Modelling the Deterioration of Infrastructures Using Network-Scale Visual Inspections

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August, 2022

MTQ
Partner

Definitions

Visual Inspections (VI): Network-scale monitoring technique

Source: Google images

Definitions

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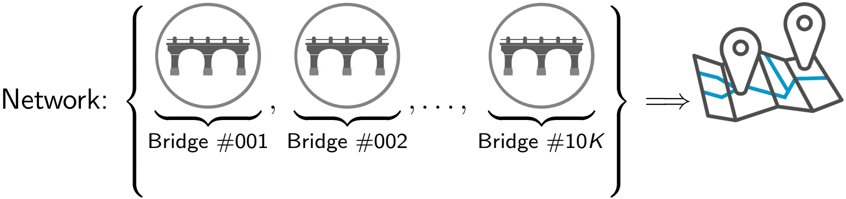
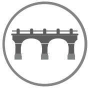


Source: Google images

Data Hierarchy



Source: MTQ, Manual of Inspection

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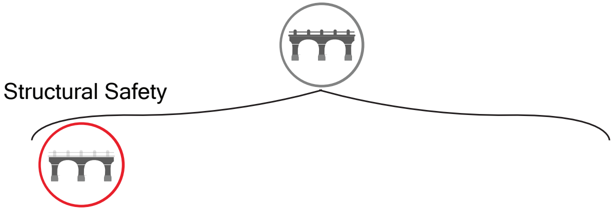

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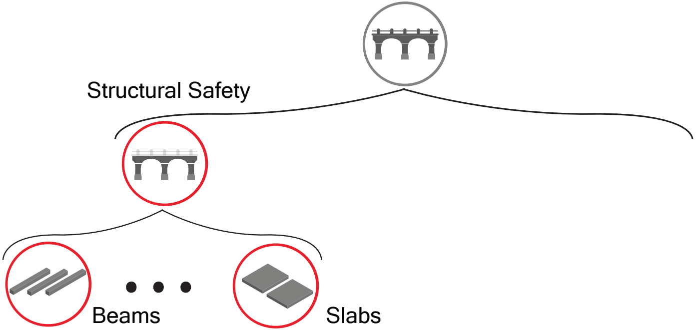

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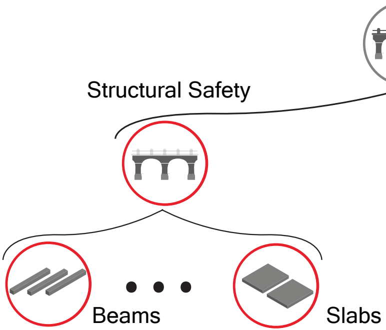

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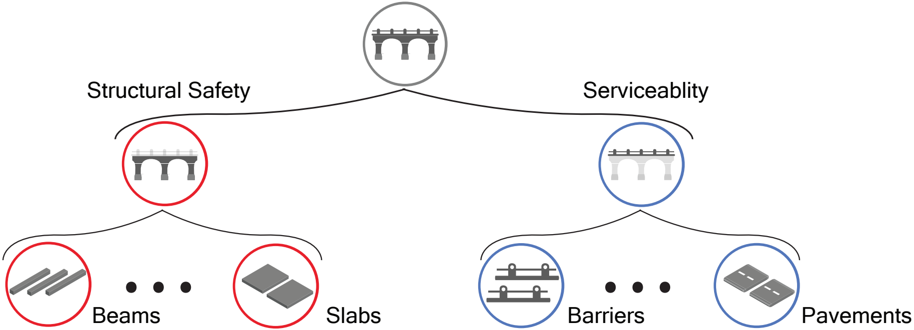

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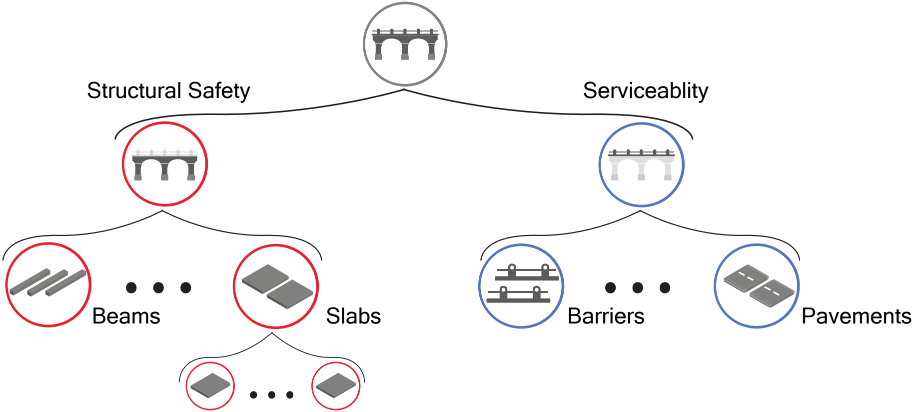

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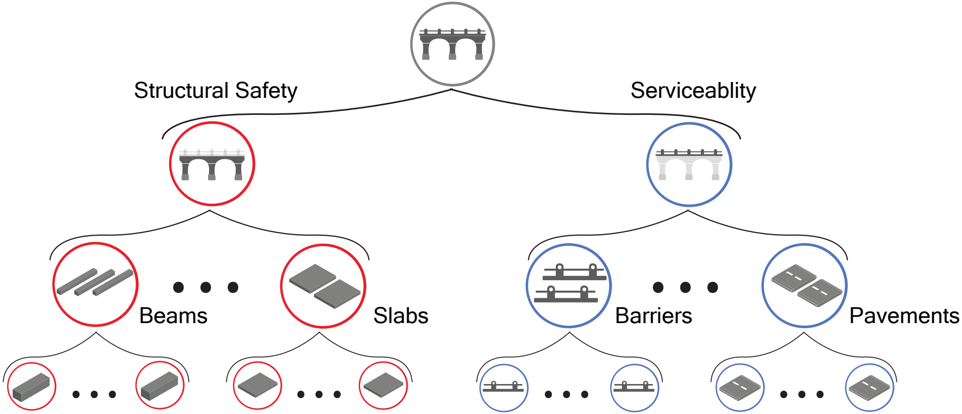

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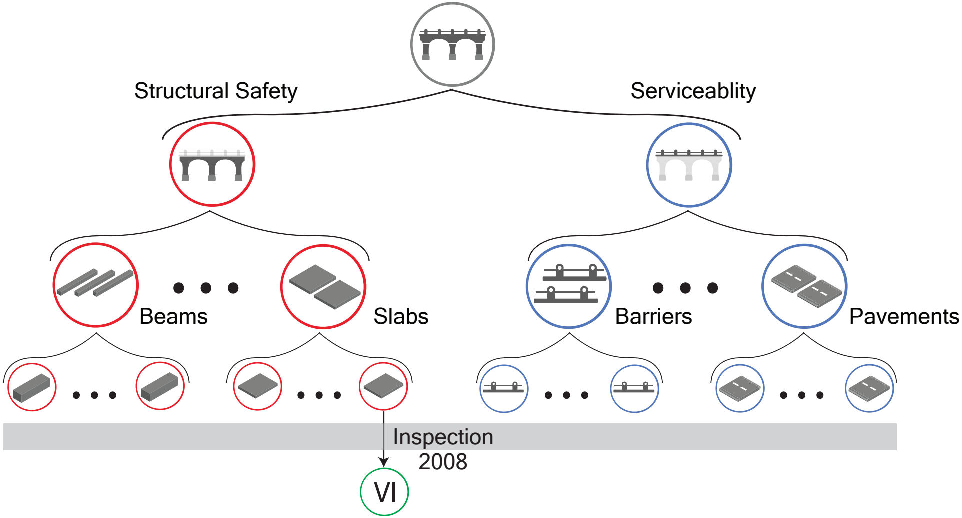

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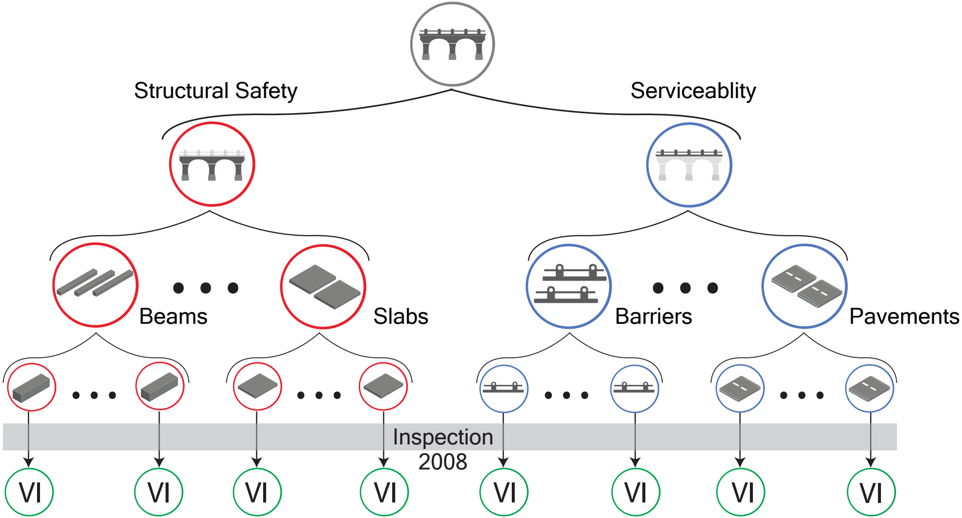

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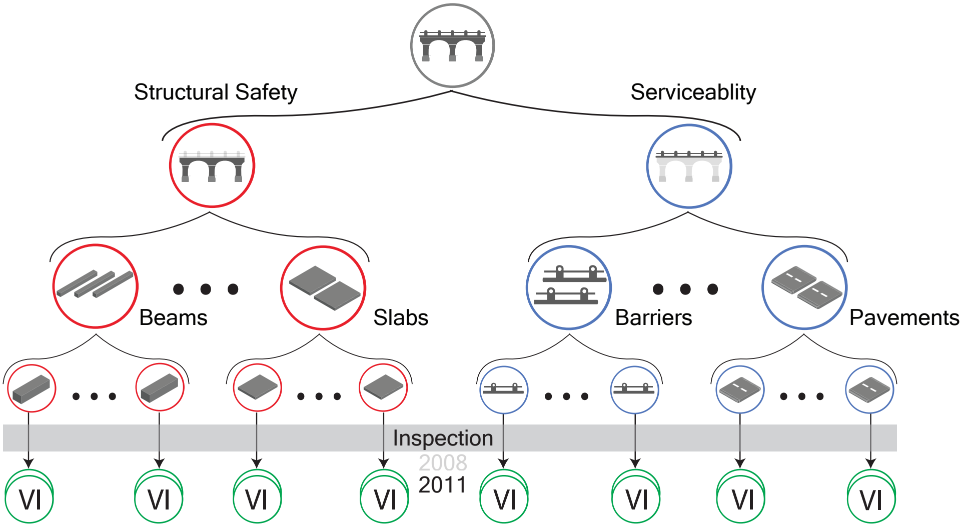

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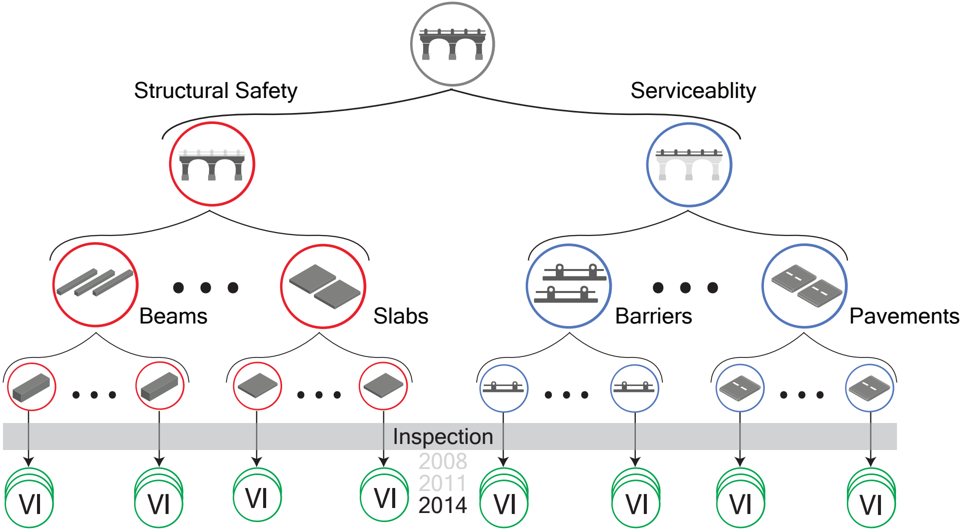

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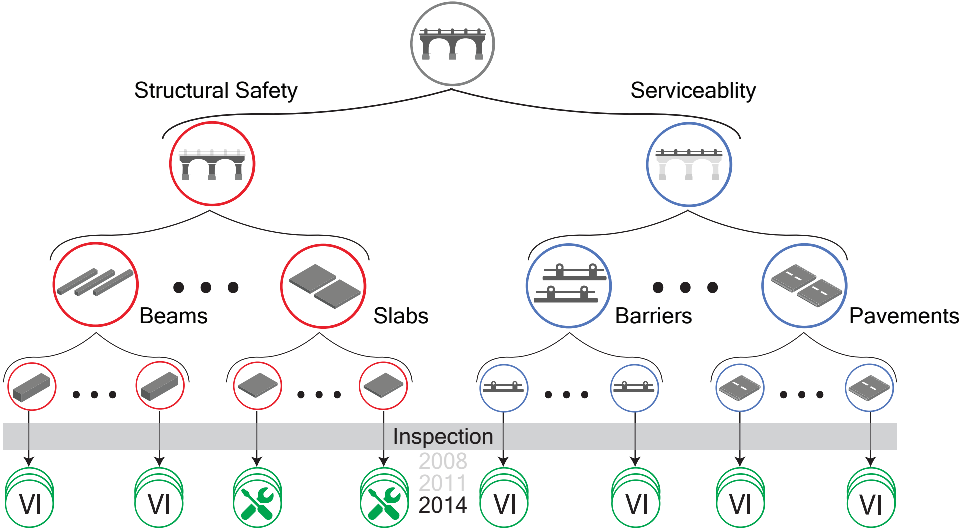

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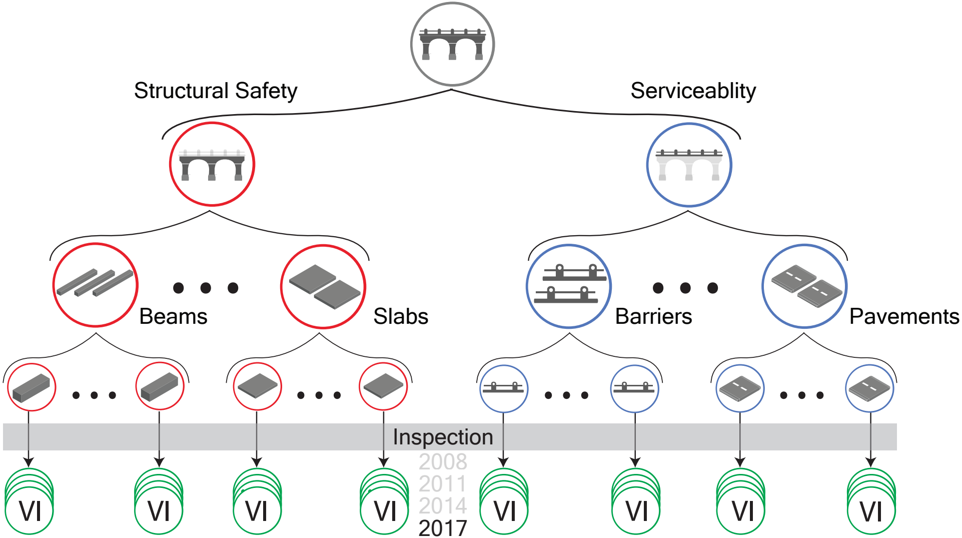

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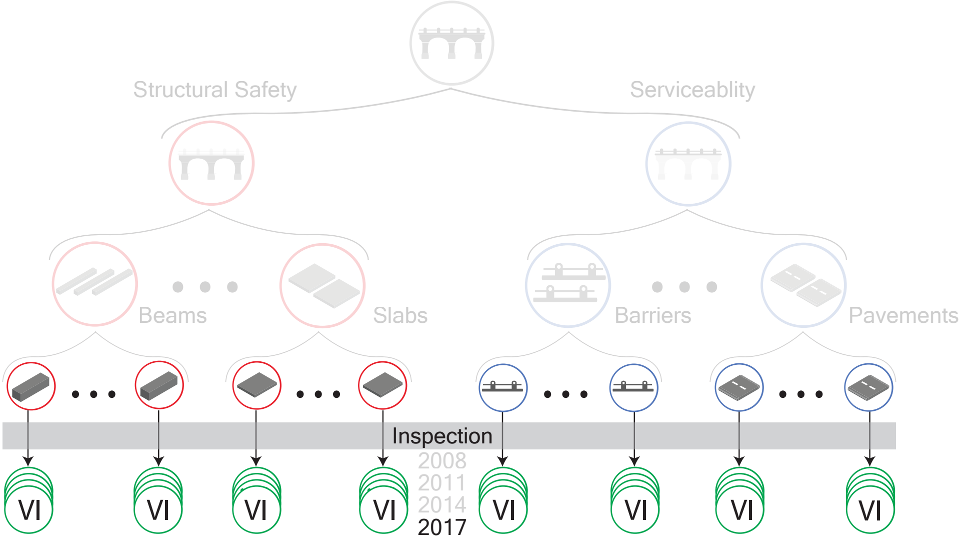

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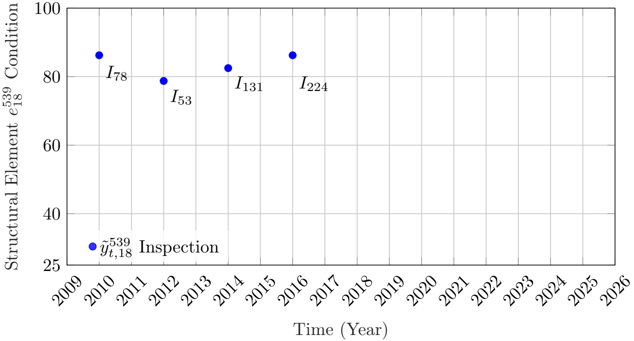
Example of Visual Inspections on a Structural Element



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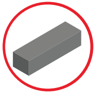

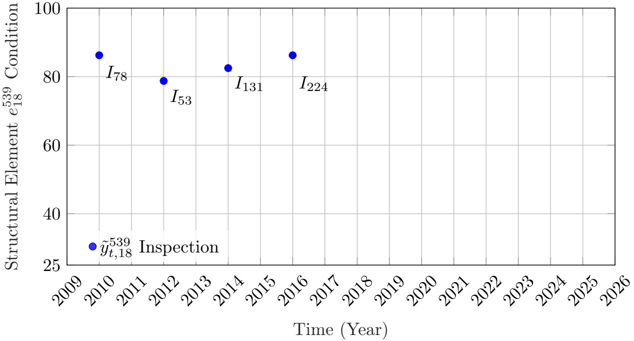

☑ Limited data.

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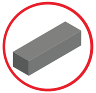
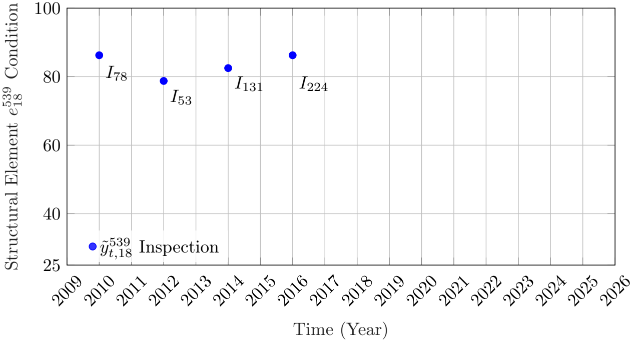
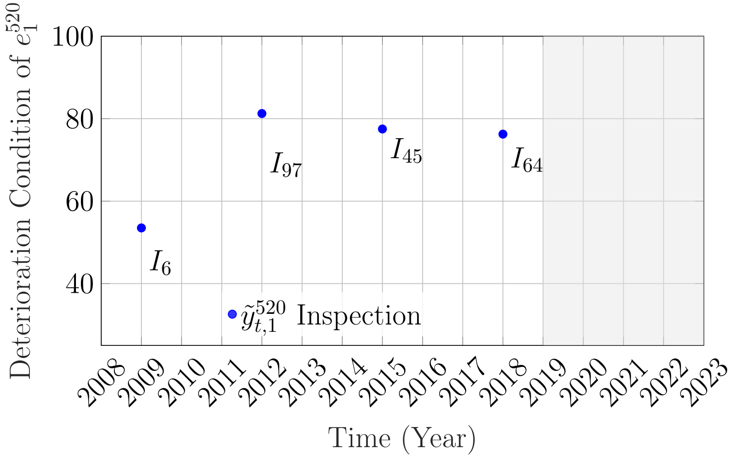


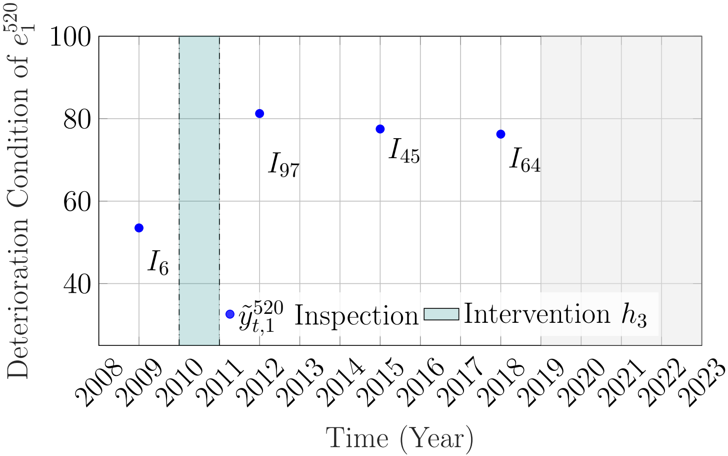


- ☑ Limited data.
- ☑ Subjective (high variability + different inspectors).

Example of Visual Inspections with an Intervention



Example of Visual Inspections with an Intervention



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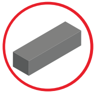

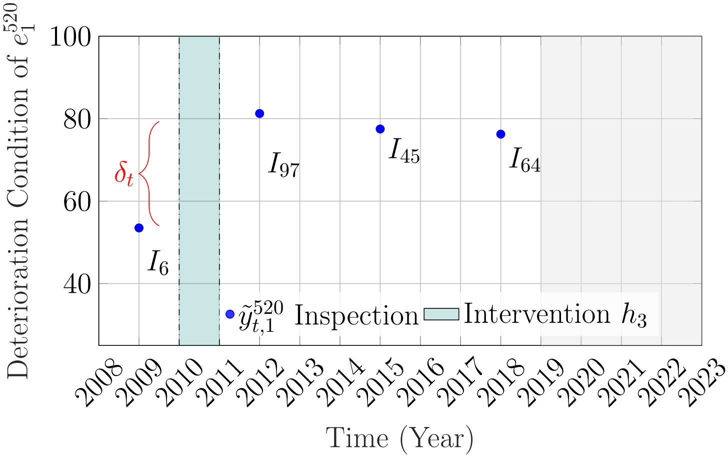

Objectives

- **Modelling infrastructures deterioration** from network-scale visual inspections.

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- **Modelling infrastructures deterioration** from network-scale visual inspections.
- Quantifying the **effects of interventions** based on visual inspections.

Deterioration Behaviour Described by Kinematics

$$\overbrace{x_{t+1} \quad = \quad x_t + \dot{x}_t \Delta t + \frac{1}{2}\ddot{x}_t \Delta t^2 + w \quad \text{(Condition)}}^{\text{Kinematic Equations}}$$

Source: Hamida and Goulet, 2020

Deterioration Behaviour Described by Kinematics

$$\overbrace{\begin{array}{rcll} x_{t+1} & = & x_t + \dot{x}_t \Delta t + \frac{1}{2}\ddot{x}_t \Delta t^2 + w & \text{(Condition)} \\ \dot{x}_{t+1} & = & \dot{x}_t + \ddot{x}_t \Delta t + \dot{w} & \text{(Speed)} \end{array}}^{\text{Kinematic Equations}}$$

Source: Hamida and Goulet, 2020

Deterioration Behaviour Described by Kinematics

$$\overbrace{\begin{array}{rcll} x_{t+1} & = & x_t + \dot{x}_t \Delta t + \frac{1}{2}\ddot{x}_t \Delta t^2 + w & \text{(Condition)} \\ \dot{x}_{t+1} & = & \dot{x}_t + \ddot{x}_t \Delta t + \dot{w} & \text{(Speed)} \\ \ddot{x}_{t+1} & = & \ddot{x}_t + \ddot{w} & \text{(Acceleration)} \end{array}}^{\text{Kinematic Equations}}$$

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Deterioration Behaviour Described by Kinematics

$$\underbrace{\begin{bmatrix} x_t \\ \dot{x}_t \\ \ddot{x}_t \end{bmatrix}}_{\boldsymbol{x}_t} = \underbrace{\begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} \\ 0 & 1 & \Delta t \\ 0 & 0 & 1 \end{bmatrix}}_{\boldsymbol{A}} \cdot \underbrace{\begin{bmatrix} x_{t-1} \\ \dot{x}_{t-1} \\ \ddot{x}_{t-1} \end{bmatrix}}_{\boldsymbol{x}_{t-1}} + \underbrace{\begin{bmatrix} w_t \\ \dot{w}_t \\ \ddot{w}_t \end{bmatrix}}_{\boldsymbol{w}_t}$$

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Method: State-Space Models

Source: Hamida and Goulet, 2020

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Method: State-Space Models

$$\overbrace{\boldsymbol{x}_t = \boldsymbol{A}\boldsymbol{x}_{t-1} + \boldsymbol{w}_t}^{\textbf{transition model}}$$

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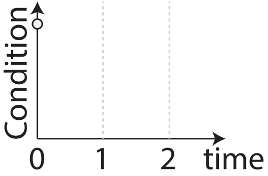

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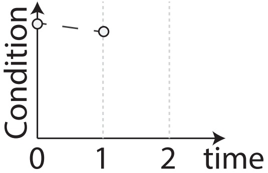

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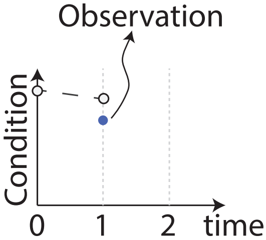

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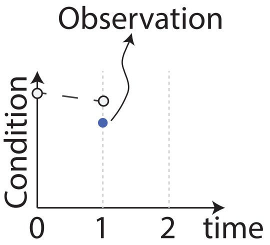

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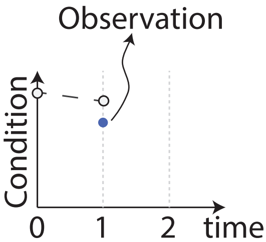

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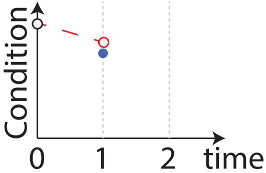

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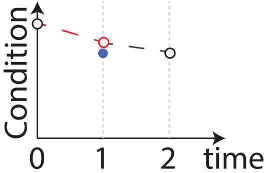

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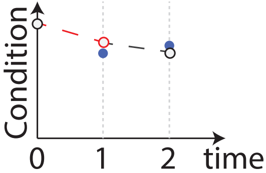

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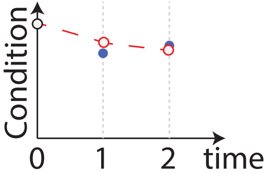


Source: Hamida and Goulet, 2020

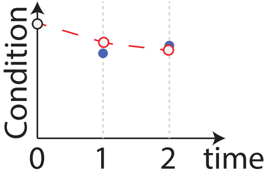
Deterioration Behaviour Described by Kinematics

$$\underbrace{\begin{bmatrix} x_t \\ \dot{x}_t \\ \ddot{x}_t \end{bmatrix}}_{\boldsymbol{x}_t} = \underbrace{\begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} \\ 0 & 1 & \Delta t \\ 0 & 0 & 1 \end{bmatrix}}_{\boldsymbol{A}} \cdot \underbrace{\begin{bmatrix} x_{t-1} \\ \dot{x}_{t-1} \\ \ddot{x}_{t-1} \end{bmatrix}}_{\boldsymbol{x}_{t-1}} + \underbrace{\begin{bmatrix} w_t \\ \dot{w}_t \\ \ddot{w}_t \end{bmatrix}}_{\boldsymbol{w}_t}$$

Method: State-Space Models

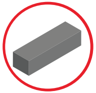
$$\overbrace{\boldsymbol{x}_t = \boldsymbol{A}\boldsymbol{x}_{t-1} + \boldsymbol{w}_t}^{\textbf{transition model}}, \ \underbrace{\boldsymbol{w}_t : \boldsymbol{W} \sim \mathcal{N}(\boldsymbol{w}; \boldsymbol{0}, \boldsymbol{Q}_t)}_{\textbf{process error}}$$

$$\overbrace{y_t = \boldsymbol{C}\boldsymbol{x}_t + v_t}^{\textbf{observation model}}, \ \underbrace{v_t : V \sim \mathcal{N}(v; 0, \sigma_V^2)}_{\textbf{observation error}}$$

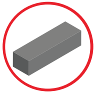


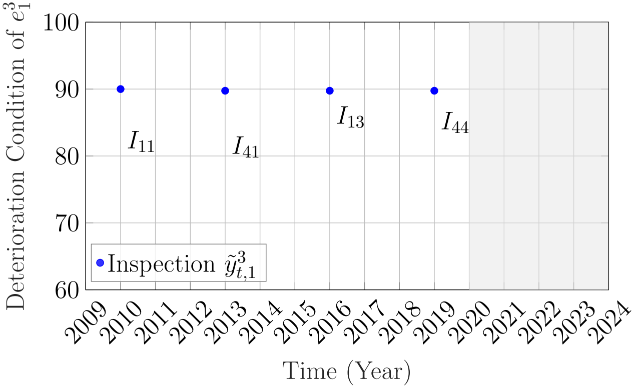
Source: Hamida and Goulet, 2020

Uncertainty of Observations (Inspectors)



Uncertainty of Observations (Inspectors)





$$\overbrace{y_t = \boldsymbol{C}\boldsymbol{x}_t + v_t}^{\text{observation model}}, \; \underbrace{v_t : V \sim \mathcal{N}(v; 0, \sigma_V^2)}_{\text{observation error}}$$

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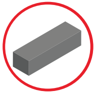

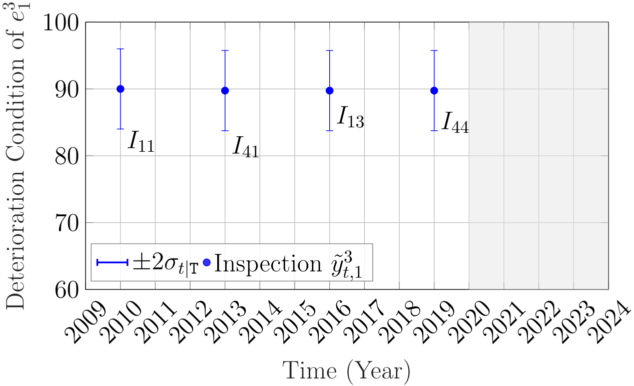

$$\overbrace{y_t = \boldsymbol{C}\boldsymbol{x}_t + v_t}^{\text{observation model}}, \; \underbrace{v_t : V \sim \mathcal{N}(v; 0, \sigma_V^2)}_{\text{observation error}}$$

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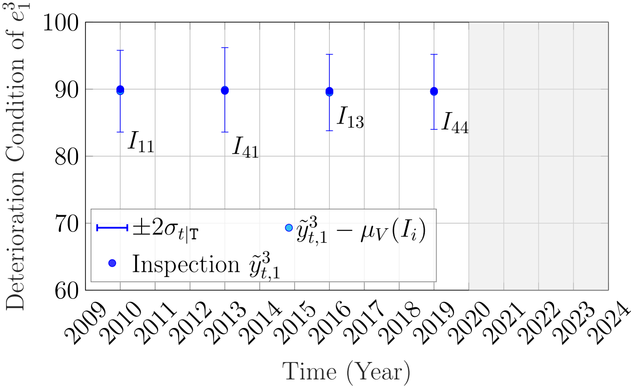
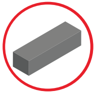
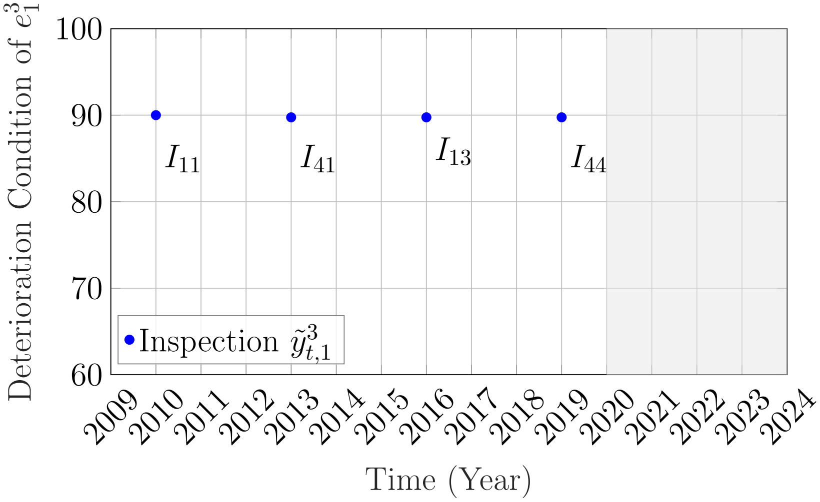


$$\overbrace{y_t = \boldsymbol{C}\boldsymbol{x}_t + v_t}^{\text{observation model}}, \quad \underbrace{v_t : V(I_i) \sim \mathcal{N}(v; \mu_V(I_i), \sigma_V^2(I_i))}_{\text{observation error}}$$

Example of a Beam Structural Element





Source: Hamida and Goulet, 2020

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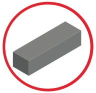

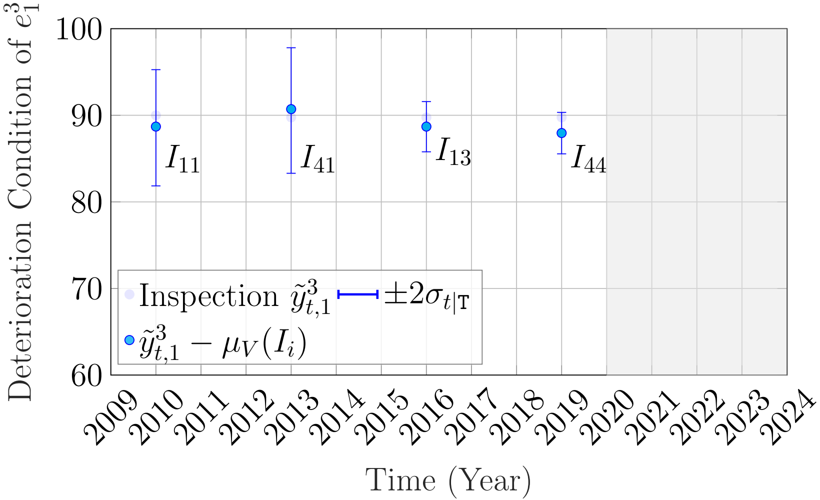

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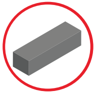
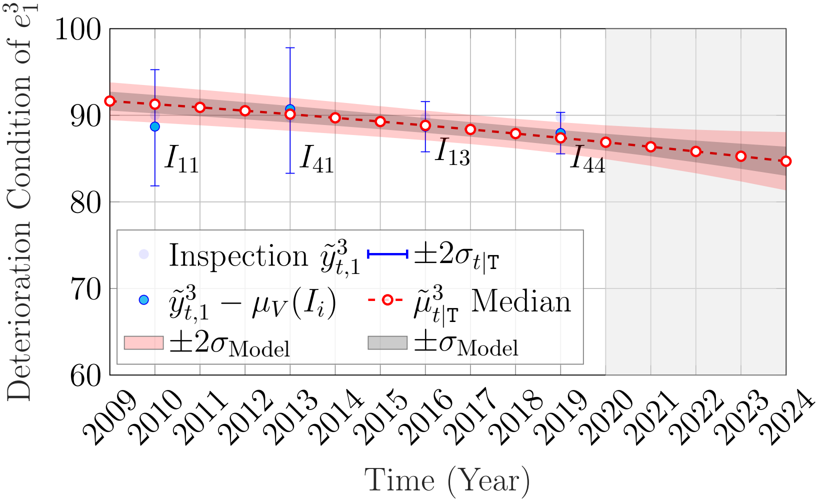
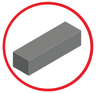
Example of a Beam Structural Element

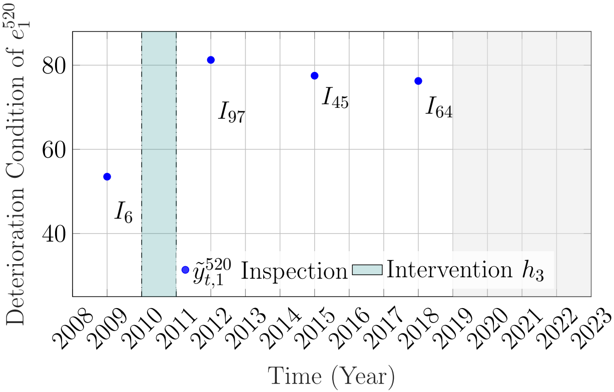


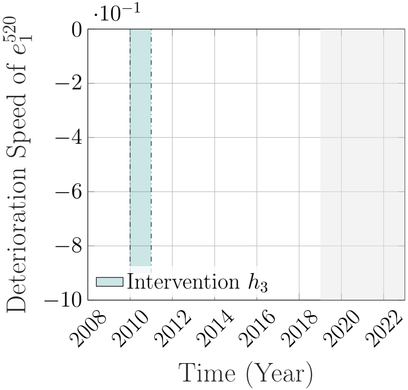


Source: Hamida and Goulet, 2020

Structural Element Underwent Reparation

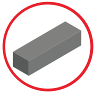


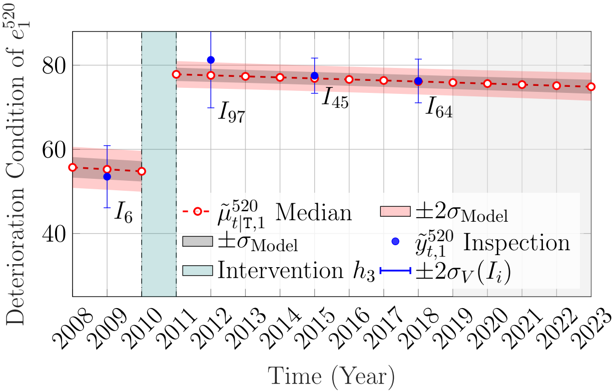


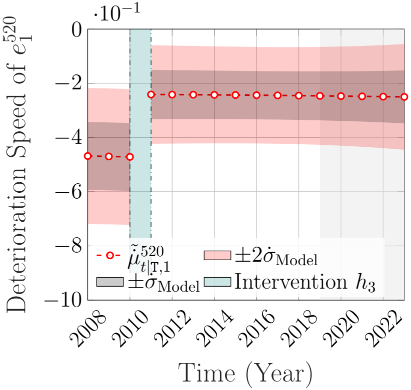


Source: Hamida and Goulet, 2021

Structural Element Underwent Reparation

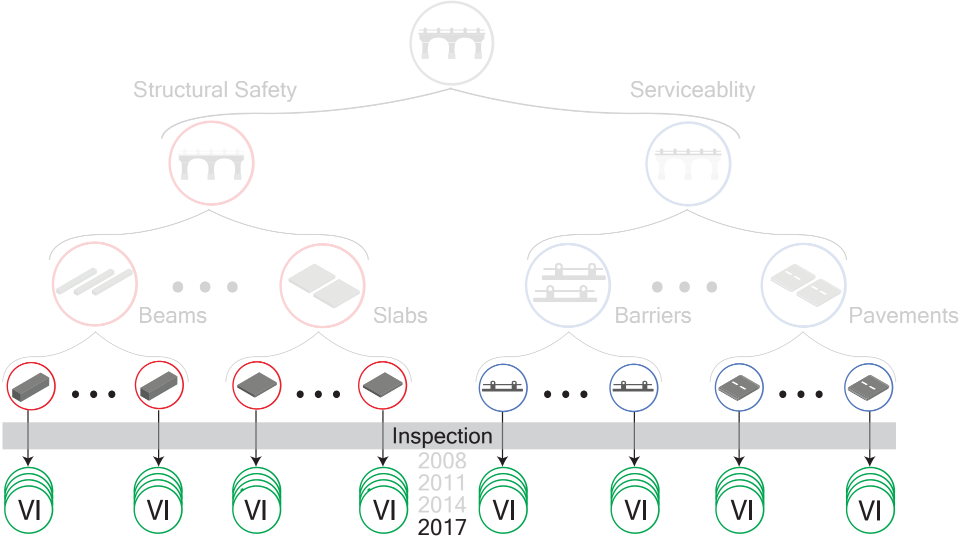






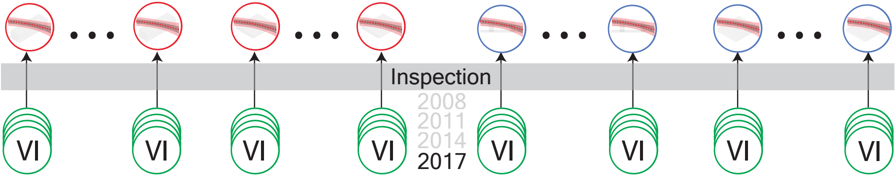
Source: Hamida and Goulet, 2021

Bridge Components



Source: MTQ, Manual of Inspection 2022
Source: Hamida and Goulet, 2022

Bridge Components



Source: Hamida and Goulet, 2022

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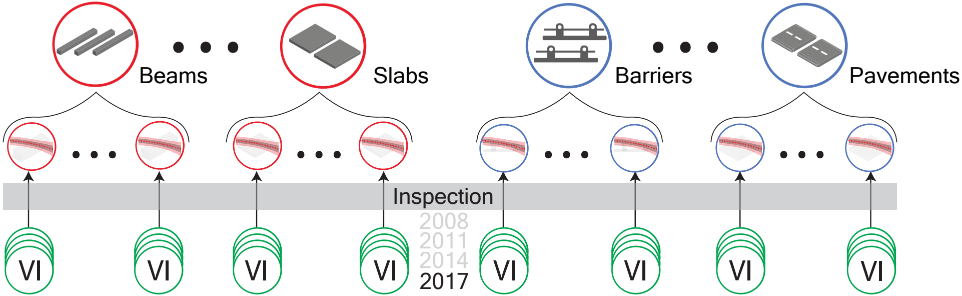

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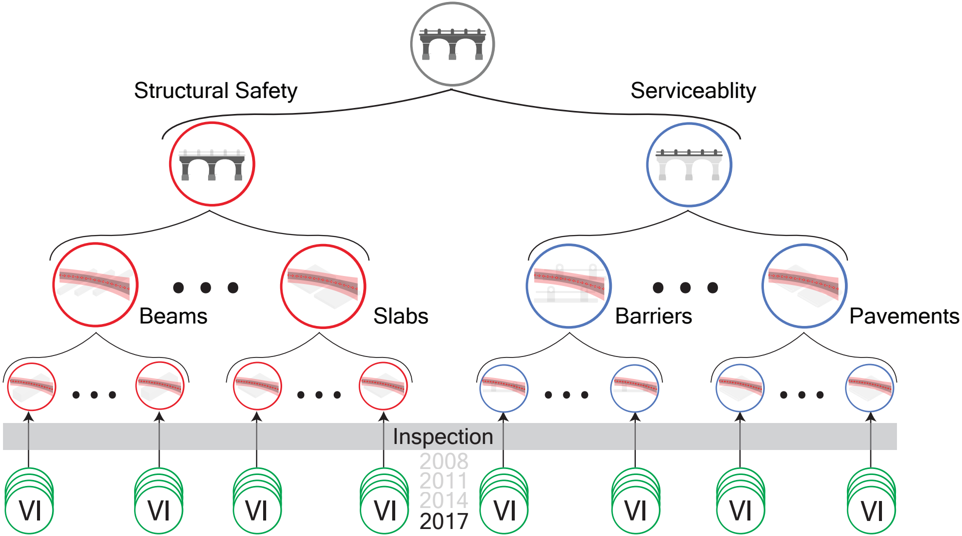
Bridge Components



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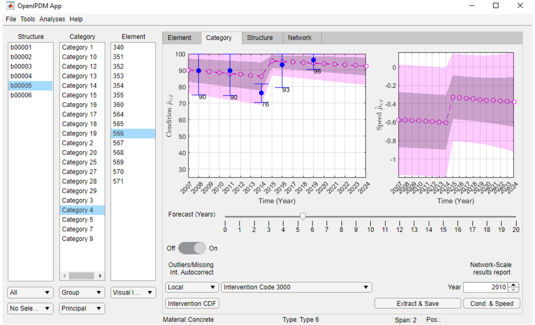
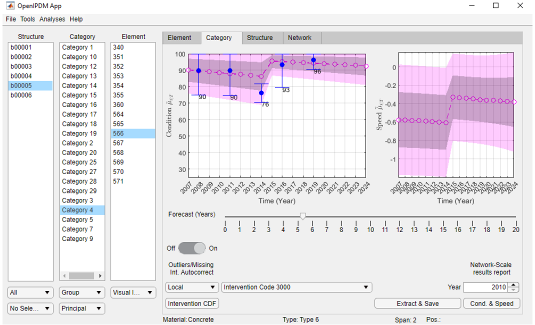
Software

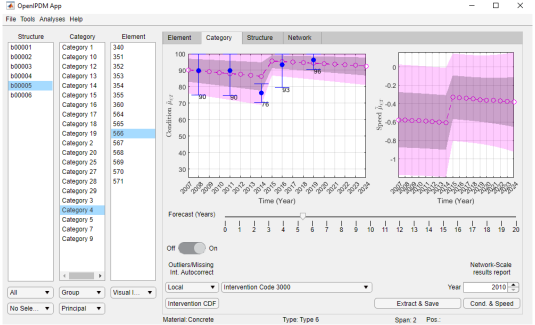
OpenIPDM



OpenIPDM

- Open-source software developed in `MATLAB`.





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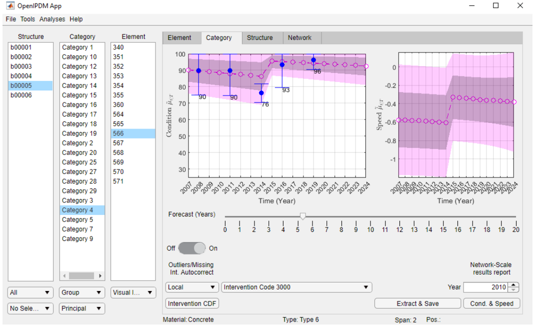
OpenIPDM



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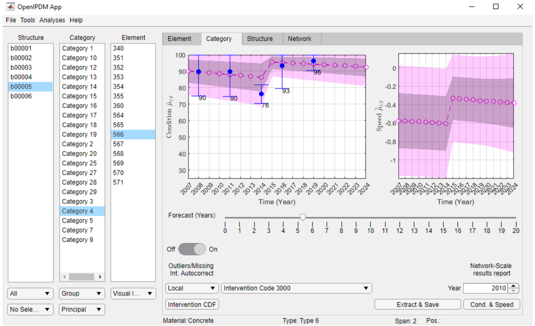

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The software **OpenIPDM** is **available online** on **GitHub**

https://github.com/CivML-PolyMtl/OpenIPDM