

Maintenance Planning for Bridges using Hierarchical Reinforcement Learning

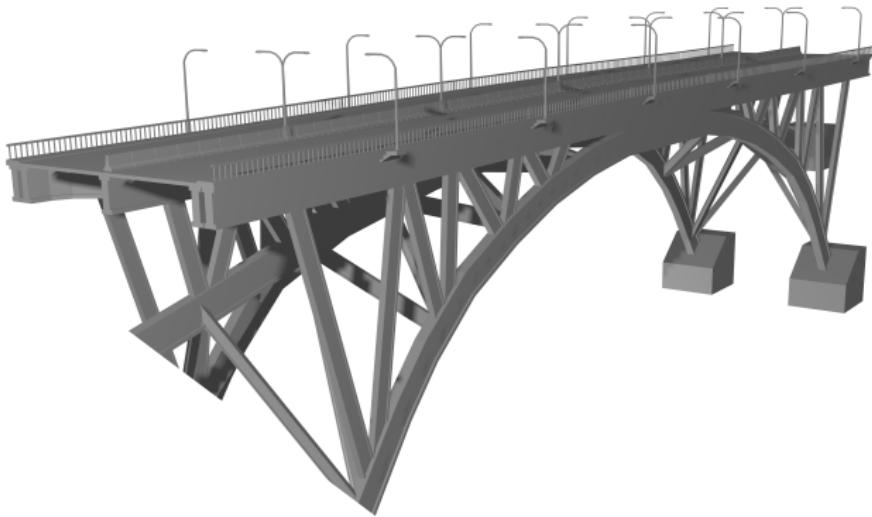
Zachary Hamida Postdoc
James-A. Goulet Professeur

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

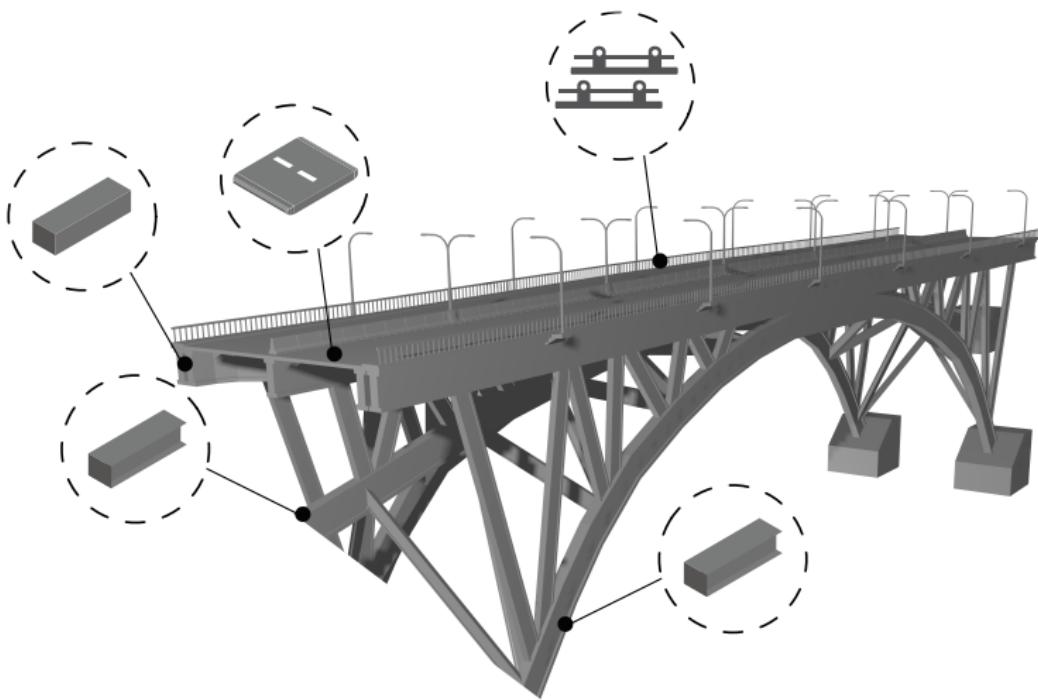
July 10, 2023

Funding:
Transportation Ministry of Quebec (MTQ)

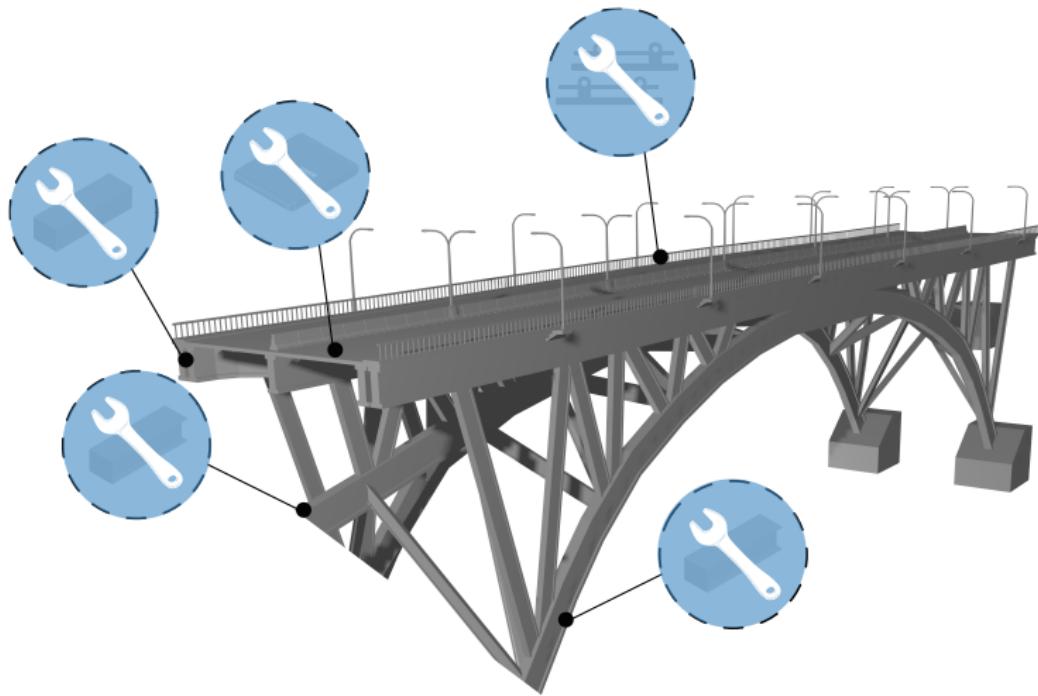
Bridge Maintenance



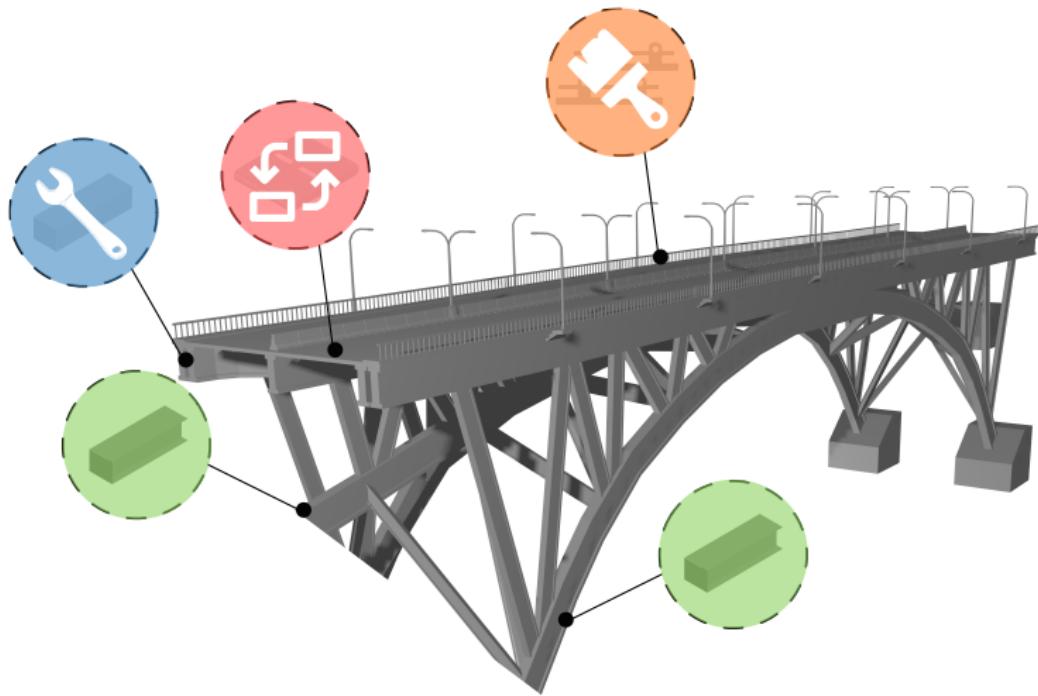
Bridge Maintenance



Bridge Maintenance



Bridge Maintenance



Context
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Preliminaries

Element Maintenance
○○

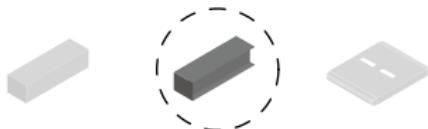
Bridge Maintenance
○○

Results & Analyses
○○

Conclusions
○

Maintenance Planning Challenges

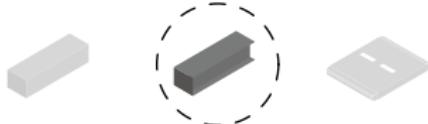
Maintenance Planning Challenges



Maintenance Planning Challenges



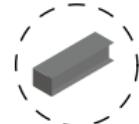
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Maintenance Planning Challenges



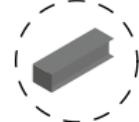
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Maintenance Planning Challenges



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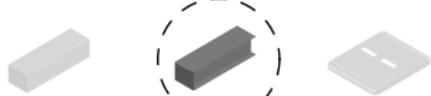
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Maintenance Planning Challenges



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Context
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Background

Element Maintenance
○○

Bridge Maintenance
○○

Results & Analyses
○○

Conclusions
○

Automate Decision-Making

Automate Decision-Making

- ▷ Health condition of structural elements

Context
○○○●○○○

Background

Element Maintenance
○○

Bridge Maintenance
○○

Results & Analyses
○○

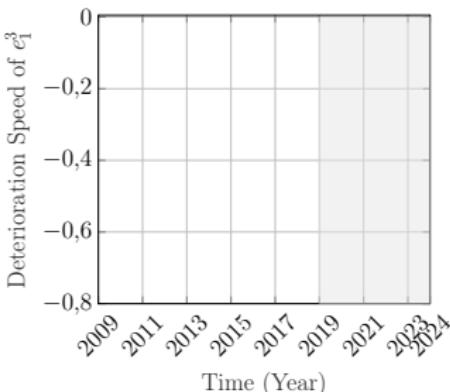
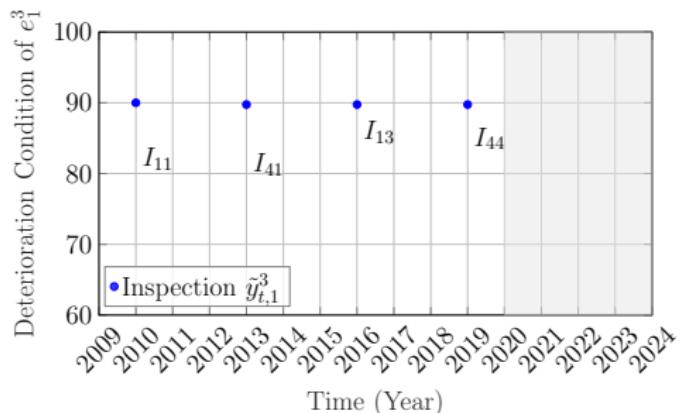
Conclusions
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Example of a Beam Element Deterioration



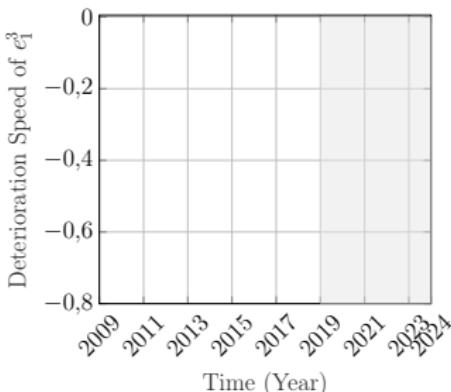
Source: Hamida & Goulet (2021)

Example of a Beam Element Deterioration



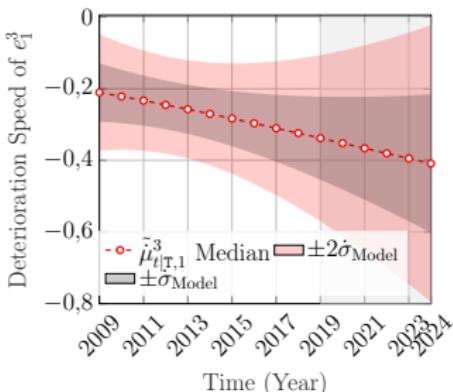
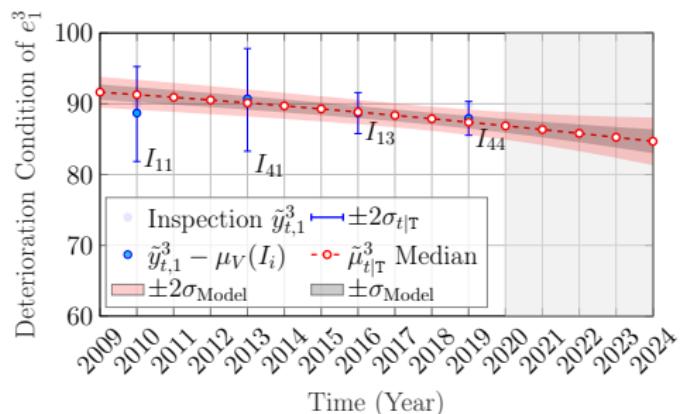
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Example of a Beam Element Deterioration



Source: Hamida & Goulet (2021)

Example of a Beam Element Deterioration

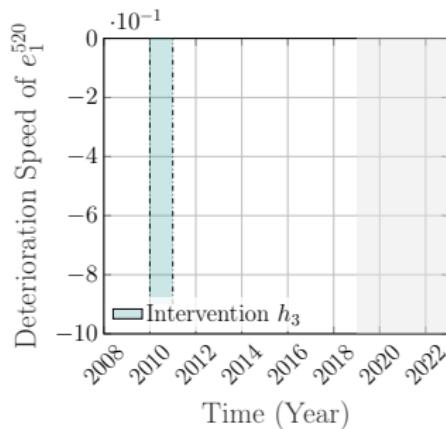
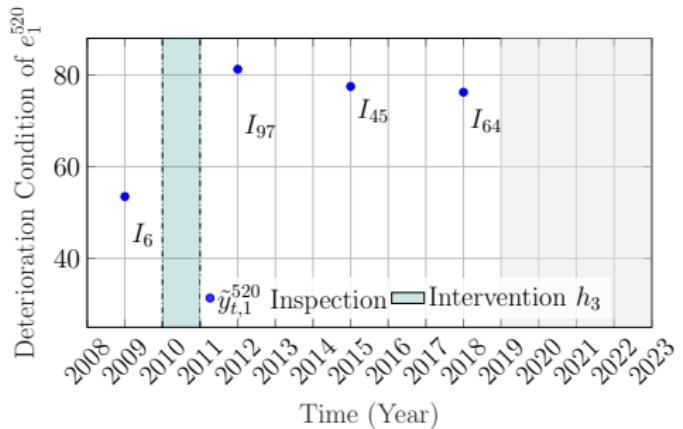


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Automate Decision-Making

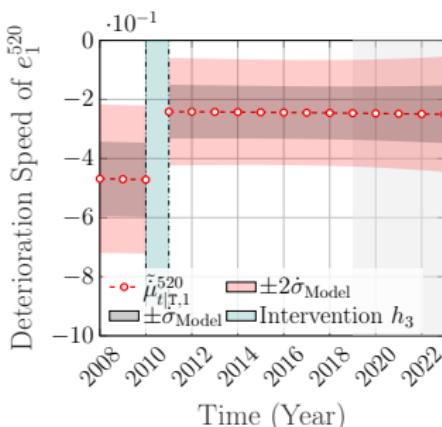
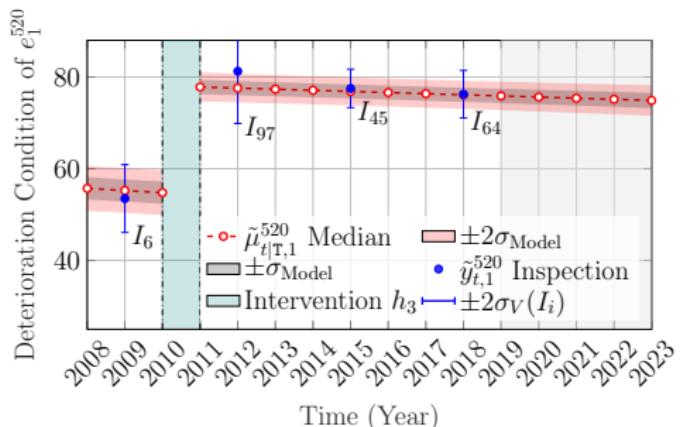
- ▷ Health condition of structural elements 
- ▷ Effect of maintenance actions

Example of Repairs on a Beam Element



Source: Hamida & Goulet (2021)

Example of Repairs on a Beam Element



Source: Hamida & Goulet (2021)

Automate Decision-Making

- ▷ Health condition of structural elements 
- ▷ Effect of maintenance actions 

Source: Hamida & Goulet (2023)

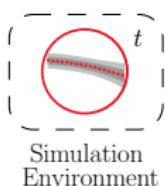
Automate Decision-Making

- ▷ Health condition of structural elements 
- ▷ Effect of maintenance actions 
- ▷ Cost of maintenance actions 

Source: Hamida & Goulet (2023)

Automate Decision-Making

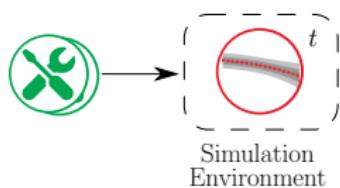
- ▷ Health condition of structural elements 
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Source: Hamida & Goulet (2023)

Automate Decision-Making

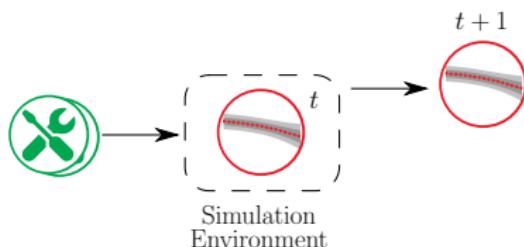
- ▷ Health condition of structural elements 
- ▷ Effect of maintenance actions 
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Source: Hamida & Goulet (2023)

Automate Decision-Making

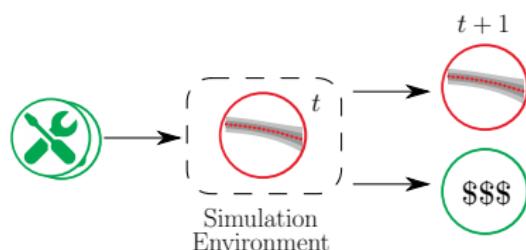
- ▷ Health condition of structural elements 
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Source: Hamida & Goulet (2023)

Automate Decision-Making

- ▷ Health condition of structural elements
- ▷ Effect of maintenance actions
- ▷ Cost of maintenance actions



Source: Hamida & Goulet (2023)

Context
○○○○○○○

Element Maintenance
●○

Bridge Maintenance
○○

Results & Analyses
○○

Conclusions
○

Element Maintenance

Reinforcement Learning

Context
○○○○○○○

Element Maintenance
●○

Bridge Maintenance
○○

Results & Analyses
○○

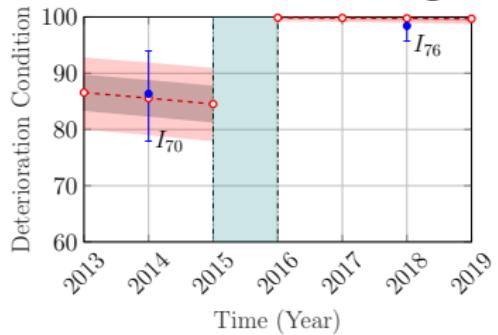
Conclusions
○

Element Maintenance

Reinforcement Learning

Element Maintenance

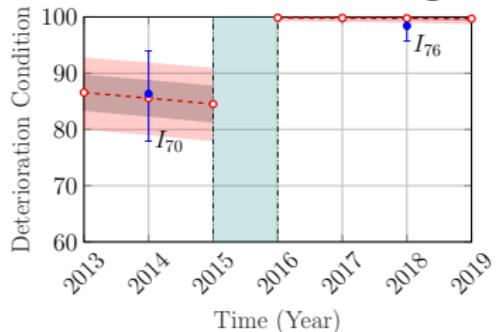
Reinforcement Learning



Replacement:

Element Maintenance

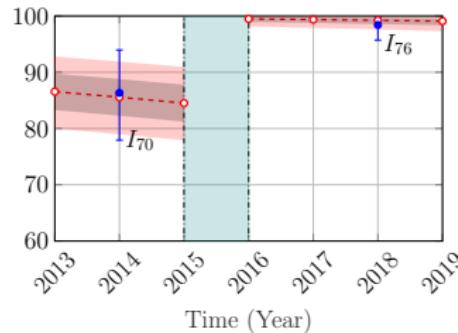
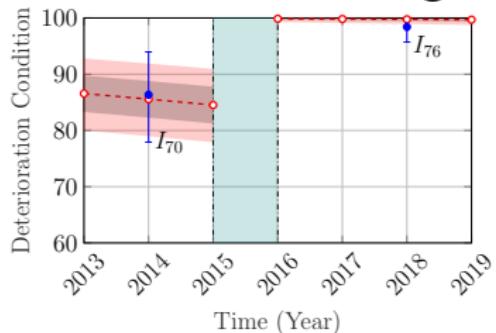
Reinforcement Learning



Replacement:

Element Maintenance

Reinforcement Learning

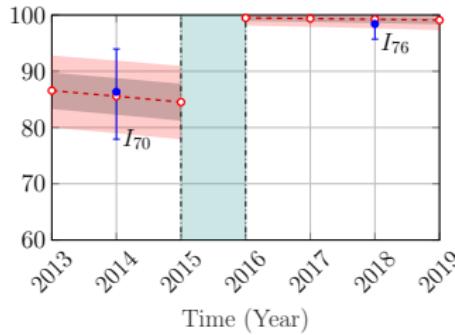
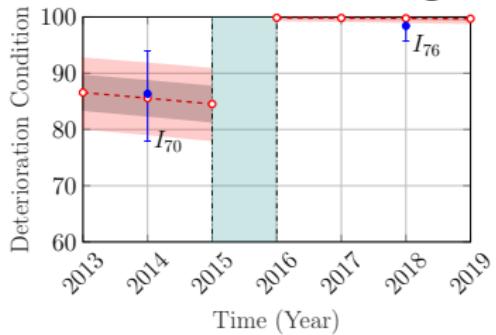


Replacement:

Repairs:

Element Maintenance

Reinforcement Learning



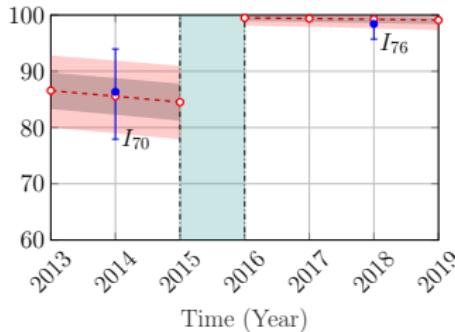
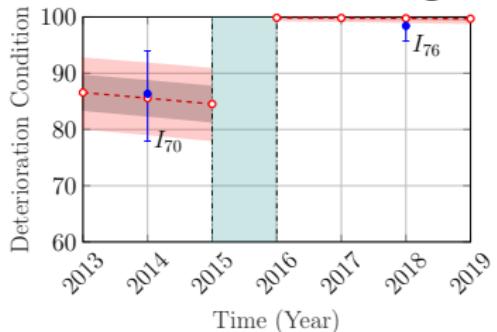
Replacement:

Repairs:

▷ Agent: decision-maker.

Element Maintenance

Reinforcement Learning



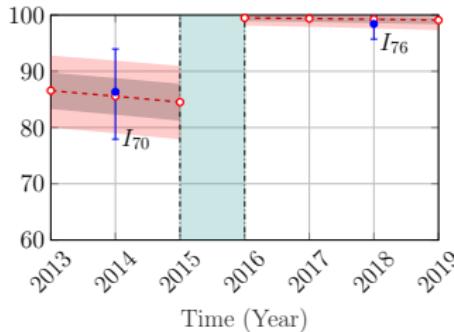
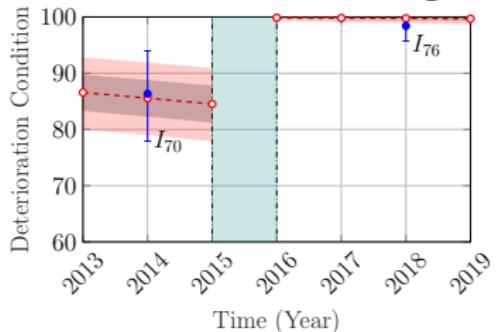
Replacement:

Repairs:

- ▷ Agent: decision-maker.
- ▷ Environment : deterioration model.

Element Maintenance

Reinforcement Learning



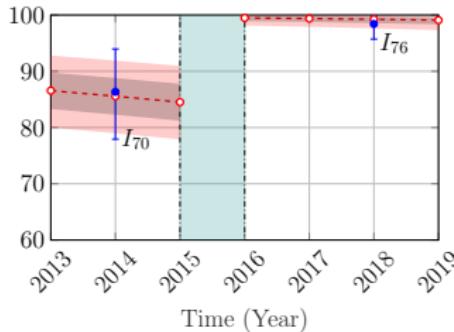
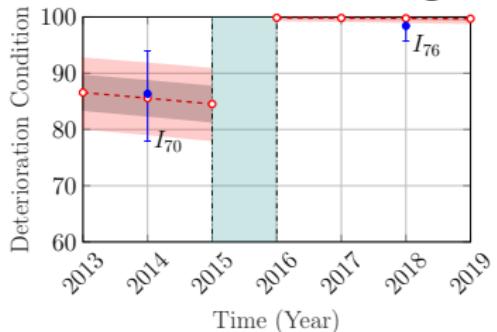
Replacement:

Repairs:

- ▷ Agent: decision-maker.
- ▷ Environment : deterioration model.
- ▷ Actions: do nothing, repair, replace.

Element Maintenance

Reinforcement Learning



Replacement:

Repairs:

- ▷ Agent: decision-maker.
- ▷ Environment : deterioration model.
- ▷ Actions: do nothing, repair, replace.
- ▷ Objective: minimize total costs.

Context
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Element Maintenance
○●

Bridge Maintenance
○○

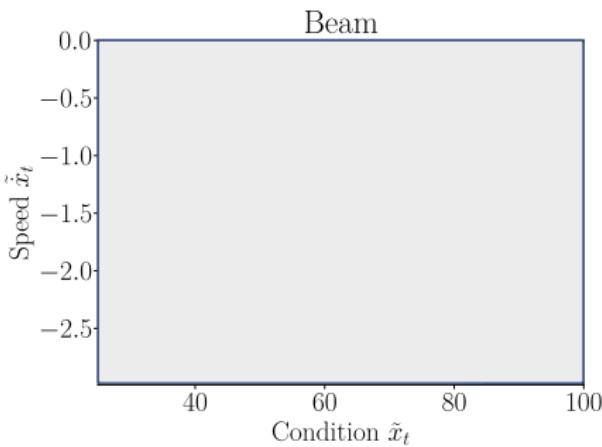
Results & Analyses
○○

Conclusions
○

Element-level Policy

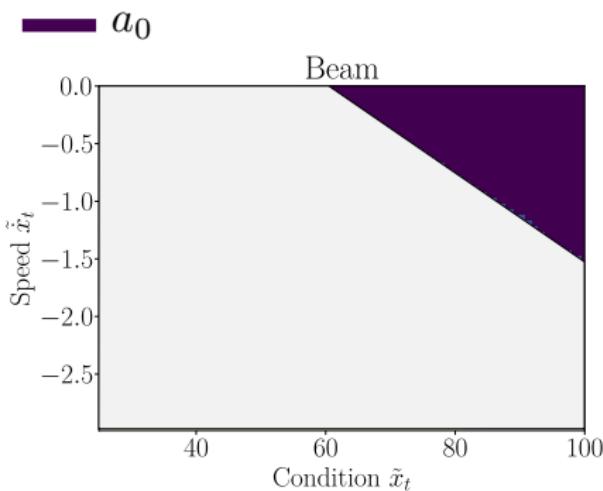
Reinforcement Learning

Reinforcement Learning



Reinforcement Learning

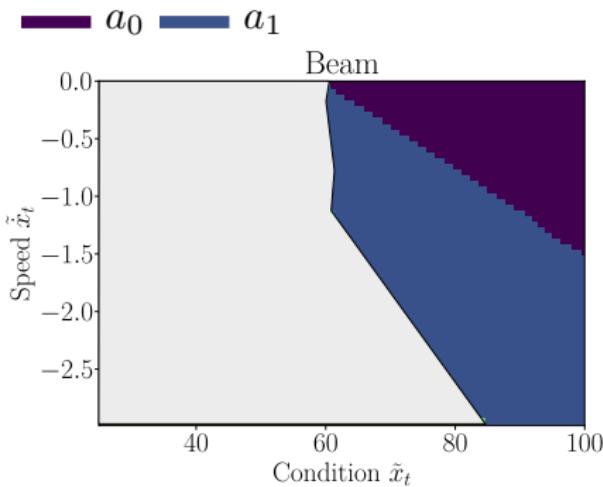
a_0 : do nothing,



Reinforcement Learning

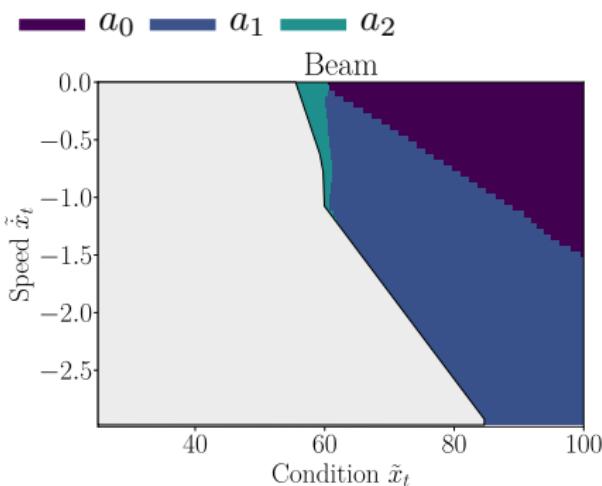
a_0 : do nothing,

a_1 : preventive repairs,



Reinforcement Learning

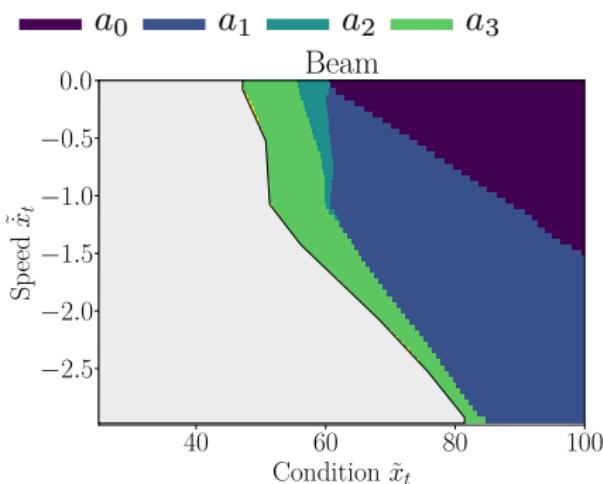
- a_0 : do nothing,
- a_1 : preventive repairs,
- a_2 : routine maintenance,



Element-level Policy

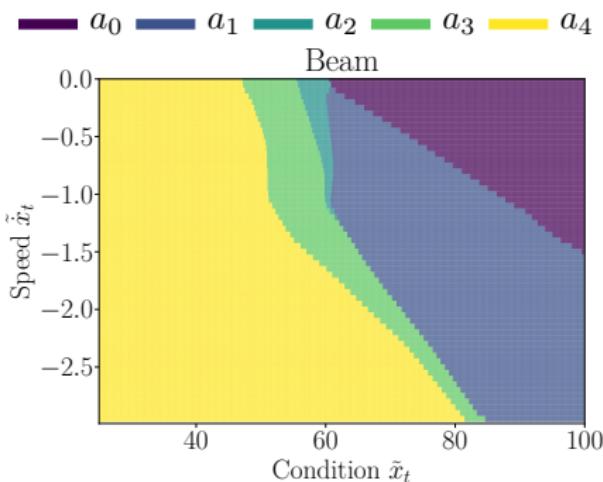
Reinforcement Learning

- a_0 : do nothing,
- a_1 : preventive repairs,
- a_2 : routine maintenance,
- a_3 : repairs,



Reinforcement Learning

- a_0 : do nothing,
- a_1 : preventive repairs,
- a_2 : routine maintenance,
- a_3 : repairs,
- a_4 : replacement.



Context
○○○○○○○

Concepts

Element Maintenance
○○

Bridge Maintenance
●○

Results & Analyses
○○

Conclusions
○

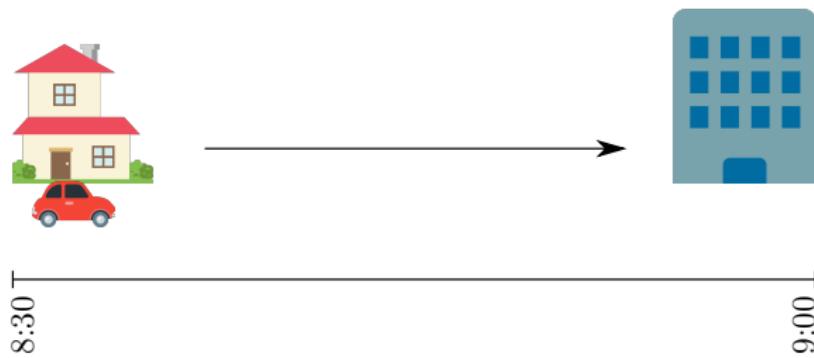
Temporal Abstraction

Temporal Abstraction

$$\mathcal{A} : \{a_0 : \text{stay at home}, a_1 : \text{go to work}\}$$

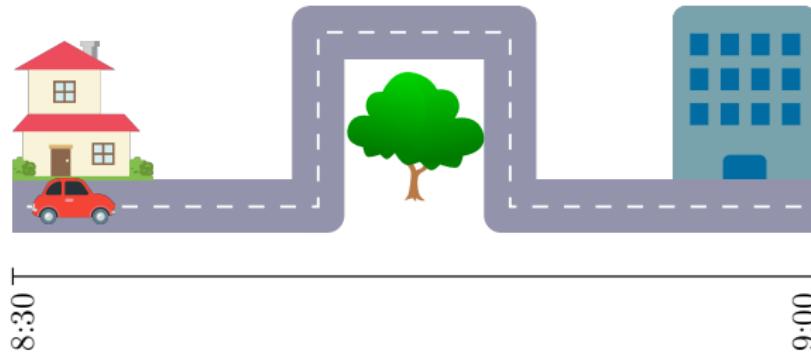
Temporal Abstraction

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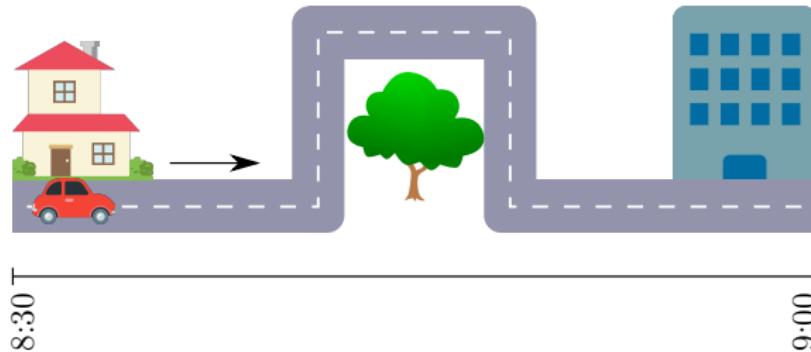
Temporal Abstraction

$$\begin{aligned}\mathcal{A} : \{a_0 : \text{stay at home}, \quad a_1 : \text{go to work}\} \\ \hookrightarrow \mathcal{A}^{a_1} : \{\uparrow, \downarrow, \rightarrow, \leftarrow\}\end{aligned}$$



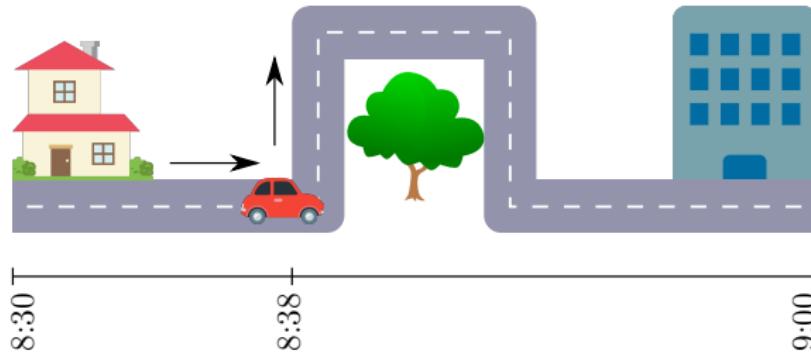
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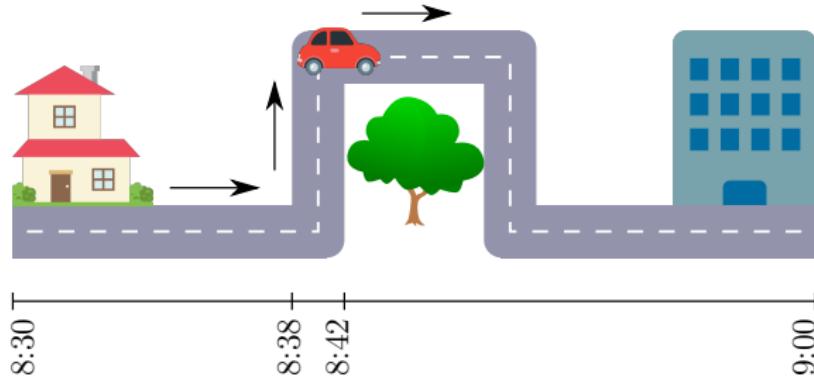
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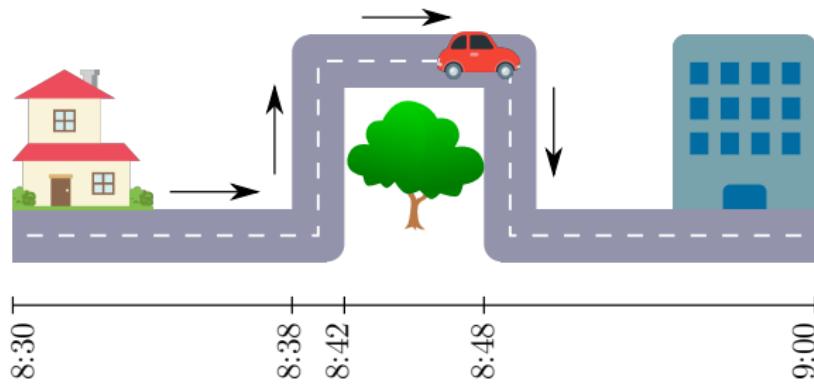
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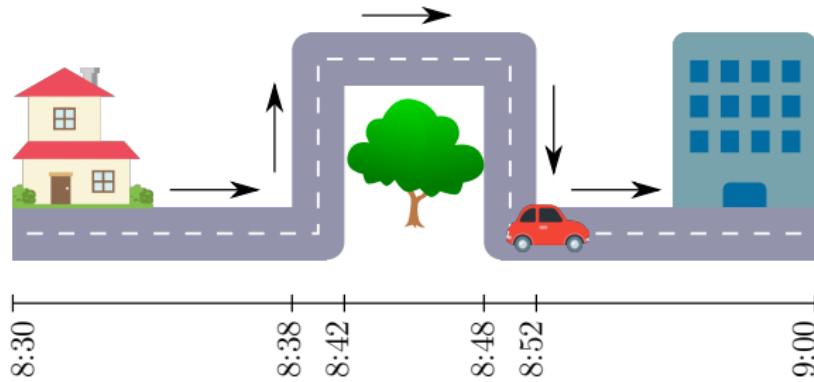
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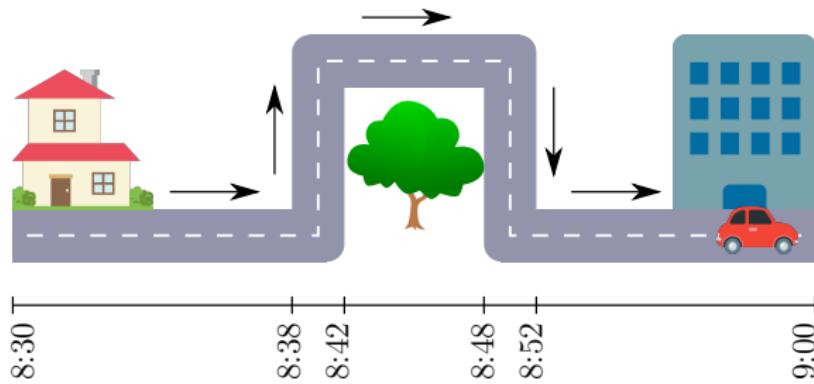
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Temporal Abstraction

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Context
○○○○○○○

Element Maintenance
○○

Bridge Maintenance
○●

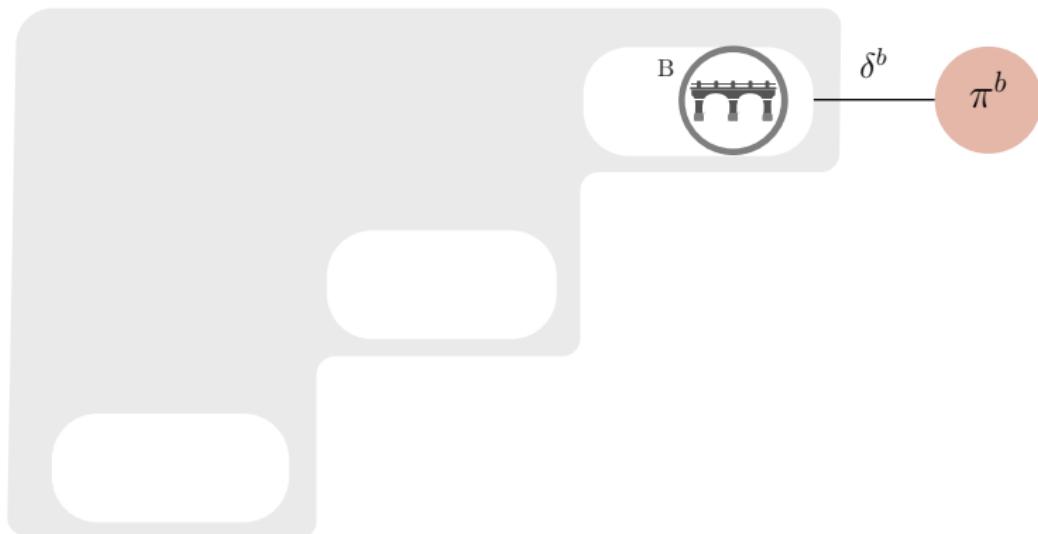
Results & Analyses
○○

Conclusions
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Decision-Making for Infrastructure

Bridge Maintenance Framework

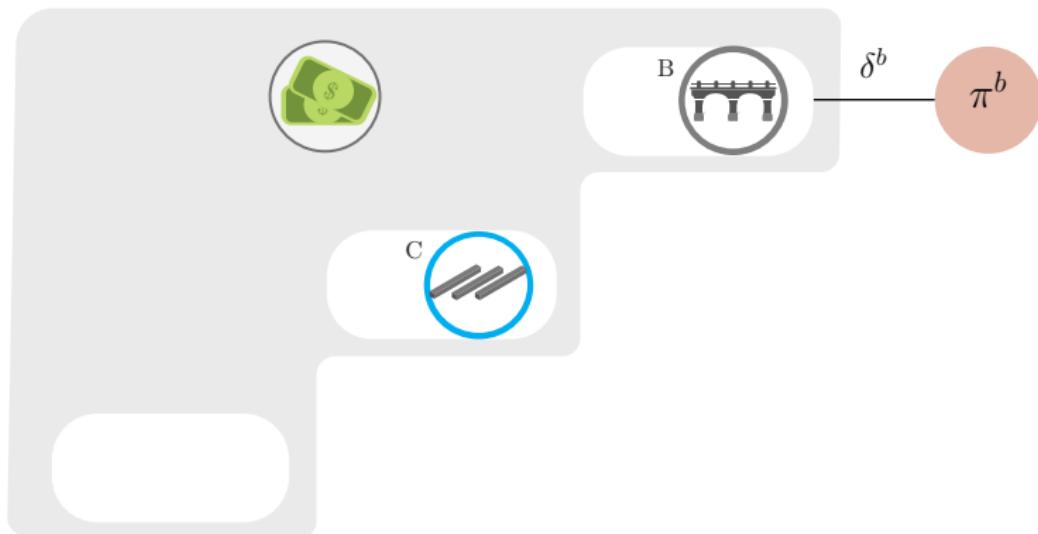
Bridge Maintenance Framework



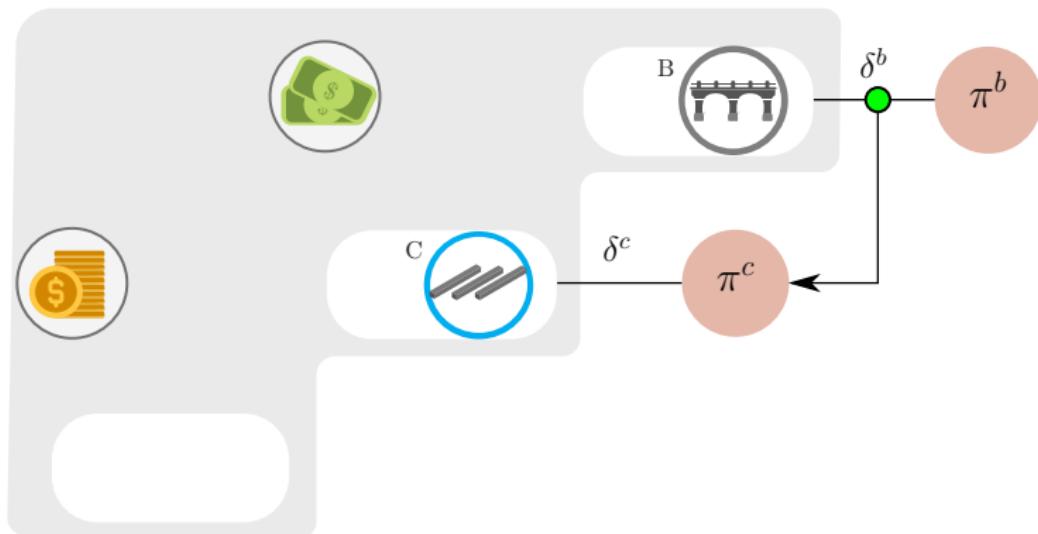
Bridge Maintenance Framework



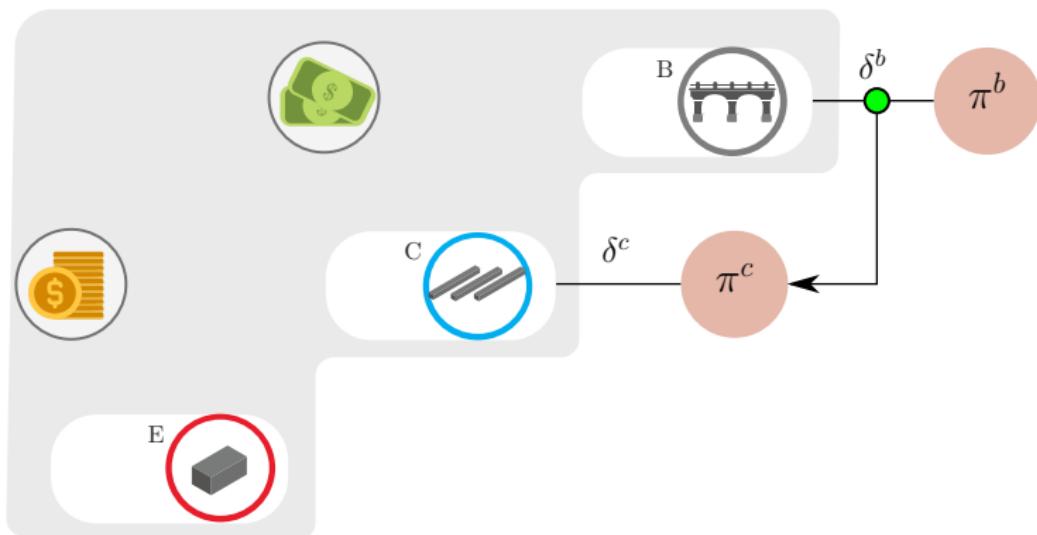
Bridge Maintenance Framework



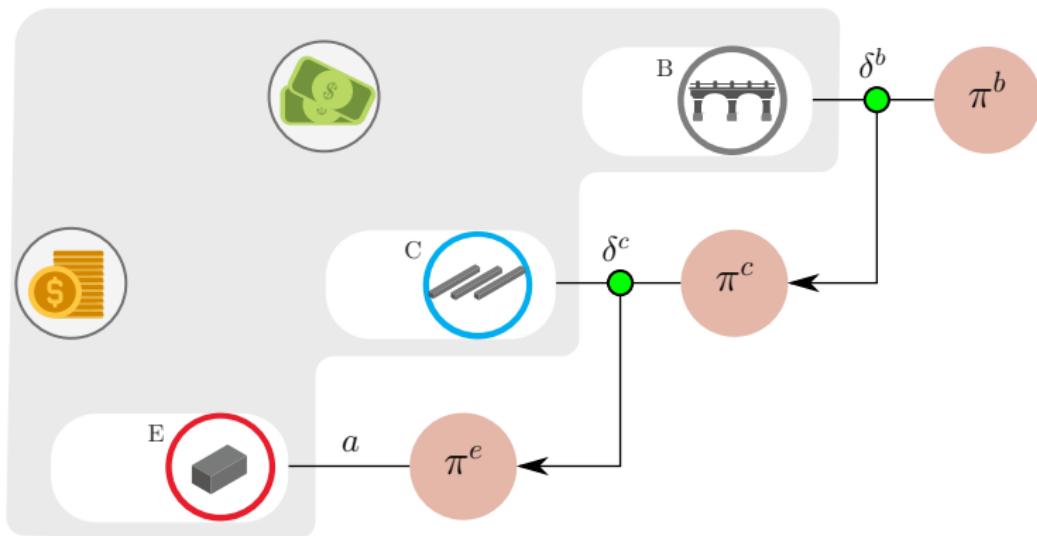
Bridge Maintenance Framework



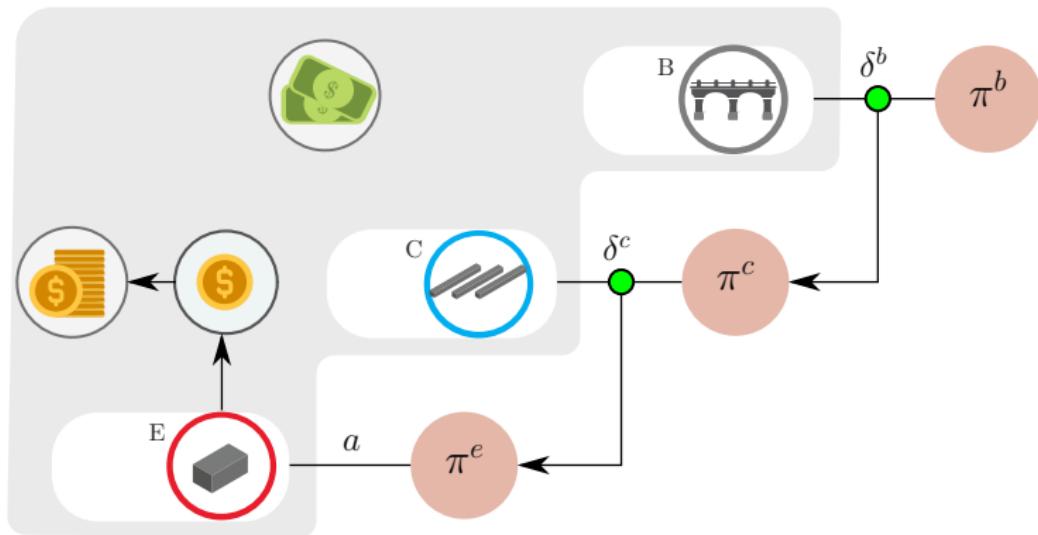
Bridge Maintenance Framework



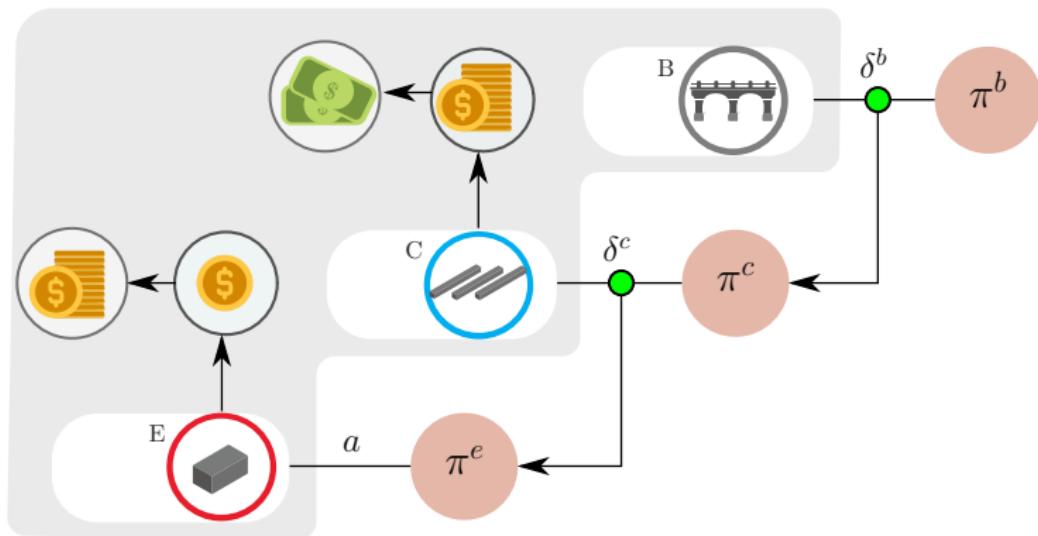
Bridge Maintenance Framework



Bridge Maintenance Framework



Bridge Maintenance Framework



Context
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Element Maintenance
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Bridge Maintenance
○○

Results & Analyses
●○

Conclusions
○

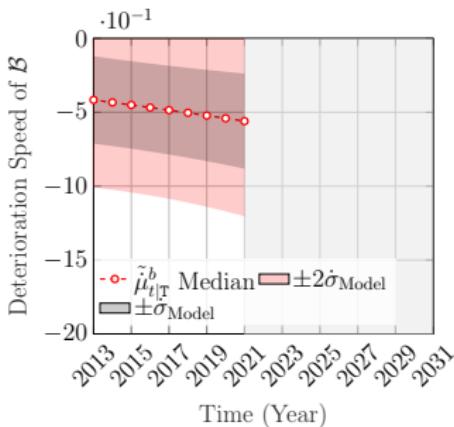
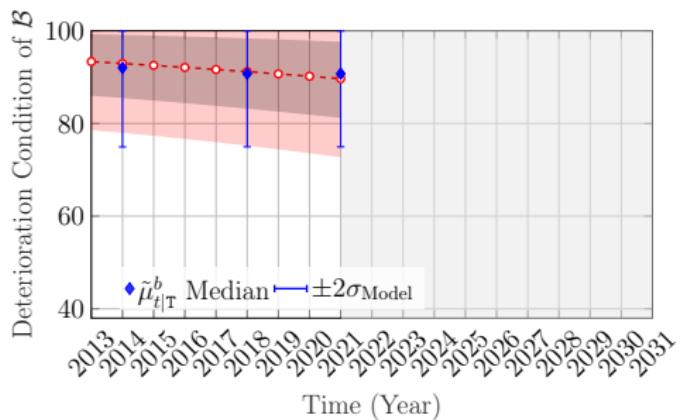
Bridge-level Policy

Example of Bridge Maintenance Policy





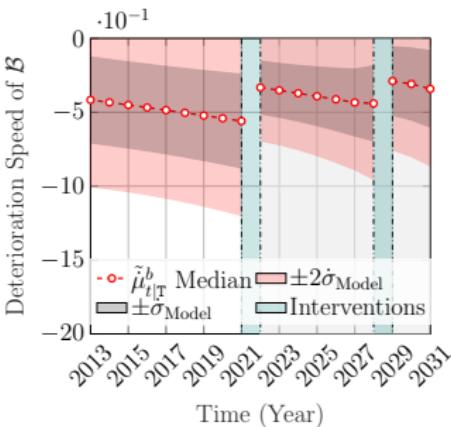
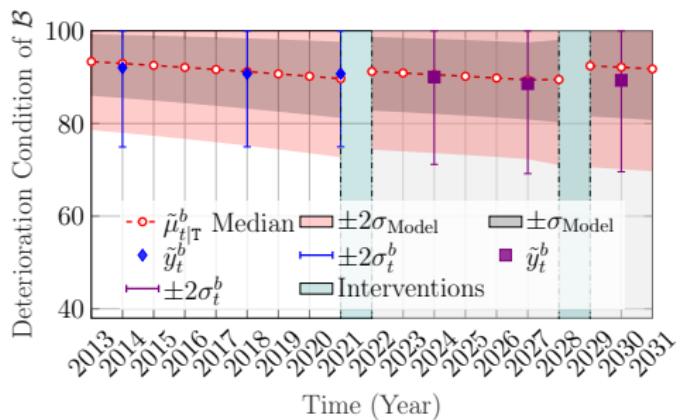
Example of Bridge Maintenance Policy



Bridge-level Policy



Example of Bridge Maintenance Policy



Context
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Element Maintenance
○○

Bridge Maintenance
○○

Results & Analyses
○●

Conclusions
○

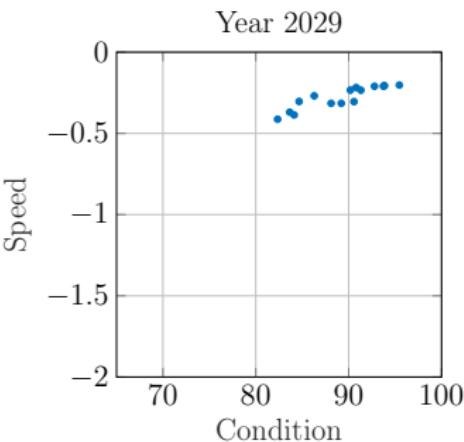
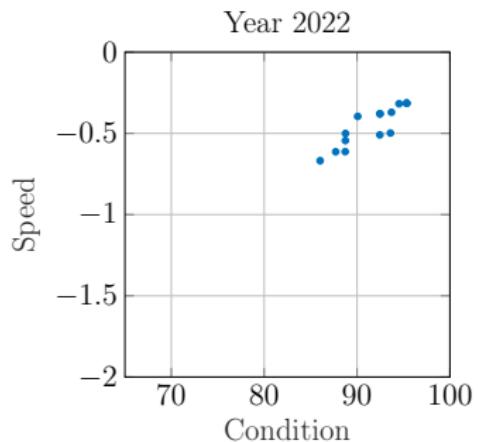
Bridge-level Policy

Example of Bridge Maintenance Policy

Bridge-level Policy

Example of Bridge Maintenance Policy

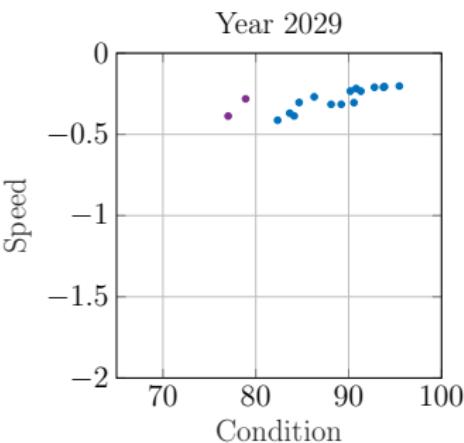
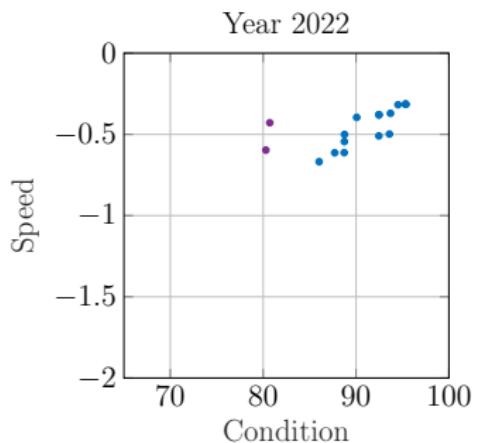
- Beam



Bridge-level Policy

Example of Bridge Maintenance Policy

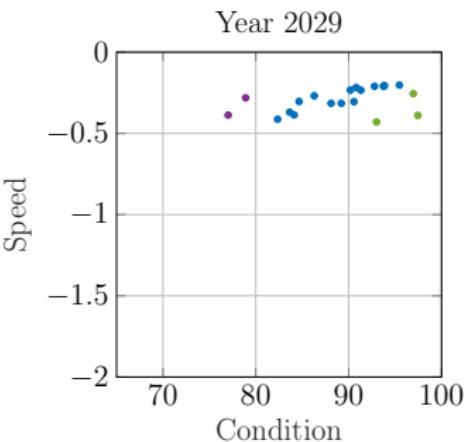
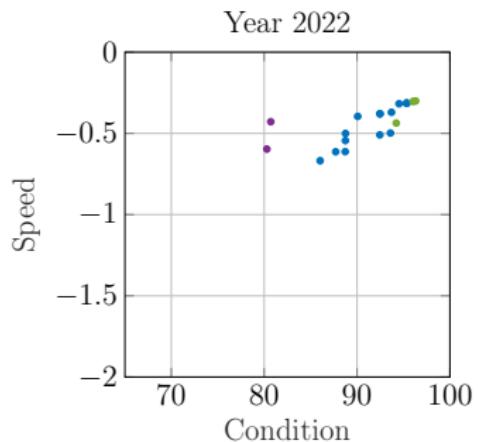
- Beam
- Front-Wall



Bridge-level Policy

Example of Bridge Maintenance Policy

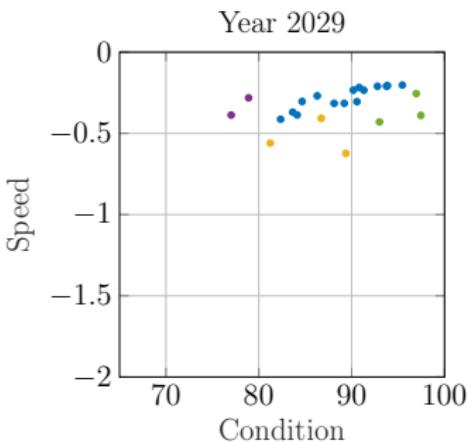
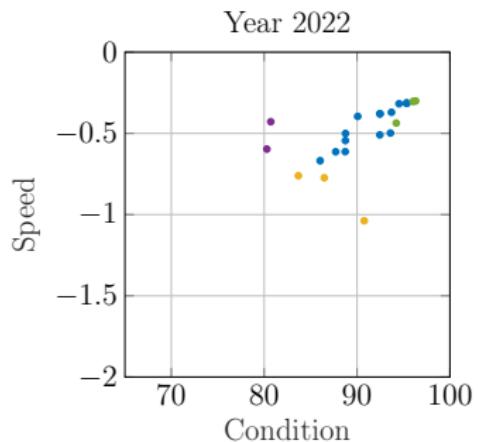
- Beam
- Front-Wall
- Pavement



Bridge-level Policy

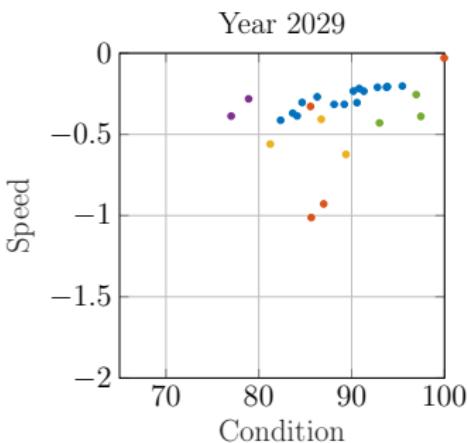
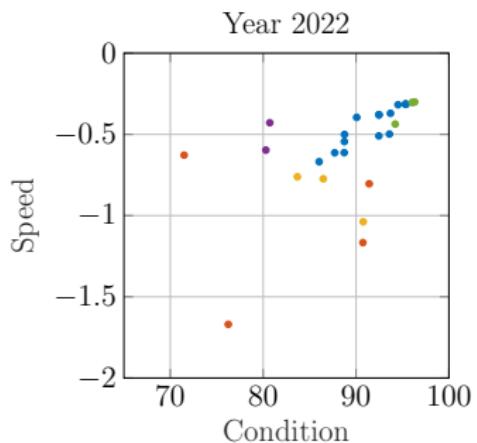
Example of Bridge Maintenance Policy

- Beam
- Front-Wall
- Pavement
- Slab



Example of Bridge Maintenance Policy

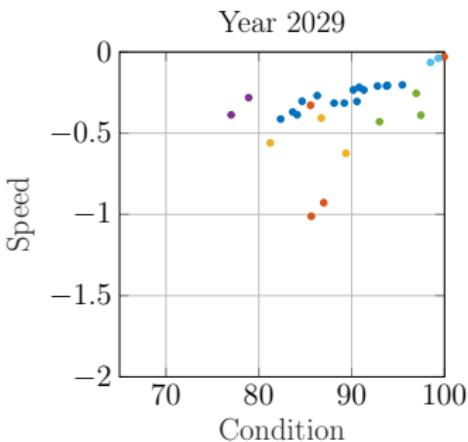
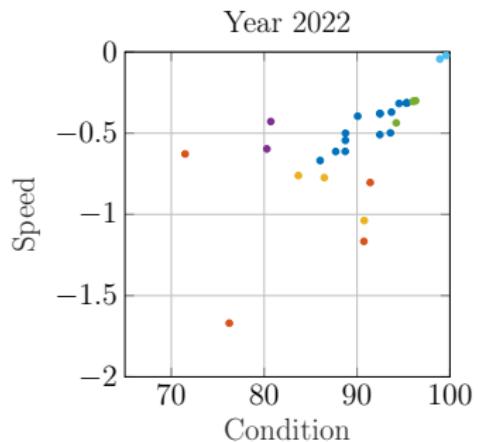
- Beam
- Front-Wall
- Pavement
- Slab
- Wing-Wall



Bridge-level Policy

Example of Bridge Maintenance Policy

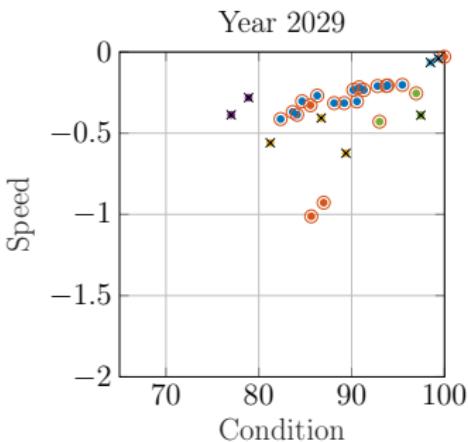
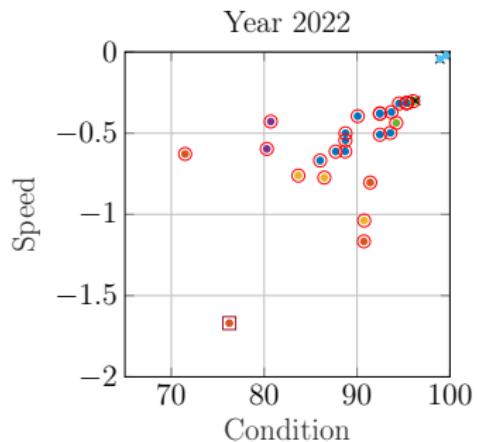
- Beam
- Front-Wall
- Pavement
- Slab
- Wing-Wall
- Guardrail



Bridge-level Policy

Example of Bridge Maintenance Policy

- Beam
- Front-Wall
- Pavement
- a_0 : do nothing
- a_4 : Replace
- Slab
- Wing-Wall
- Guardrail
- a_1 : routine maintenance



Context
○○○○○○○

Conclusions

Element Maintenance
○○

Bridge Maintenance
○○

Results & Analyses
○○

Conclusions
●

Conclusions

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InfraPlanner



RL environment is **available online** on  GitHub

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