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Vehicle Terrain Performance Laboratory

Instantaneous IRI

John B. Ferris
Associate Professor, Mechanical Engineering
Director, Vehicle Terrain Performance Lab

Instantaneous IRI

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~~Motivation~~

Background

- Golden Qcar is Linear Time-Invariant (LTI)
- LTI → Impulse Response and Superposition

Proposed Definition of Instantaneous IRI (IRI_i)

- Contribution of Input to Response, f_{ij}
- Problem: IRI is nonlinear integrator
- Desired Properties: average IRI_i = IRI
- Definition of IRI_i
- Validate Properties

Comments and Discussion

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Associate Professor

Golden Qcar is Linear Time-Invariant

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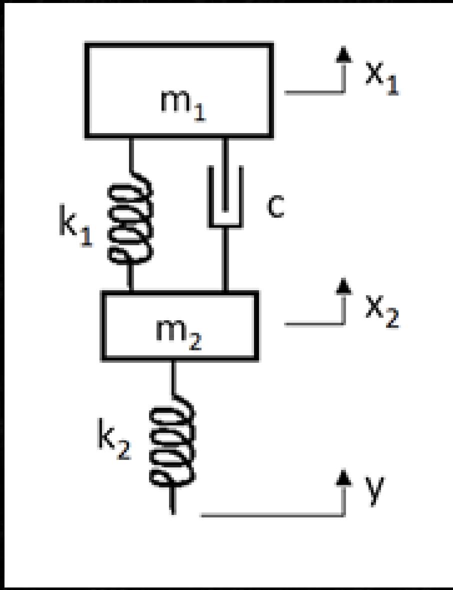
Qcar model comprises

- Masses – mass does not change
- Linear Springs – rate doesn't change
- Linear Dampers – doesn't change

→ Linear Time Invariant (LTI)



Equations of Motion are

$$m_1\ddot{x}_1 + c\dot{x}_1 - c\dot{x}_2 + k_1x_1 - k_1x_2 = 0$$

$$m_2\ddot{x}_2 + c\dot{x}_2 - c\dot{x}_1 + (k_1 + k_2)x_2 - k_1x_1 = f(t) = k_2y$$

LTI → Impulse Response

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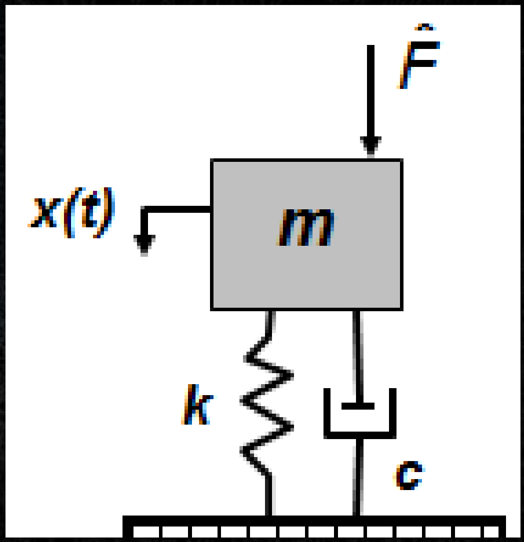
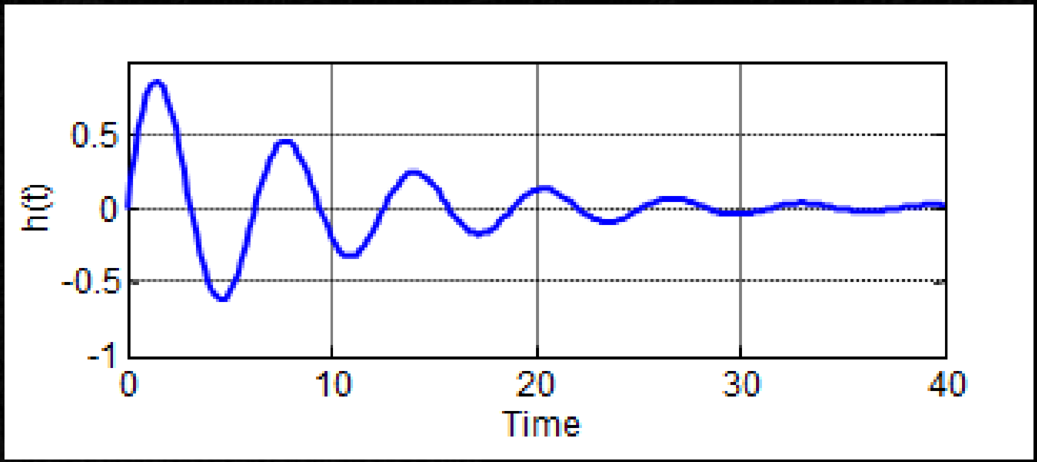
Linear Time Invariant (LTI)

→ Completely defined by ***Impulse Response***

"Hit" it (impulse, $\hat{F}$) at $t=0$

→ Response contains all info about LTI system





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LTI → Superposition

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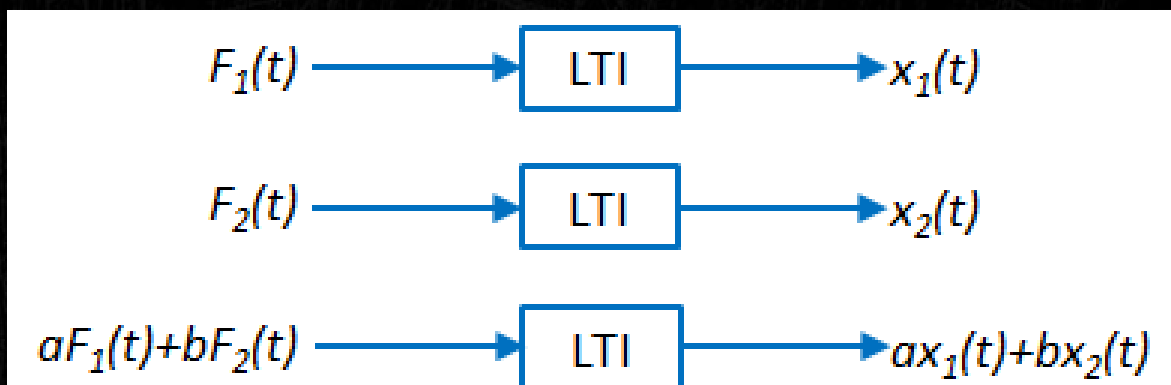
Why do we care: LTI Systems → Superposition

- Break up complicated forces into sums of simpler forces, compute the response and add to get the total solution
- If x_1 and x_2 are solutions to an LTI system then



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LTI → Superposition

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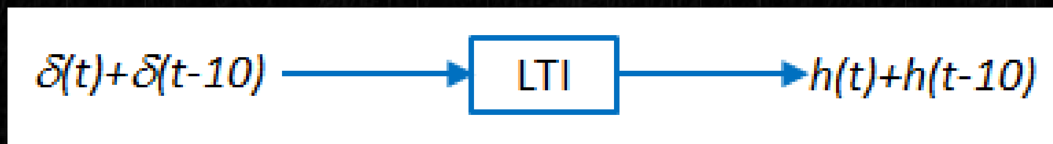
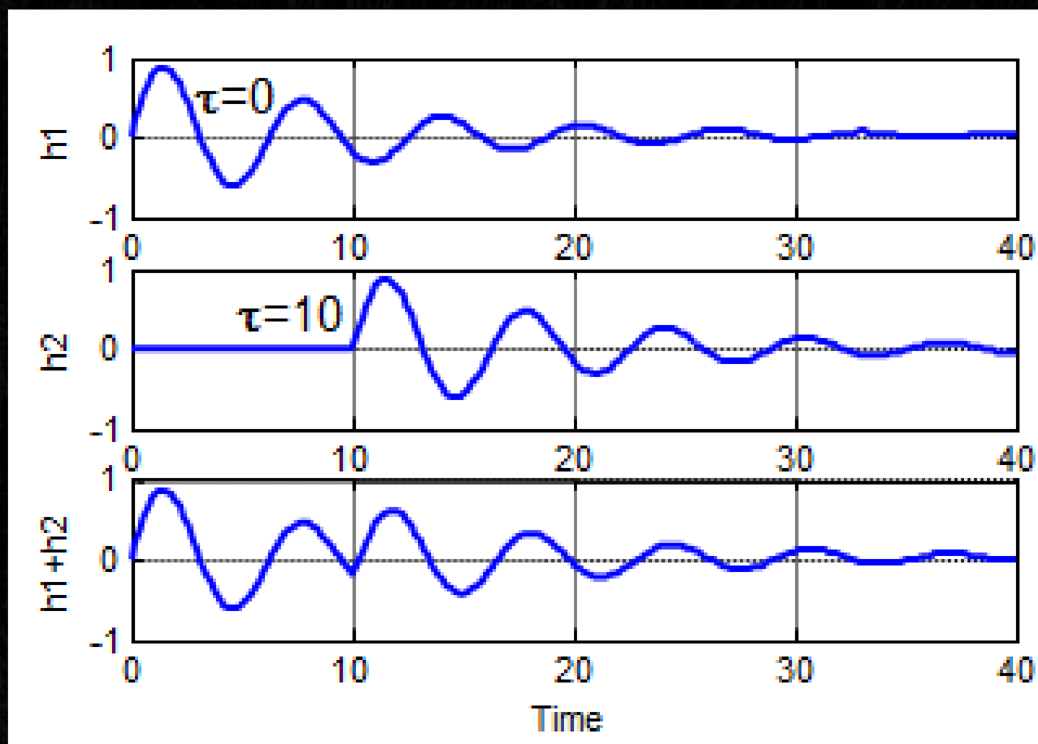
Why do we care: LTI Systems → Superposition





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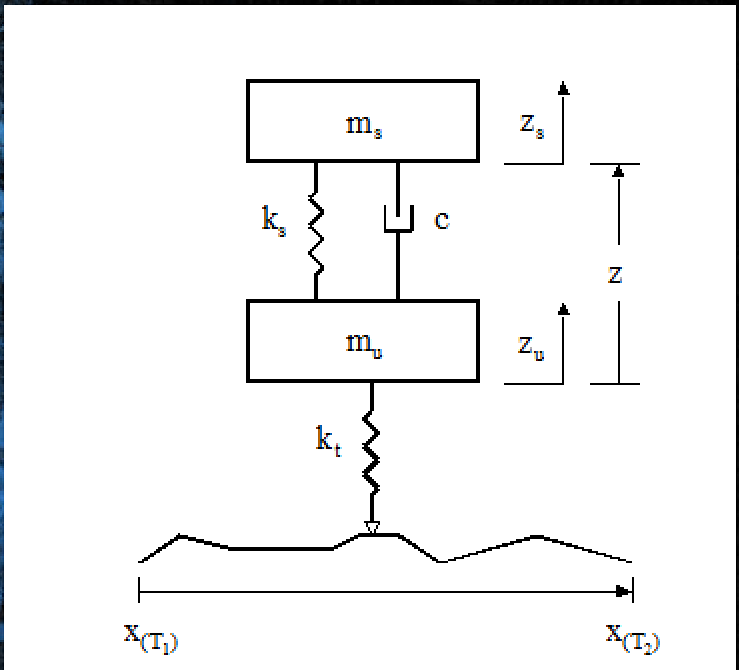
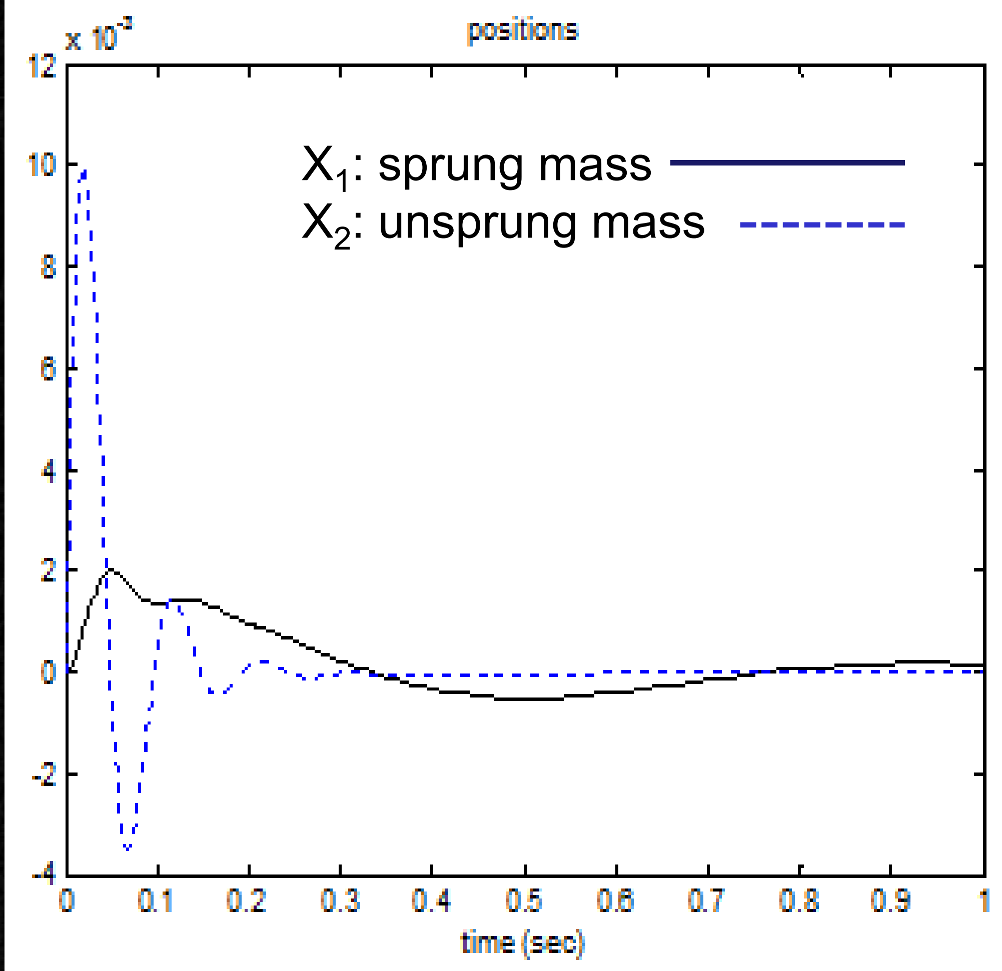
Qcar is LTI

Linear Time Invariant (LTI)

→ Completely defined by ***Impulse Response***





Qcar is LTI

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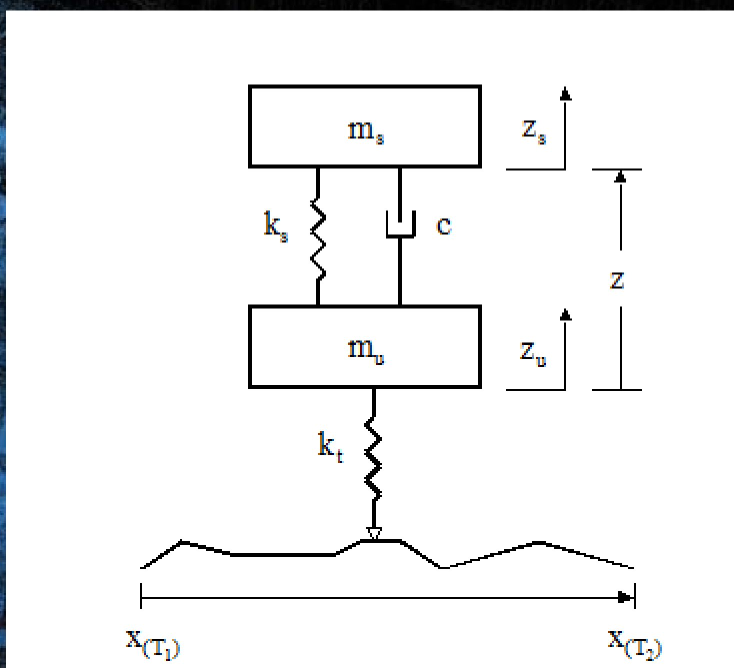
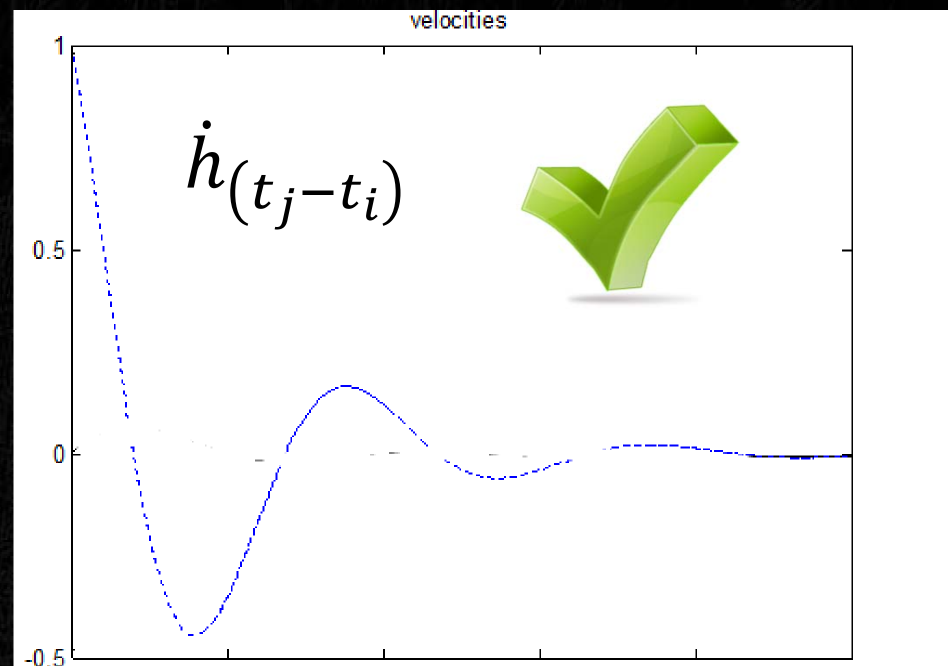
$\dot{z}$: suspension velocity

$\dot{h}$: Impulse Response for suspension velocity
a function of the Qcar parameters





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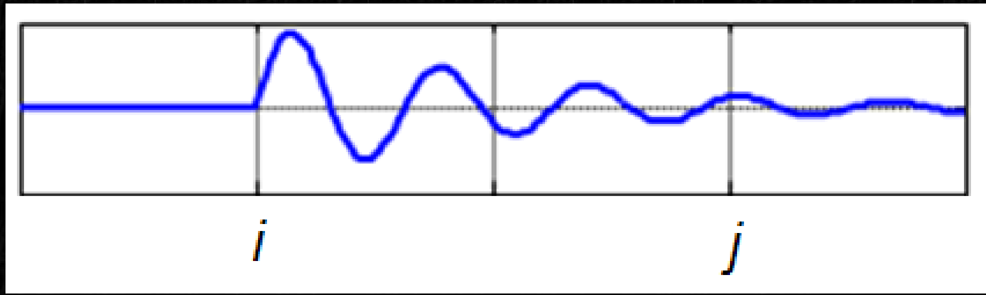
Contribution of Input to Response

f

f_{ij} : fraction of response at *j* due to excitation at *i*



Properties of f_{ij}

$$f_{ij} \geq 0 \ \forall i, j, and \, f_{ij} = 0 \ \forall \mathrm{i} > \mathrm{j}$$

$$\sum_{i=1}^{N} f_{ij} = 1$$

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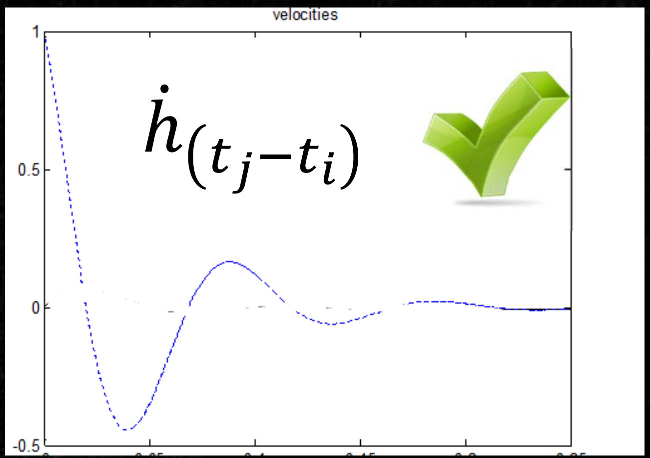
Contribution of Input to Response

Skipping some math… define f_{ij} as

$$f_{ij} = \frac{\left|(t_j - t_i)\dot{h}_{(t_j - t_i)} z_i\right|}{\sum_{i=1}^{j} \left|(t_j - t_i)\dot{h}_{(t_j - t_i)} z_i\right|}$$

Which is just a function of the impulse response, the road heights, and the times



Golden Qcar is LTI

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So… what's the problem??

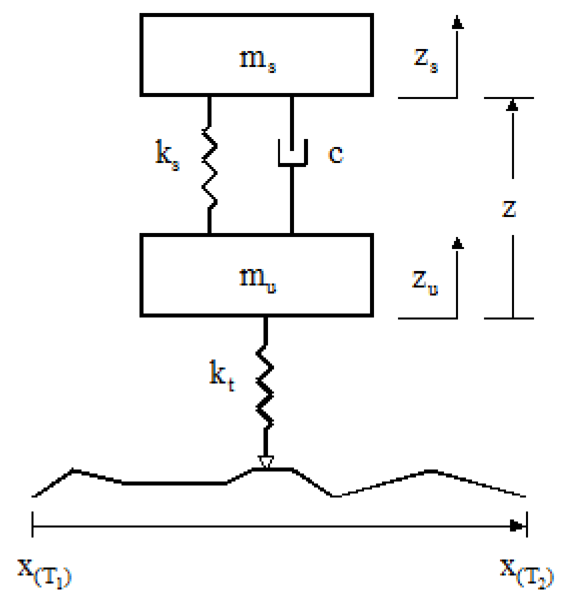
- IRI is *nonlinear* (abs values)
- We can rewrite IRI for sampled data as

$$\mathrm{IRI} = \frac{\int_{T_1}^{T_2} \left|\dot{z}_{(t)}\right| dt}{x_{(T_2)} - x_{(T_1)}}$$

$$\mathrm{IRI} = \frac{1}{L}\sum_{j=1}^{N} \left|\Delta z_j\right|$$

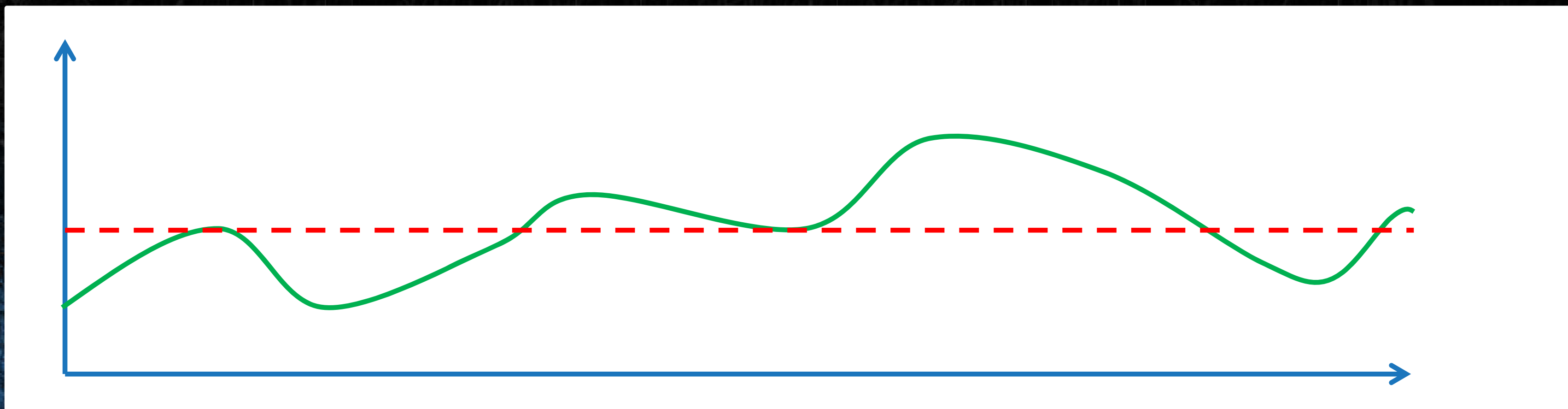
$$\left|\Delta z_j\right| = \left|z_j - z_{j-1}\right|$$

$$L = x_{(T_2)} - x_{(T_1)}$$



Desired Properties of IRI_i

Average IRI_i = IRI



$$\mathrm{IRI} = \frac{1}{\mathrm{L}}\sum_{\mathrm{j}=1}^{\mathrm{N}} IRI_i$$

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Definition of IRI_i

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Substitute

$$\sum_{i=1}^{N} f_{ij} = 1$$

into

$$\mathrm{IRI} = \frac{1}{\mathrm{L}} \sum_{\mathrm{j}=1}^{\mathrm{N}} |\Delta \mathrm{z_j}|$$

Gives

$$\mathrm{IRI} = \frac{1}{\mathrm{L}} \sum_{\mathrm{j}=1}^{\mathrm{N}} \left(\sum_{i=1}^{N} f_{ij} \right) |\Delta \mathrm{z_j}|$$

$$\mathrm{L} = \sum_{\mathrm{j}=1}^{\mathrm{N}} \Delta x$$

Define

$$IRI_i = \frac{1}{\Delta x} \sum_{\mathrm{j}=1}^{\mathrm{N}} f_{ij} |\Delta \mathrm{z_j}|$$

Validate Properties of IRI_i

Define

$$IRI_i = \frac{1}{\Delta x}\sum_{j=1}^{N} f_{ij}\left|\Delta z_j\right|$$

Okay…is this valid?

Average IRI_i = IRI??

$$\frac{1}{N}\sum_{i=1}^{N} IRI_i = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{\Delta x}\sum_{j=1}^{N} f_{ij}\left|\Delta z_j\right|\right)$$

$$= \frac{1}{N\Delta x}\sum_{j=1}^{N}\left|\Delta z_j\right|\left(\sum_{i=1}^{N} f_{ij}\right)$$

=L

=1

$$Average\ IRI_i = \frac{1}{L}\sum_{j=1}^{N}\left|\Delta z_j\right| = IRI$$

Comments and Discussion

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Definition of Instantaneous IRI, IRI_i

$$IRI_i = \frac{1}{\Delta x} \sum_{j=1}^{N} f_{ij} \left| \Delta z_j \right|$$

Can have varying speeds and is purely a function of the Qcar parameters, the measurement times and the road heights!

Thank you! Questions??