Initializing Kalman Filter for Visual Inspections of Bridge Network + Demo

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January 21, 2019

Transports, Mobilité durable et Électrification des transports Québec Partenaire

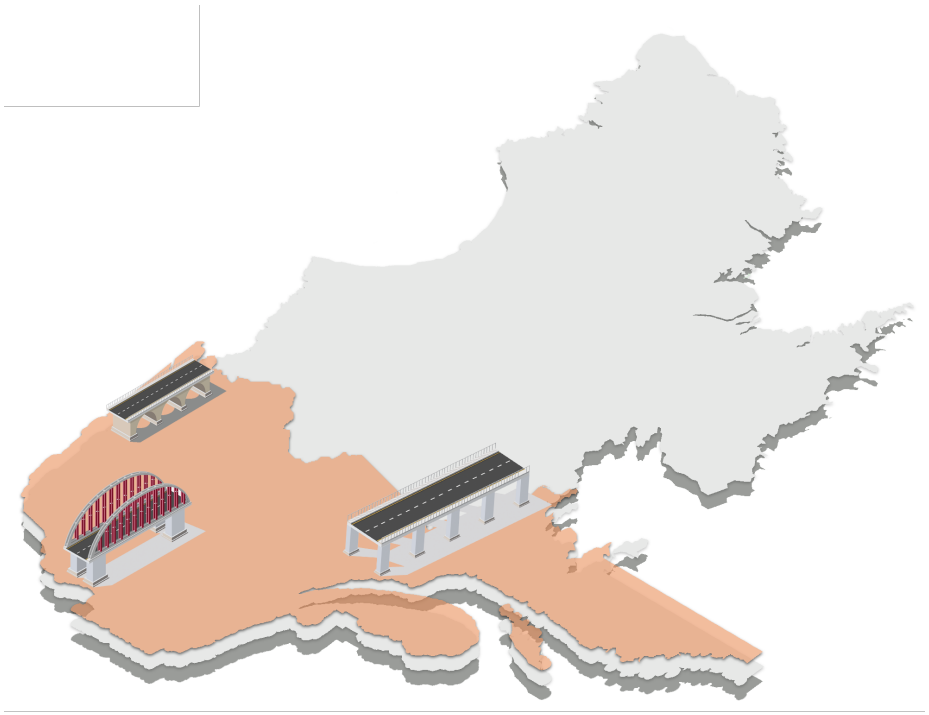
Outline

Context

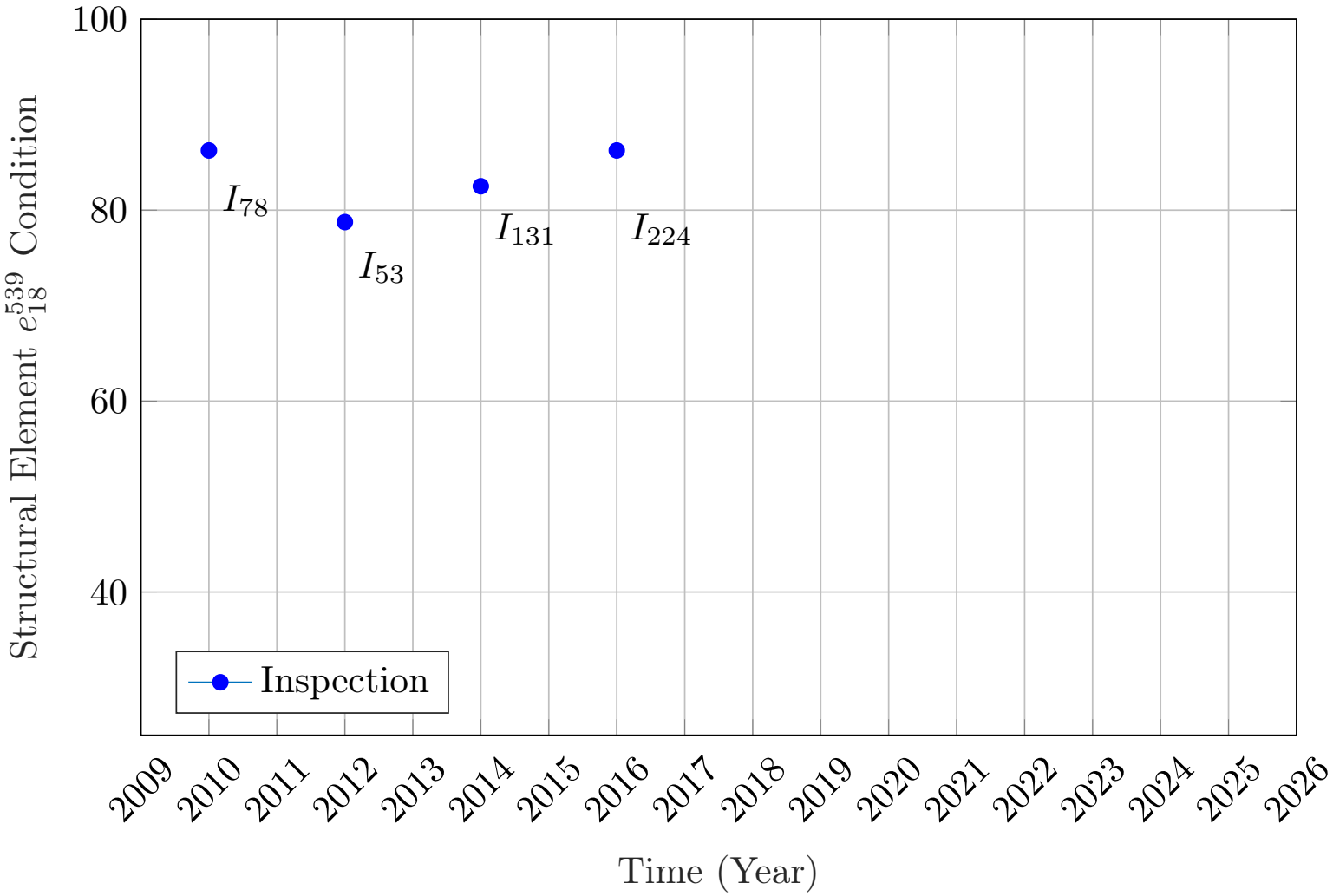
Visual Inspection
data of $\sim$ 10K Bridge,

100's of Inspectors,

2-4 inspections/element,
1-4 years Inspection span,
$\sim$ 1.3M inspections reported.



Example: Series of Inspections on Structural Element



Objectives

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

Deterioration Behaviour Described by Kinematics

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

Deterioration Behaviour Described by Kinematics

Kinematic Equations

$$
\begin{aligned}
x_t &= x_{t-1} + \dot{x}_{t-1}\Delta t + \tfrac{1}{2}\ddot{x}_{t-1}\Delta t^2 + w && \text{(Condition)} \\
\dot{x}_t &= \dot{x}_{t-1} + \ddot{x}_{t-1}\Delta t + \dot{w} && \text{(Speed)}
\end{aligned}
$$

Deterioration Behaviour Described by Kinematics

Kinematic Equations

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x_t &= x_{t-1} + \dot{x}_{t-1}\Delta t + \tfrac{1}{2}\ddot{x}_{t-1}\Delta t^2 + w && \text{(Condition)} \\
\dot{x}_t &= \dot{x}_{t-1} + \ddot{x}_{t-1}\Delta t + \dot{w} && \text{(Speed)} \\
\ddot{x}_t &= \ddot{x}_{t-1} + \ddot{w} && \text{(Acceleration)}
\end{aligned}
$$

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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Model Parameter Estimation

$$\mathcal{P} = \left\{ \underbrace{\sigma_v(l_1), \sigma_v(l_2), \cdots, \sigma_v(l_I)}_{\text{Inspector std.}}, \overbrace{\sigma_w}^{\text{Process error std.}}, \underbrace{n}_{\text{Transform. Param.}}, \overbrace{\dot{\mu}_0, \ddot{\mu}_0, \sigma_0^x, \sigma_0^{\dot{x}}, \sigma_0^{\ddot{x}}}^{\text{Initial state.}} \right\}$$

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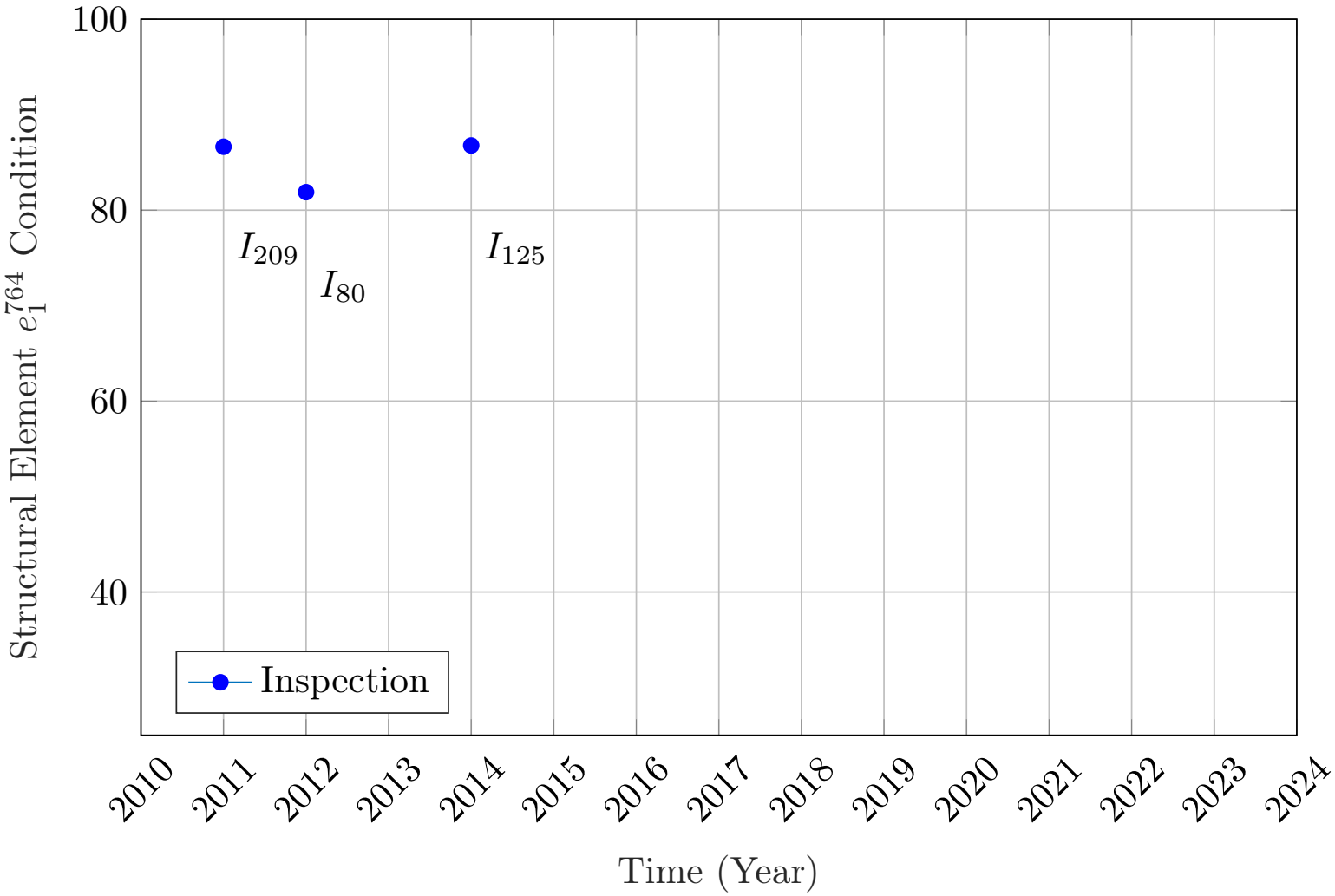
$$\mathcal{P}^* = \arg\max_{\mathcal{P}} \quad \mathcal{L}(\mathcal{P}),$$

subject to: (parameters feasible domain)

Performance Verification



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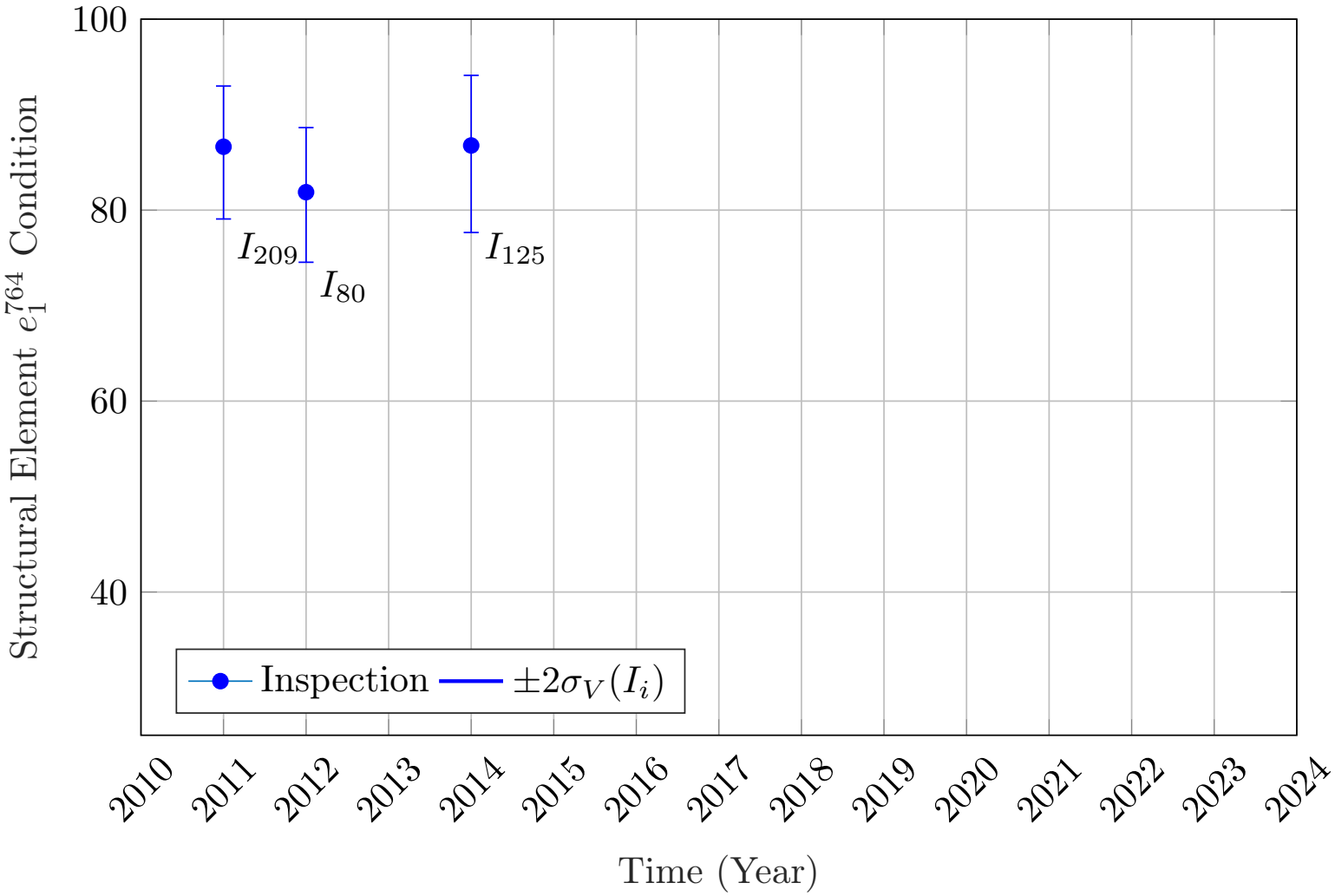

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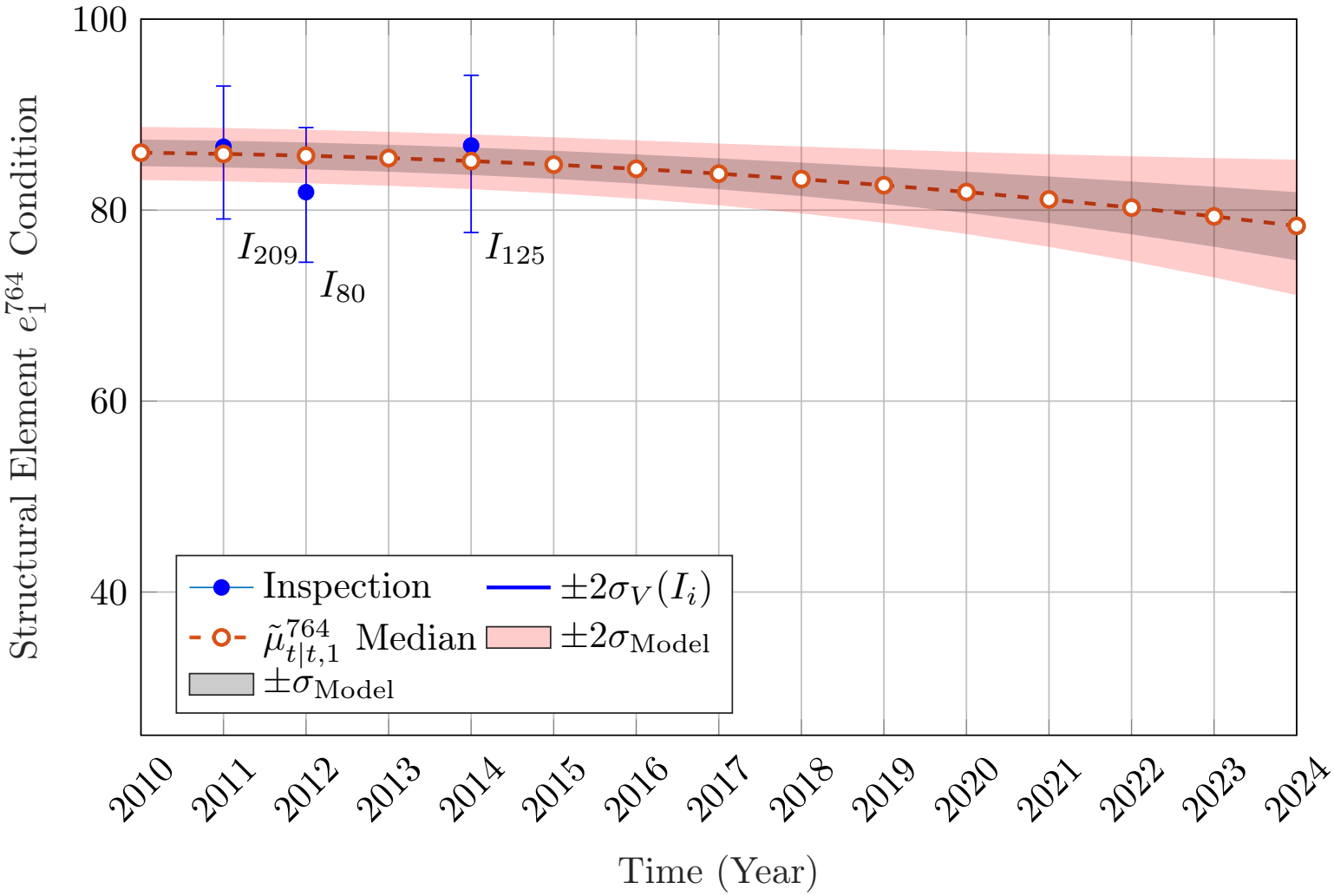

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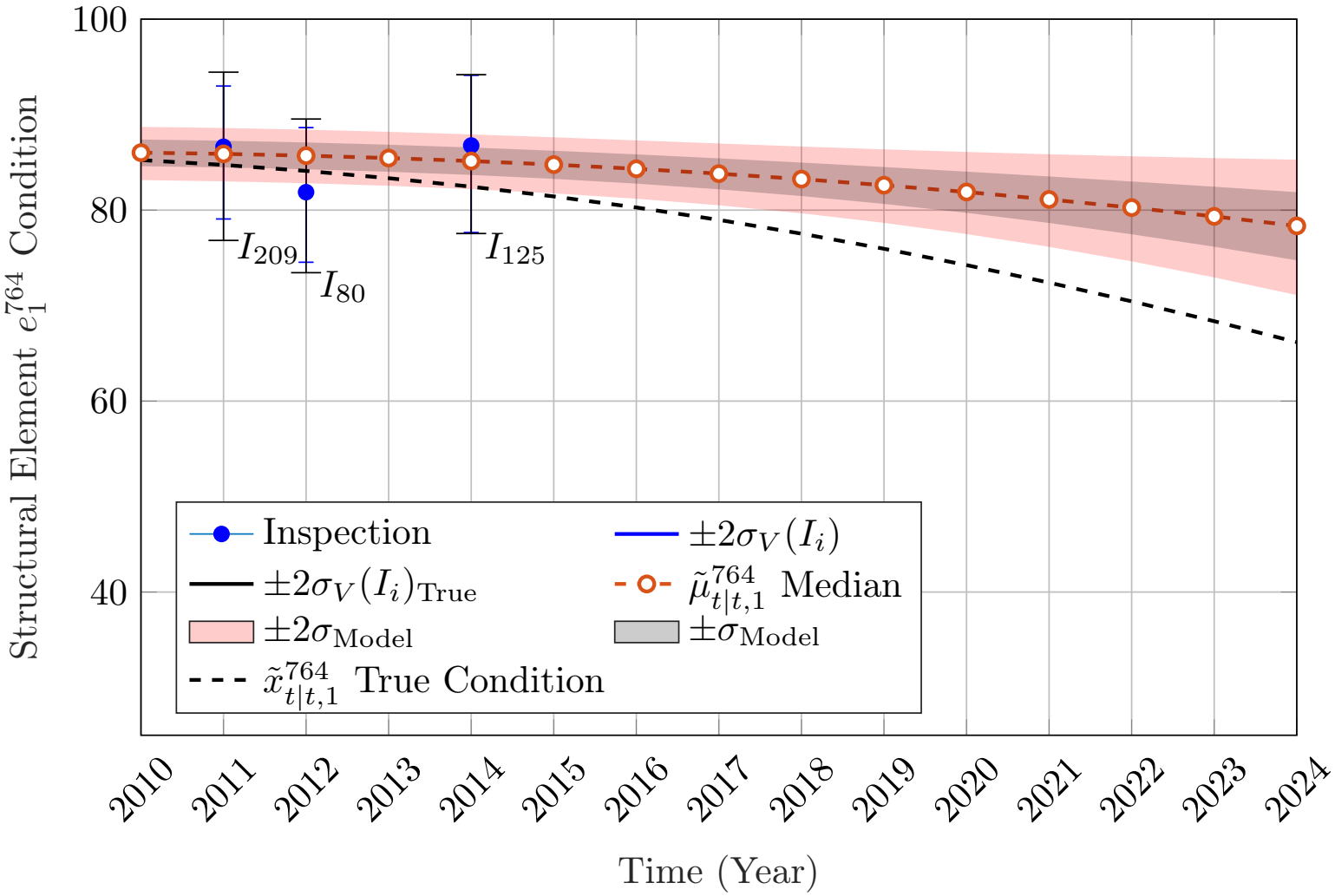

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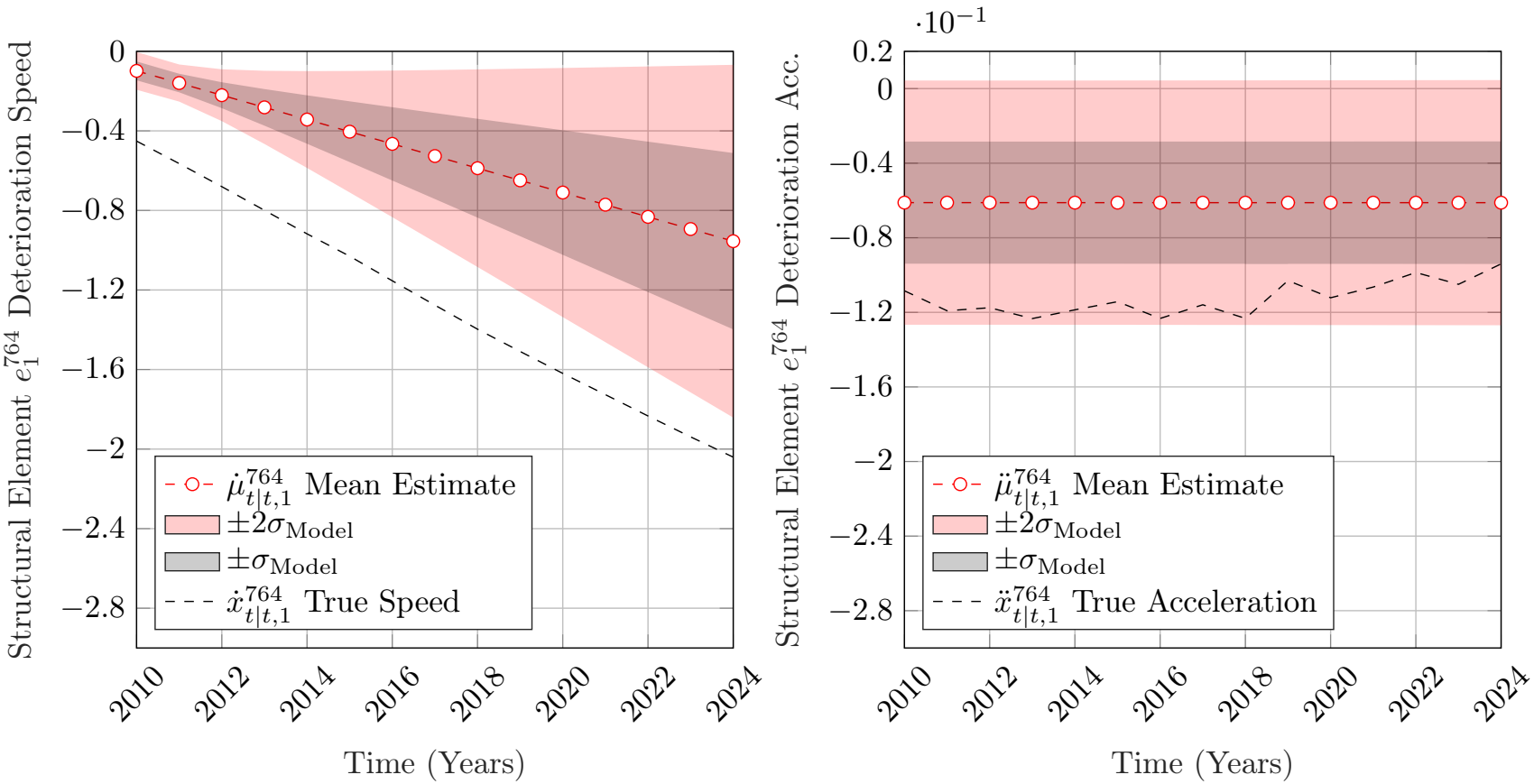

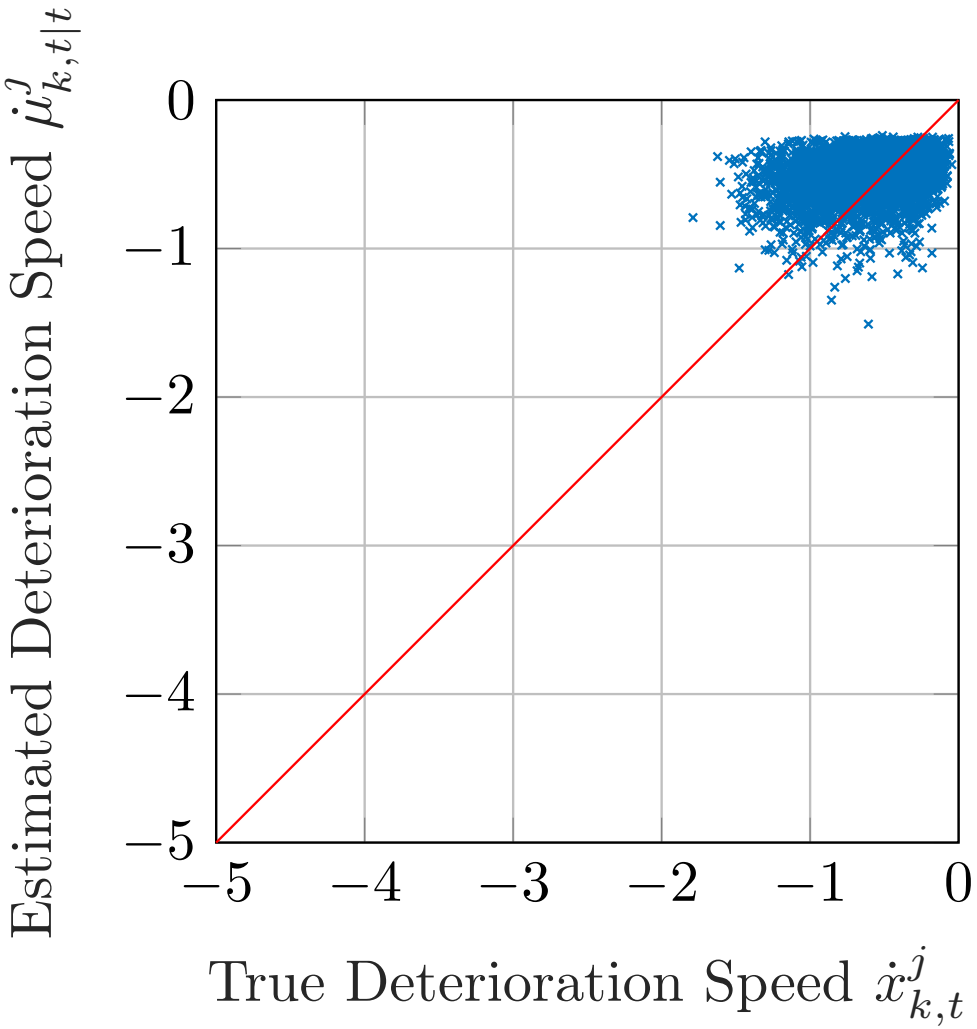

☐ 1. Examine the deterioration speed.

Plan de la section

Init. State Analyses with Synthetic Data

Synthetic Inspection Data

☑ 1. Same number of structural elements.

Synthetic Inspection Data

- ☑ 1. Same number of structural elements.
- ☑ 2. Same number of inspectors.

Synthetic Inspection Data

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- ☑ 3. Same number of inspections per-structural element.

Generating Synthetic Data

Method: Transition & Observation Models

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$$\boldsymbol{x}_0 = \begin{bmatrix} \mu_0 \\ \dot{\mu}_0 \\ \ddot{\mu}_0 \end{bmatrix}$$

$$\mu_0 \sim \mathcal{U}(a = 70, b = 100)$$
$$\dot{\mu}_0 \sim \mathcal{U}(a = -0.2, b = -0.0001)$$
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Problem: the combinations among the condition, the speed and the acceleration are too random to be real.

$$\mu_0 = 100,$$
$$\dot{\mu}_0 \sim \ln\mathcal{N}(\lambda, \zeta) \quad ;\mathbb{E}[\dot{\mu}_0] = -0.05,\ \text{var}[\dot{\mu}_0] = 0.015^2,$$
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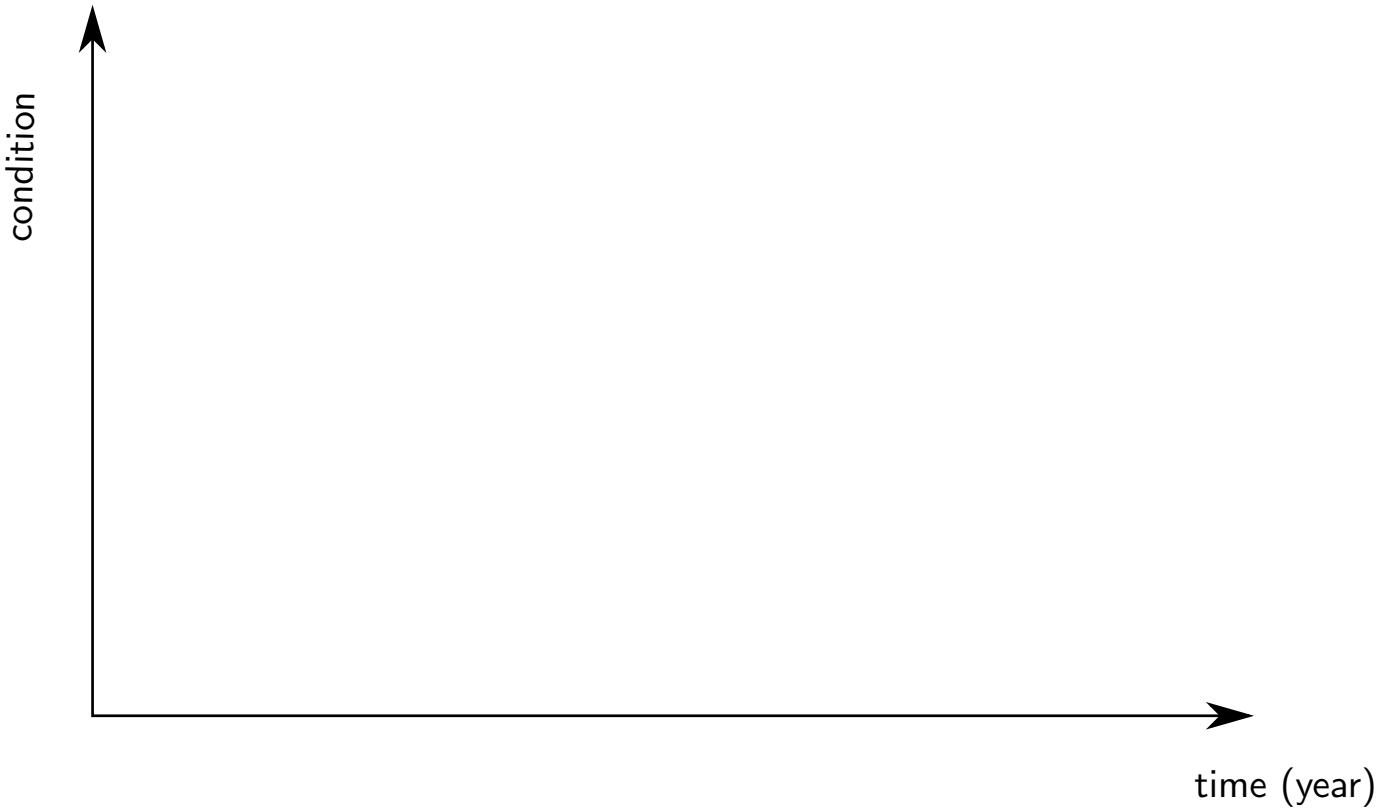

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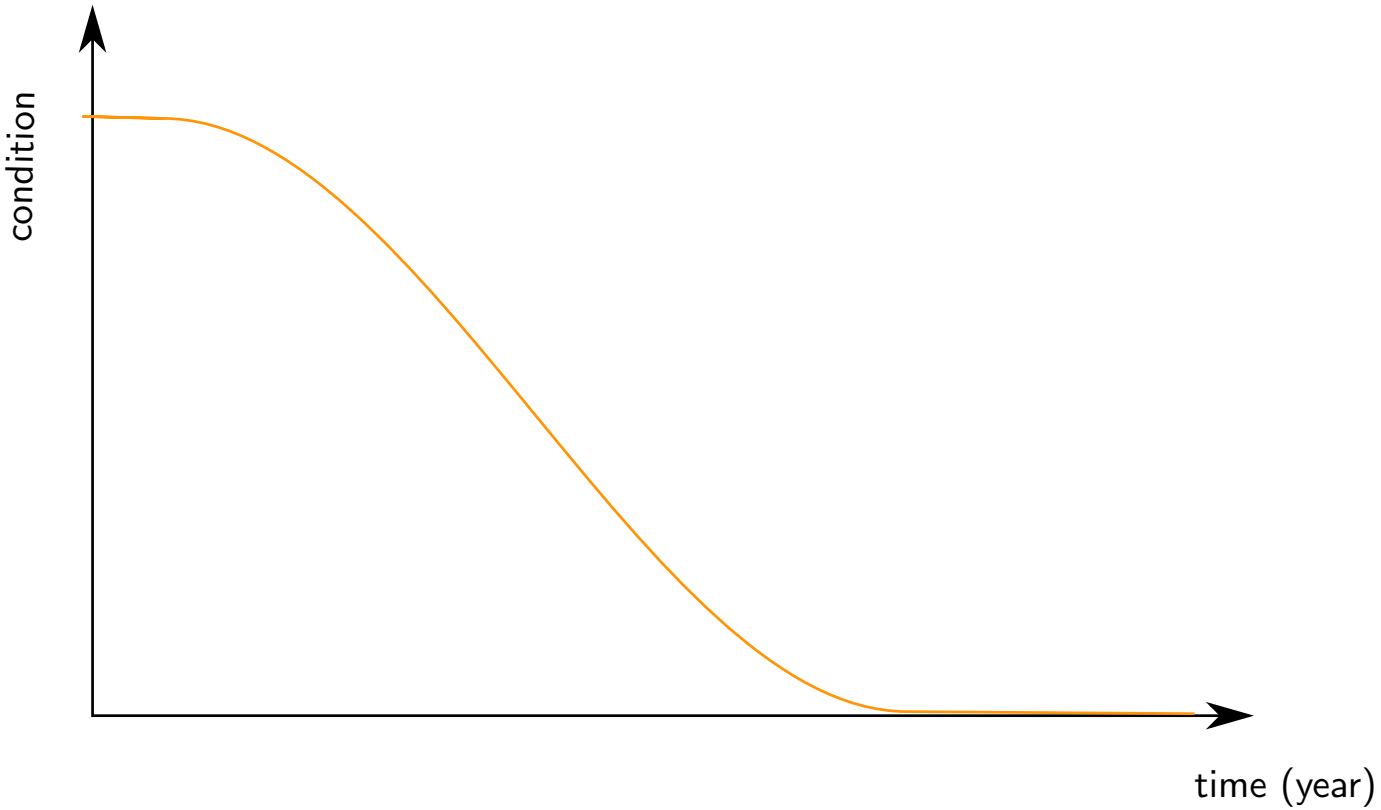

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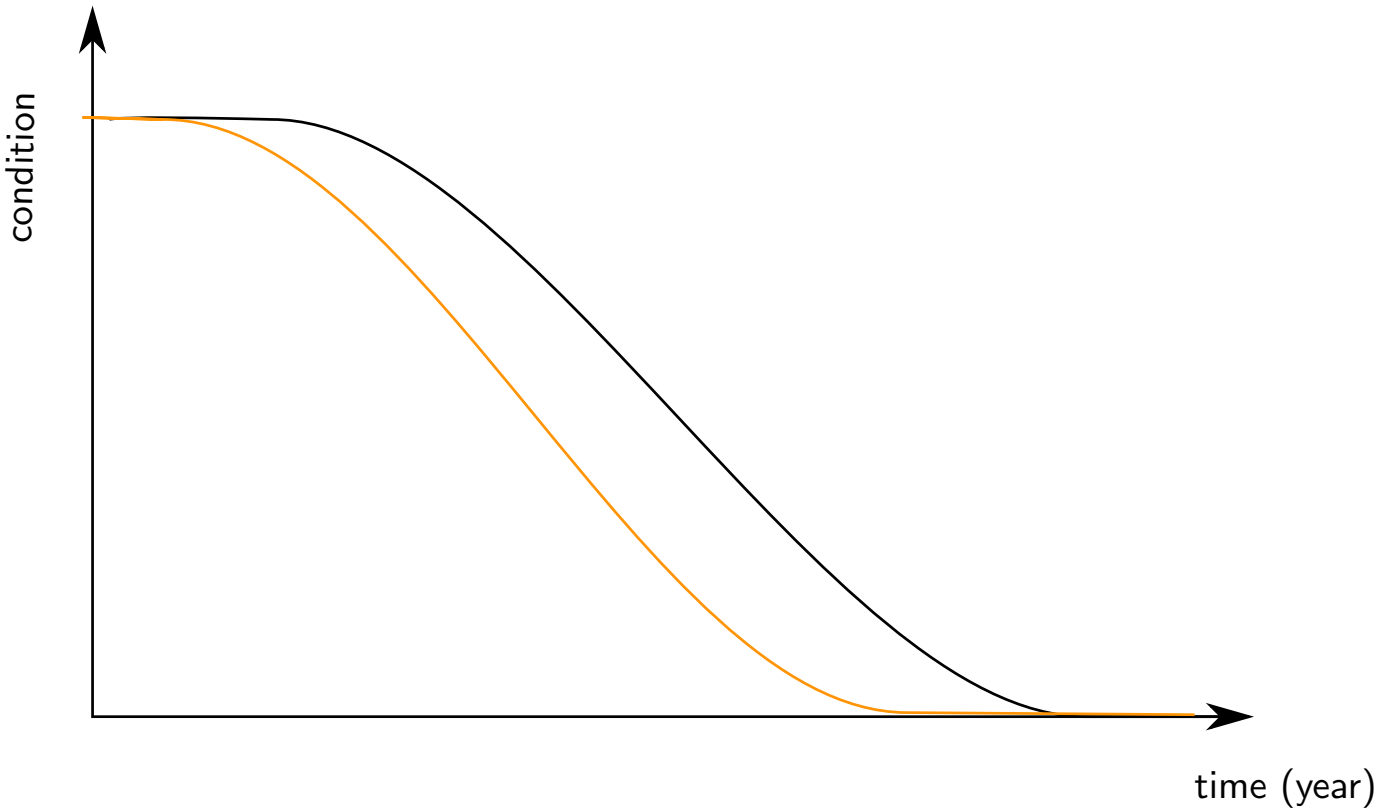

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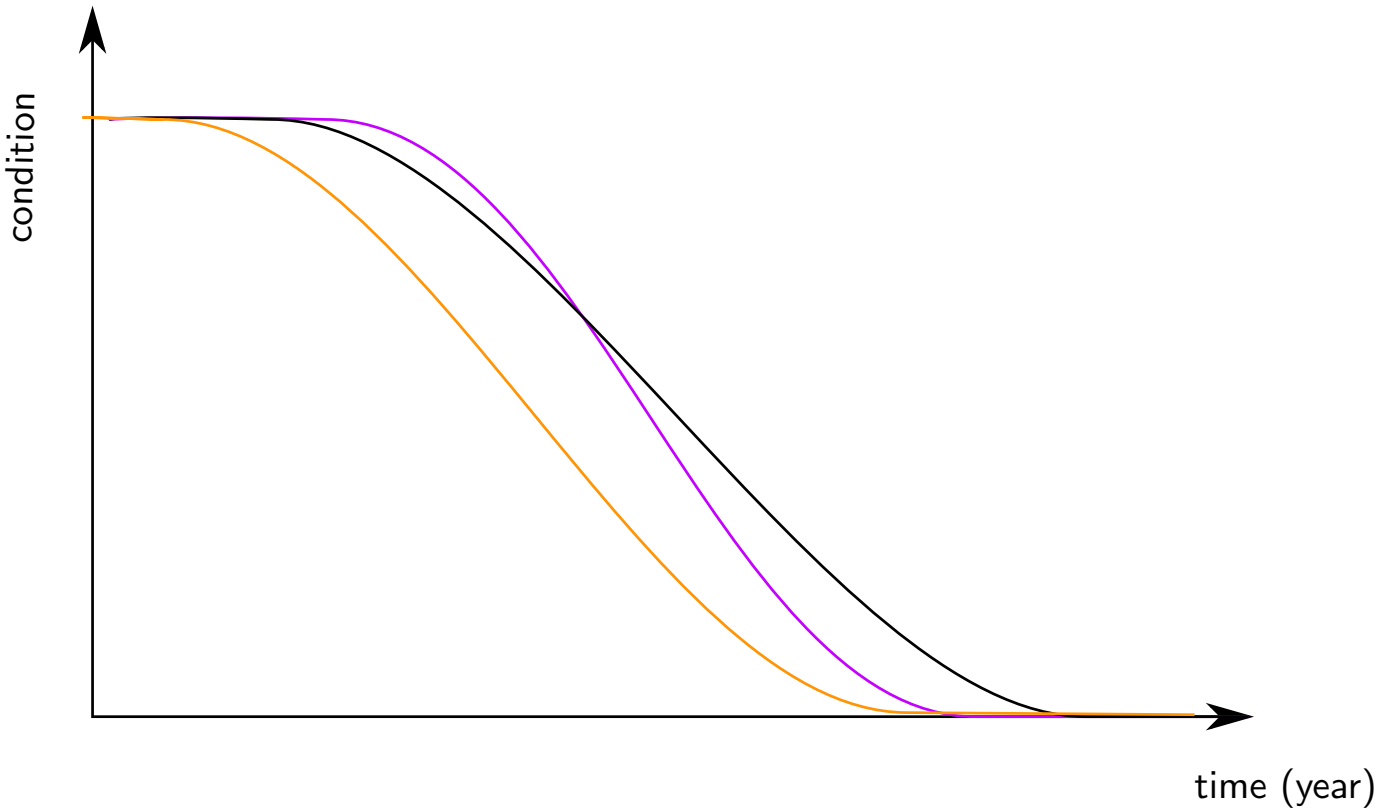

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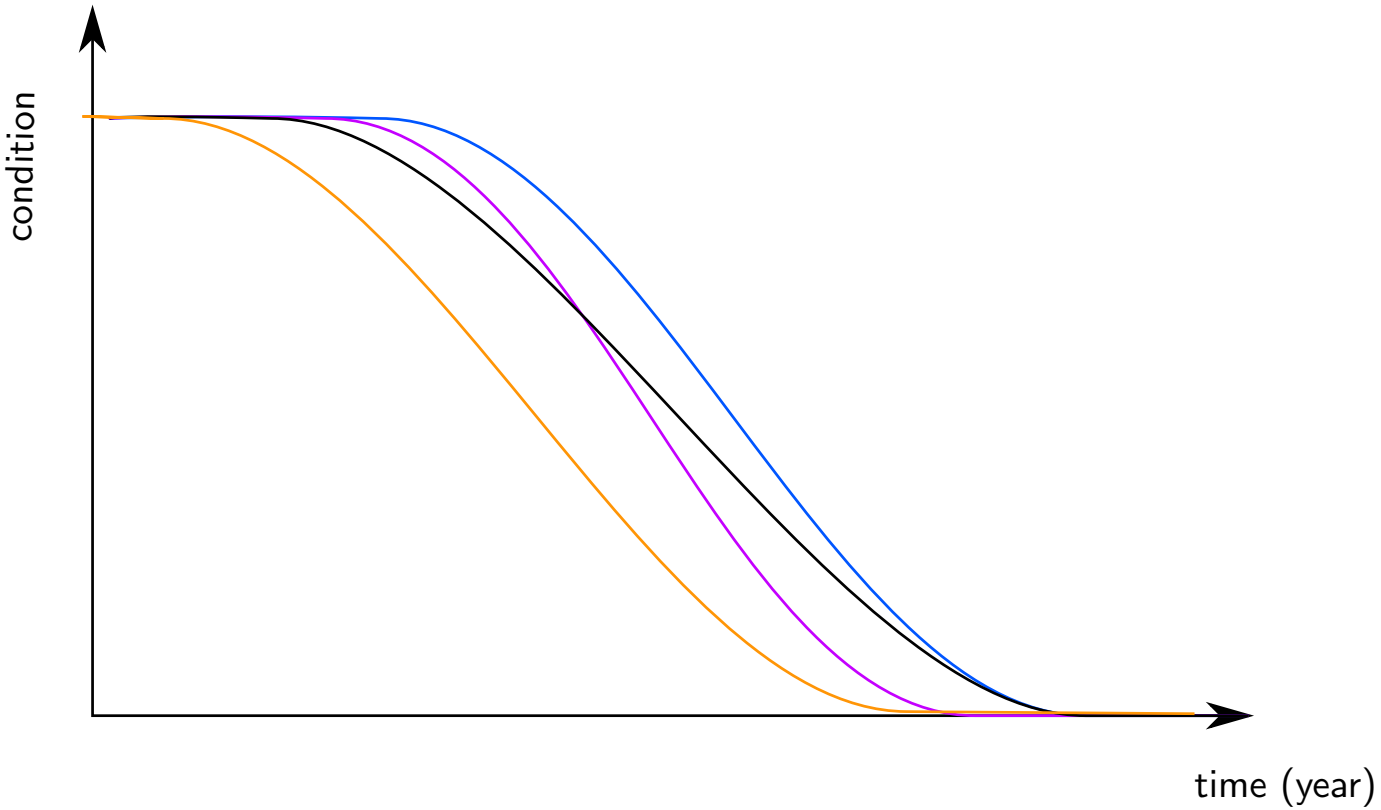

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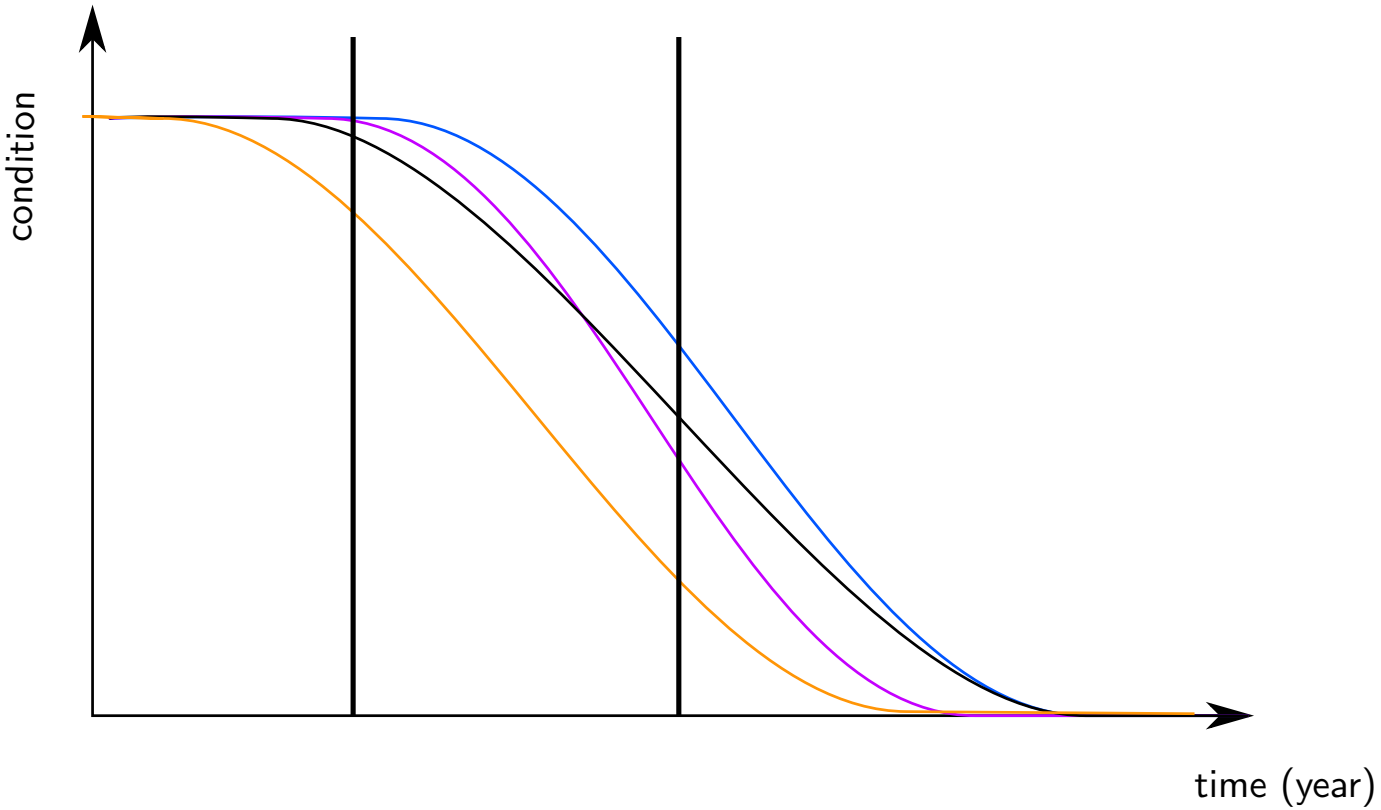

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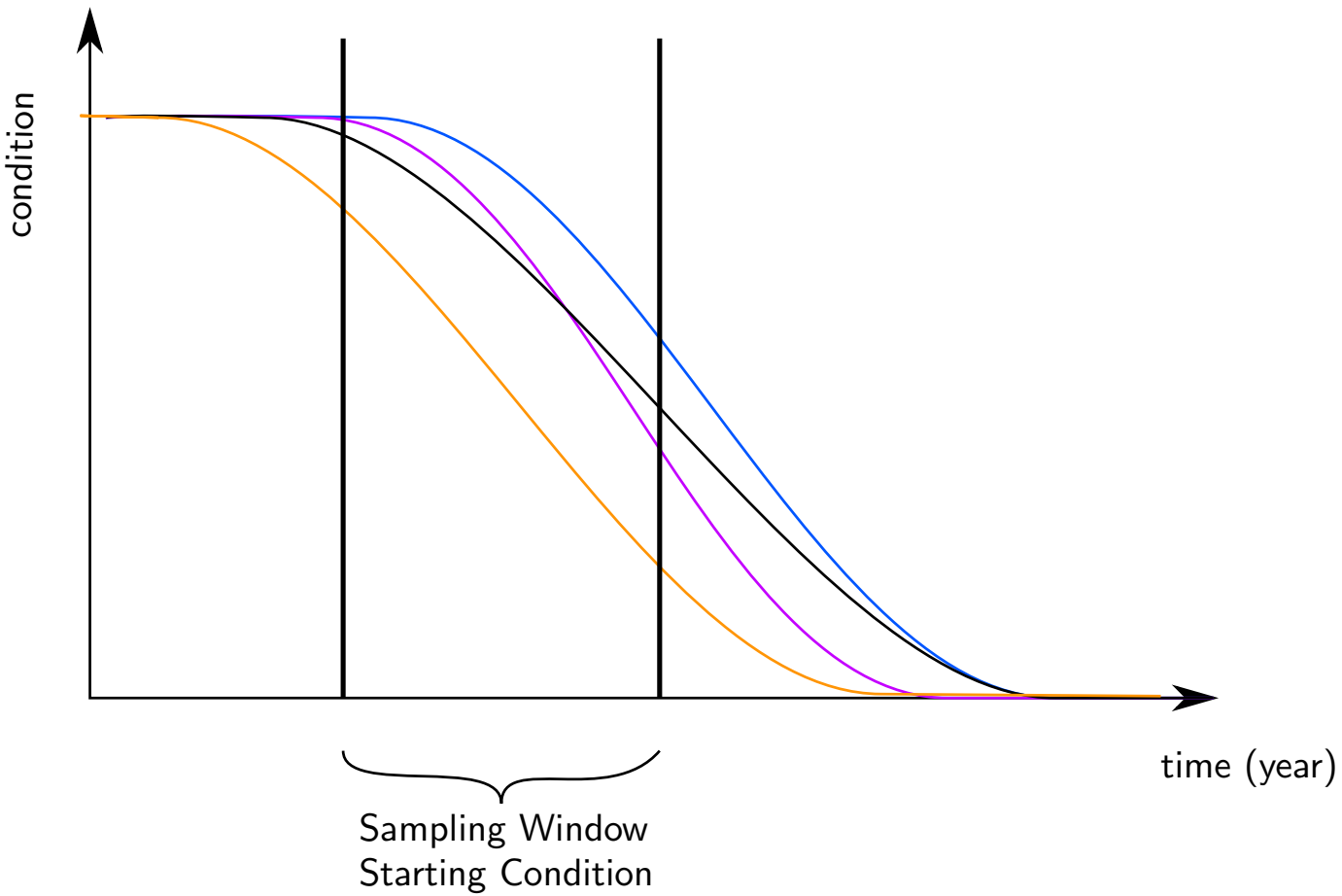

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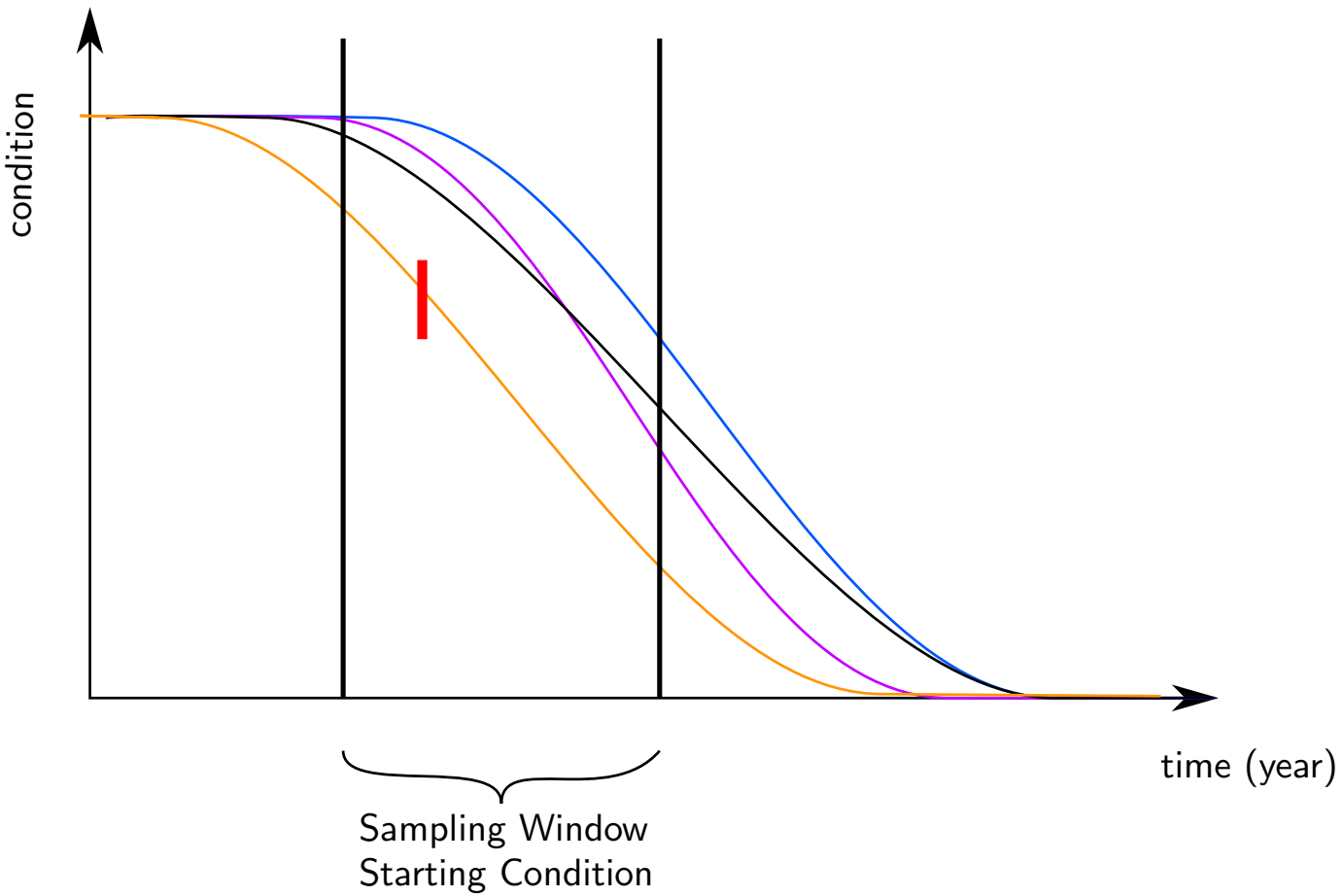

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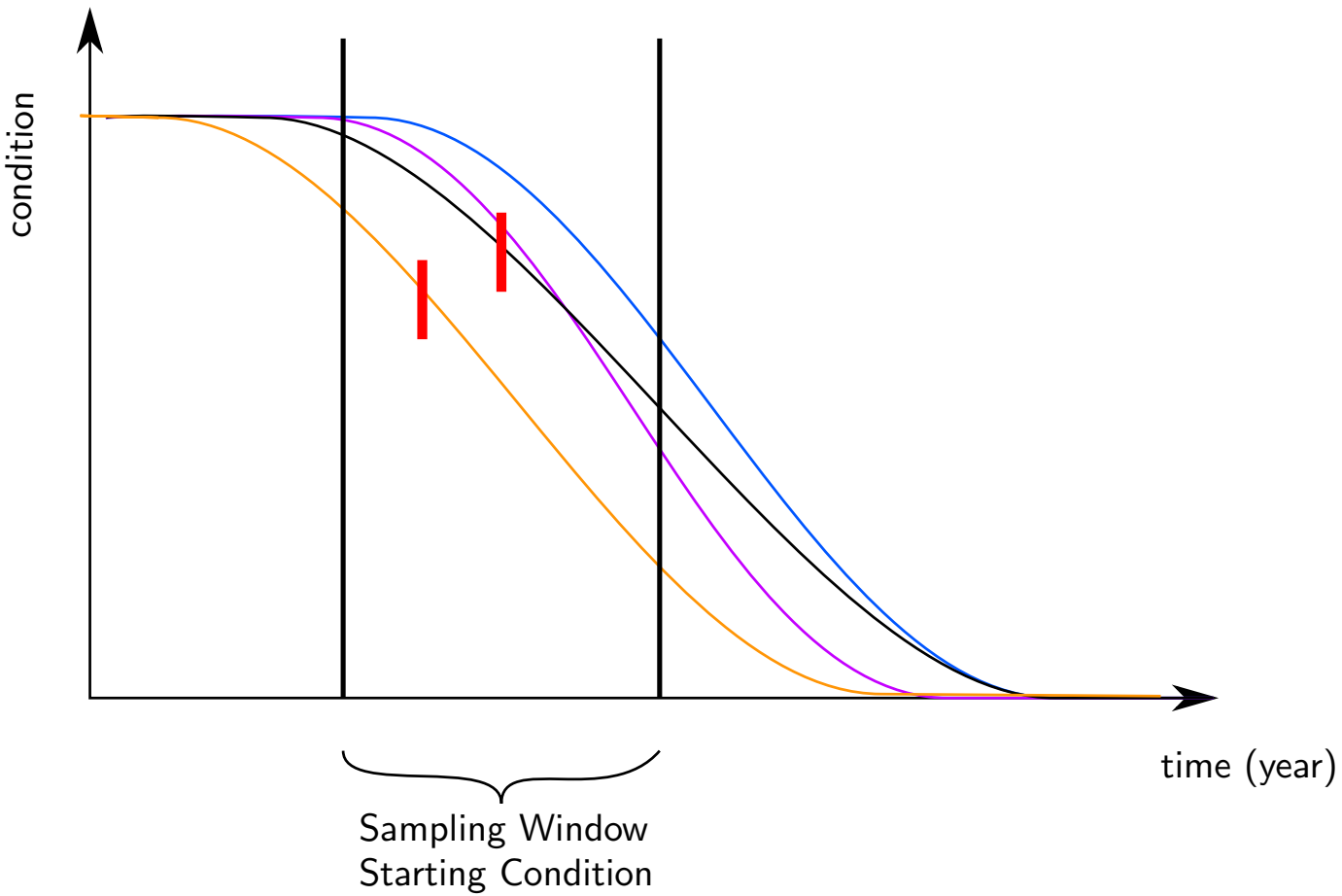

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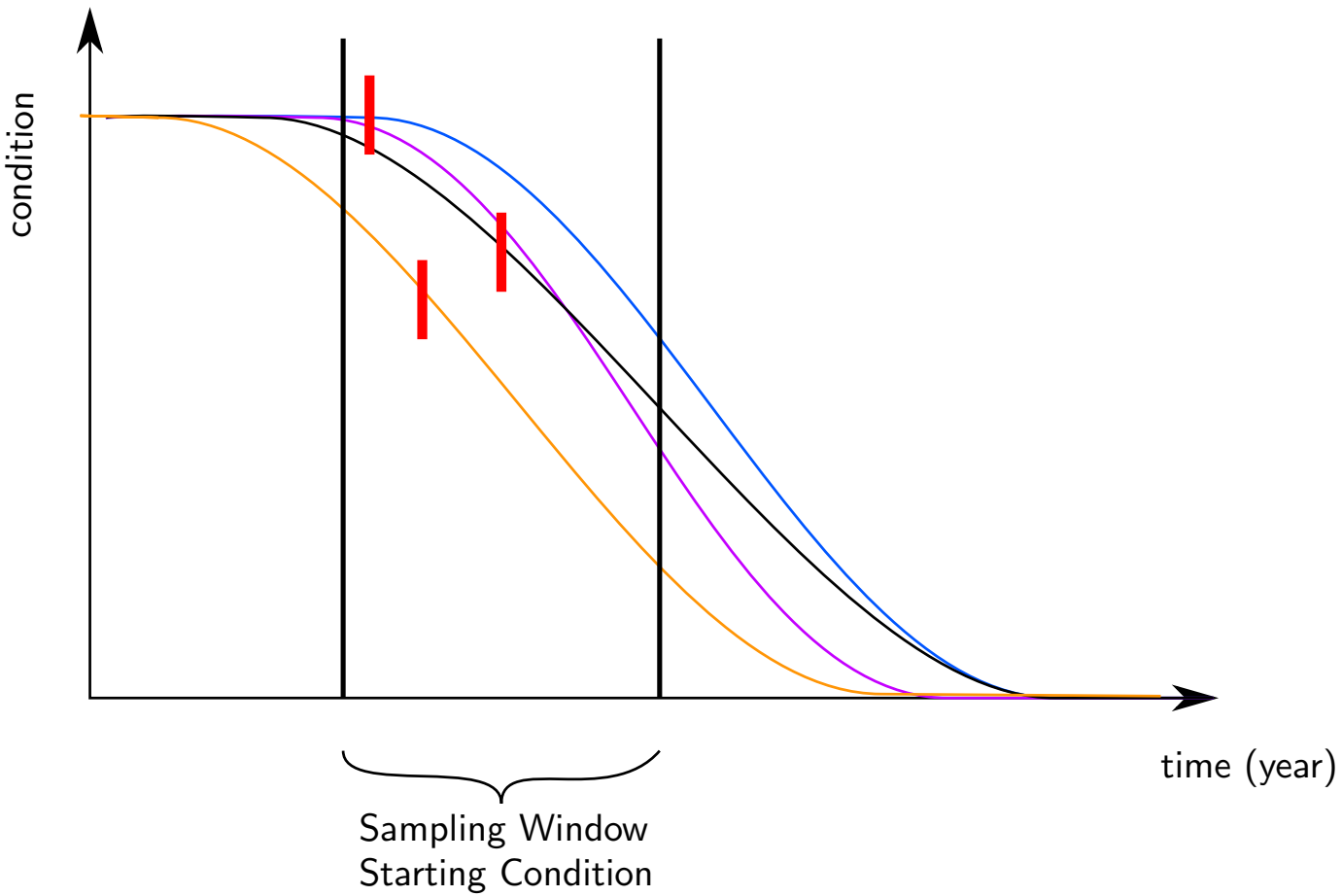

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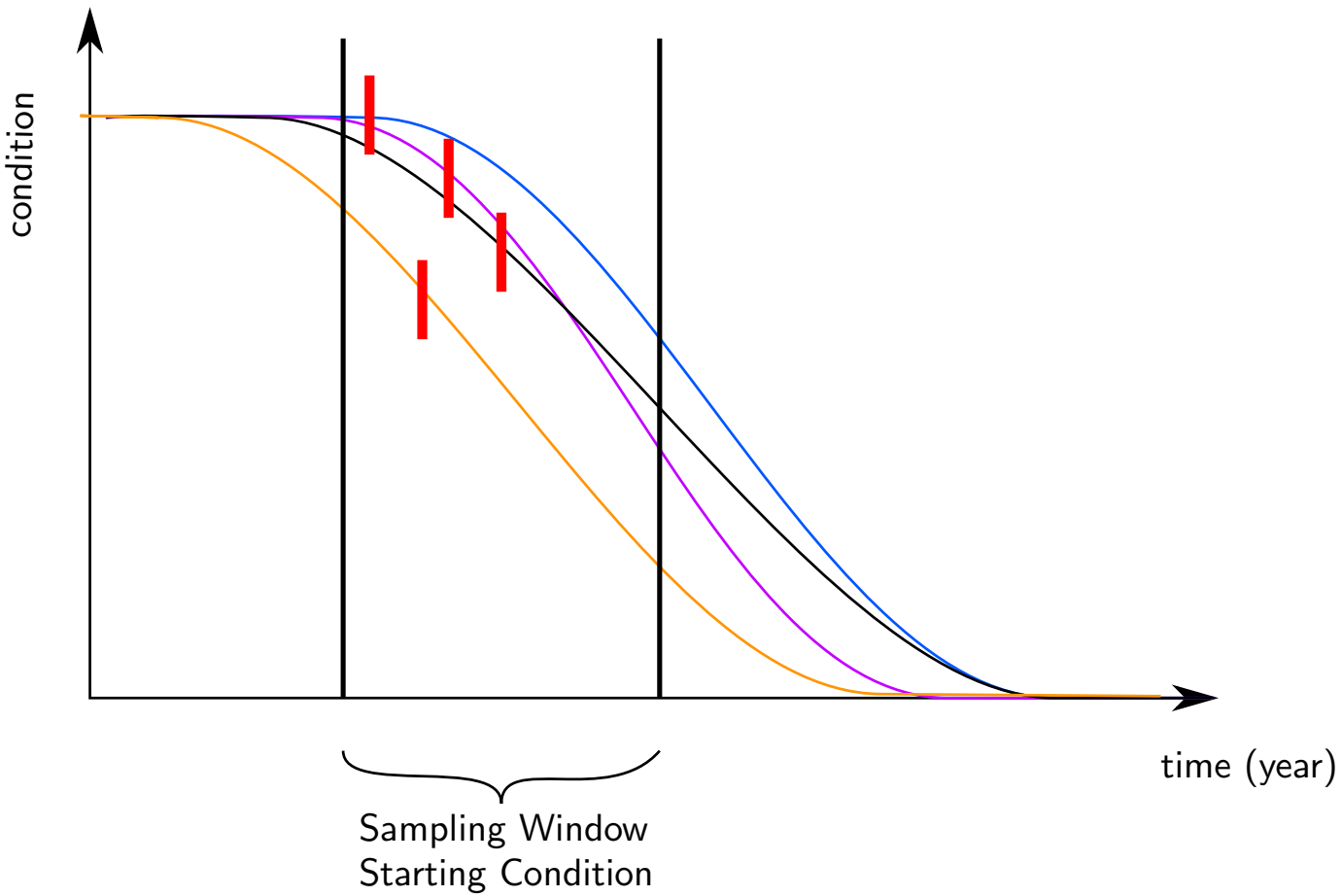
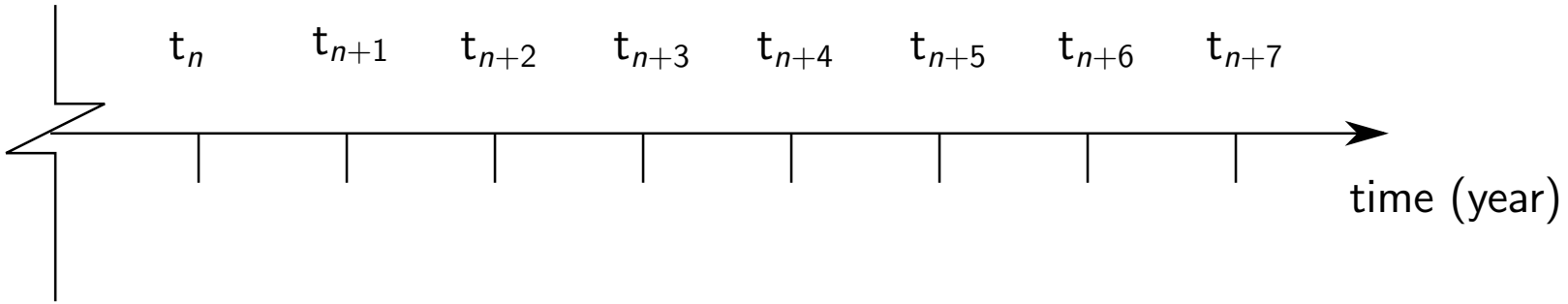


Proposition



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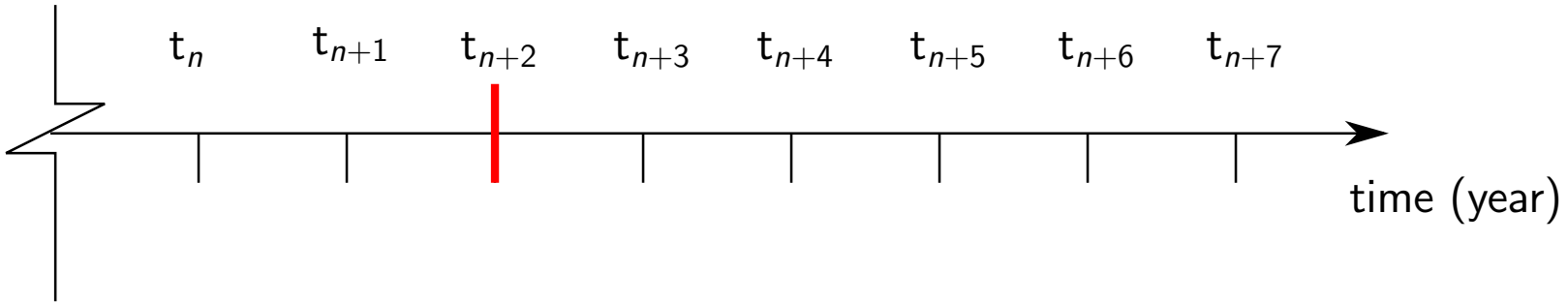

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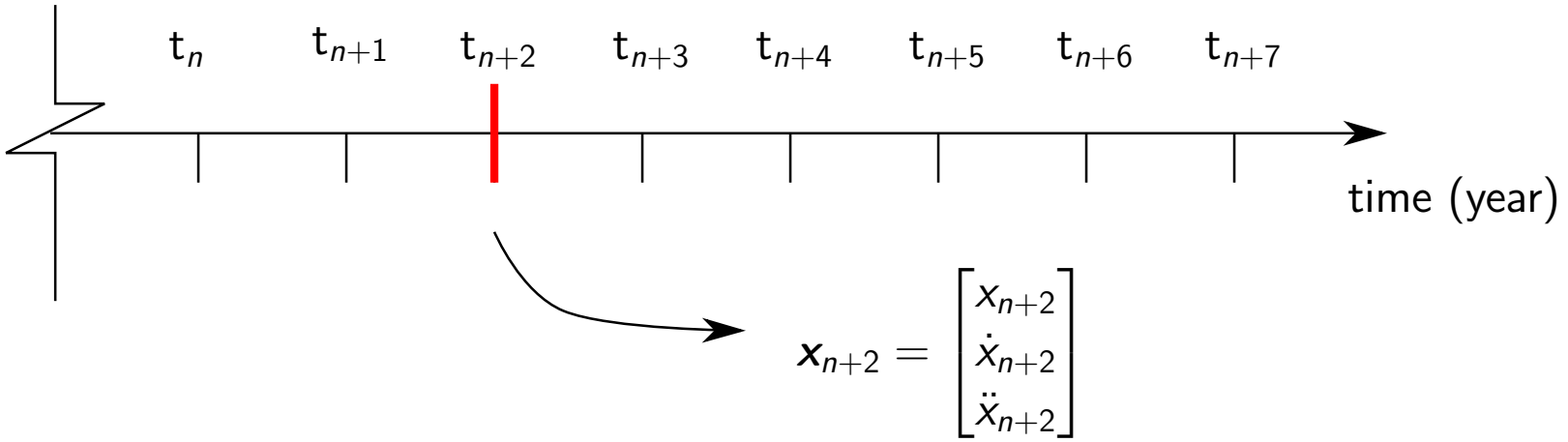

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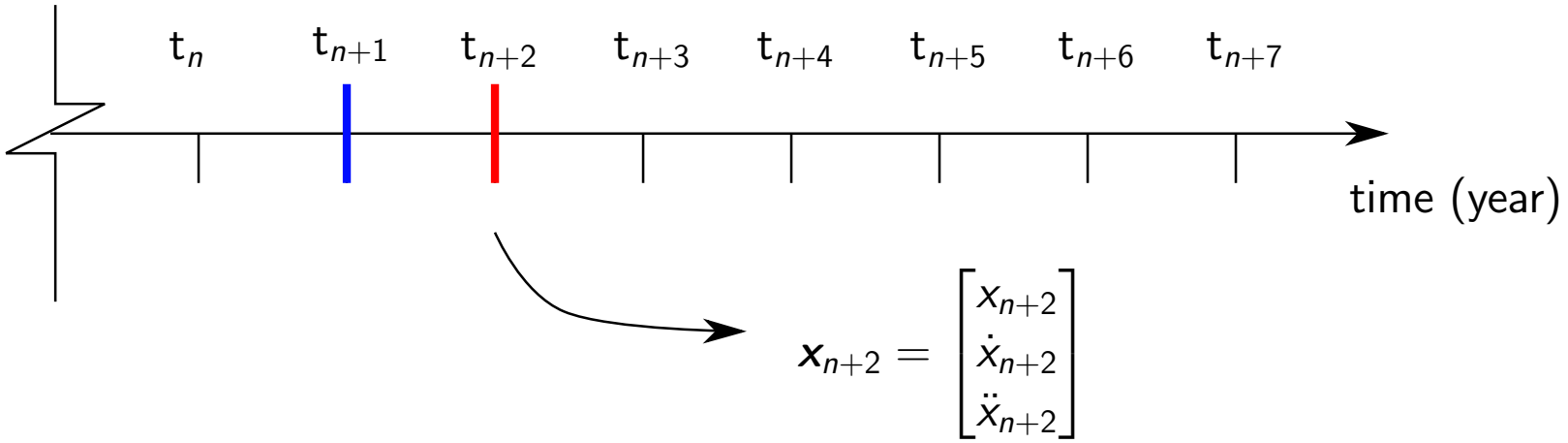

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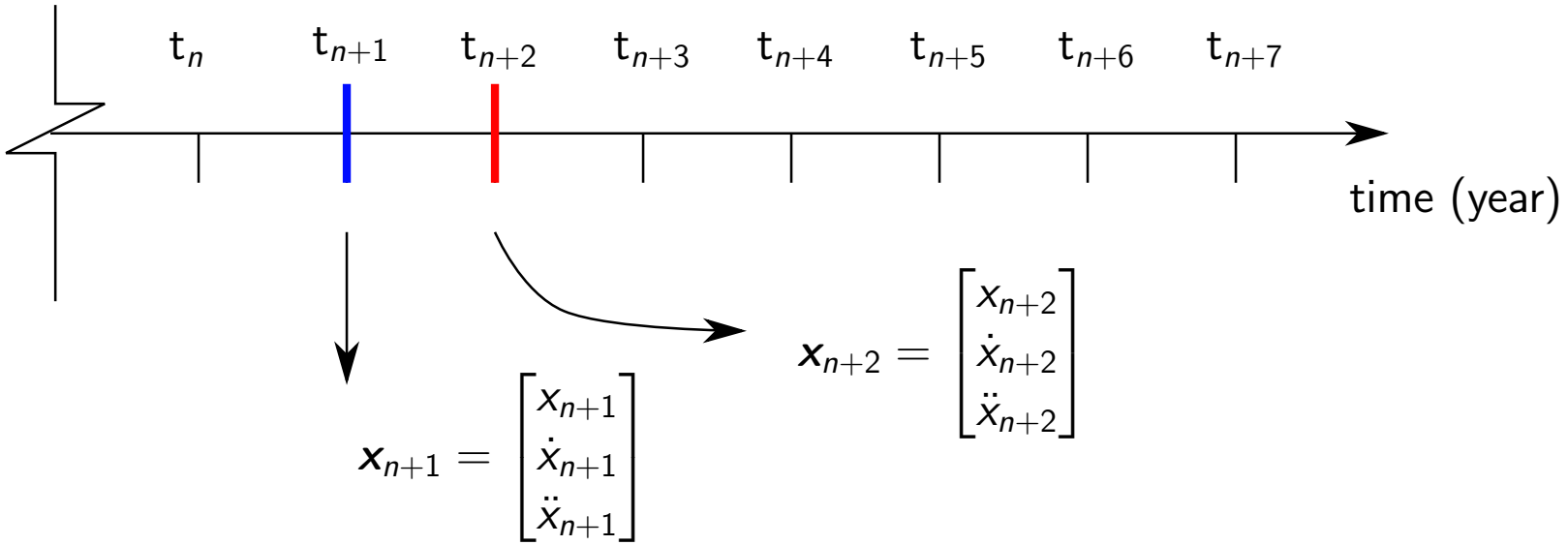

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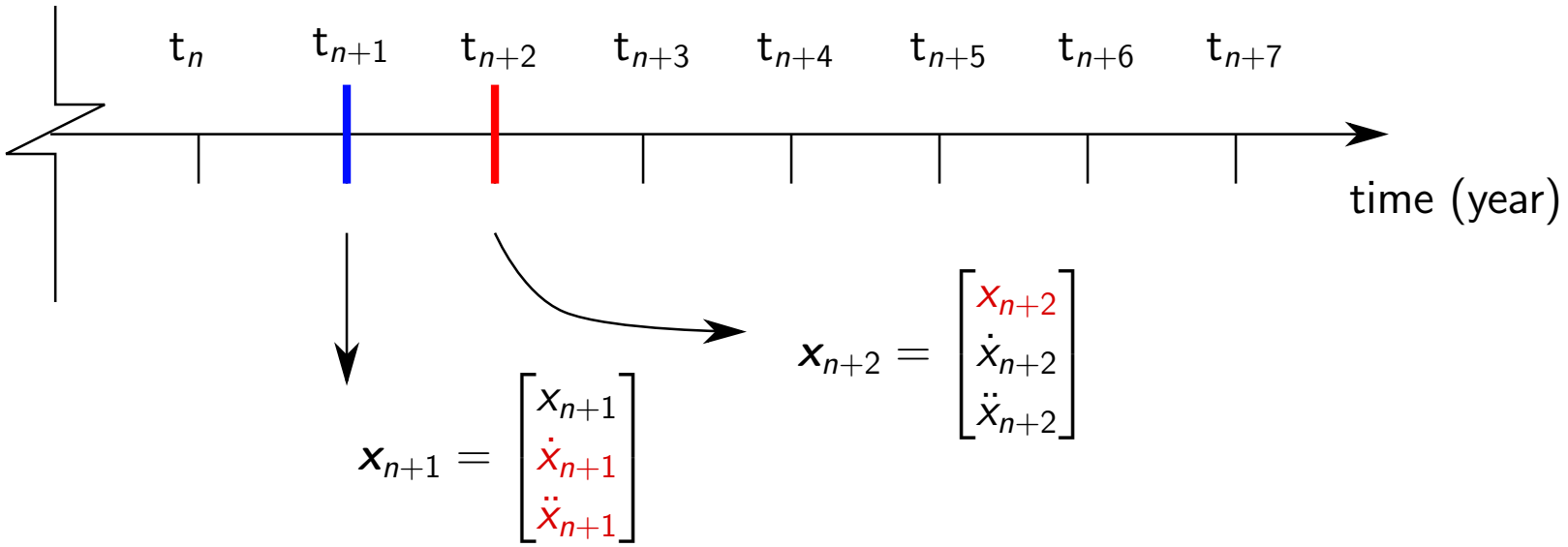

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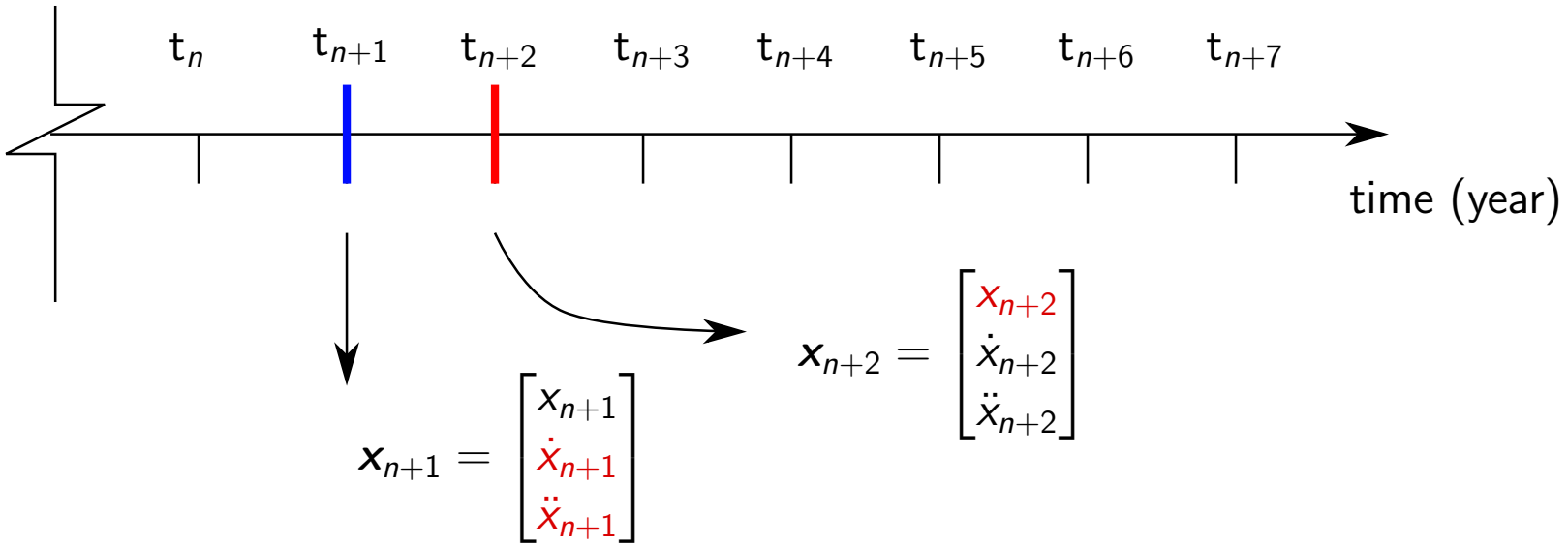
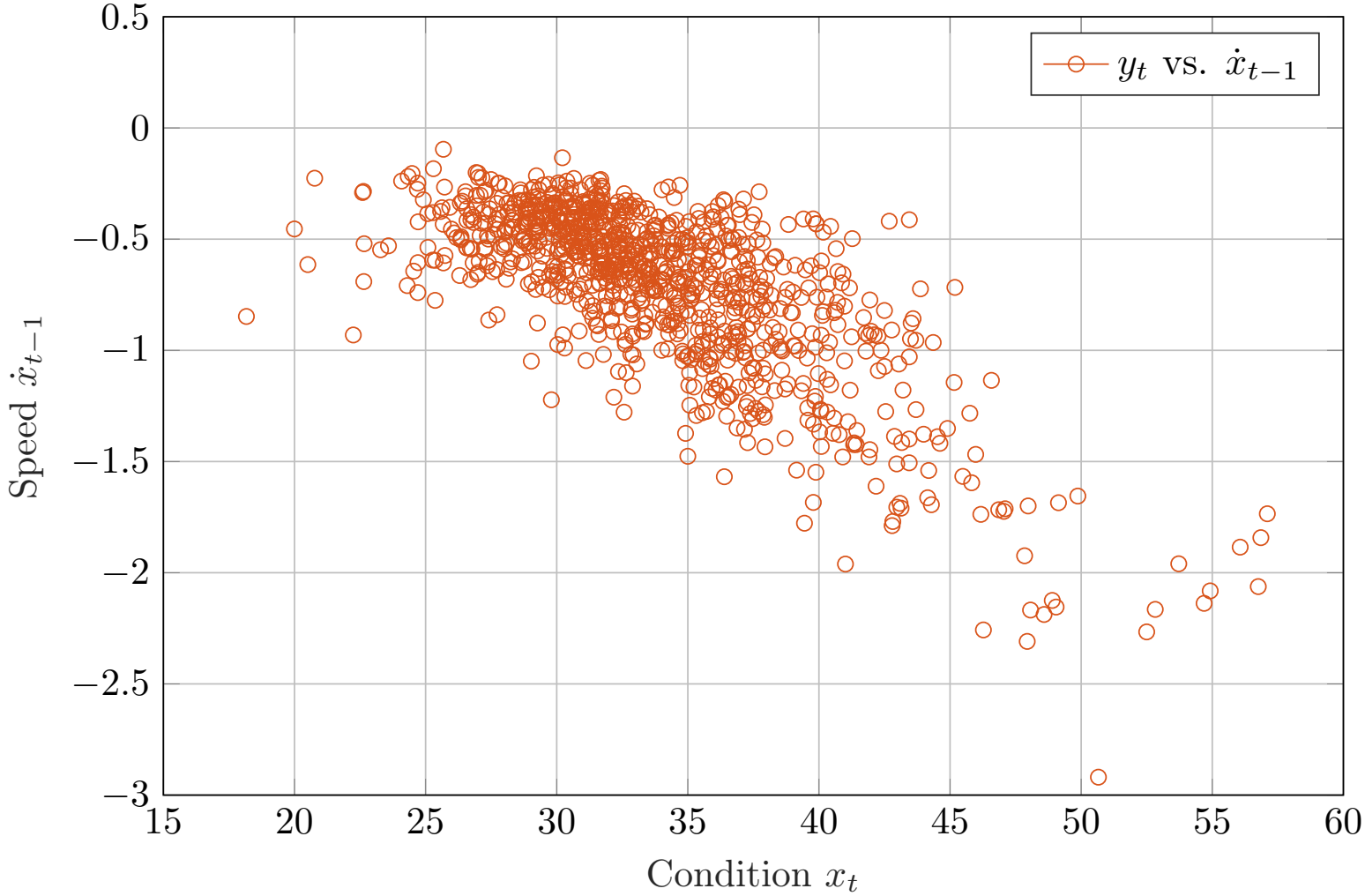
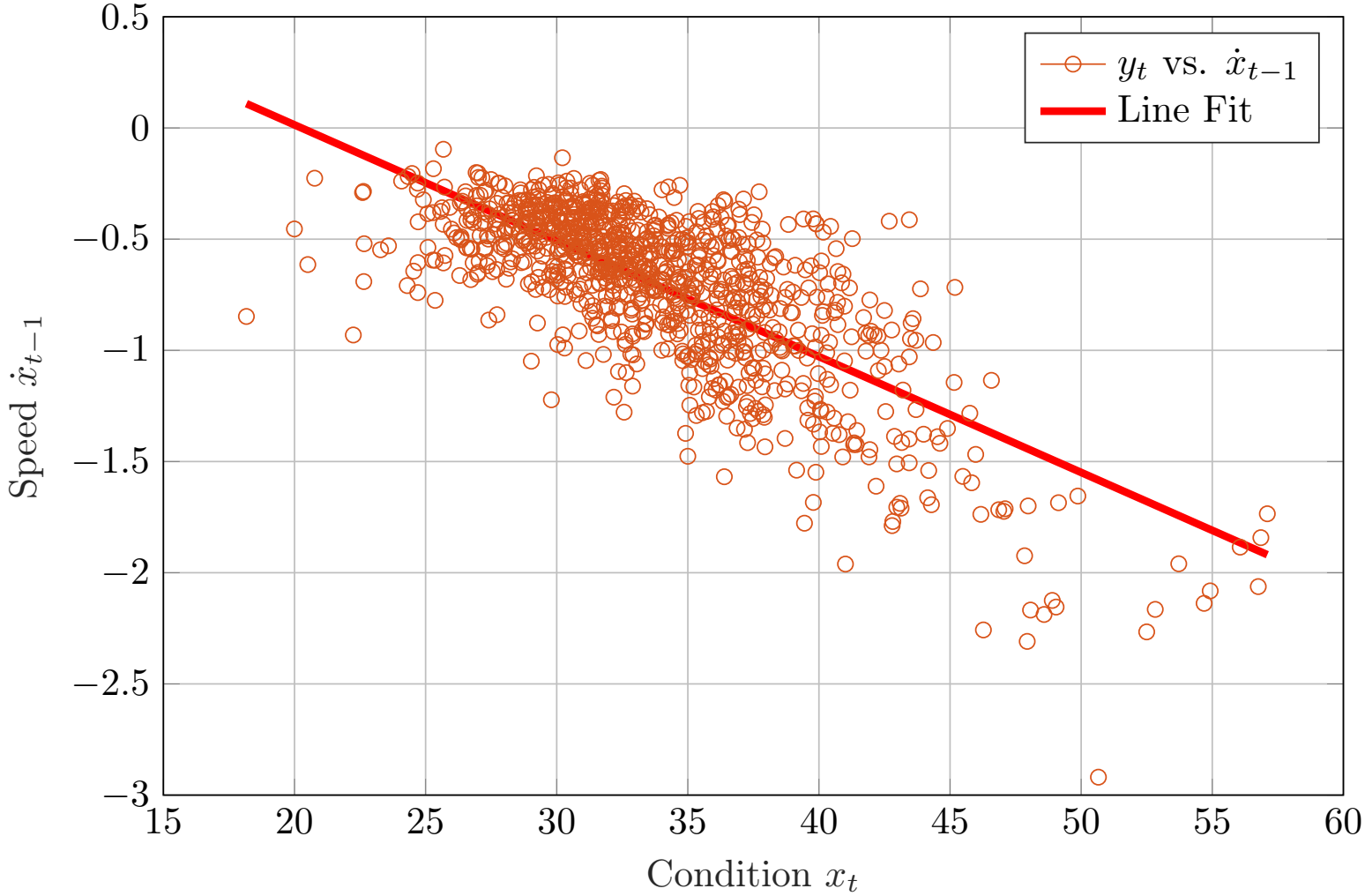


$$\overbrace{\boldsymbol{y}_t = \boldsymbol{C}\boldsymbol{x}_t + \boldsymbol{v}_t}^{\text{observation model}}, \quad \underbrace{\boldsymbol{v}_t : \boldsymbol{V}(I_i) \sim \mathcal{N}(\boldsymbol{v}; \boldsymbol{0}, \boldsymbol{R}_t(I_i))}_{\text{observation error}}$$

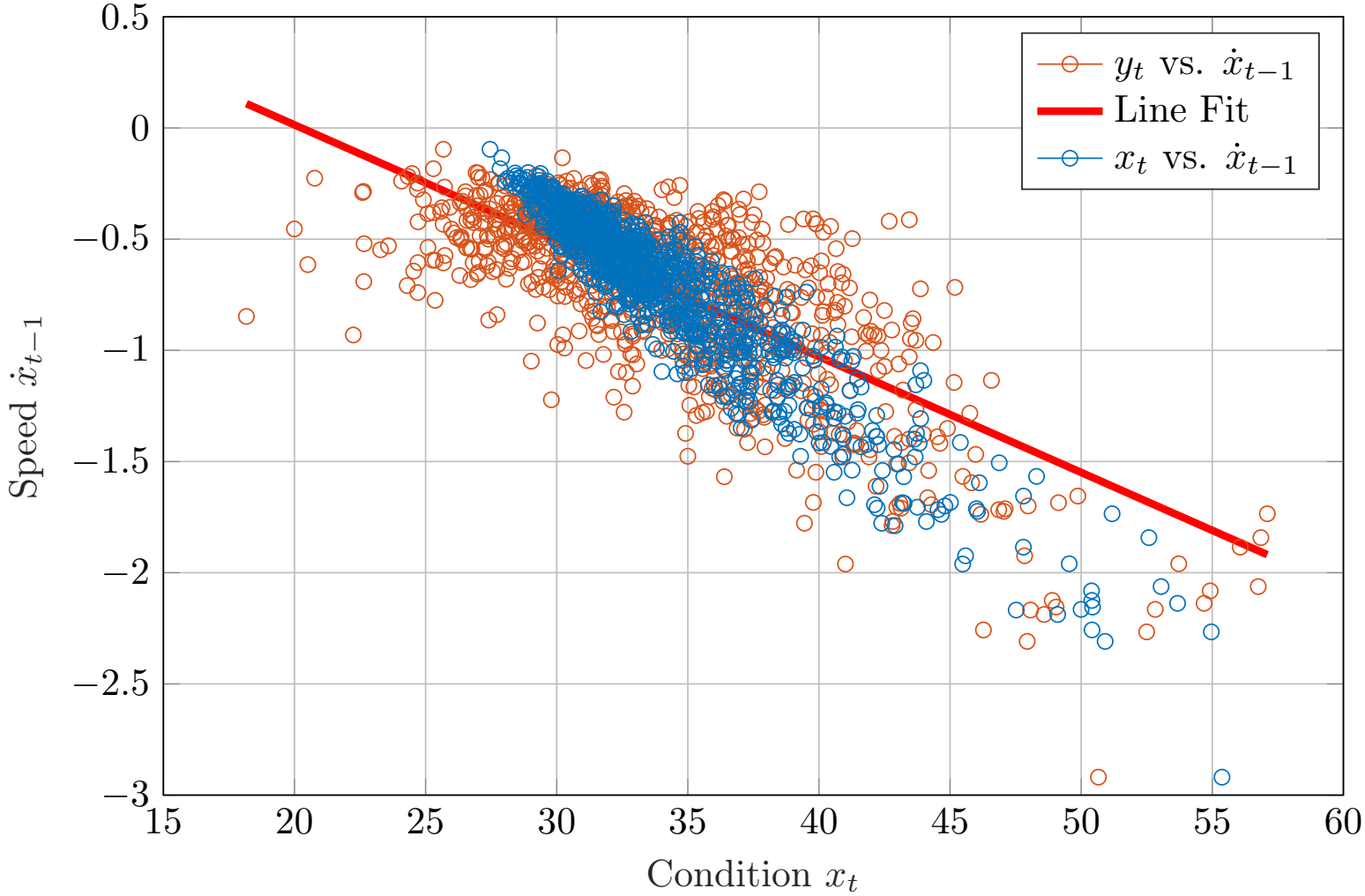
Initial Speed & Condition:



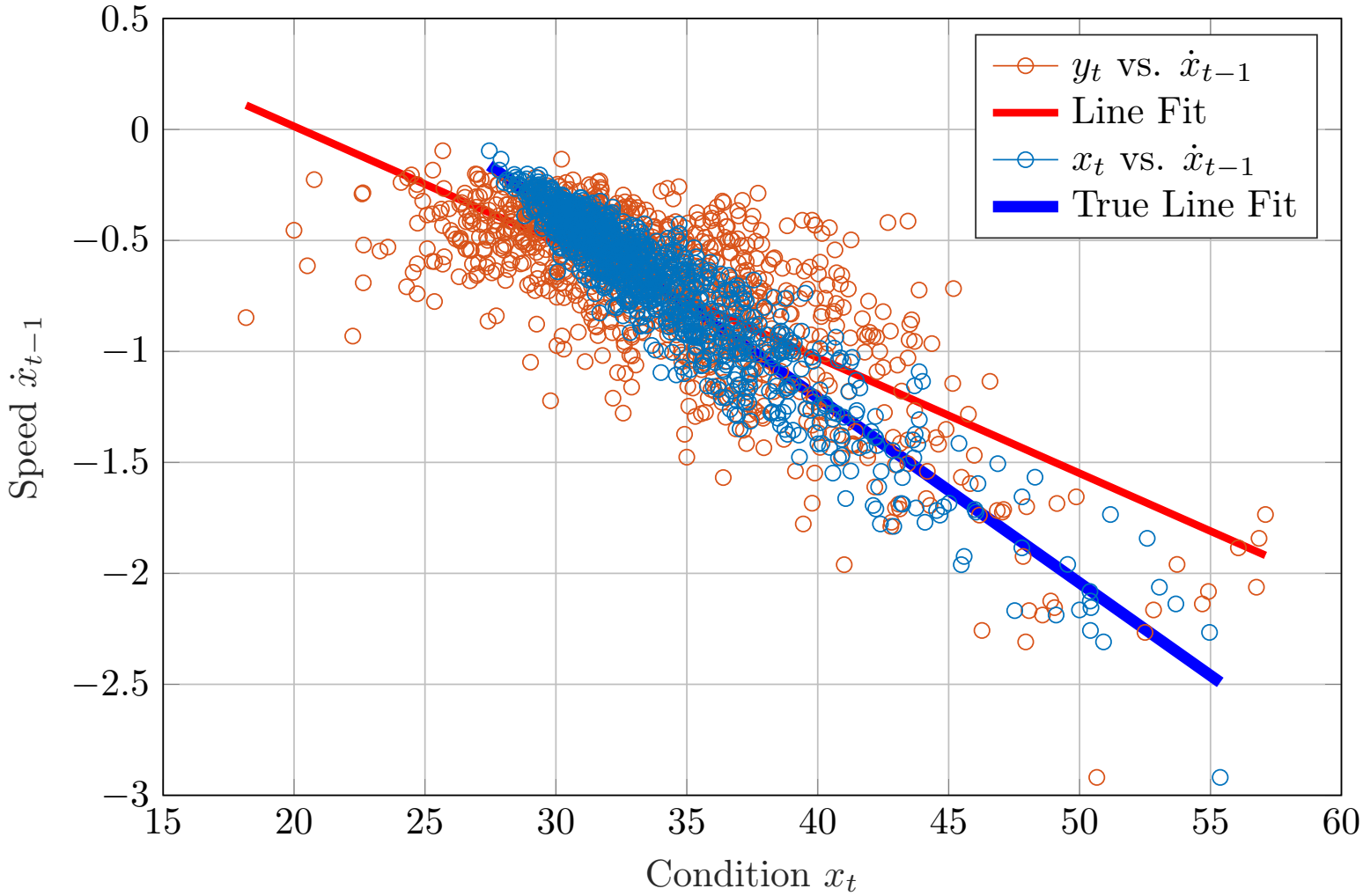
Initial Speed & Condition:



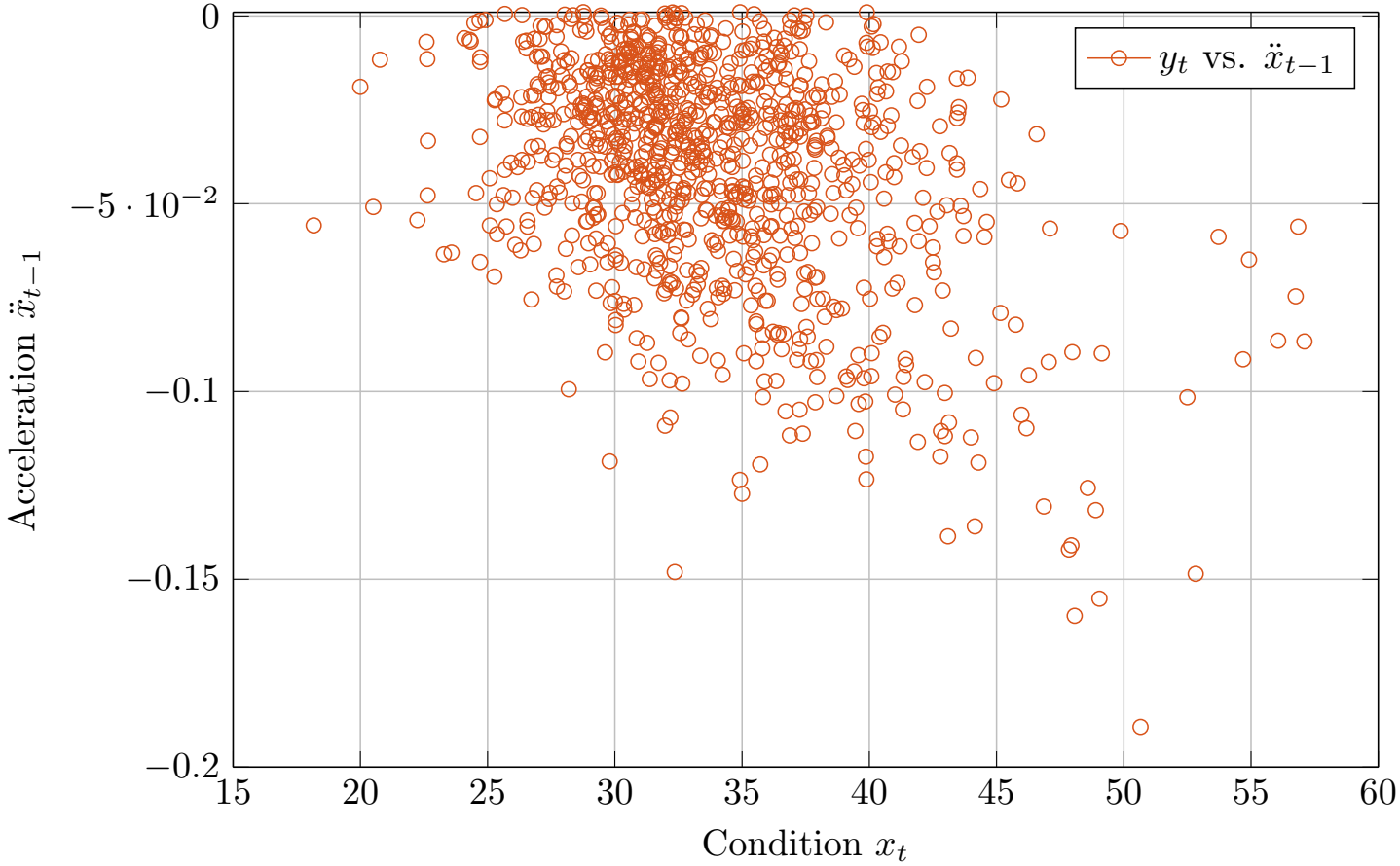
Initial Speed & Condition:



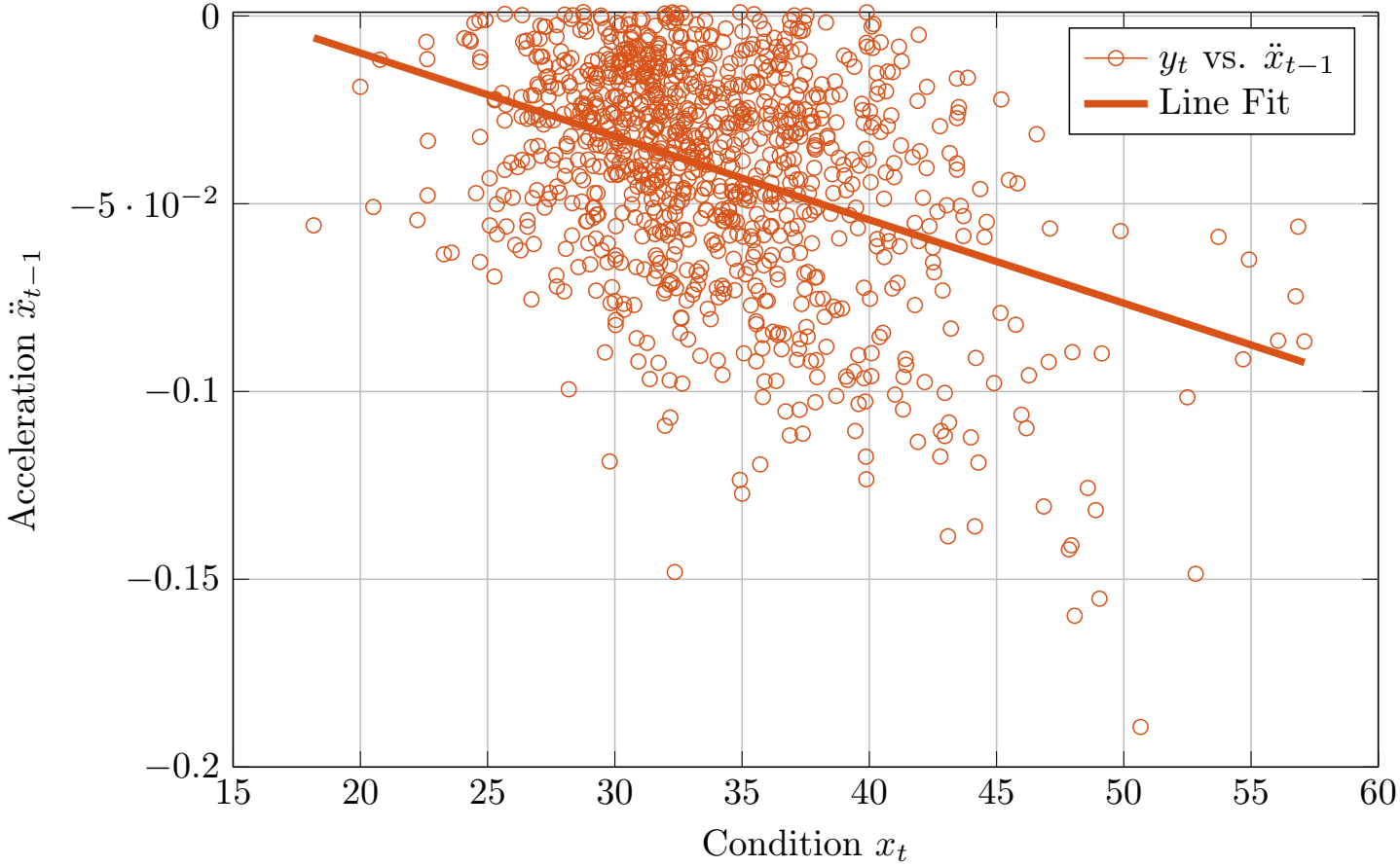
Initial Speed & Condition:



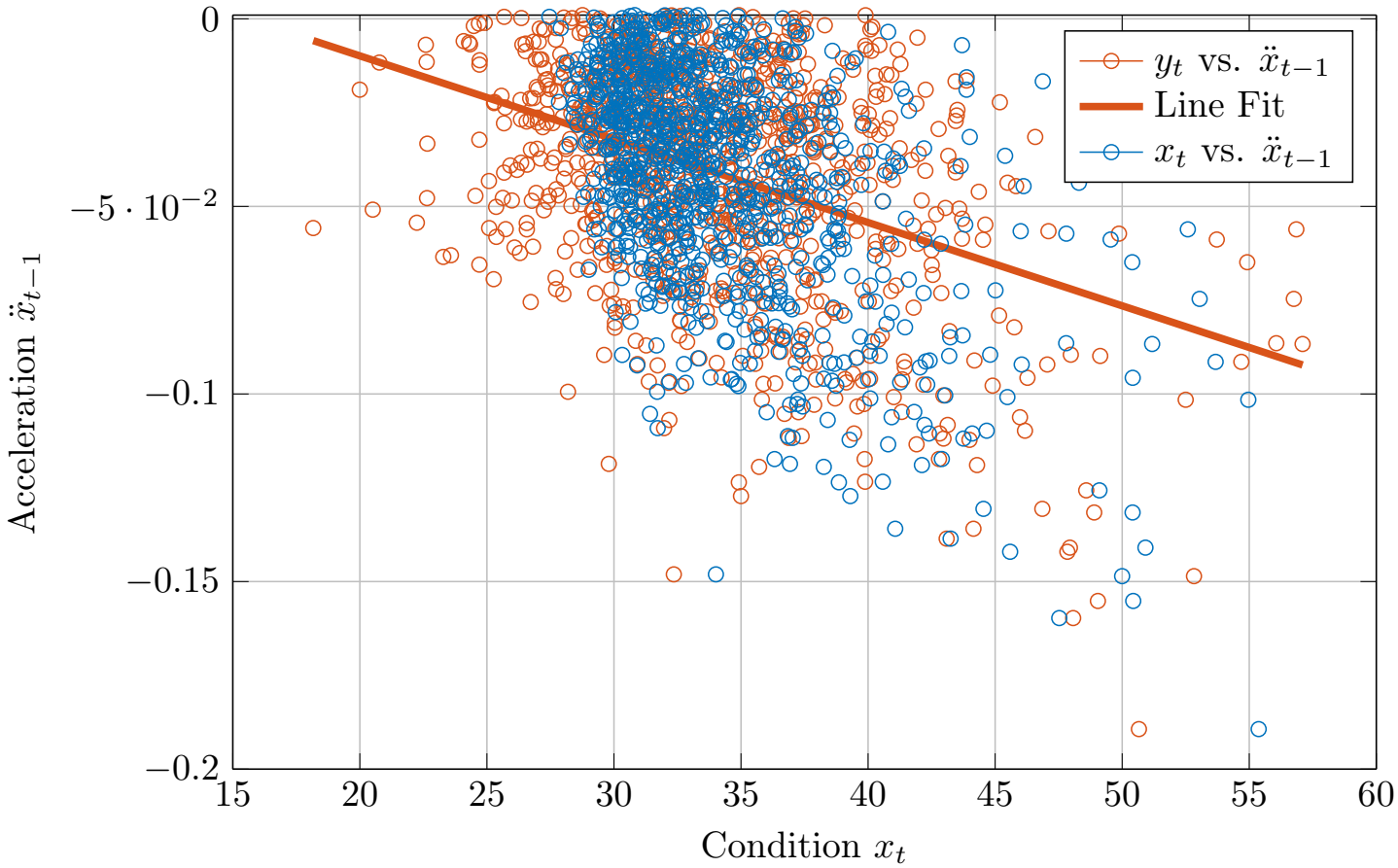
Initial Acc. Analyses:



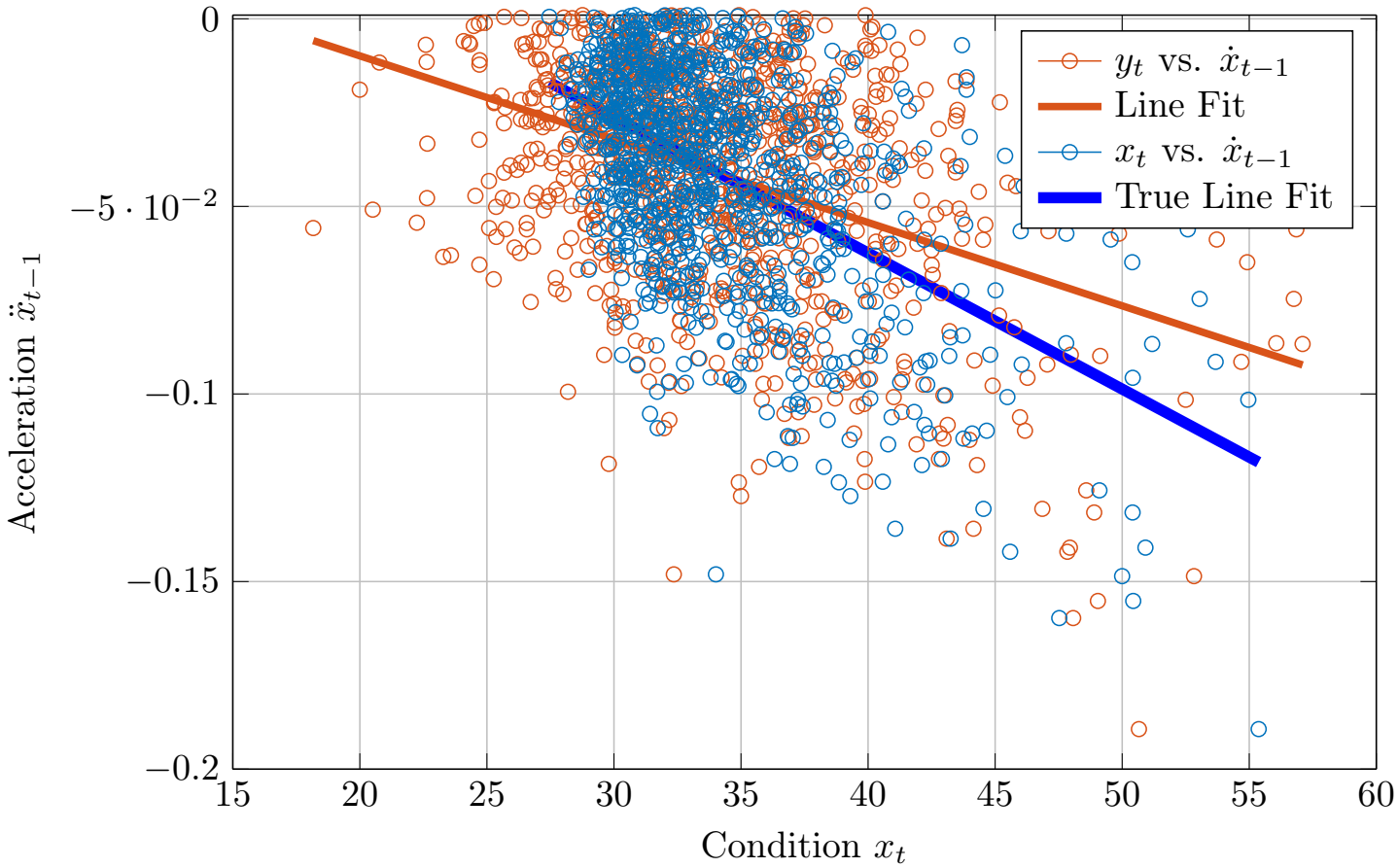
Initial Acc. Analyses:



Initial Acc. Analyses:



Initial Acc. Analyses:



Estimating Initial Speed & Acc.:

$$\mu_0 = y_1, \quad \dot{\mu}_0 = p_1 \times \text{ Condition}, \quad \ddot{\mu}_0 = p_2 \times \text{ Condition}.$$

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$$\text{Condition: } \begin{cases} y_1 \\ \end{cases}$$

Estimating Initial Speed & Acc.:

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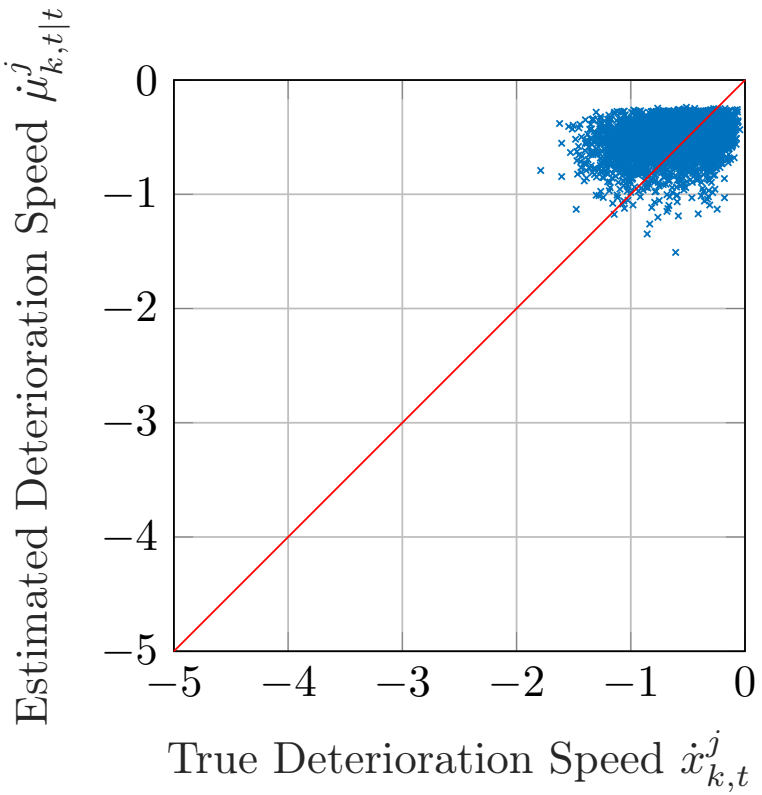
$$\text{Condition: } \begin{cases} y_1 \\ x_{0|T} \text{ (Smoothed State)} \end{cases}$$

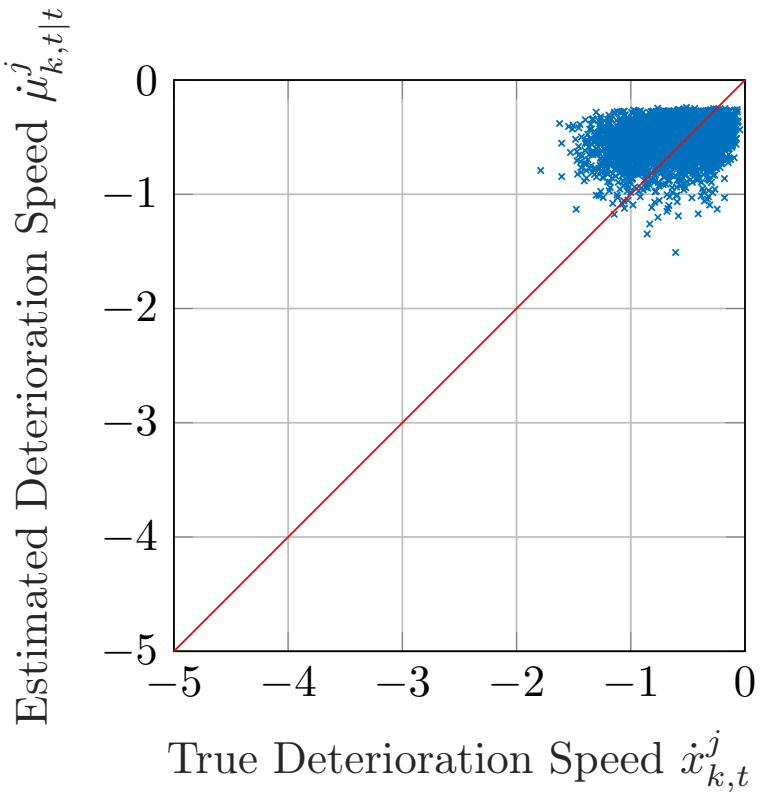
Estimating Speed after the First Observation:

Before:

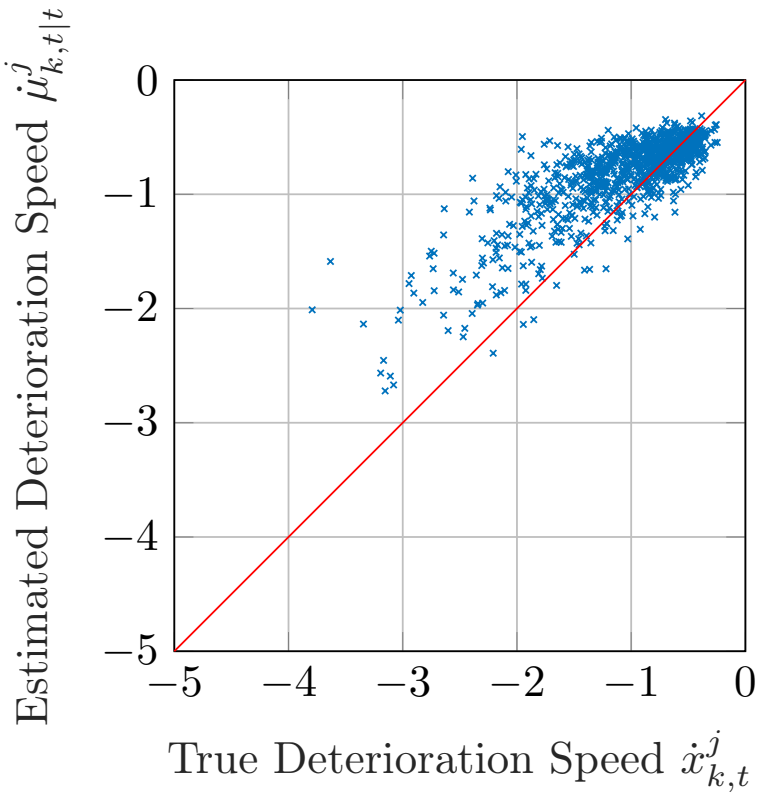


Estimating Speed after the First Observation:

Before:



After:



Plan de la section

Data Navigation

4.1 Limitations in User Experience

4.2 Solution

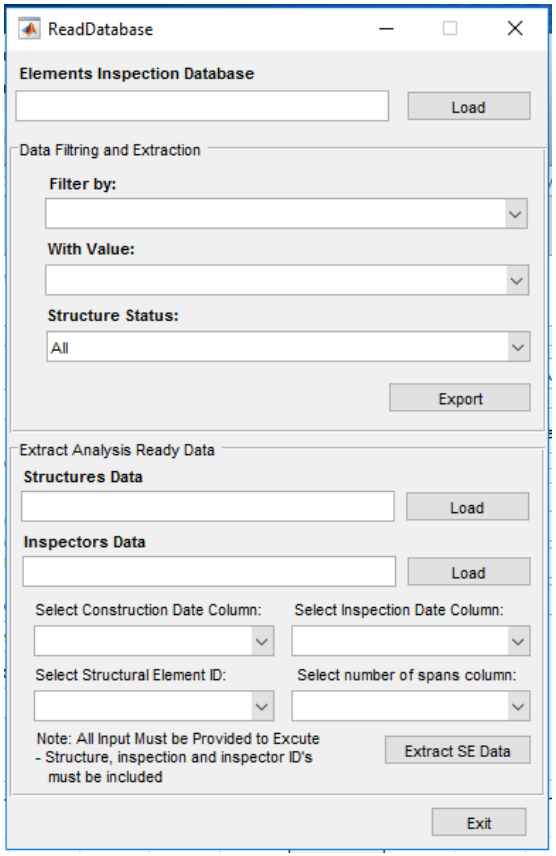
User - Model - Data

User

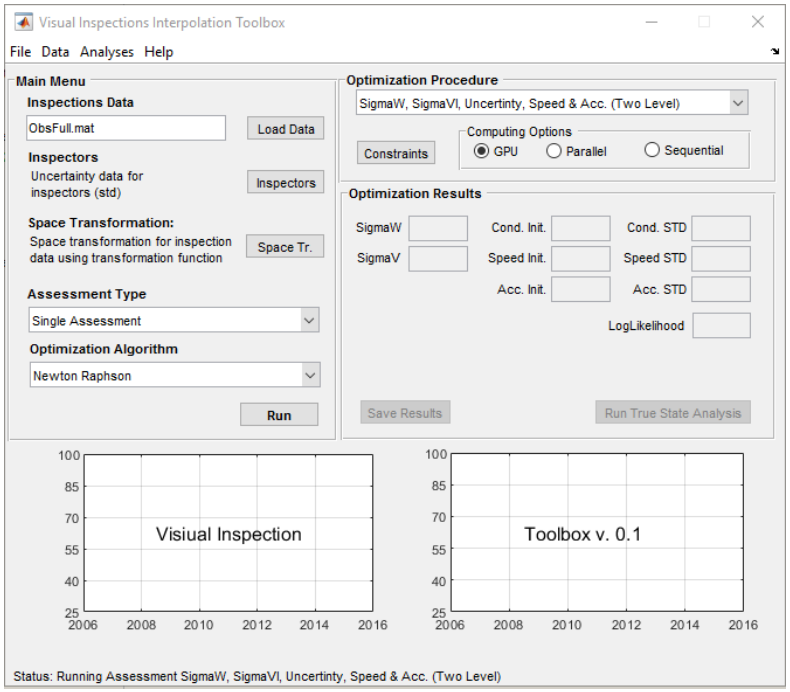
Model

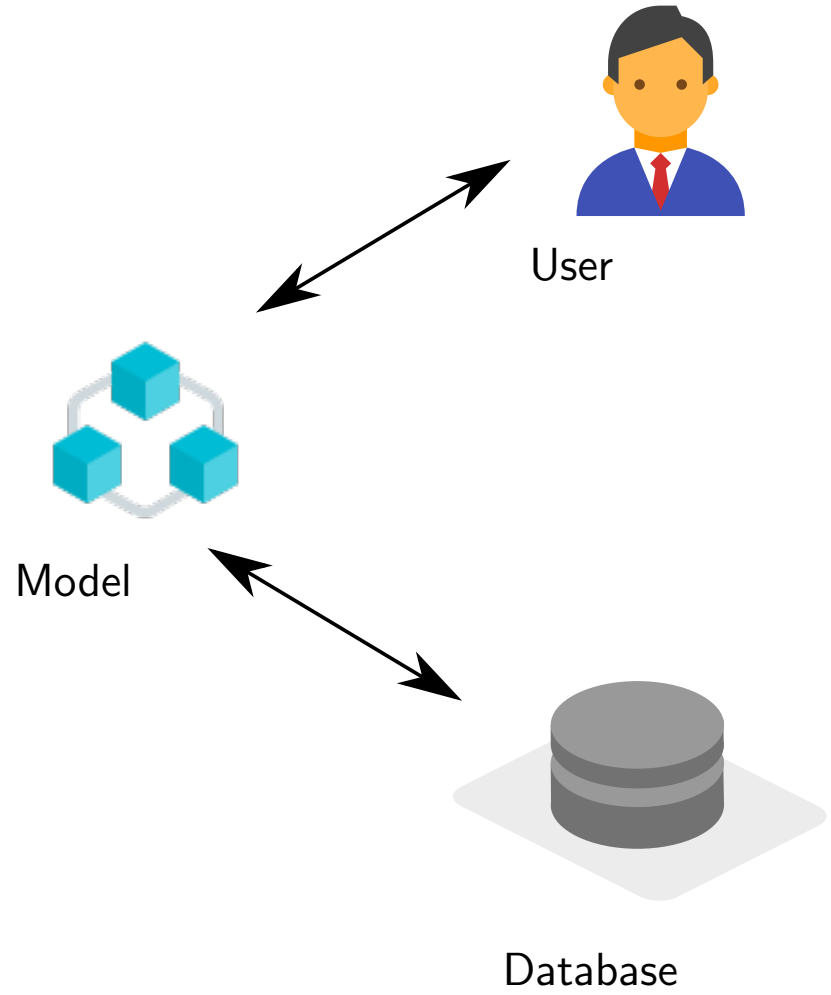
Database

User - Model - Data

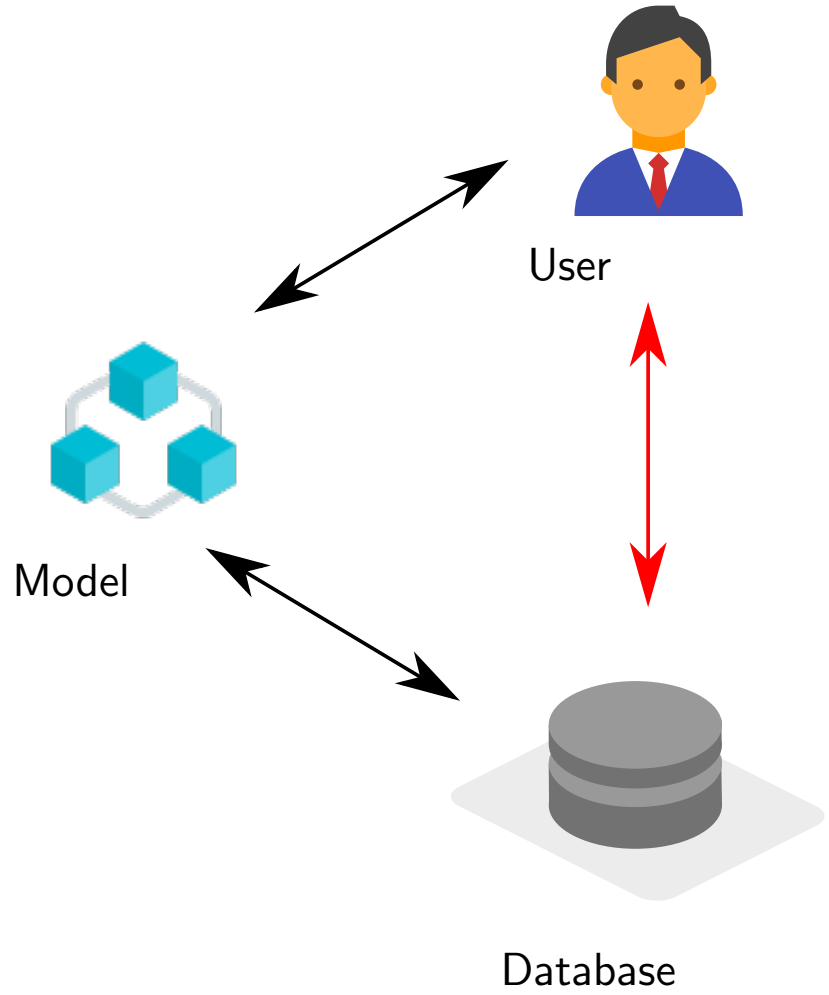


User - Model - Data

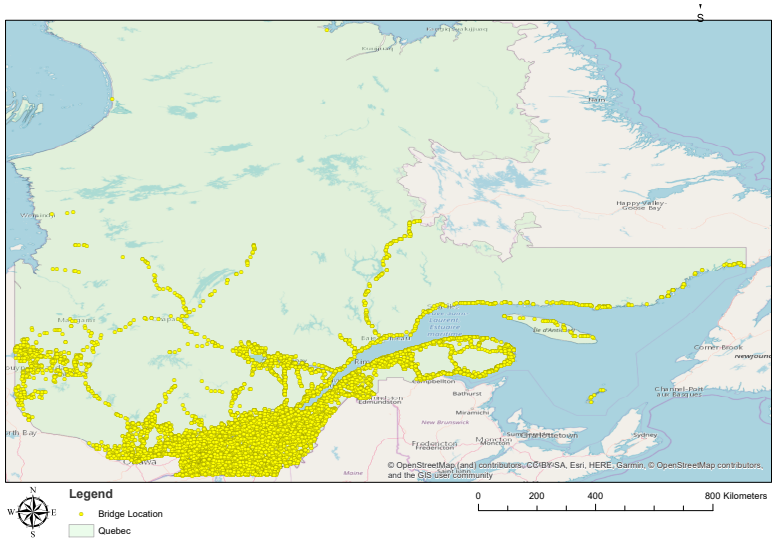


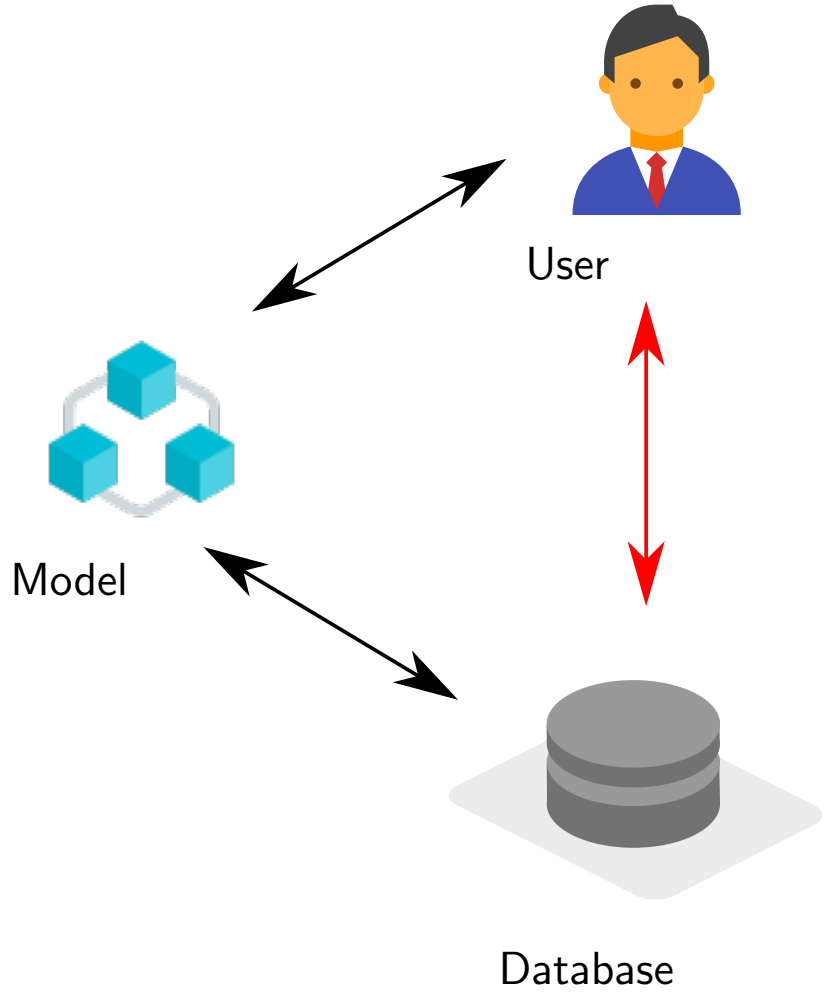


User - Model - Data



User - Model - Data





Build a solution from Scratch!

Interactive Bridge Network Map

(Demo)

Plan de la section

Progress & Next Steps

5.1 Project Progress

5.2 Next Steps

Advancement Summary

1. Run analyses on GPU/CPU (+code optimization).

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   a. Number of structures inspected by each inspector.

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   a. Number of structures inspected by each inspector.
   b. Material and condition reported by each inspector.

Advancement Summary

1. Run analyses on GPU/CPU (+code optimization).
2. Improve the way synthetic data is generated:
   a. Examine speed vs. condition.
   b. Examine acceleration vs. condition.
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   a. Number of structures inspected by each inspector.
   b. Material and condition reported by each inspector.
4. Develop Synthetic Data Analyses Toolbox + Merge Scripts.

Advancement Summary

1. Run analyses on GPU/CPU (+code optimization).
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6. Added more optimization options.

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7. Build Interactive Bridge Network Map.

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4. Develop Synthetic Data Analyses Toolbox + Merge Scripts.
5. Improve Read Database Toolbox [State-Space + Regression].
6. Added more optimization options.
7. Build Interactive Bridge Network Map.
8. Access All toolboxes from one place.

Next:

1. Code Optimization.

Next:

1. Code Optimization.
2. Test different optimization frameworks.