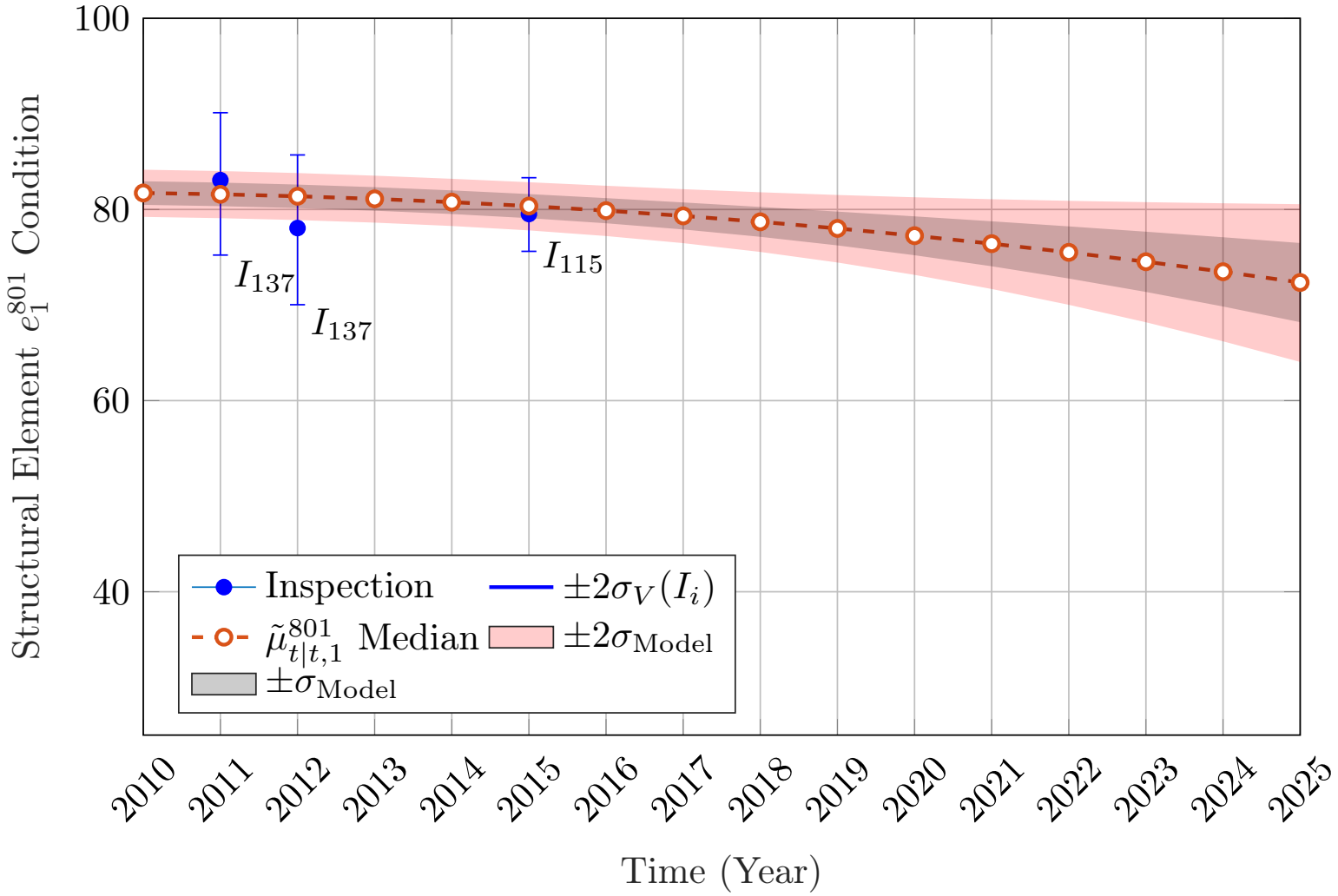
Modeling Deterioration: Condition Estimate



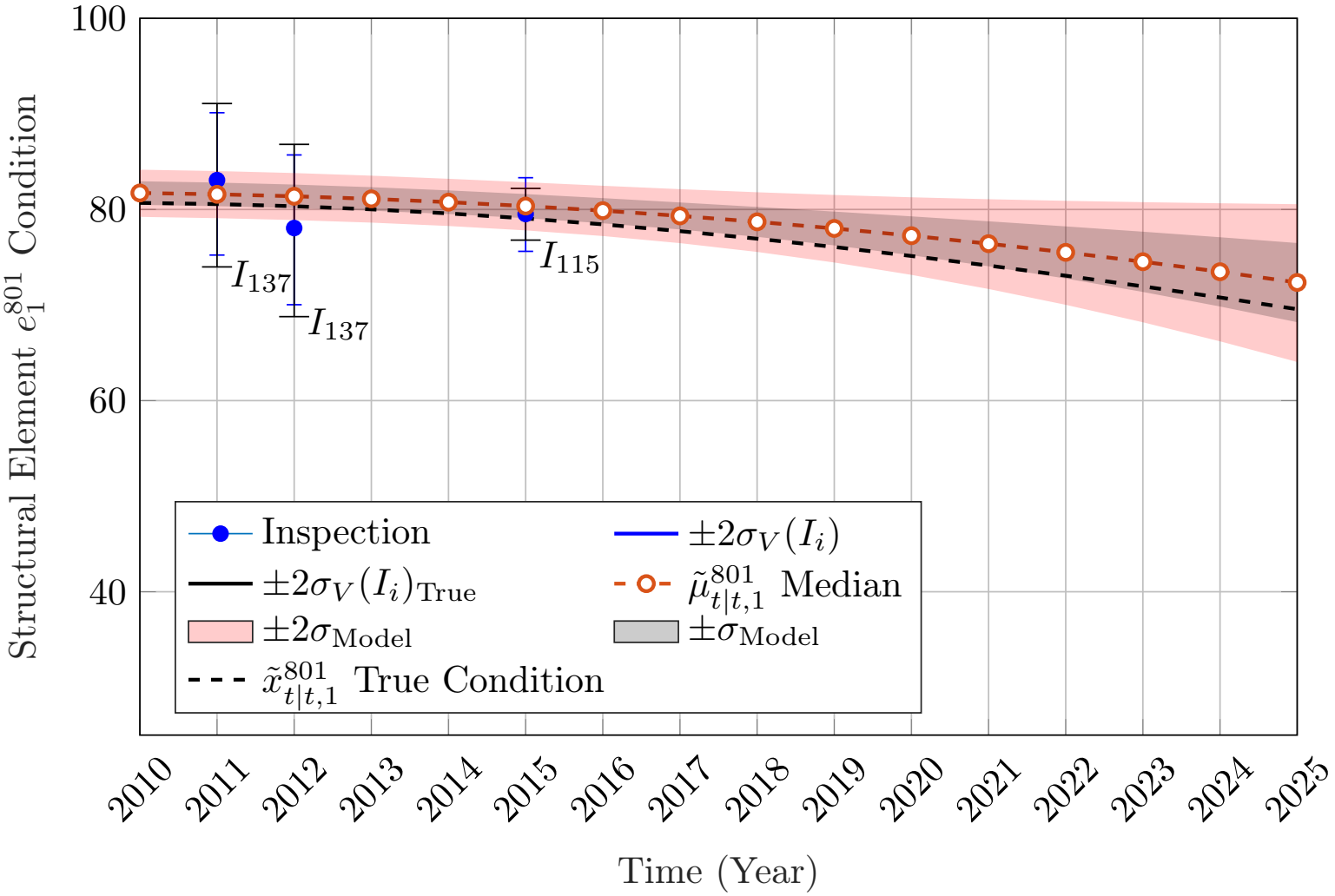
Modeling Deterioration: Condition Estimate



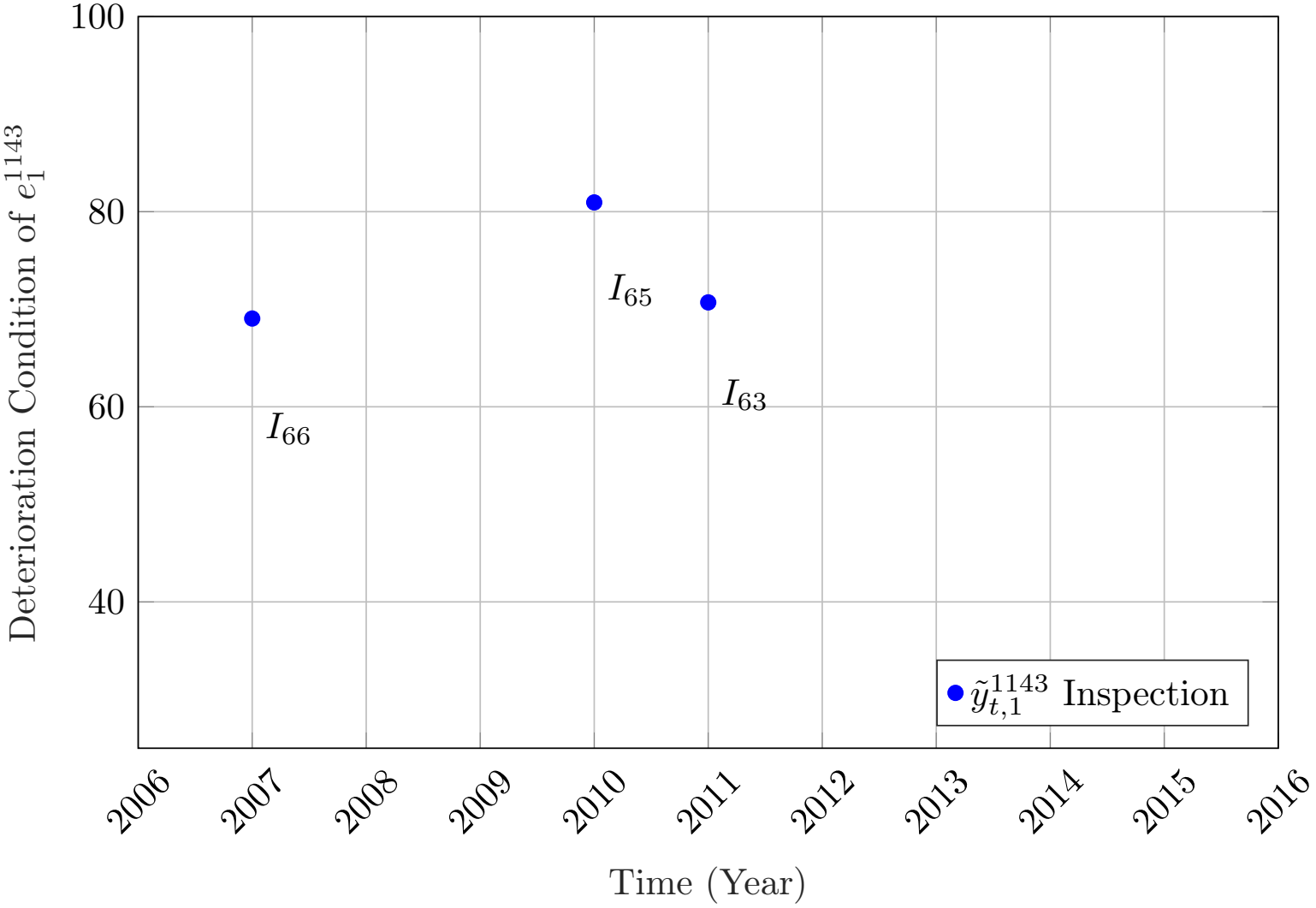
Modeling Deterioration: Condition Estimate



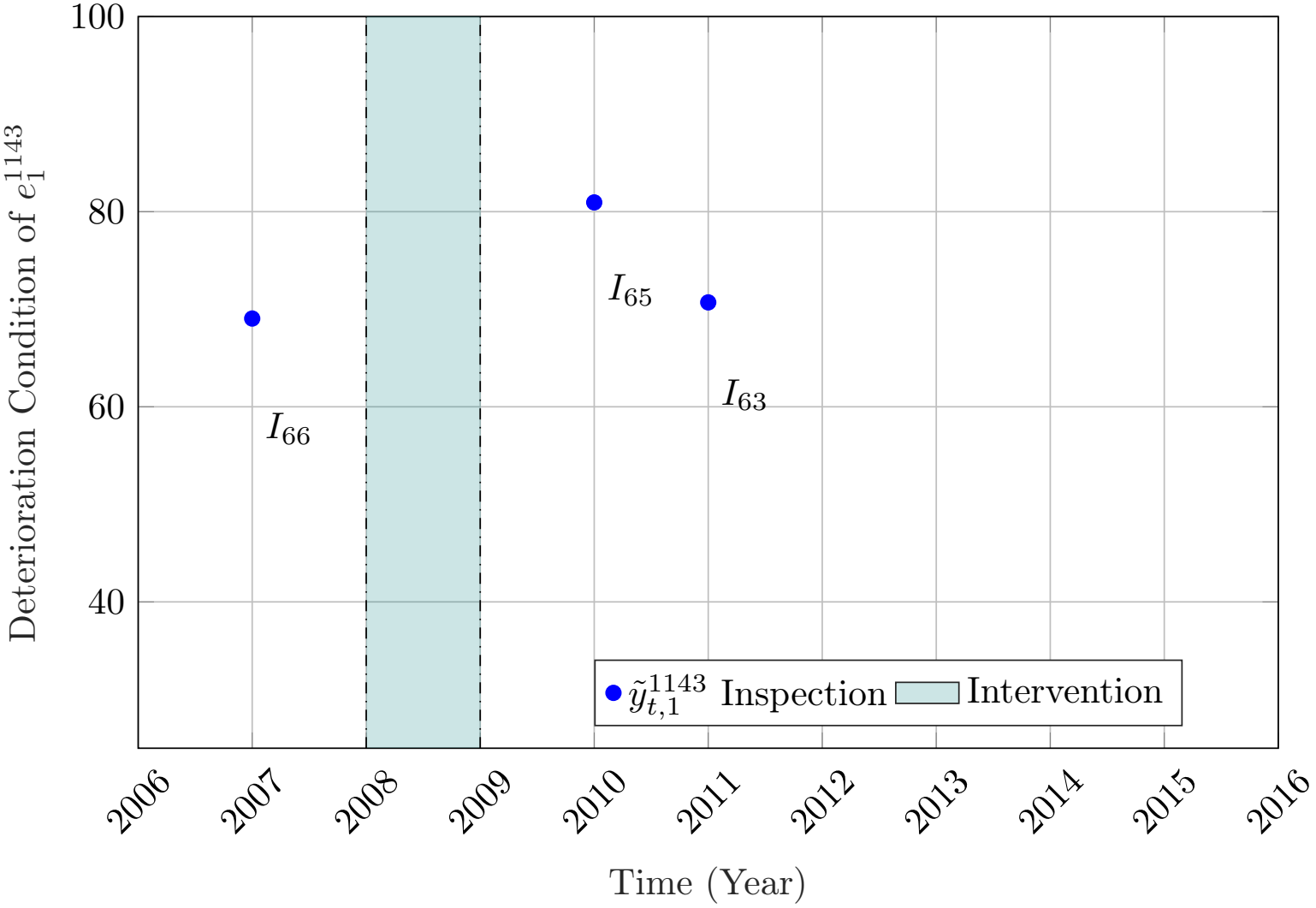
Modeling Deterioration: Condition Estimate



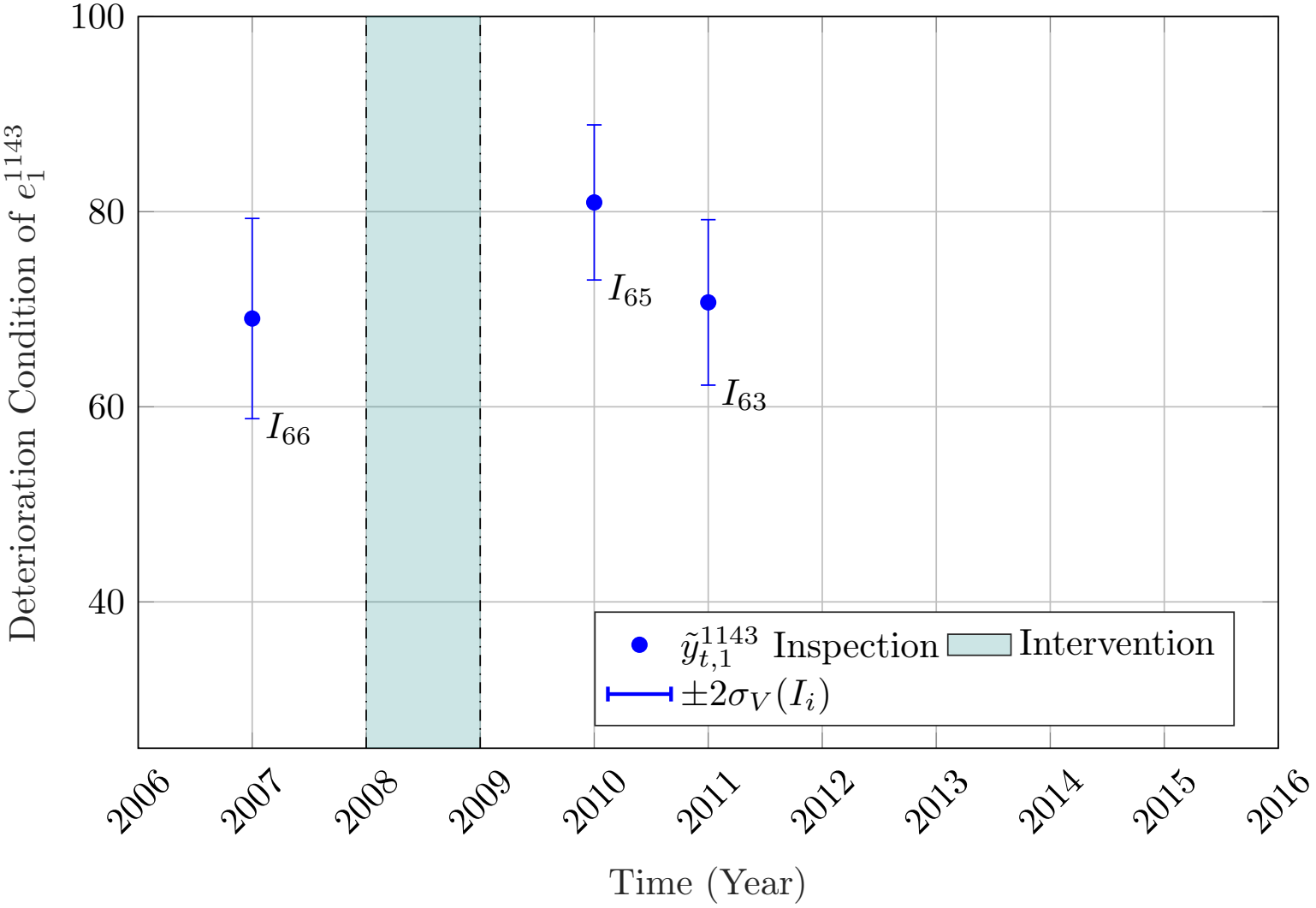
Modeling Interventions: Condition Estimate



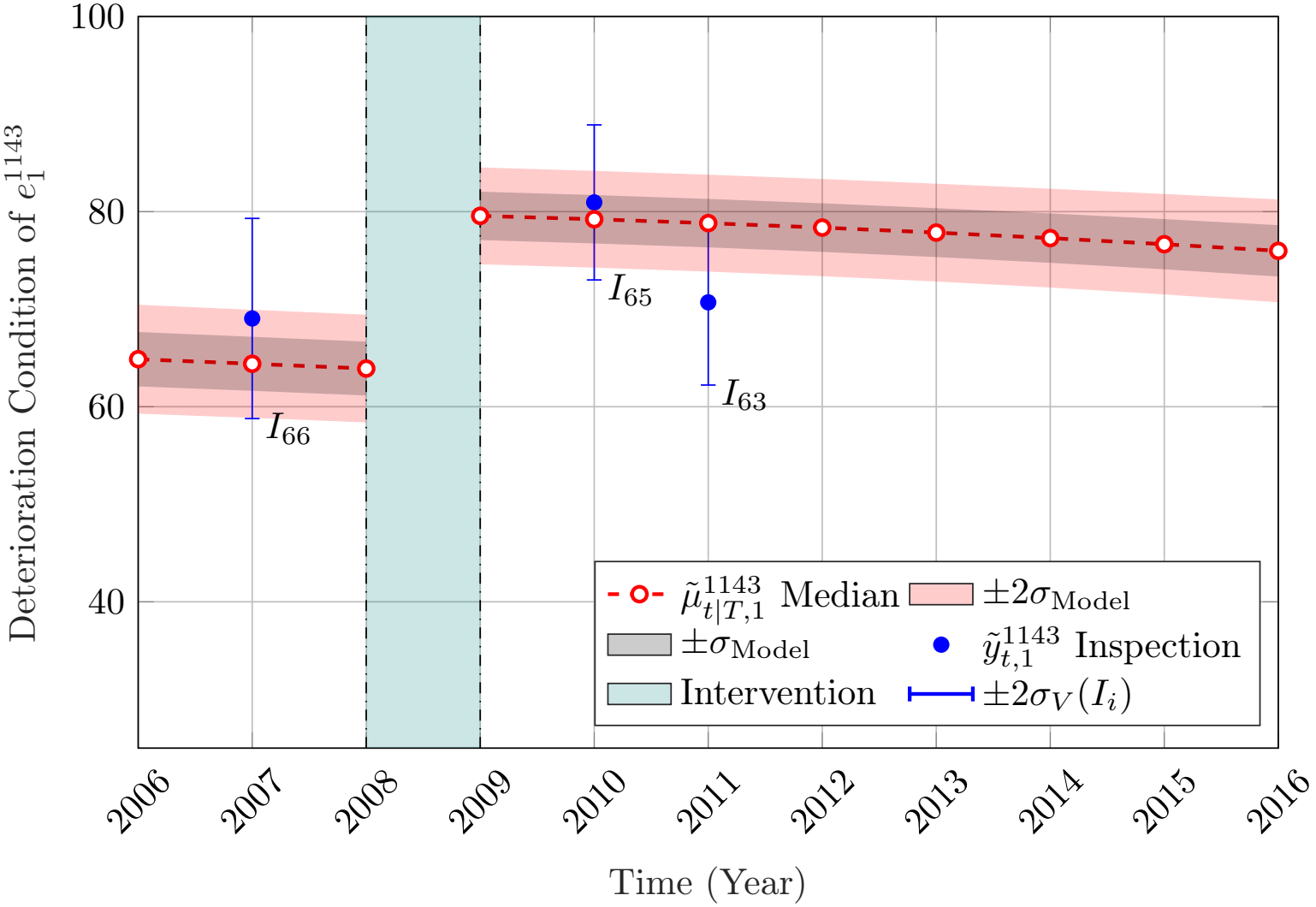
Modeling Interventions: Condition Estimate



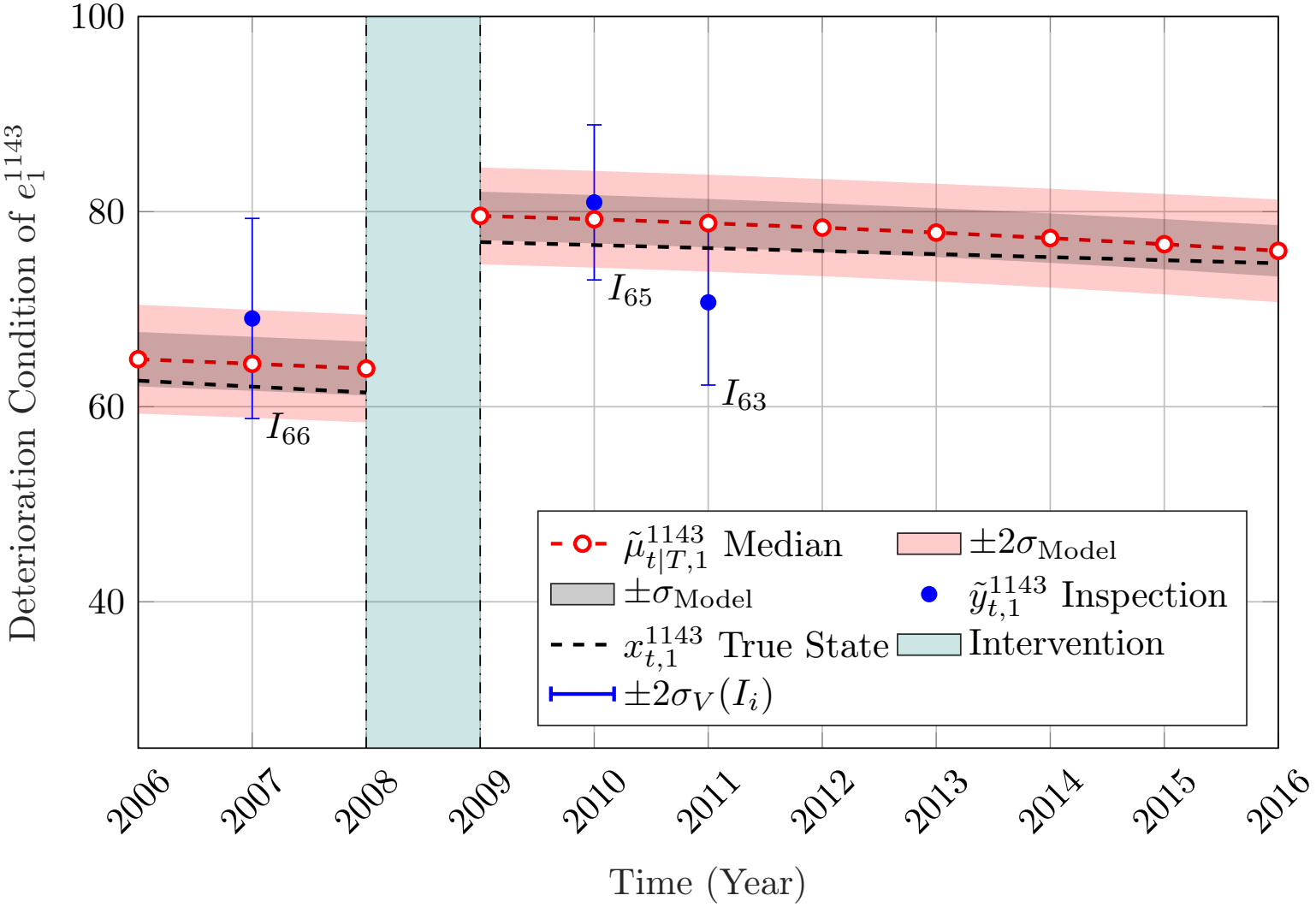
Modeling Interventions: Condition Estimate



Modeling Interventions: Condition Estimate



Modeling Interventions: Condition Estimate



Tools for Decision Makers

Tools for Decision Makers

- For a given budget, at a given year, which subset of **bridges** I should maintain.

Tools for Decision Makers

- For a given budget, at a given year, which subset of **bridges** I should maintain.
- If I change my budget, how much gain/loss I will have in the **overall health state of the network**.

Tools for Decision Makers

- For a given budget, at a given year, which subset of **bridges** I should maintain.
- If I change my budget, how much gain/loss I will have in the **overall health state of the network**.

We need an estimate for:

Tools for Decision Makers

- For a given budget, at a given year, which subset of **bridges** I should maintain.
- If I change my budget, how much gain/loss I will have in the **overall health state of the network**.

We need an estimate for:

- The health state of each bridge.

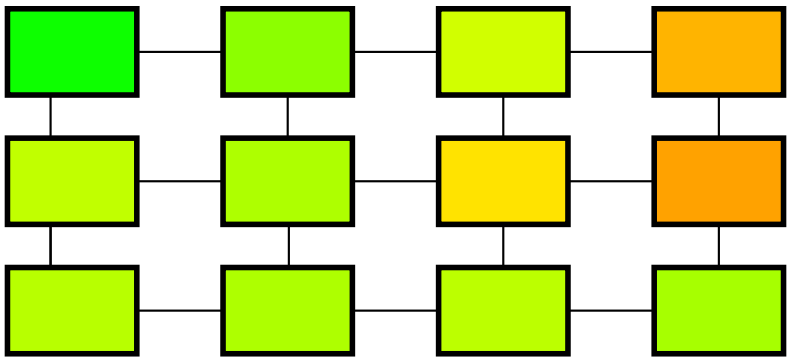
Tools for Decision Makers

- For a given budget, at a given year, which subset of **bridges** I should maintain.
- If I change my budget, how much gain/loss I will have in the **overall health state of the network**.

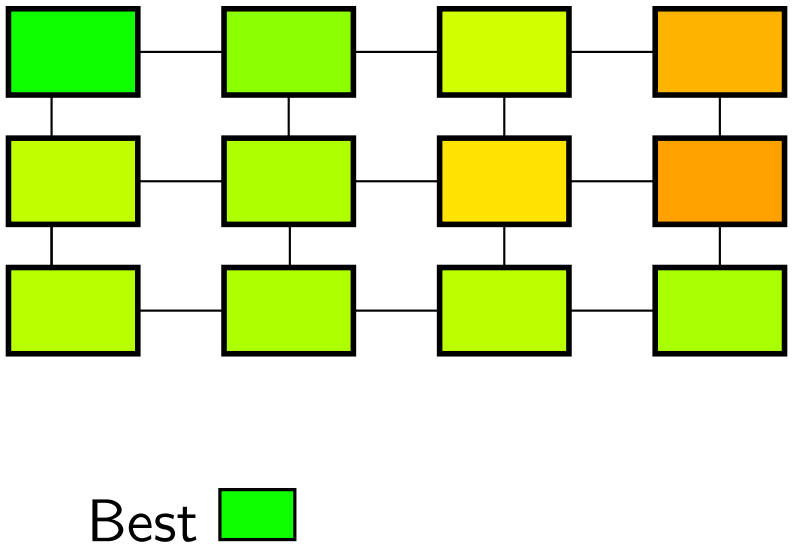
We need an estimate for:

- The health state of each bridge.
- The overall health state of the bridges network.

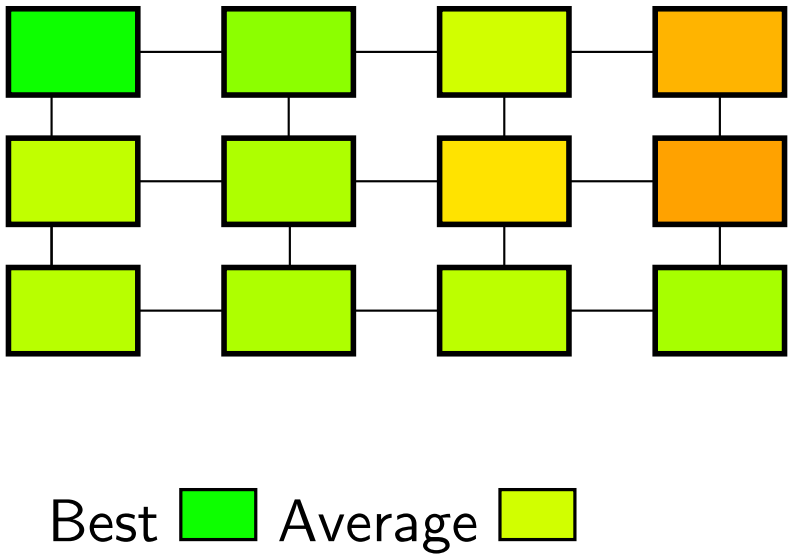
Bridge & Network Condition



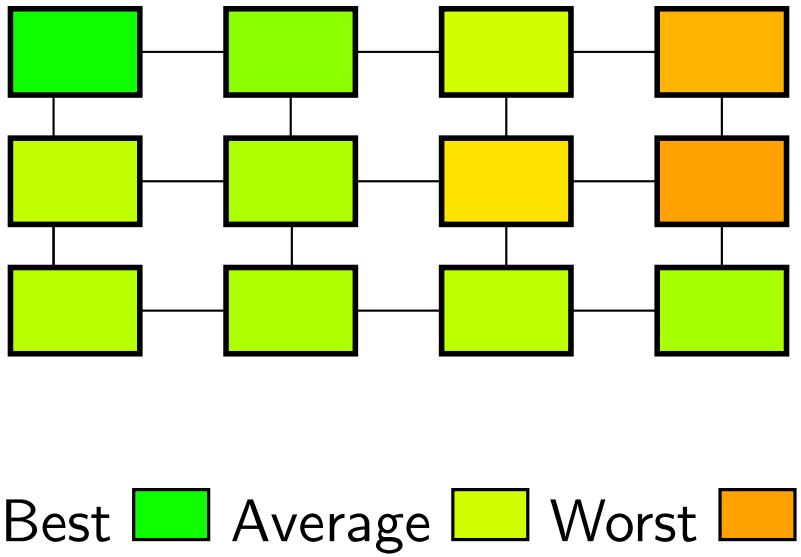
Bridge & Network Condition



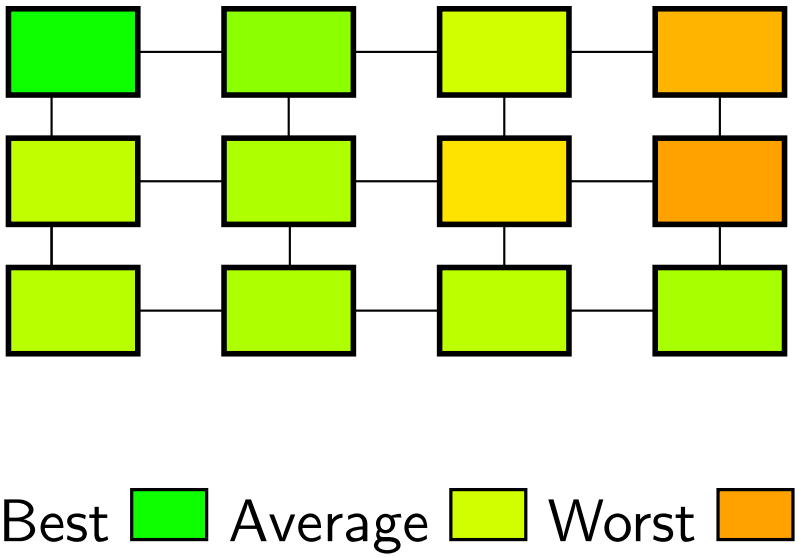
Bridge & Network Condition



Bridge & Network Condition



Bridge & Network Condition



It really depends on what you are looking for!

Methods for Evaluating Bridge Health:

Methods for Evaluating Bridge Health:

- Ratio-based condition index.

Methods for Evaluating Bridge Health:

- Ratio-based condition index.
- Weighted average.

Methods for Evaluating Bridge Health:

- Ratio-based condition index.
- Weighted average.
- Worst conditioned component.

Methods for Evaluating Bridge Health:

- Ratio-based condition index.
- Weighted average.
- Worst conditioned component.
- Qualitative method.

Ratio-based condition index:

Ratio-based condition index:

Notations:

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.
- Element replacement cost c.

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.
- Element replacement cost c.
- Element value function $q(.)$.

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.
- Element replacement cost c.
- Element value function $q(.)$.
- Bridge value function $\hat{q}(.)$.

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.
- Element replacement cost c.
- Element value function $q(.)$.
- Bridge value function $\hat{q}(.)$.

Evaluation method:

Ratio-based condition index:

Notations:

- Element expected deterioration condition μ.
- Element replacement cost c.
- Element value function $q(.)$.
- Bridge value function $\hat{q}(.)$.

Evaluation method:

$$\mathbb{E}[\hat{q}(b_j)] = \frac{\sum_p \mathbb{E}[q(e_p^j)]}{\sum_p \mathbb{E}[q(e_{0,p}^j)]} \begin{cases} \mathbb{E}[q(e_p^j)] & = c_p^j \times \mu_{t,p}^j \\ \mathbb{E}[q(e_{0,p}^j)] & = c_p^j \times u \end{cases}$$

Ratio-based condition index:

Ratio-based condition index:

Limitations:

Ratio-based condition index:

Limitations:

- Element replacement cost data c.

Ratio-based condition index:

Limitations:

- Element replacement cost data c.

Weighted average:

Weighted average:

Relies on:

Weighted average:

Relies on:

- Estimate of deterioration condition.

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).
  - 3 . Group (Code).

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).
  - 3 . Group (Code).
  - 4 . Bridge (Traffic).

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).
  - 3 . Group (Code).
  - 4 . Bridge (Traffic).

Limitations:

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).
  - 3 . Group (Code).
  - 4 . Bridge (Traffic).

Limitations:

- Estimation of importance factors is challenging.

Weighted average:

Relies on:

- Estimate of deterioration condition.
- Importance factor.
  - 1 . Damage (Code).
  - 2 . Element (Code).
  - 3 . Group (Code).
  - 4 . Bridge (Traffic).

Limitations:

- Estimation of importance factors is challenging.

Worst conditioned component:

Worst conditioned component:

Relies on:

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Strength:

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Strength:

- Useful for estimating the vulnerability of a bridge in case of extreme events.

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Strength:

- Useful for estimating the vulnerability of a bridge in case of extreme events.

Limitations:

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Strength:

- Useful for estimating the vulnerability of a bridge in case of extreme events.

Limitations:

- Does not provide the full picture about the deterioration in the bridge.

Worst conditioned component:

Relies on:

- Estimate of element deterioration condition based on (stability, safety and durability) + damage extent of elements (Qualitative).
- Estimate of group deterioration condition based on worst element + number of damaged elements in group.
- Estimate of bridge based on worst group.

Strength:

- Useful for estimating the vulnerability of a bridge in case of extreme events.

Limitations:

- Does not provide the full picture about the deterioration in the bridge.

Qualitative method:

Qualitative method:

Relies on:

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Strength:

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Strength:

- Useful for big picture about the network.

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Strength:

- Useful for big picture about the network.

Limitations:

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Strength:

- Useful for big picture about the network.

Limitations:

- Categorical values can not be used for prioritizing maintenance.

Qualitative method:

Relies on:

- Percentage of elements being in particular category.

Strength:

- Useful for big picture about the network.

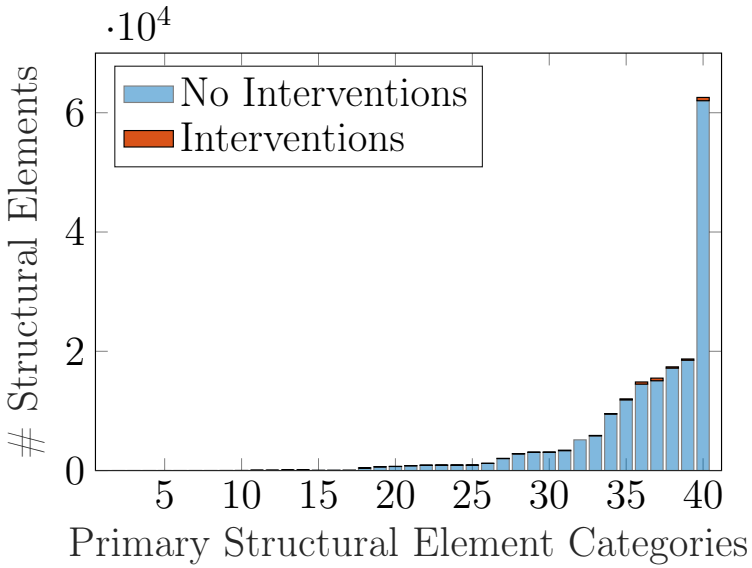
Limitations:

- Categorical values can not be used for prioritizing maintenance.

Database

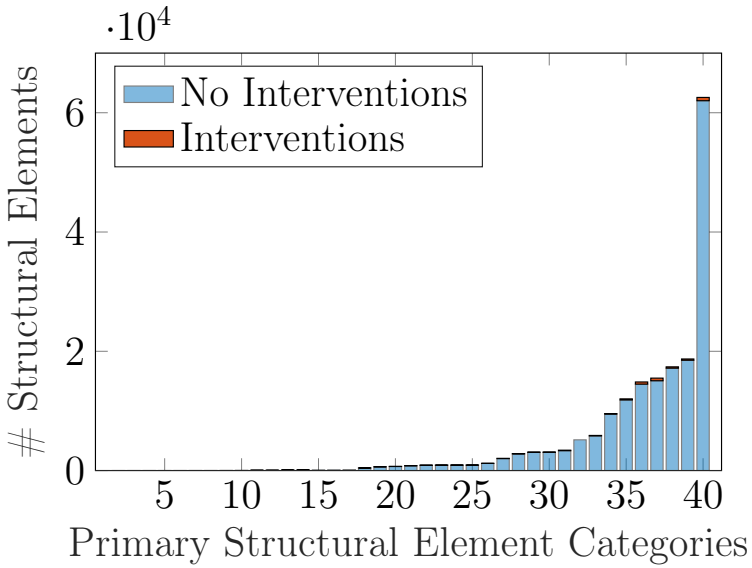
Database

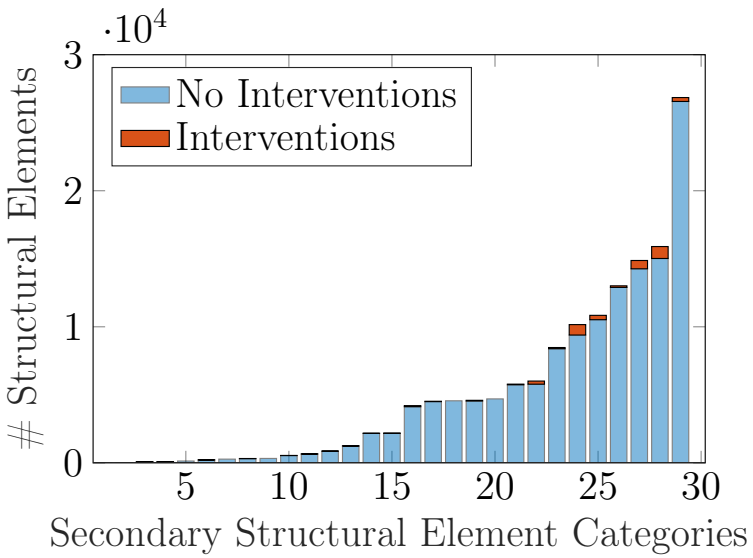
Two types of structural categories:



Database

Two types of structural categories:





Order	Primary	Secondary
1	$\mathcal{S}^1_{40}$: Beams	$\mathcal{S}^2_{29}$: Wing/return walls
2	$\mathcal{S}^1_{39}$: Bearing Seat	$\mathcal{S}^2_{28}$: Safety Barriers (left or right)
3	$\mathcal{S}^1_{38}$: Bearing pad	$\mathcal{S}^2_{27}$: Road Surface

Order	Primary	Secondary
1	$\mathcal{S}^1_{40}$: Beams	$\mathcal{S}^2_{29}$: Wing/return walls
2	$\mathcal{S}^1_{39}$: Bearing Seat	$\mathcal{S}^2_{28}$: Safety Barriers (left or right)
3	$\mathcal{S}^1_{38}$: Bearing pad	$\mathcal{S}^2_{27}$: Road Surface

- Primary elements has 40/45 categories evaluated using VI.

Order	Primary	Secondary
1	$\mathcal{S}^1_{40}$: Beams	$\mathcal{S}^2_{29}$: Wing/return walls
2	$\mathcal{S}^1_{39}$: Bearing Seat	$\mathcal{S}^2_{28}$: Safety Barriers (left or right)
3	$\mathcal{S}^1_{38}$: Bearing pad	$\mathcal{S}^2_{27}$: Road Surface

- Primary elements has 40/45 categories evaluated using VI.
- Secondary elements has 29/44 categories evaluated using VI.

Order	Primary	Secondary
1	$\mathcal{S}^1_{40}$: Beams	$\mathcal{S}^2_{29}$: Wing/return walls
2	$\mathcal{S}^1_{39}$: Bearing Seat	$\mathcal{S}^2_{28}$: Safety Barriers (left or right)
3	$\mathcal{S}^1_{38}$: Bearing pad	$\mathcal{S}^2_{27}$: Road Surface

- Primary elements has 40/45 categories evaluated using VI.
- Secondary elements has 29/44 categories evaluated using VI.

The rest of the categories are evaluated using CEC

Database

CEC: the ability of a structural element to play its role in the structure.

Database

CEC: the ability of a structural element to play its role in the structure.

		Reduction in Performance	
		Principal	Secondary
CEC	1	$0 - 10\%$	$0 - 10\%$
	2	$10 - 20\%$	$10 - 30\%$
	3	$20 - 30\%$	$30 - 50\%$
	4	$> 30\%$	$> 50\%$

Database

Total number of structures:

- 3777 Culverts (from 4.6 to 859.5 m)
- 6952 Bridges (from 3.75 to 2708.3 m)
- 672 Roads with retaining walls (from 25.7 to 7170 m)
- 10 Tunnels (from 91 to 2121 m)
- $\mathrm{B} \approx 11 \times 10^3$ bridges.

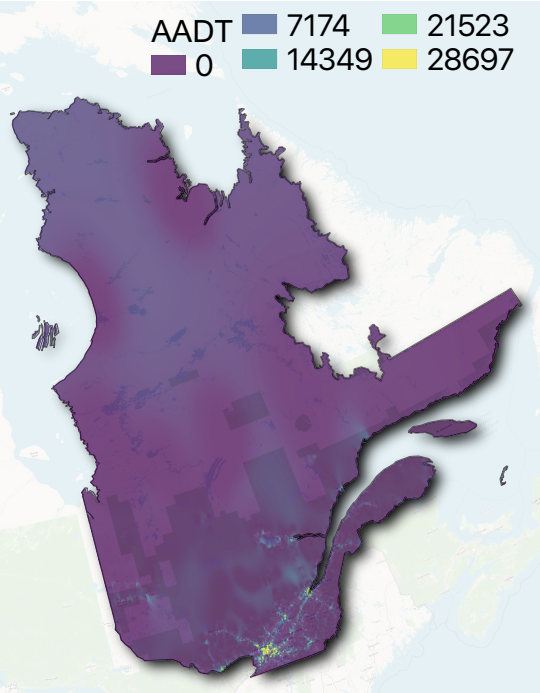
Database

Total number of structures:

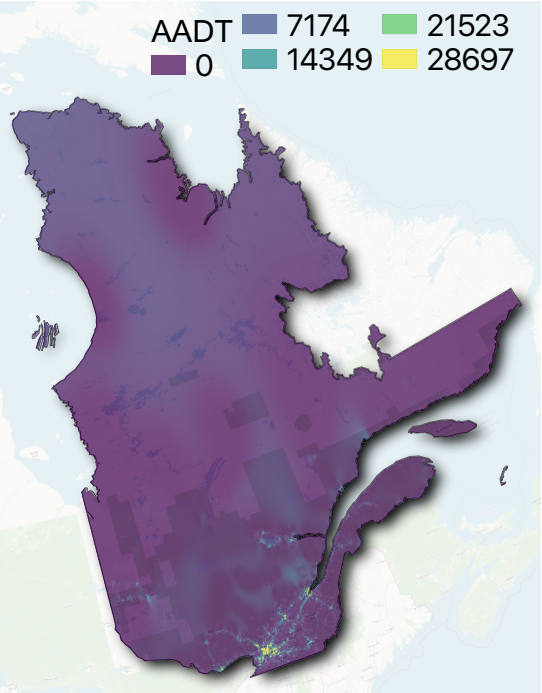
- 3777 Culverts (from 4.6 to 859.5 m)
- 6952 Bridges (from 3.75 to 2708.3 m)
- 672 Roads with retaining walls (from 25.7 to 7170 m)
- 10 Tunnels (from 91 to 2121 m)
- $\mathrm{B} \approx 11 \times 10^3$ bridges.

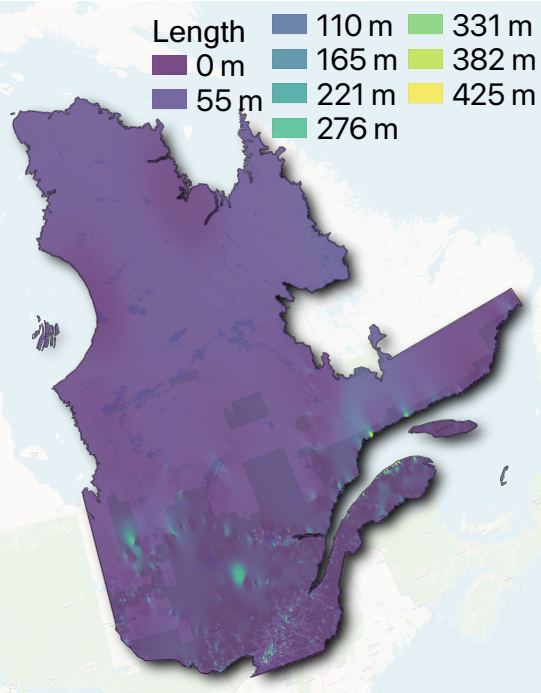
Structural Attributes

Structural Attributes

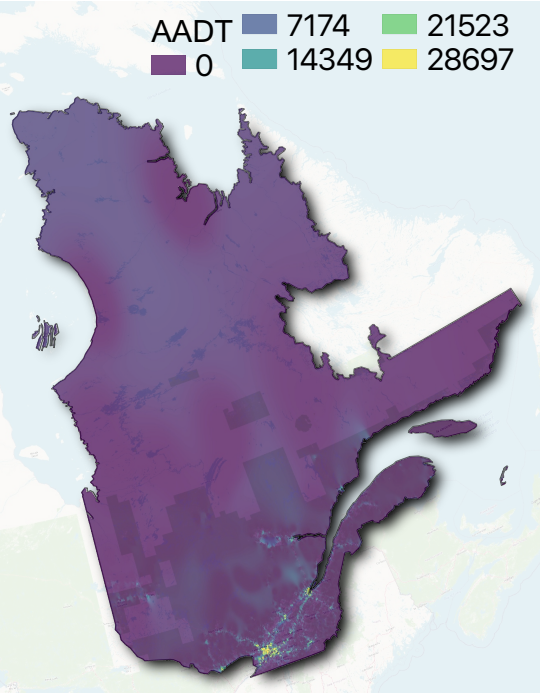


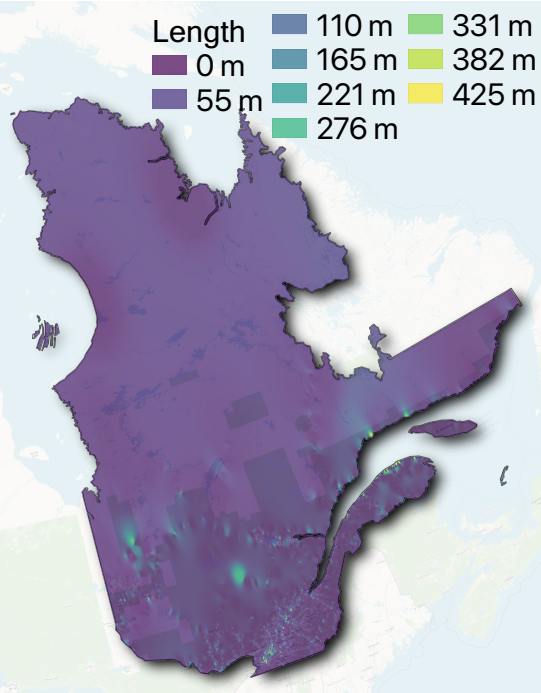
Structural Attributes

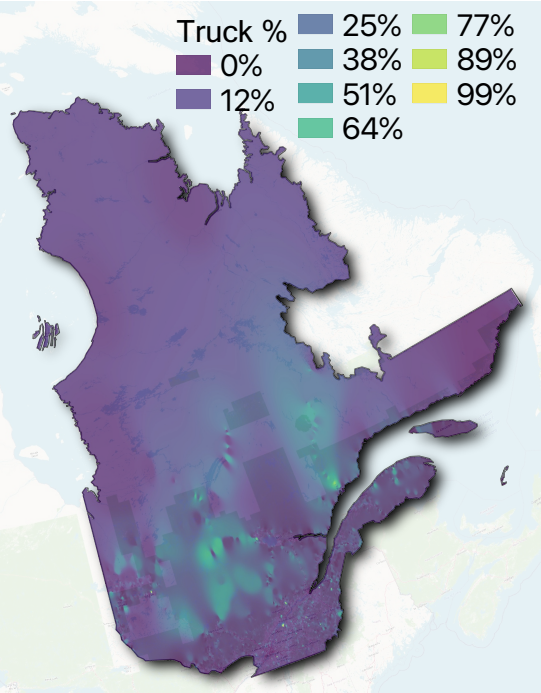




Structural Attributes

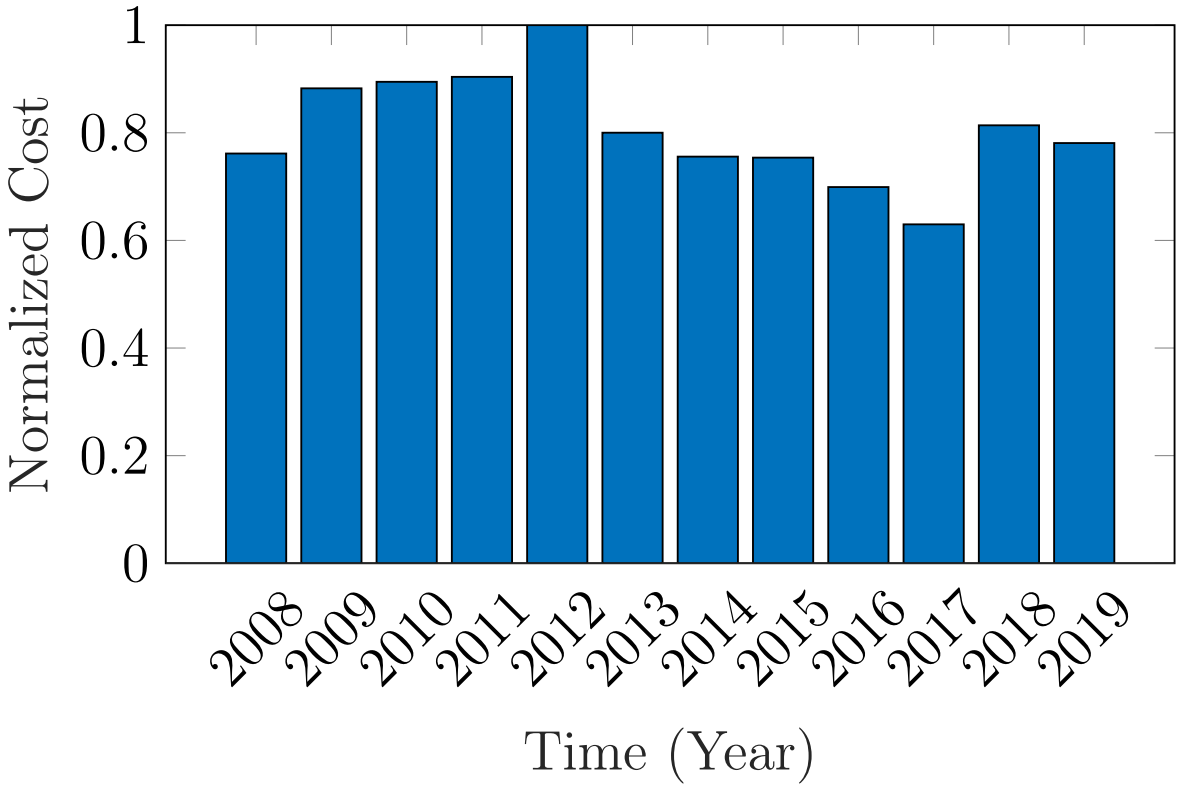






Interventions and Costs

Interventions and Costs



Estimation Method

Estimation Method

- Structural category deterioration estimate:

Estimation Method

- Structural category deterioration estimate:

$$\hat{\boldsymbol{o}}^{j}_{m,t} = \sum_{p=1}^{\mathrm{P}^{j}_{m}} \left(\boldsymbol{x}^{j}_{p,t} \times \frac{d^{j}_{p}}{\sum_{p} d^{j}_{p}} \right), \tag{1}$$

Estimation Method

- Structural category deterioration estimate:

$$\hat{\boldsymbol{o}}^{j}_{m,t} = \sum_{p=1}^{\mathrm{P}^{j}_{m}} \left(\boldsymbol{x}^{j}_{p,t} \times \frac{d^{j}_{p}}{\sum_{p} d^{j}_{p}} \right), \tag{1}$$

- Bridge-level deterioration estimate:

Estimation Method

- Structural category deterioration estimate:

$$\hat{\boldsymbol{o}}^{j}_{m,t} = \sum_{p=1}^{\mathrm{P}^{j}_{m}} \left(\boldsymbol{x}^{j}_{p,t} \times \frac{d^{j}_{p}}{\sum_{p} d^{j}_{p}} \right), \tag{1}$$

- Bridge-level deterioration estimate:

$$\hat{\boldsymbol{s}}_{j,t} = \sum_{m=1}^{\mathrm{S}_{j}} \frac{\hat{\boldsymbol{o}}^{j}_{m,t}}{\mathrm{S}_{j}}, \tag{2}$$

Estimation Method

- Structural category deterioration estimate:

$$\hat{\boldsymbol{o}}^{j}_{m,t} = \sum_{p=1}^{\mathrm{P}^{j}_{m}} \left(\boldsymbol{x}^{j}_{p,t} \times \frac{d^{j}_{p}}{\sum_{p} d^{j}_{p}} \right), \tag{1}$$

- Bridge-level deterioration estimate:

$$\hat{\boldsymbol{s}}_{j,t} = \sum_{m=1}^{\mathrm{S}_{j}} \frac{\hat{\boldsymbol{o}}^{j}_{m,t}}{\mathrm{S}_{j}}, \tag{2}$$

- Network-scale deterioration estimate:

Estimation Method

- Structural category deterioration estimate:

$$\hat{\boldsymbol{o}}^{j}_{m,t} = \sum_{p=1}^{\mathrm{P}^{j}_{m}} \left(\boldsymbol{x}^{j}_{p,t} \times \frac{d^{j}_{p}}{\sum_{p} d^{j}_{p}} \right), \tag{1}$$

- Bridge-level deterioration estimate:

$$\hat{\boldsymbol{s}}_{j,t} = \sum_{m=1}^{\mathrm{S}_{j}} \frac{\hat{\boldsymbol{o}}^{j}_{m,t}}{\mathrm{S}_{j}}, \tag{2}$$

- Network-scale deterioration estimate:

$$\hat{\boldsymbol{q}}_{t} = \sum_{j=1}^{\mathrm{B}} \left(\hat{\boldsymbol{s}}_{j,t} \times \frac{z_{j}}{\sum_{j} z_{j}} \right). \tag{3}$$

Next:

- Train the deterioration model on each structural category.

Next:

- Train the deterioration model on each structural category.
- Perform analyses on bridges.