Planning Interventions for Infrastructures Using Reinforcement Learning

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Transportation Ministry of Quebec (MTQ)

Outline

Recap & Objectives

Simulation Environment for Infrastructures

Decision Making for Infrastructures

Analyses & Results

Quick Recap

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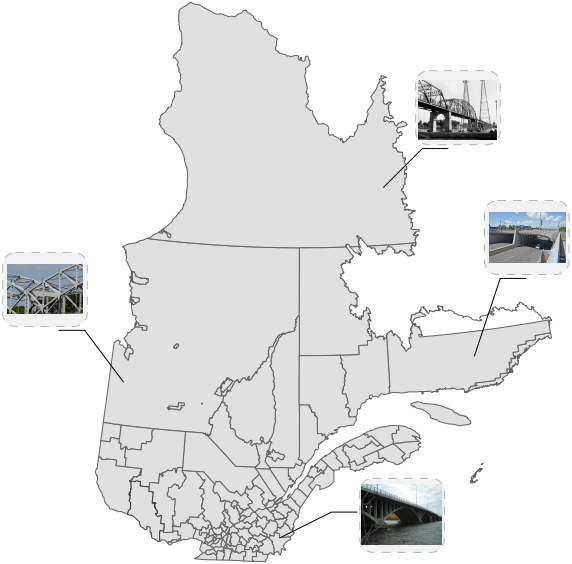

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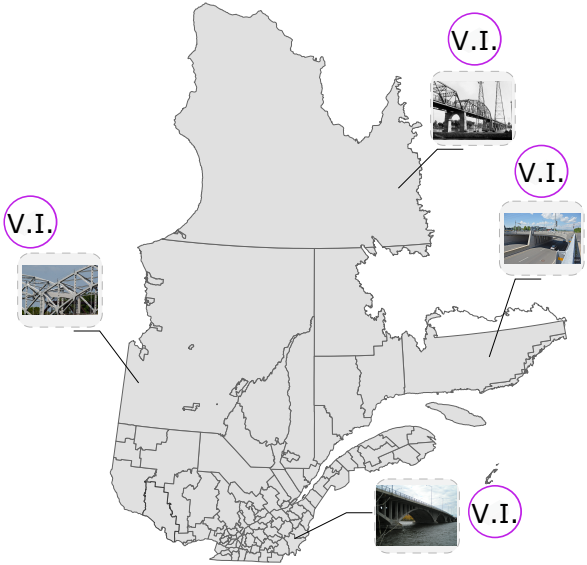

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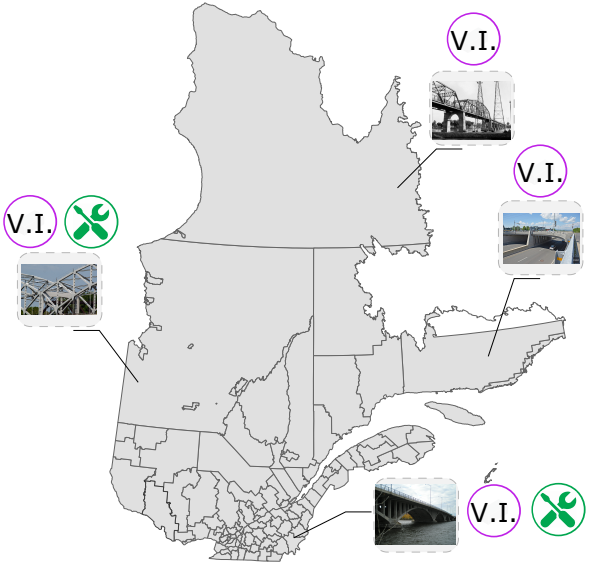
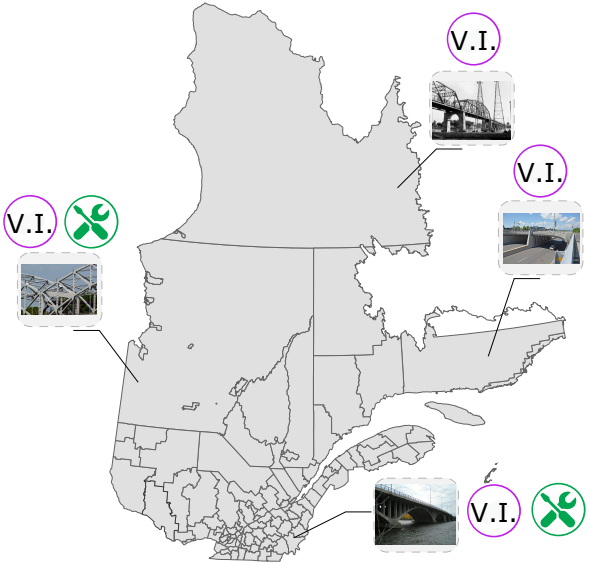


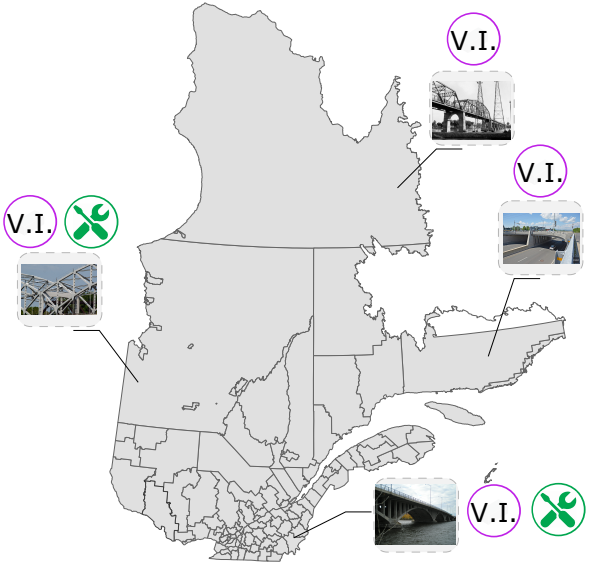
Quick Recap

- Element level data.



Quick Recap

- ▷ Element level data.
- ▷ Deterioration model:



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- Element level data.
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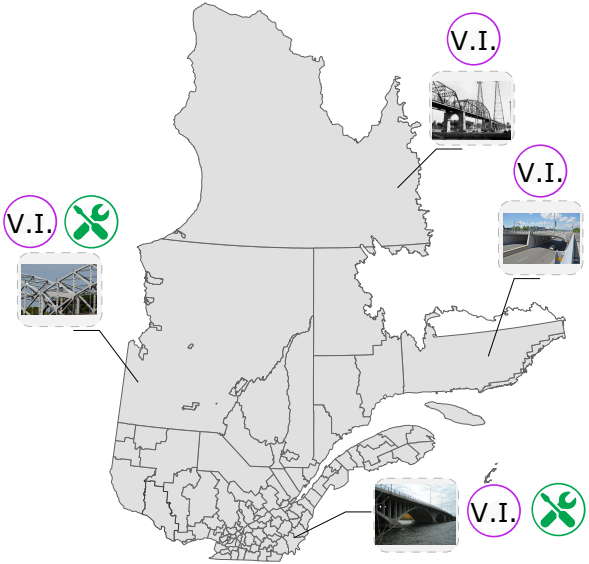

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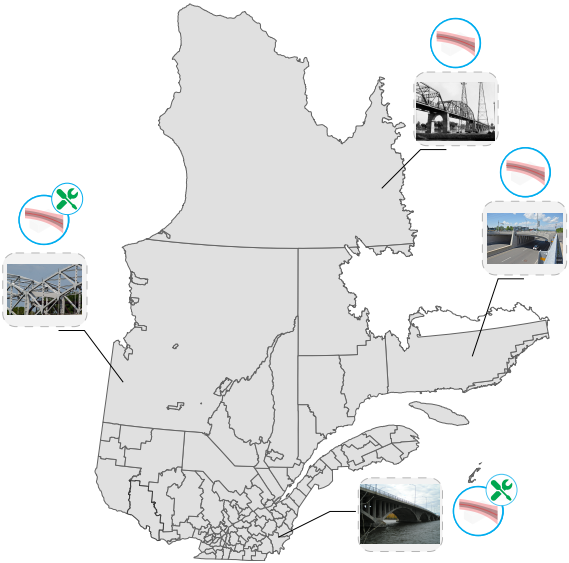
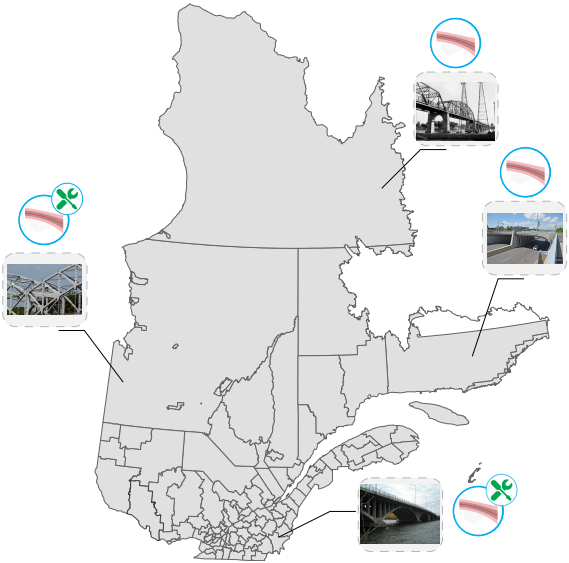


Quick Recap

- Element level data.
- Deterioration model:
  - Predict the deterioration.
  - Element → Bridge.



Research Objective

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  - Identify the most cost-effective timing of interventions on bridges.
  - Determine the type of interventions at the element-level.
- Validate the results with existing interventions policies.

Environment

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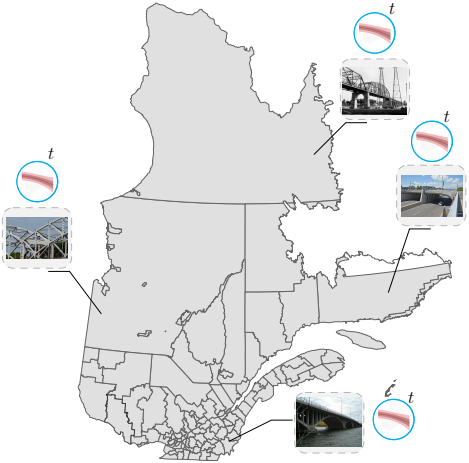

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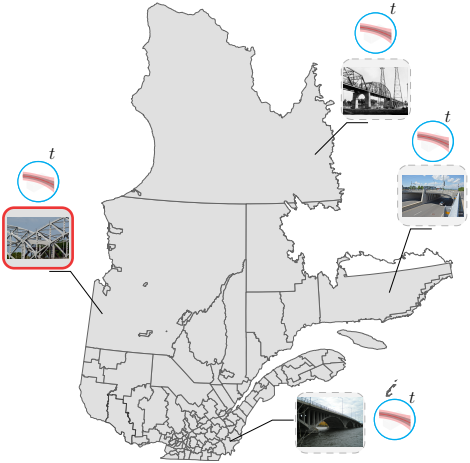

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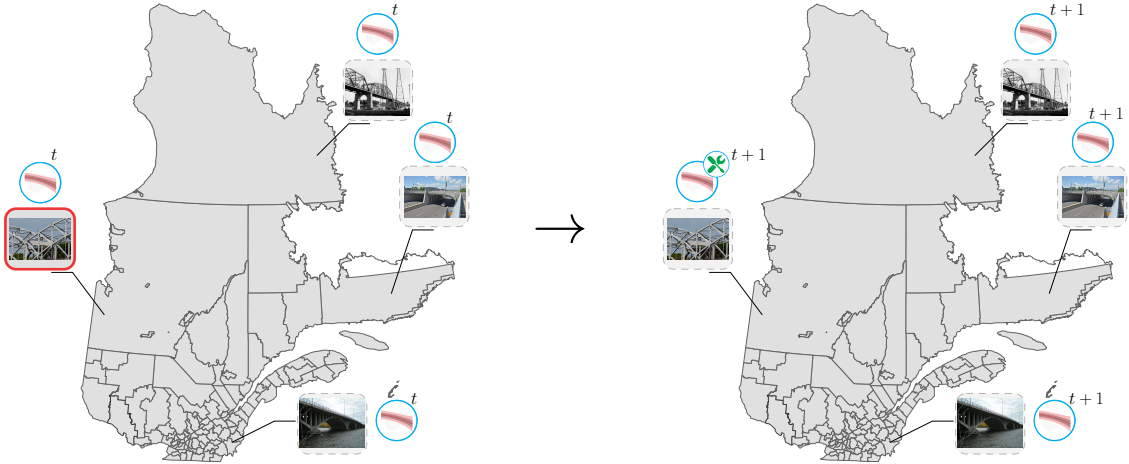

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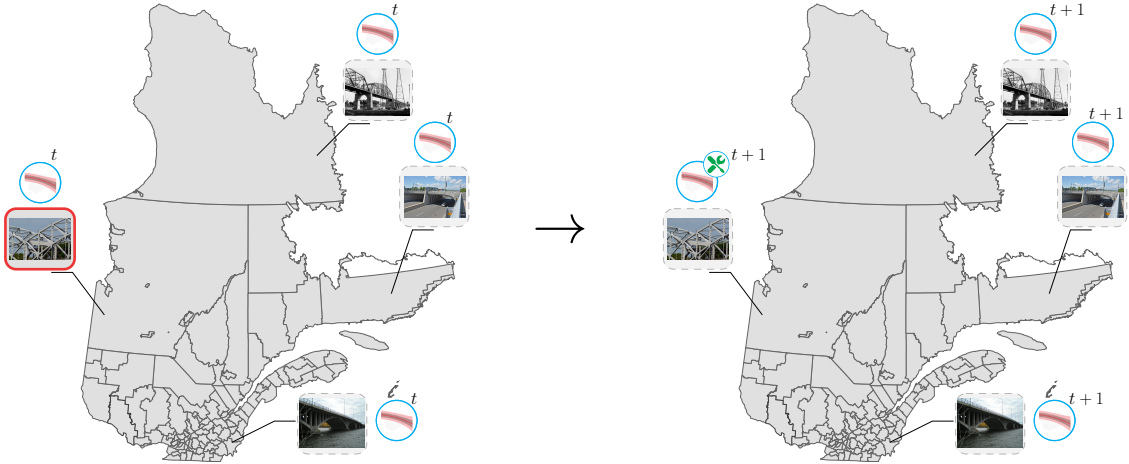

Provide access to the short & long term effect of an intervention.

Environment

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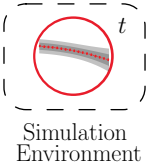

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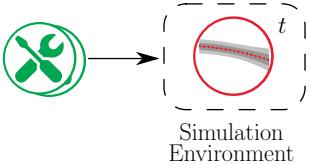

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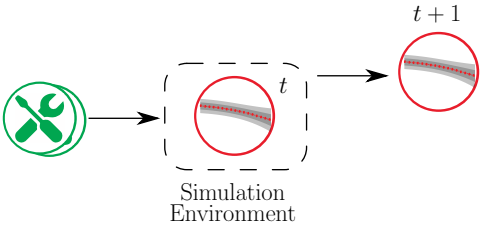

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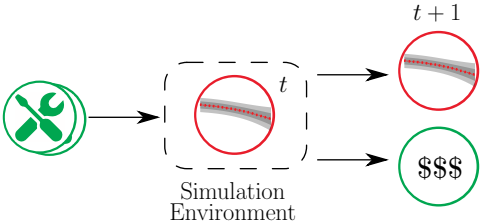

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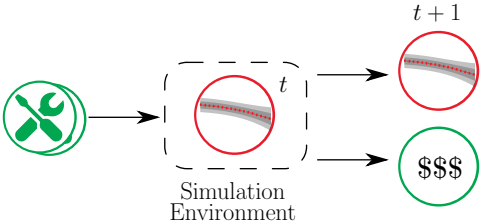
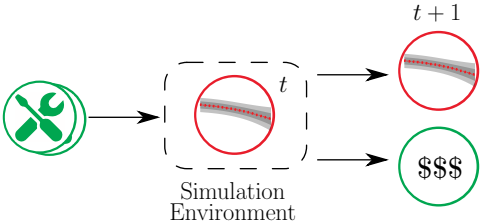


▷ Interventions (Actions).

Environment



- ▷ Interventions (Actions).
- ▷ Costs.

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Information about structure-level maintenance actions is limited.

Environment Costs

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No detailed information about service-stoppage costs.

Interventions Criteria (MTQ)

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Source: MTQ, Manual of Inspections

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It is possible to derive a baseline intervention policy (Expert).

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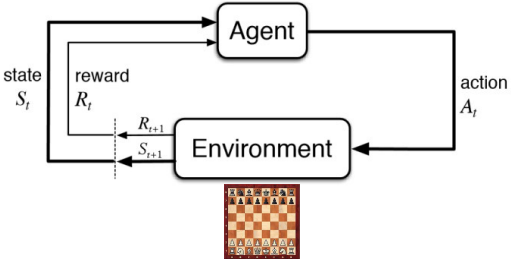
Reinforcement Learning (RL)

Source: Google Images

Reinforcement Learning (RL)



▷ Agent: decision maker.

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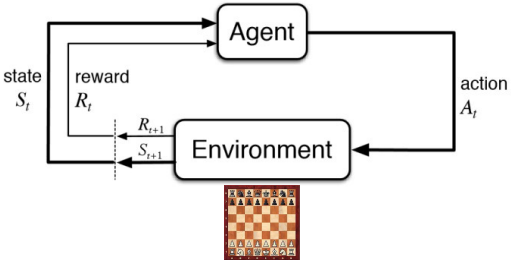

- ▷ Agent: decision maker.
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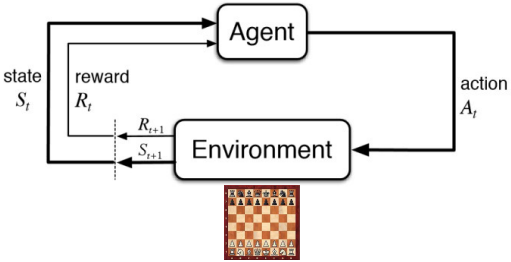

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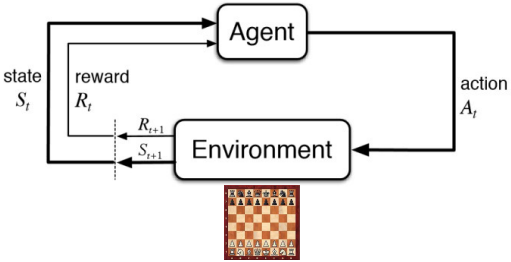

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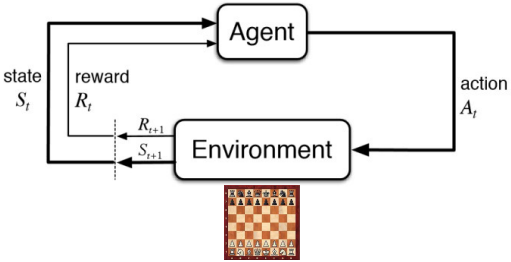

- ▷ Agent: decision maker.
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Learn a policy that maximizes the total expected discounted rewards.

Source: Google Images

Developing The RL Agent

Source: google images

Developing The RL Agent

Agent

v.s.

Programmed Script

Source: google images

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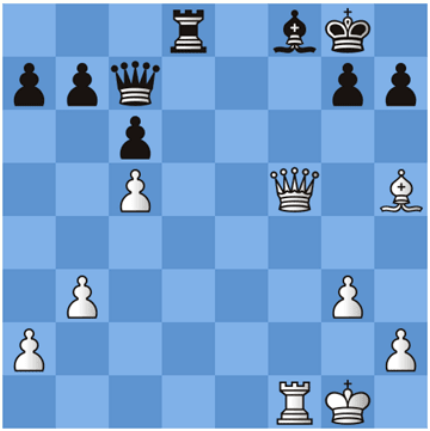

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Programmed Script

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Developing The RL Agent

v.s.

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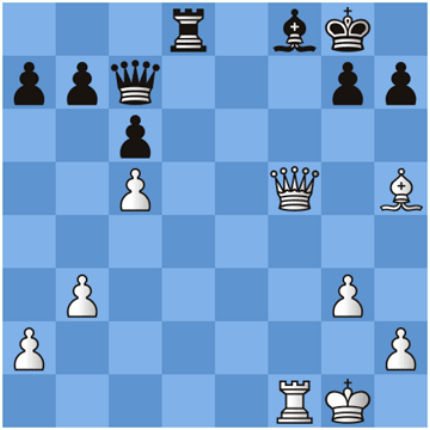
(+1)



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Programmed Script

(-1)

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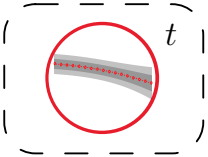

Simulation Environment

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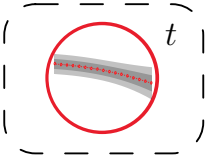

Simulation Environment

Programmed Script (**Expert**)

Source: google images

Developing The RL Agent

v.s.

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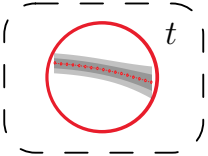

Simulation Environment

(**Total costs after time** T)

Programmed Script (**Expert**)

Source: google images

Developing The RL Agent

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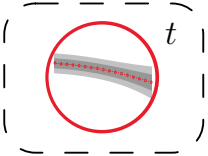
Agent

(+1)



Simulation Environment

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Programmed Script

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(-1)

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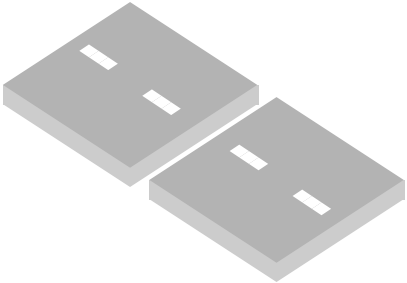
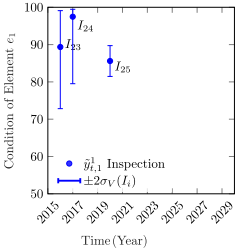
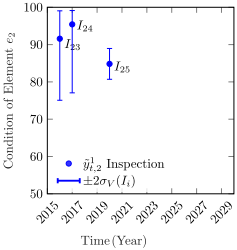
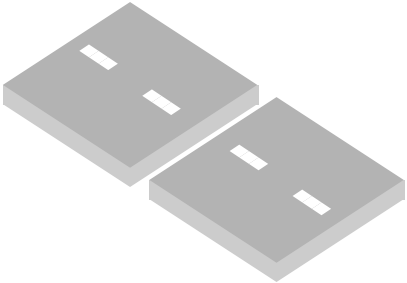
Toy Problem:

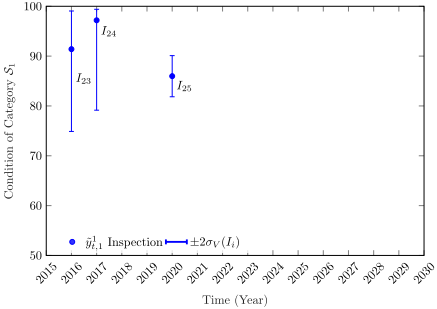



100
90
80
70
60
50
Condition of Element e_1
I_{23}
I_{24}
I_{25}
$\tilde{y}^1_{i,1}$ Inspection
$\pm 2\sigma_V(I_i)$
2015
2017
2019
2021
2023
2025
2027
2029
Time (Year)


100
90
80
70
60
50
Condition of Element e_2
I_{23}
I_{24}
I_{25}
$\tilde{y}^1_{i,2}$ Inspection
$\pm 2\sigma_V(I_i)$
2015
2017
2019
2021
2023
2025
2027
2029
Time (Year)

Toy Problem:




Condition of Category S_1
Time (Year)
I_{23}
I_{24}
I_{25}
$\bar{y}^1_{i,1}$ Inspection
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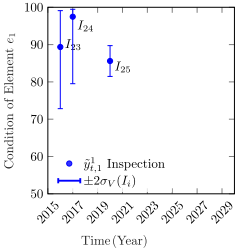
Condition of Element e_1
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I_{25}
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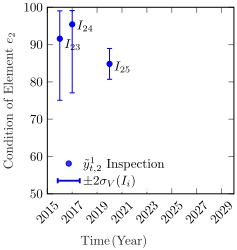
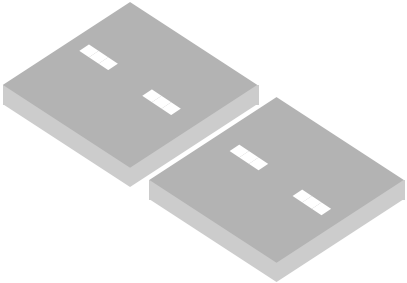
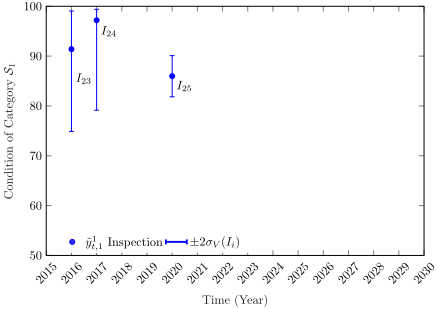
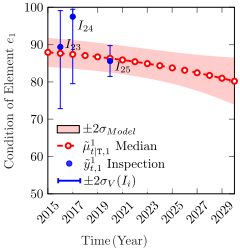
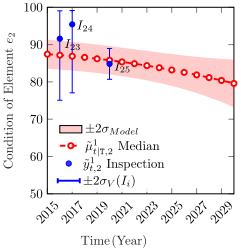

Condition of Element e_2
Time (Year)
I_{23}
I_{24}
I_{25}
$\bar{y}^1_{i,2}$ Inspection
$\pm 2\sigma_V(I_i)$

Toy Problem:

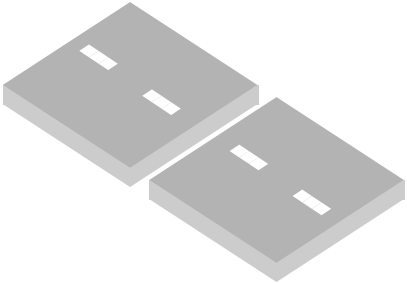


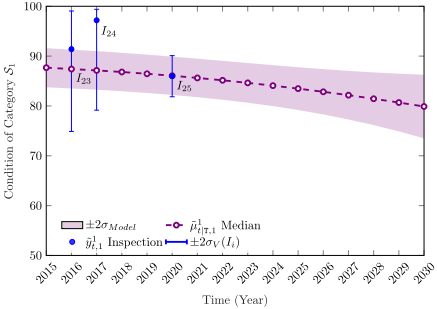

Condition of Category S_1
Time (Year)
I_{23}
I_{24}
I_{25}
$\bar{y}^1_{i,1}$ Inspection
$\pm 2\sigma_V(I_i)$

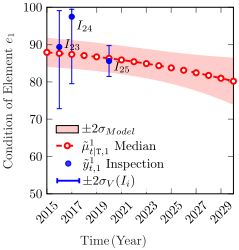

Condition of Element e_1
Time (Year)
I_{23}
I_{24}
I_{25}
$\pm 2\sigma_{Model}$
$\bar{\mu}^1_{i[\mathrm{T},1}$ Median
$\bar{y}^1_{i,1}$ Inspection
$\pm 2\sigma_V(I_i)$

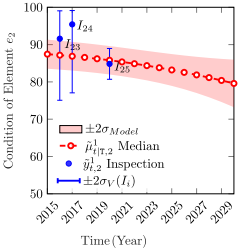

Condition of Element e_2
Time (Year)
I_{23}
I_{24}
I_{25}
$\pm 2\sigma_{Model}$
$\bar{\mu}^1_{i[\mathrm{T},2}$ Median
$\bar{y}^1_{i,2}$ Inspection
$\pm 2\sigma_V(I_i)$

Toy Problem:

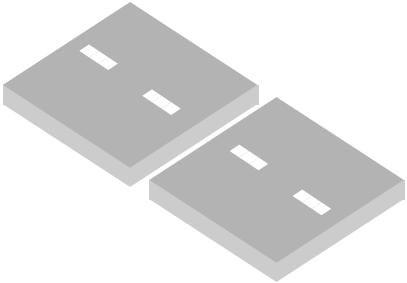


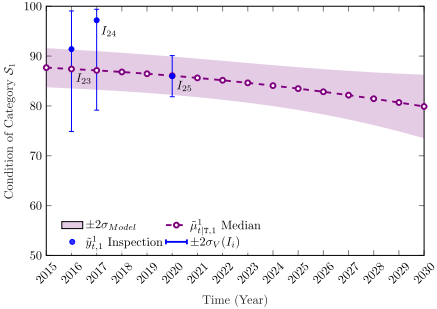

Condition of Category S_1
Time (Year)
I_{23}
I_{24}
I_{25}
$\pm 2\sigma_{Model}$
$\bar{\mu}^1_{t|\mathrm{T},1}$ Median
$\bar{y}^1_{i,1}$ Inspection
$\pm 2\sigma_V(I_i)$

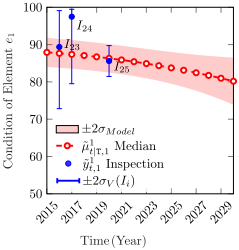

Condition of Element e_1
Time (Year)
I_{23}
I_{24}
I_{25}
$\pm 2\sigma_{Model}$
$\bar{\mu}^1_{t|\mathrm{T},1}$ Median
$\bar{y}^1_{i,1}$ Inspection
$\pm 2\sigma_V(I_i)$

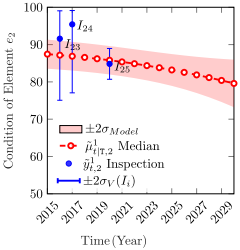

Condition of Element e_2
Time (Year)
I_{23}
I_{24}
I_{25}
$\pm 2\sigma_{Model}$
$\bar{\mu}^1_{t|\mathrm{T},2}$ Median
$\bar{y}^1_{i,2}$ Inspection
$\pm 2\sigma_V(I_i)$

Toy Problem:



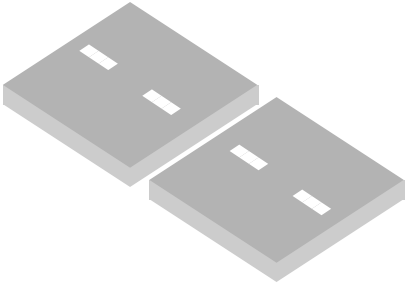


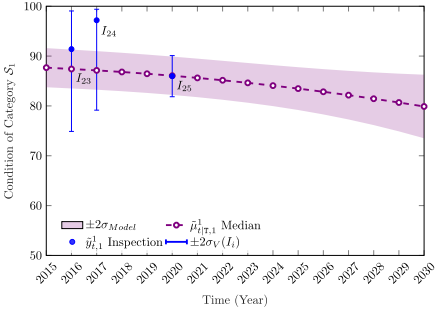


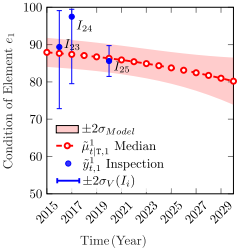


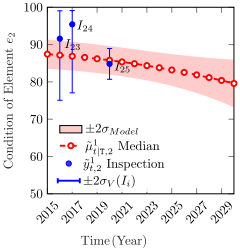
Find a policy for the intervention time,

Toy Problem:









Find a policy for the intervention time, given a fixed (known) policy of actions.

Total Costs - Training:

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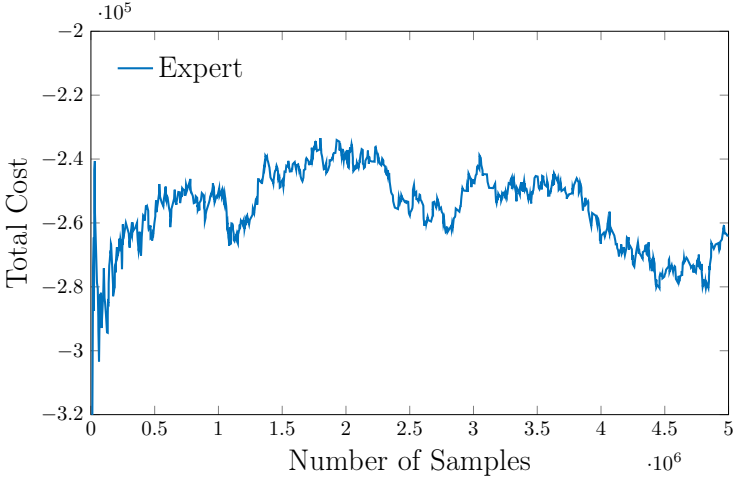
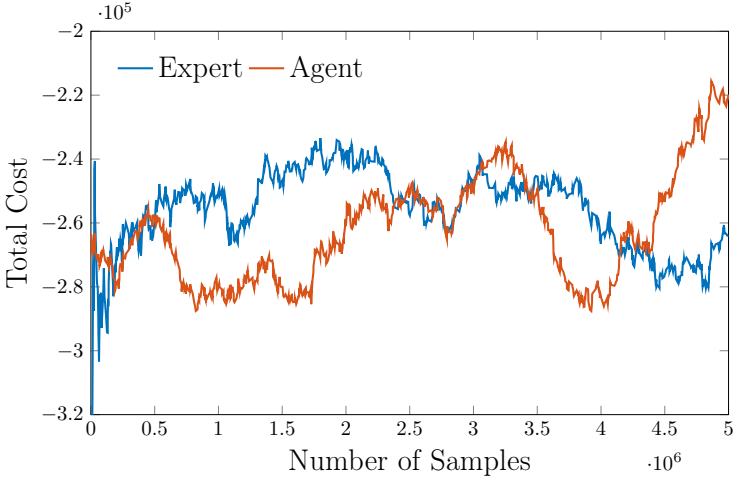
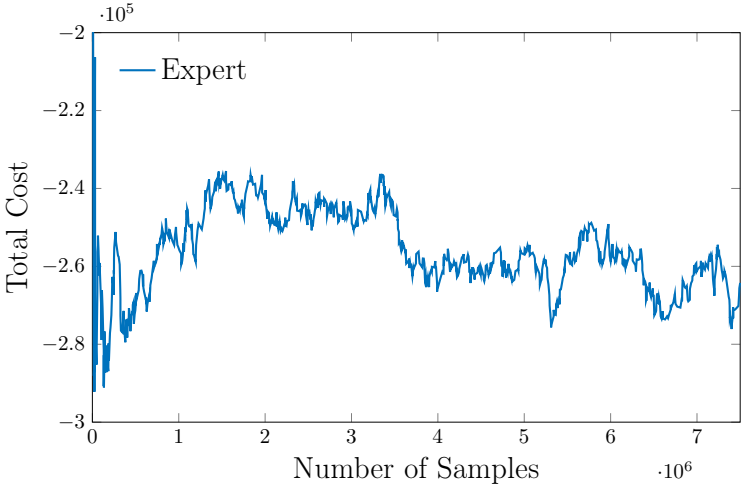


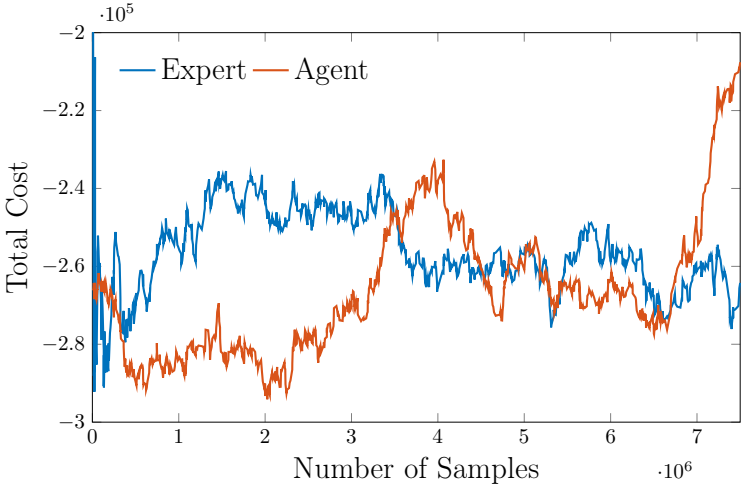
Total Costs - Training:



Total Costs - Training:



Total Costs - Training:



Total Costs - Testing:

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- Number of senarios: 100.

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	Expert	Agent

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Avg. Total Costs ($\times 10^3$)	238 ± 133	

Total Costs - Testing:

- Number of senarios: 100.
- Total time: 100 years.

	Expert	Agent
Avg. Total Costs ($\times 10^3$)	238 ± 133	162 ± 126

Next Steps & Current Issues

- Improve the agent performance v.s. the expert.

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- Improve the agent performance v.s. the expert.
  - Agent #1 v.s. Expert.

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- Improve the agent performance v.s. the expert.
  - Agent #1 v.s. Expert.
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  - MinCost(Agent #1 v.s. Expert) v.s. Agent #2.

Next Steps & Current Issues

- Improve the agent performance v.s. the expert.
  - Agent #1 v.s. Expert.
  - Agent #1 v.s. Agent #2.
  - MinCost(Agent #1 v.s. Expert) v.s. Agent #2.
- Extend the application to multiple structures.