Extracting Weigh-in-Motion Data from Bridge Response Using Search Based Optimization Algorithms

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Outline

- Background for Application
- Search based algorithms
- Proposed method
- Parametric Studies
- Conclusions

Salmon River Bridge Corrosion-free Deck

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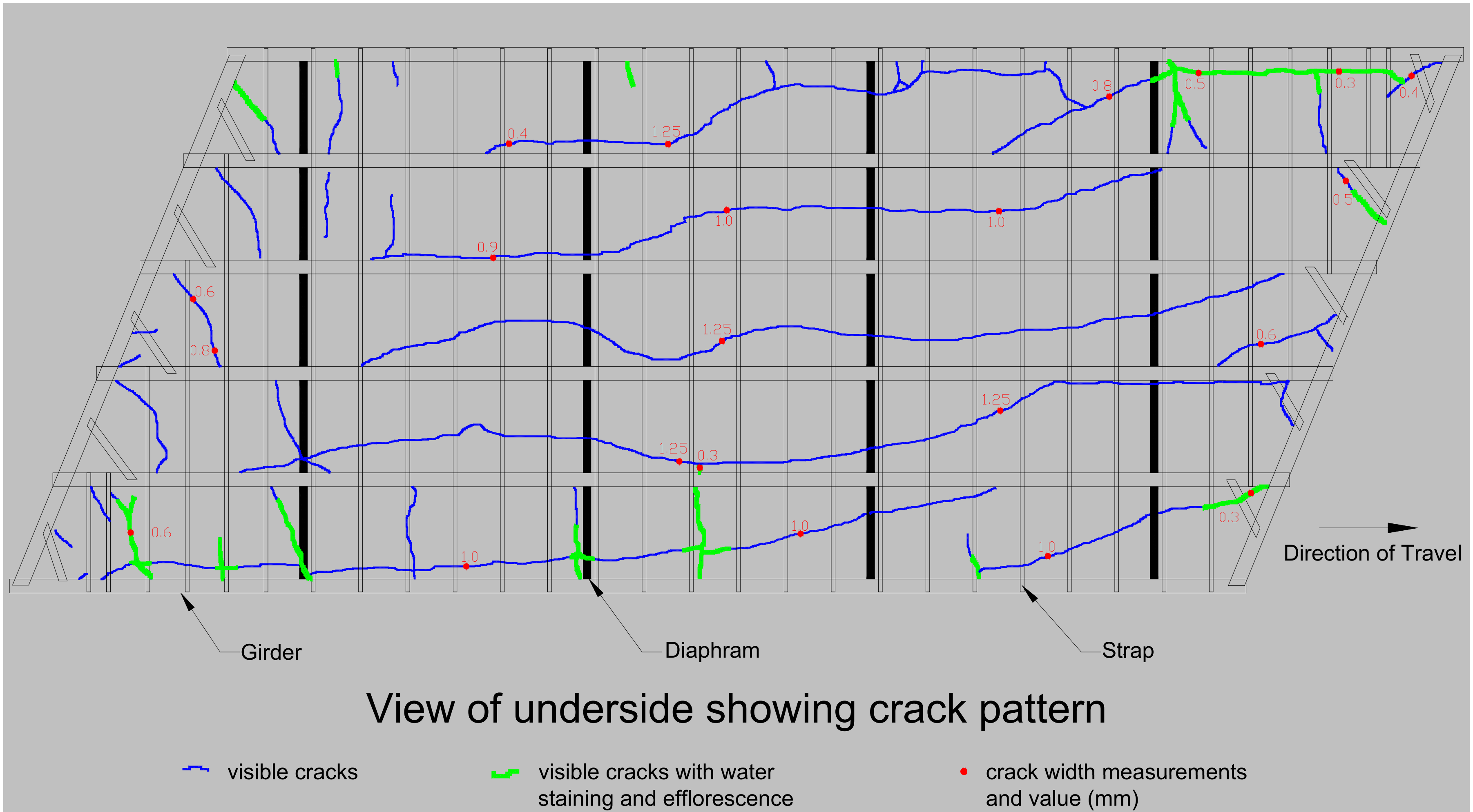
Deck Cracking



View of underside showing crack pattern

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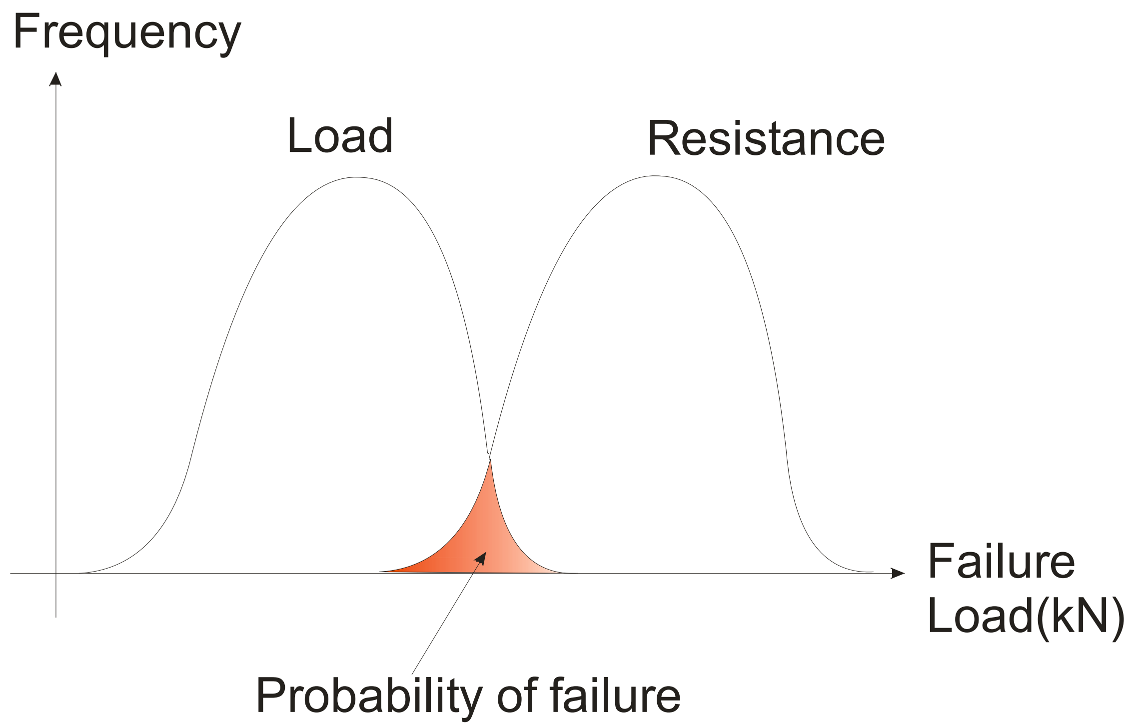
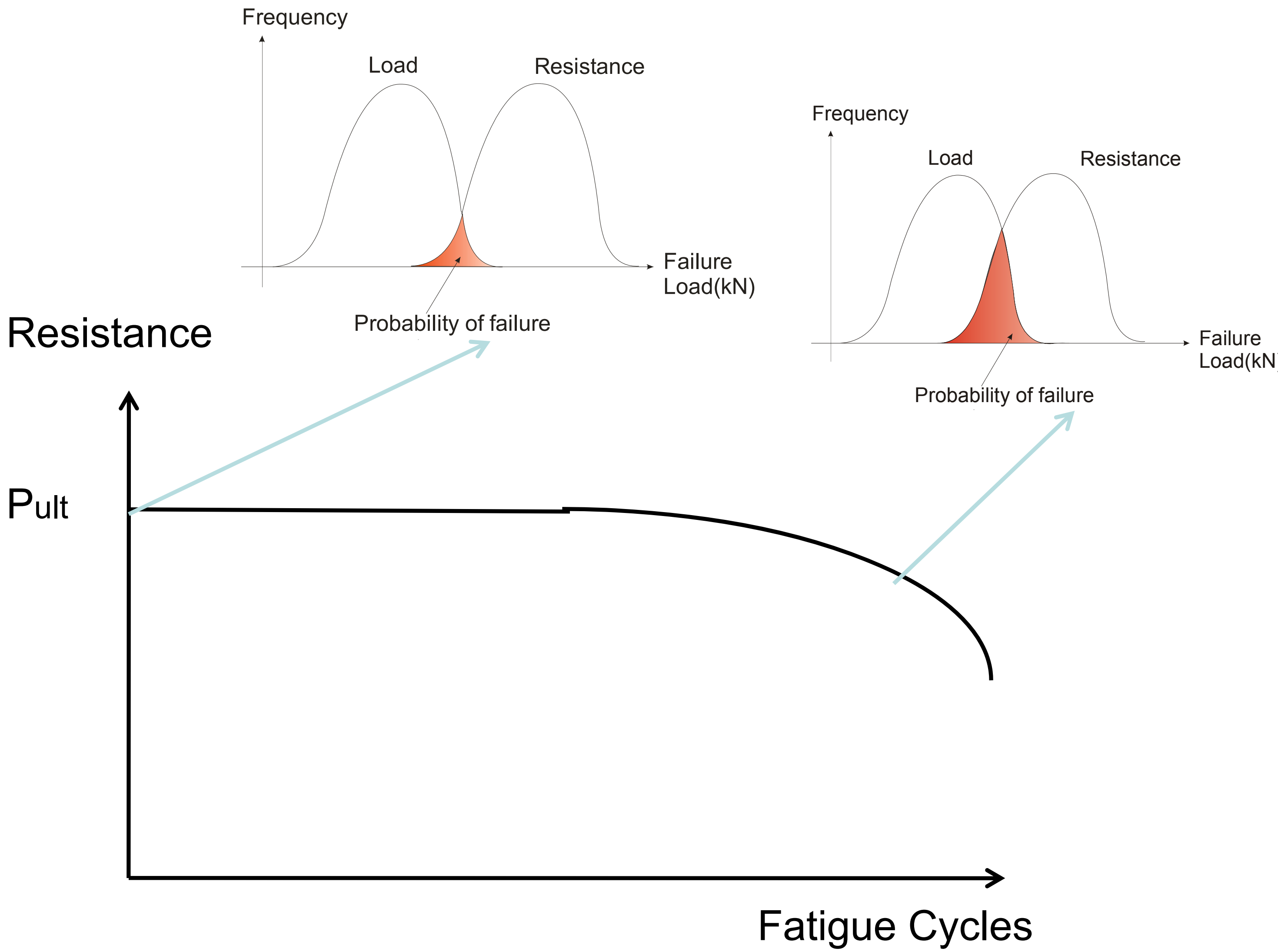
Reliability Analysis

Failure probability(t)=Probability(Resistance(t)-Loading(t)<0)



Strength Reduction with Cumulative Damage



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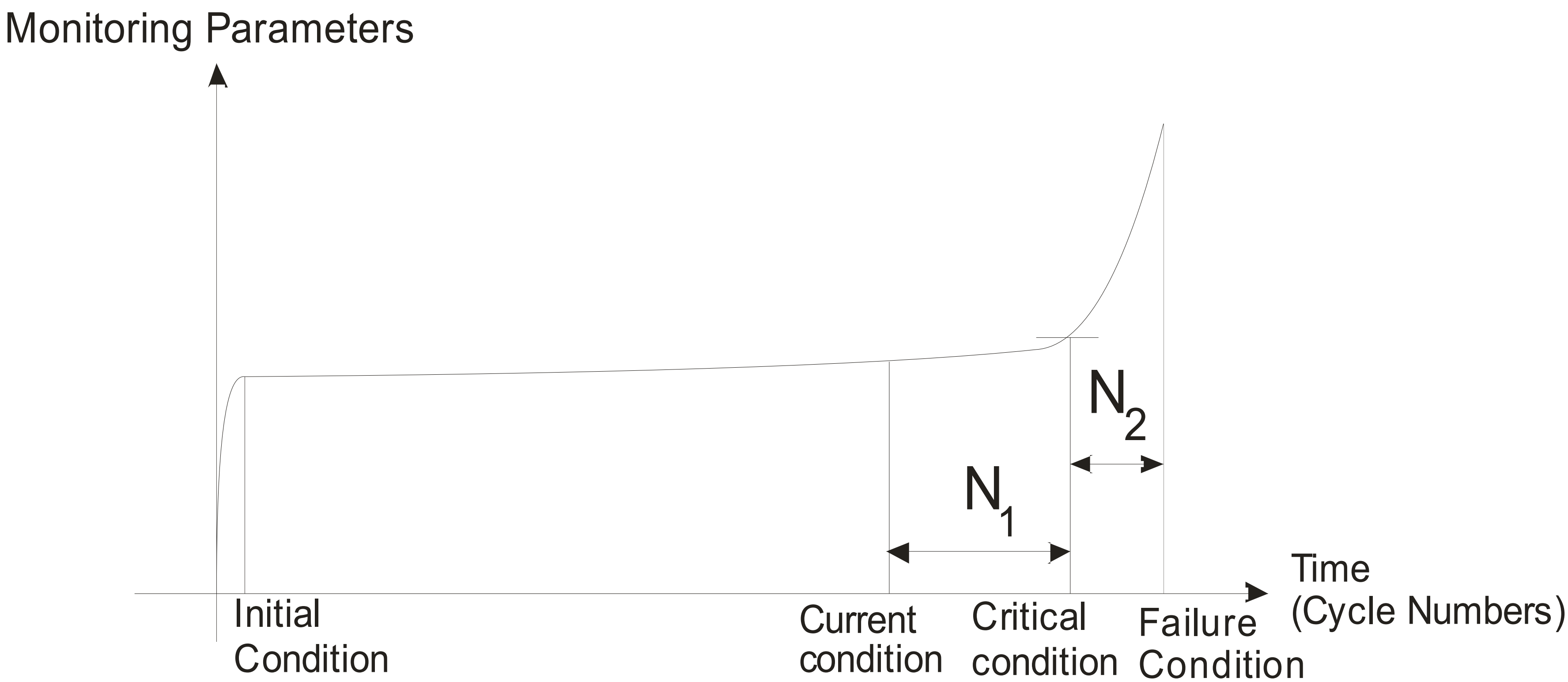
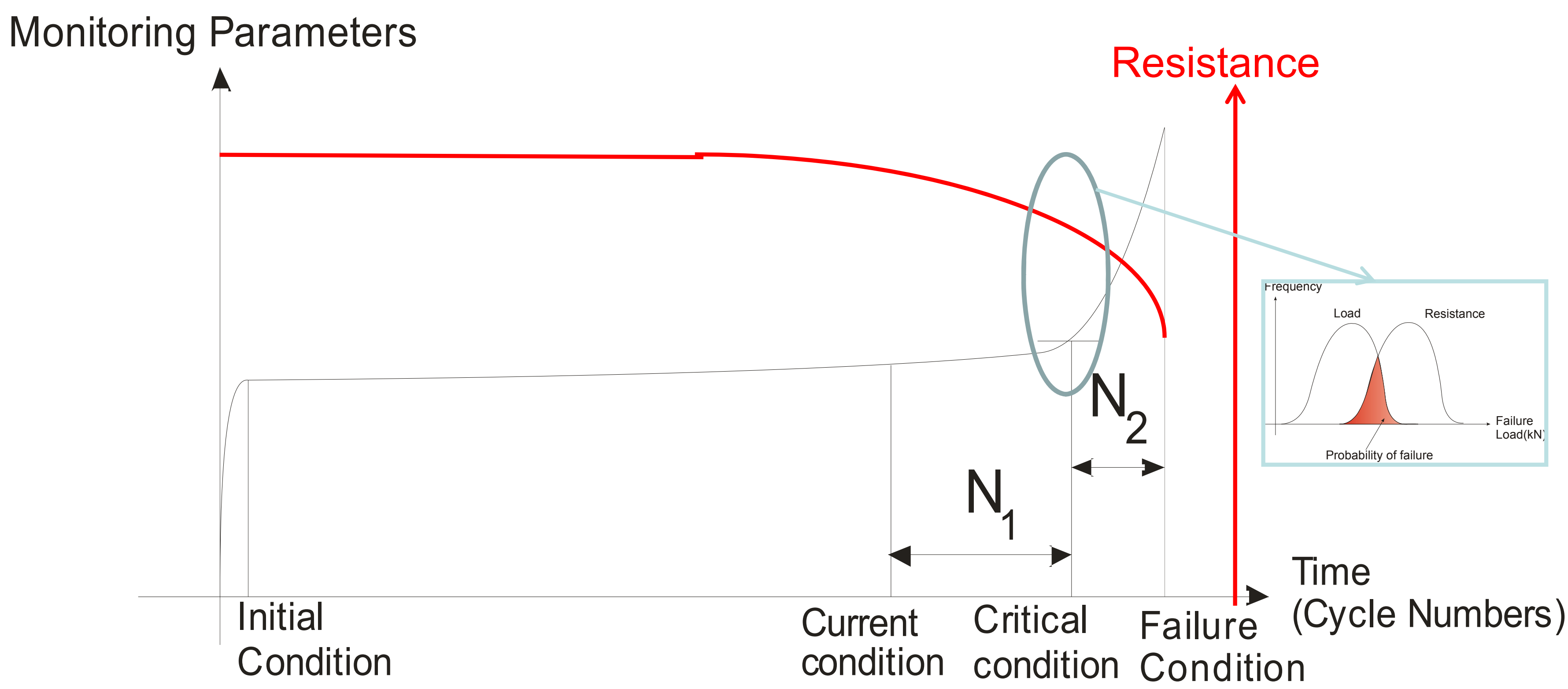
Monitoring Parameters Variation



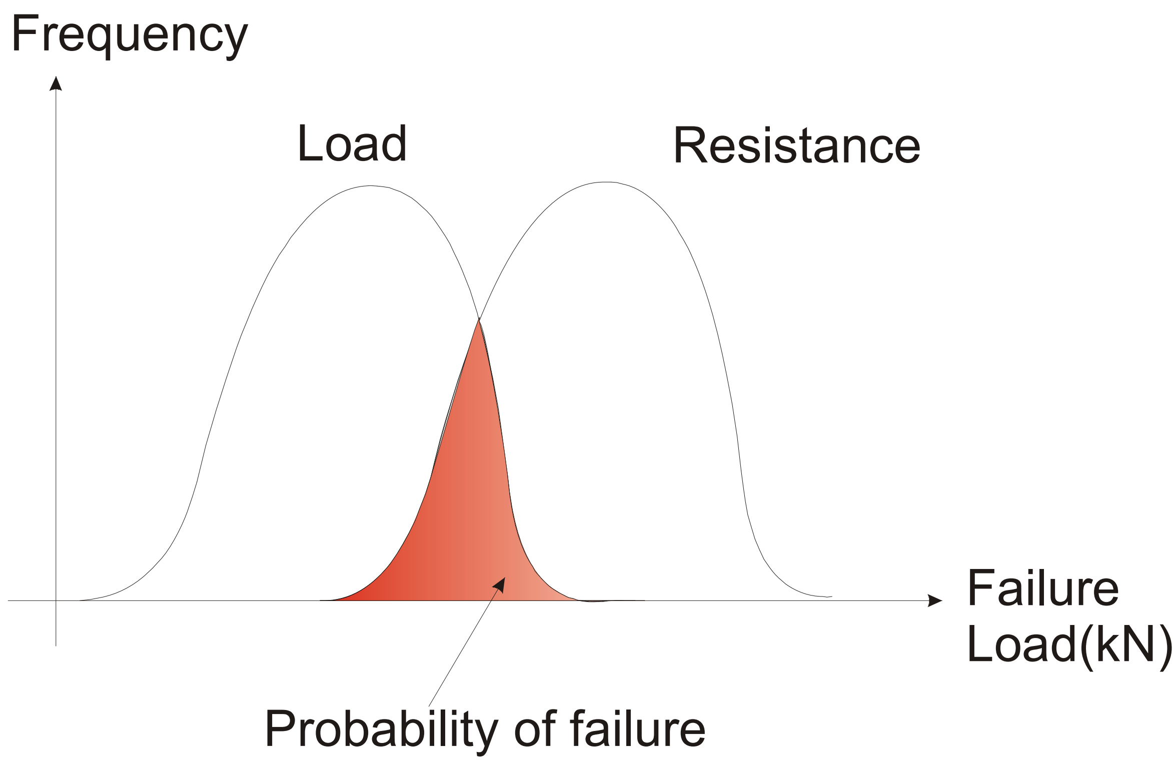
Monitoring Parameters like Crack width, Deck deflection, Strap starin

Monitoring Parameters Variation

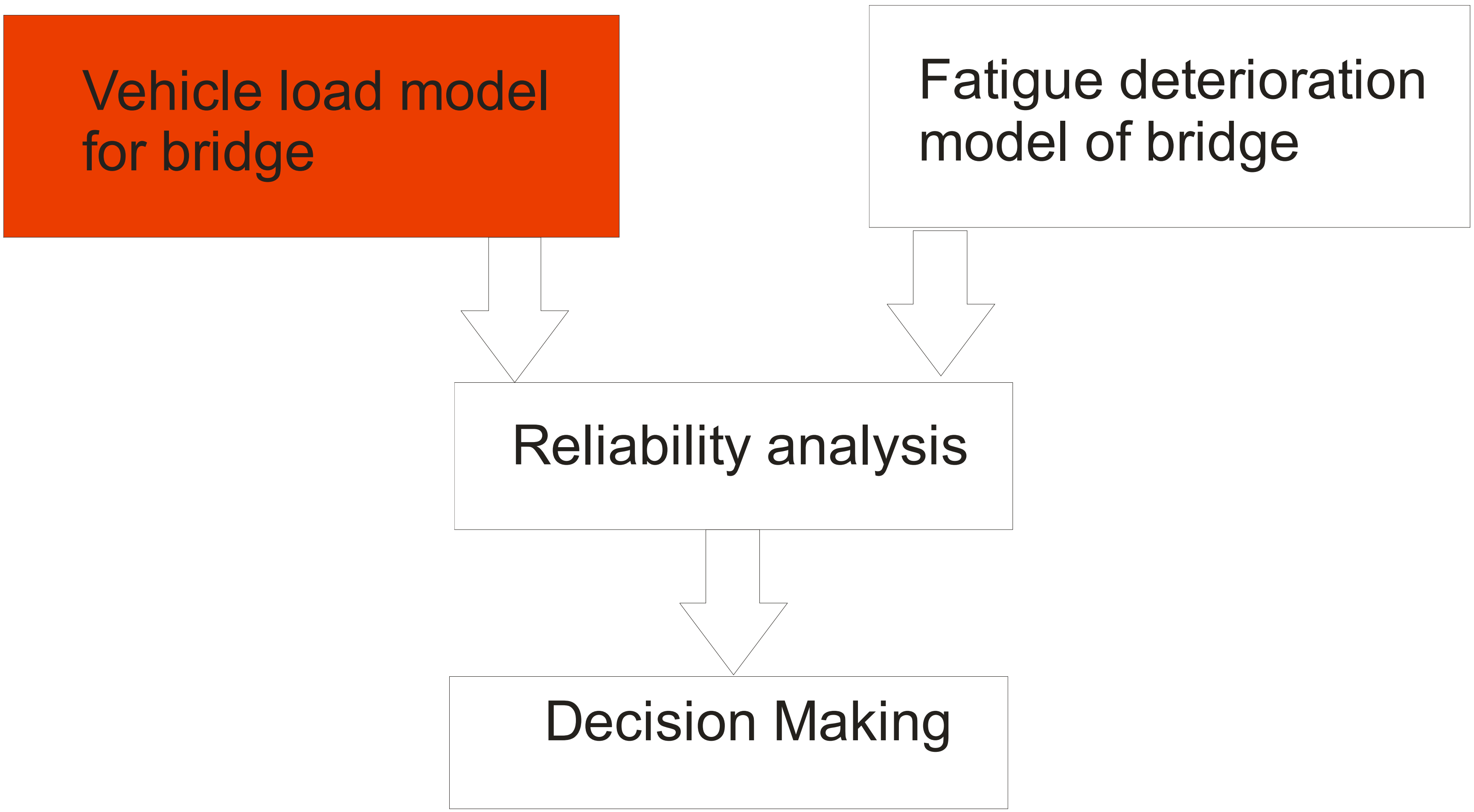


Combine Cumulative Fatigue Damage with Structural Safety

Reliability Analysis



Overall Bridge assessment process



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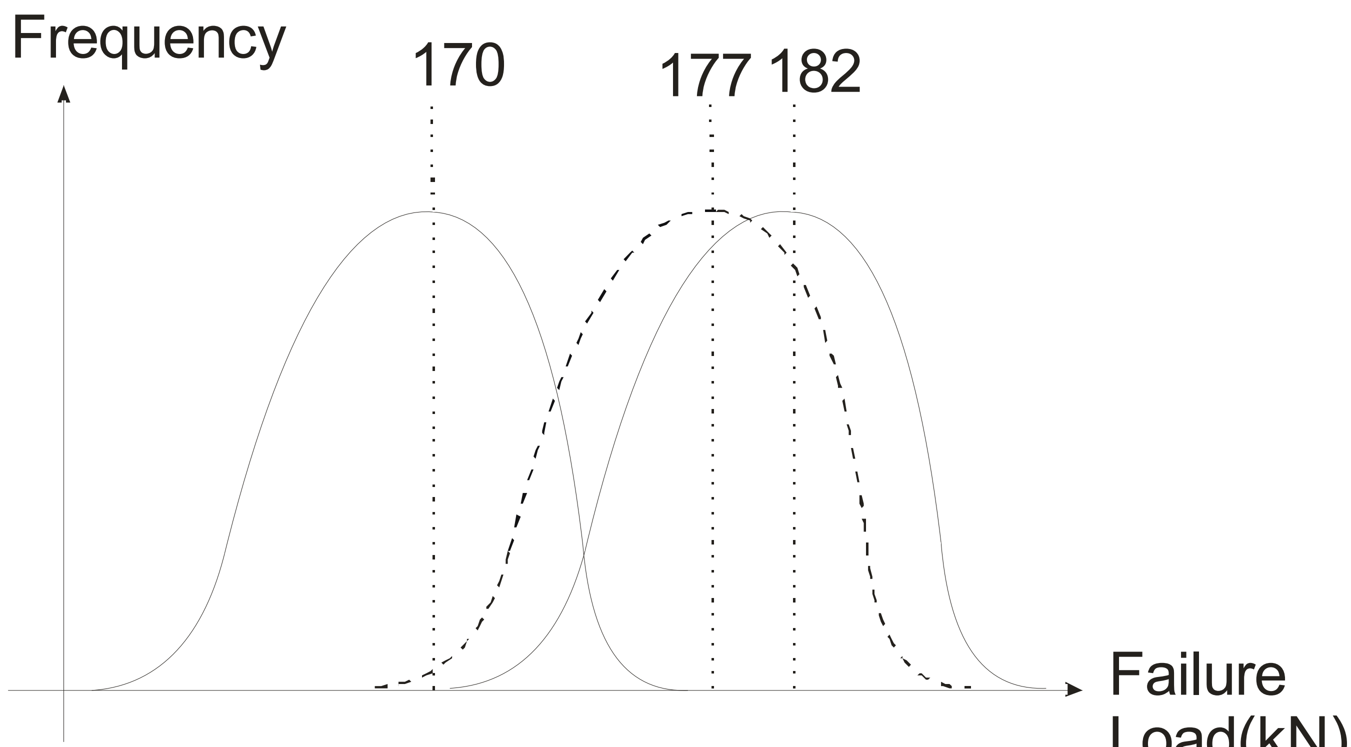
Statistical Characteristics of Static Punching Load (kN)

	Average	Standard Deviation	Covariance
Interior spans	182	17.4	9.1%
Exterior spans	170	15.5	9.5%
All Tests	177	17.4	9.8%



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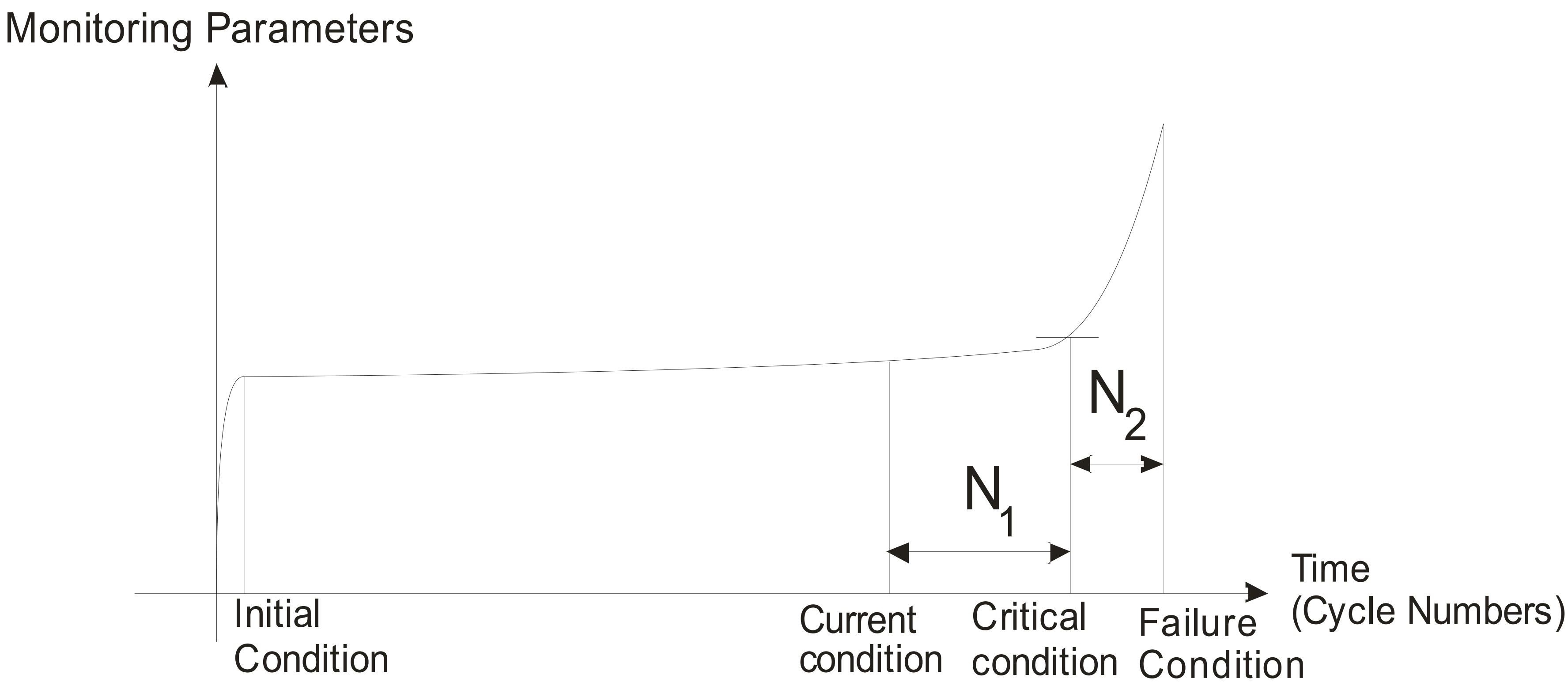
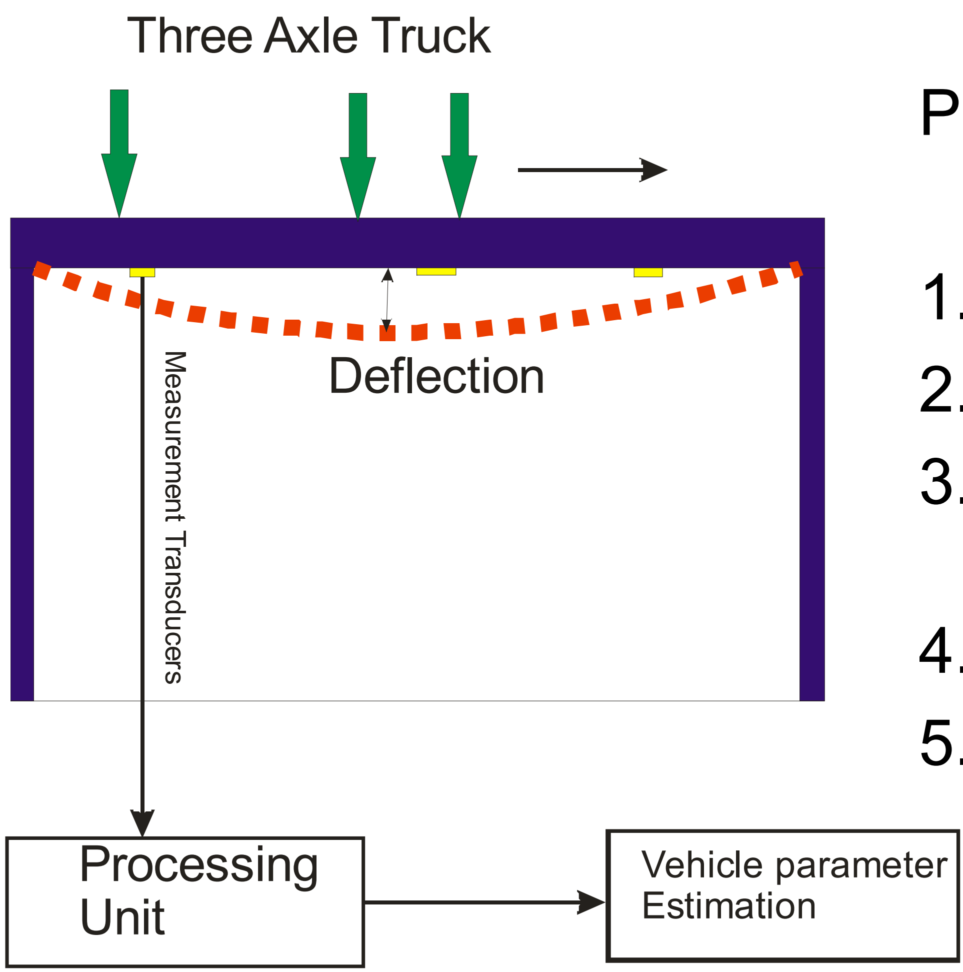
Characteristic Fatigue Behaviour



Monitoring Parameters like Crack width, Deck deflection, Strap starin

Components of Weigh in Motion



Parameters to be identified:

1. Speed of vehicle
2. Spacing of axles
3. Transverse location on the bridge
4. Weight of axles
5. Gross weight of vehicle

Key Sources for Previous WIM

- Weigh-in-Motion of Axles and Vehicles for Europe (WAVE)

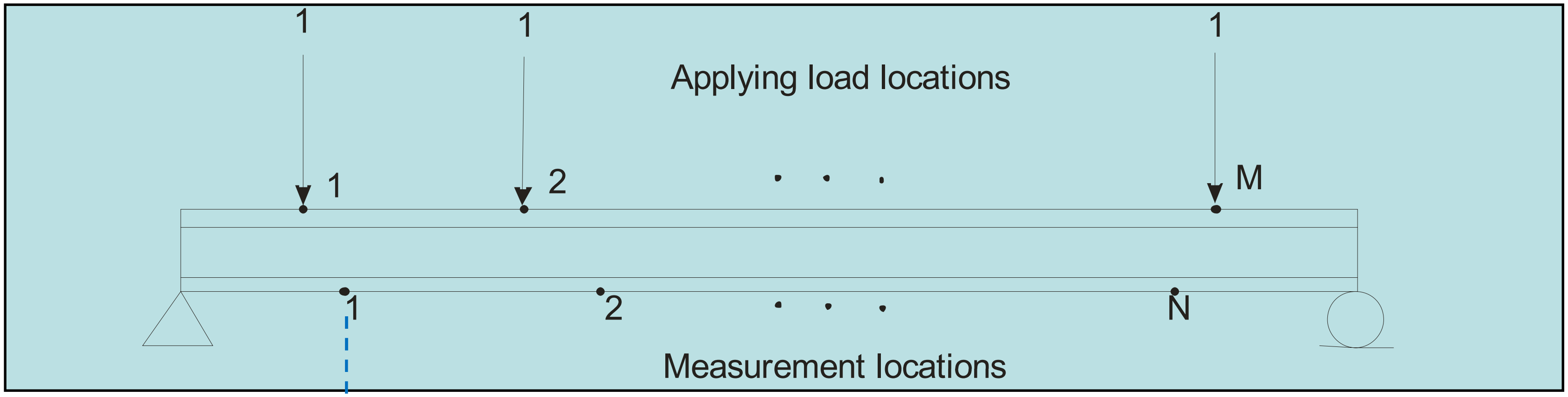
- Free of Axle Detector Method (FAD)

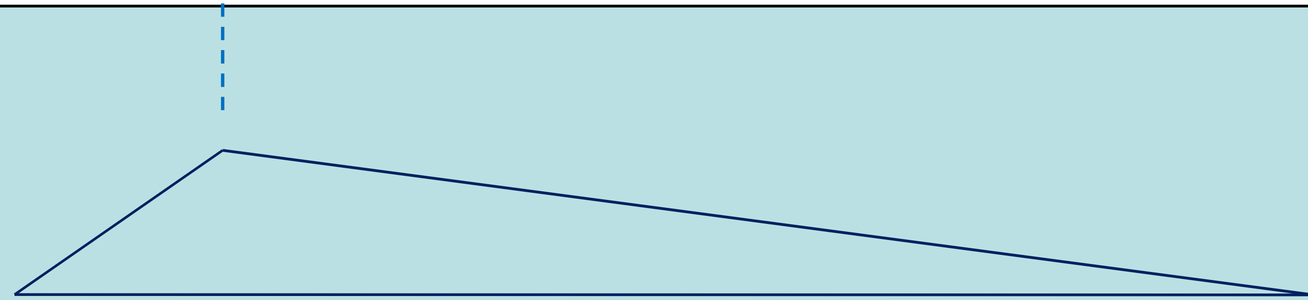
- E. O'Brien, B. Jacob, A. Znidaric, A. Gonzalez

The overview of proposed algorithm

- Constructing experimental influence ~~line~~ Matrix for the bridge
- Initial estimation of speed and axles spacing by Free of Axle Detector Method (FAD)
- Adjusting the position of axles and speed and determining the axle weight by optimizing the objective function using search based optimization method axle by axle

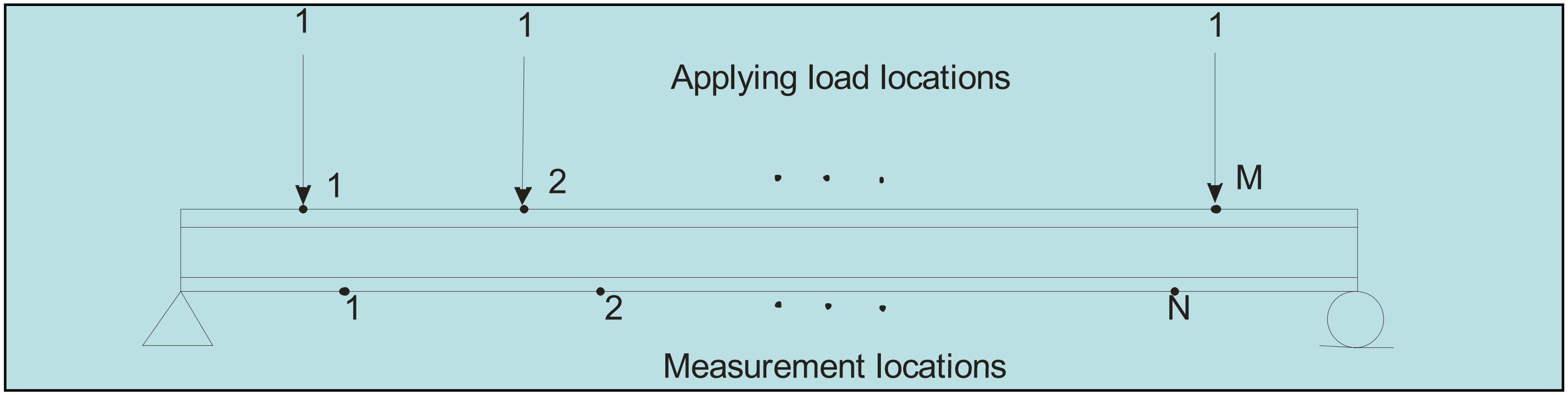
Influence line matrix construction





Influence line for point 1

Influence line matrix construction



$$Influence \quad Matrix = \begin{bmatrix} I_{11} & I_{12} & \cdots & I_{1M} \\ I_{21} & I_{22} & \cdots & I_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ I_{N1} & I_{N2} & \cdots & I_{NM} \end{bmatrix}$$

response at location k from axle load: B_k

axles weights: A_k

$$B_k = \sum_{i=1}^{M} A_i I_{ik}$$

Problem Formulation

Axle loads matrix: A

Bridge response matrix: B

Influence line matrix: I

Estimated response matrix: $\hat{B}$

Estimated loads: $\hat{A}$

Forward problem:

$$[B] = [I] \times [A]$$

$$[\hat{B}] = [I] \times [\hat{A}]$$

Our goal is to:

$$[A] = [I]^{-1} \times [B]$$

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Solution Problems

Considerations

Influence matrix not exact

Response signal has noise

Exact location of loads not known

ACCURACY OF PREDICTED AXLE WEIGHT

Possible Solution

Solution

1. Estimate Load Position (Wu, Mufti, Bakht and Sidhu 2007)

2. Measure all available sensors' response [B]

3. Estimate Load Function [A] Calculate Response $[\hat{B}]$

4. Optimizing the objective function

$$U = \left([B] - \left[\hat{B} \right] \right)^T \times [P] \times \left([B] - \left[\hat{B} \right] \right)$$

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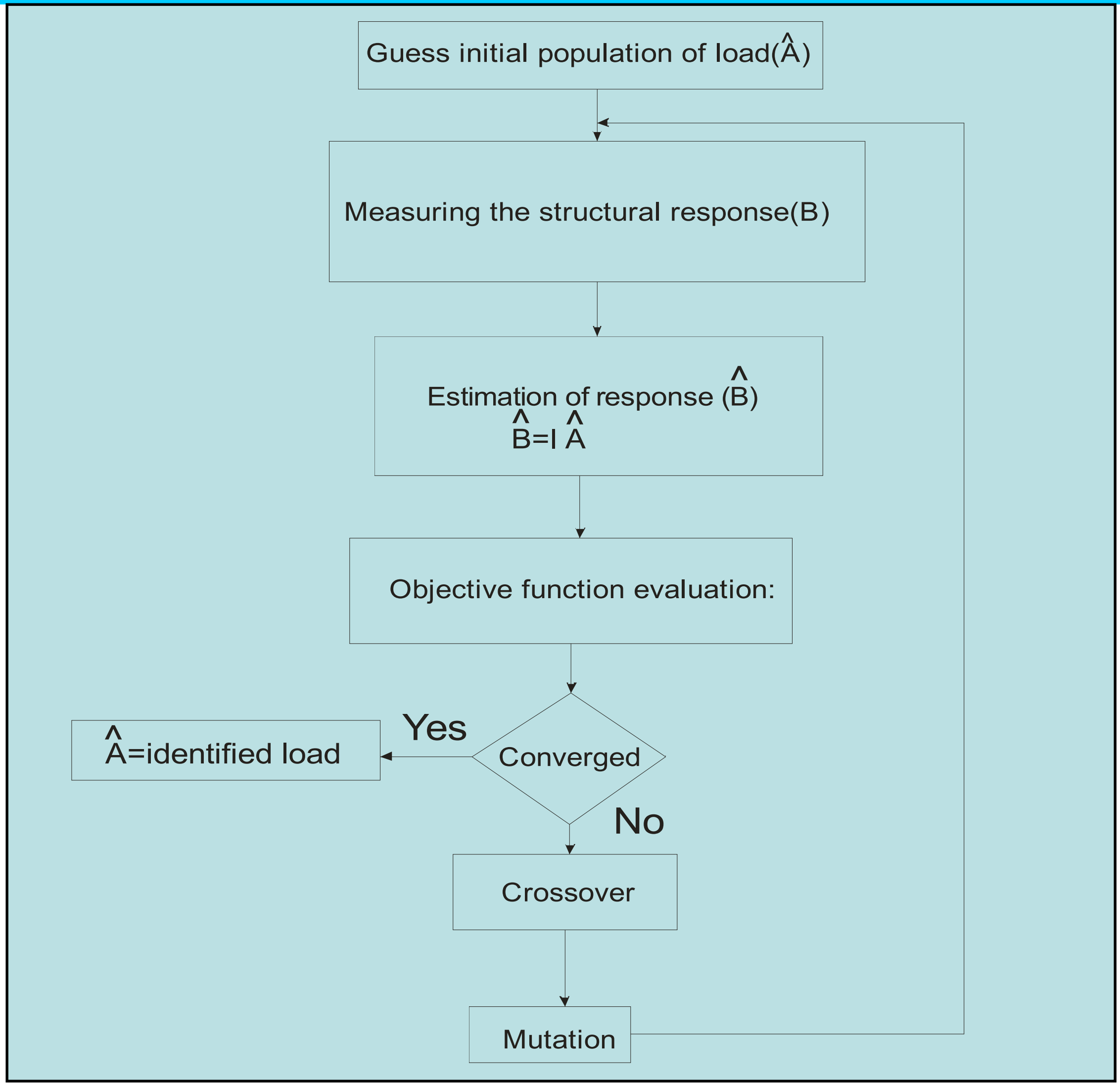
Proposed Algorithm



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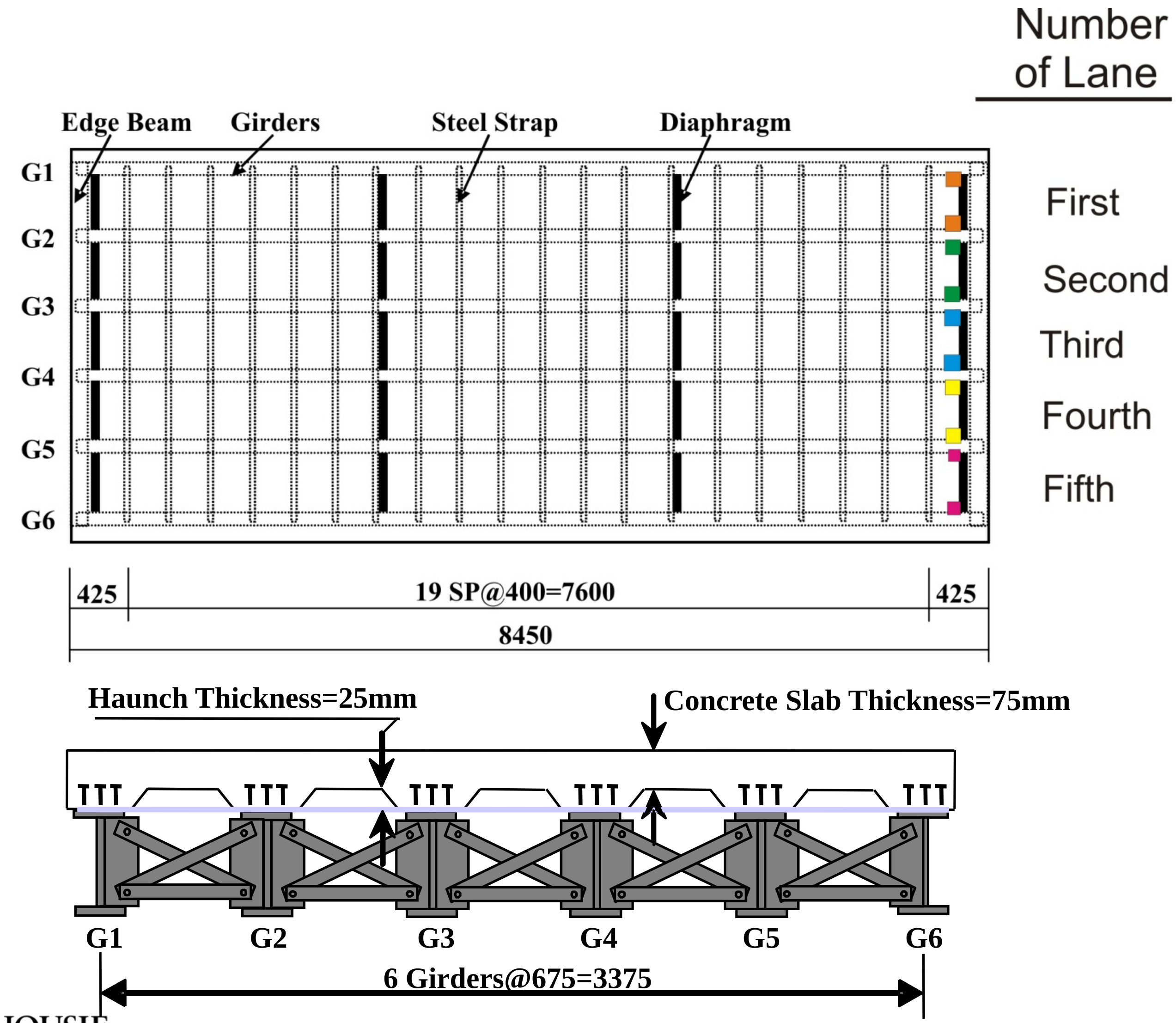
Derivative free optimization methods

1. Pattern Search method

- ✓ -Mesh
- ✓ -Pattern: Example $V_1 = [1 \;\; 0]; V_2 = [0 \;\; 1]; V_3 = [-1 \;\; 0]; V_4 = [0 \;\; -1]$
- ✓ -Mesh size
- ✓ -New set of points
- ✓ -Stopping point

1/3 model of the Salmon River bridge



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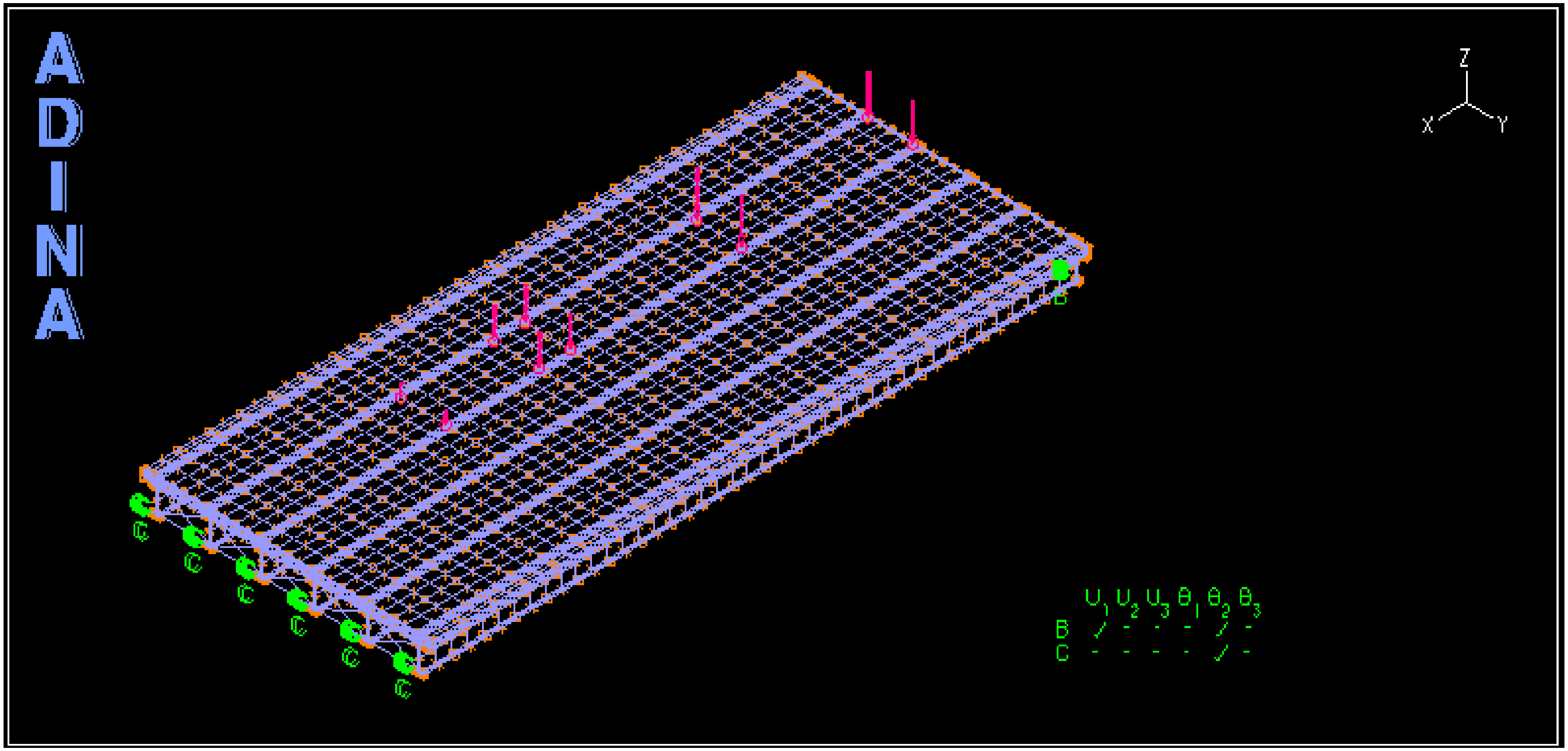
ADINA model of 1/3 model of Salmon River Bridge

- Position of applying load: 120
- Position of recording data: 36



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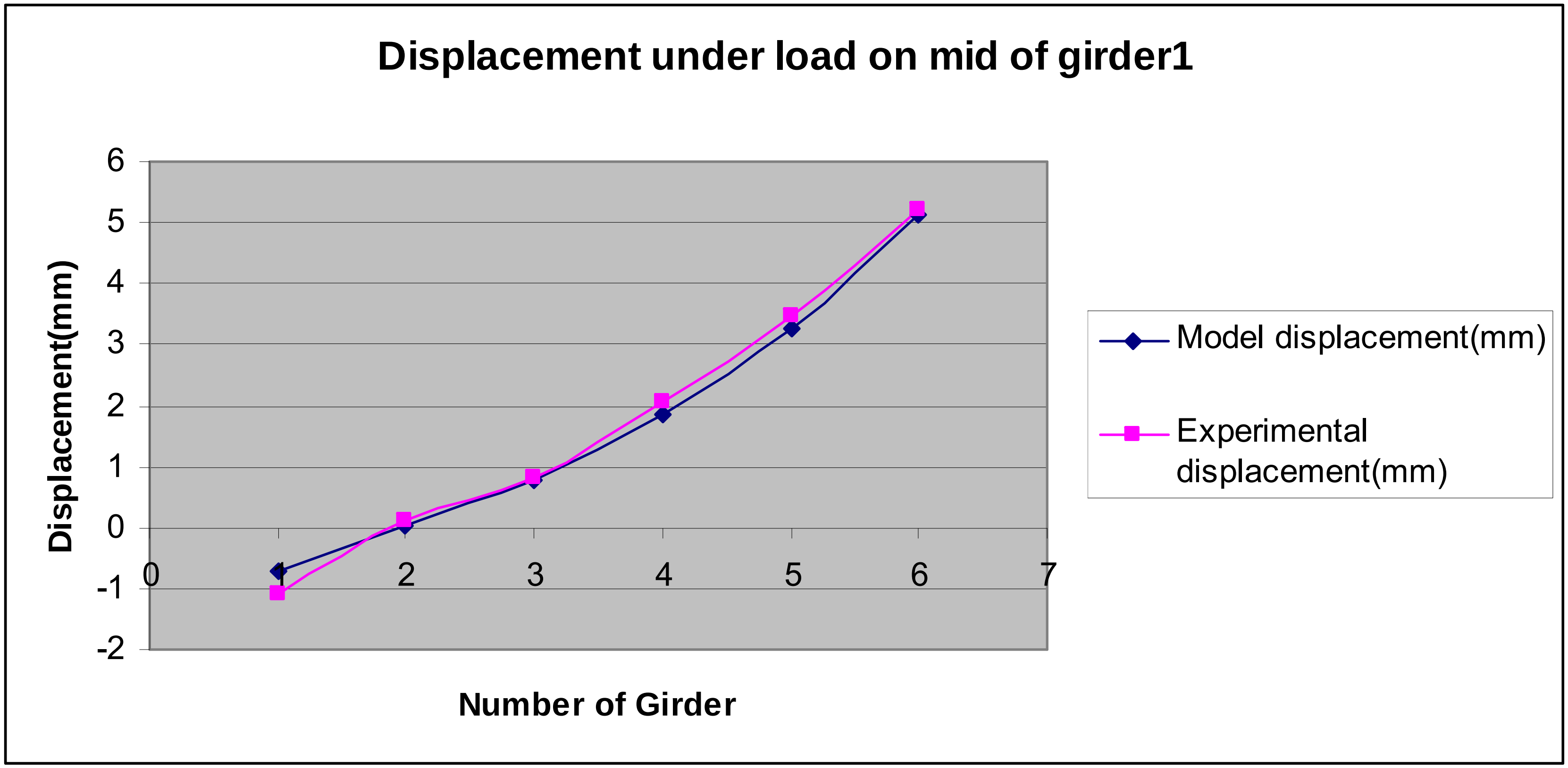
Comparison of actual and modeled response of bridge



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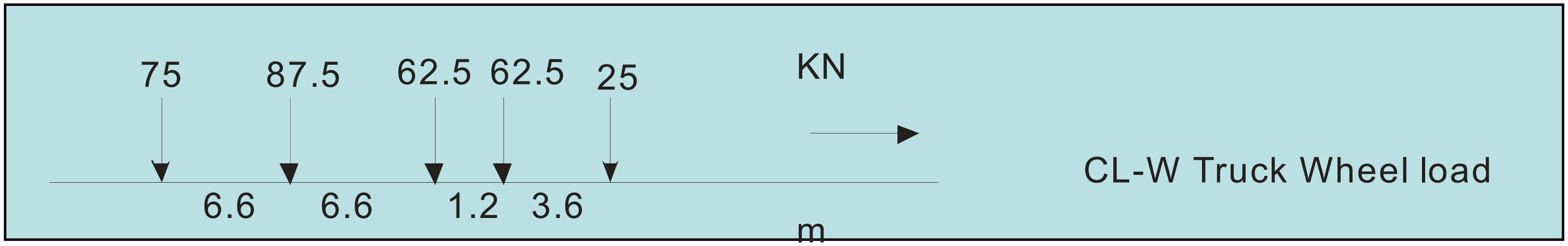
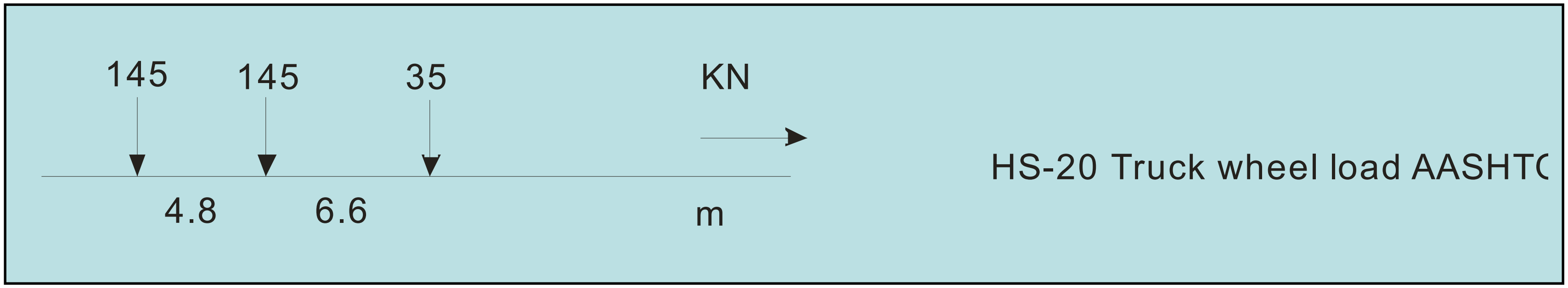
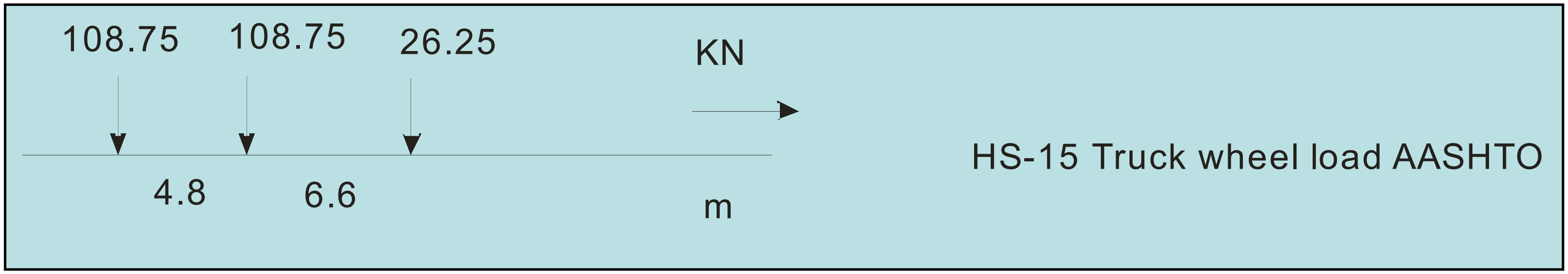
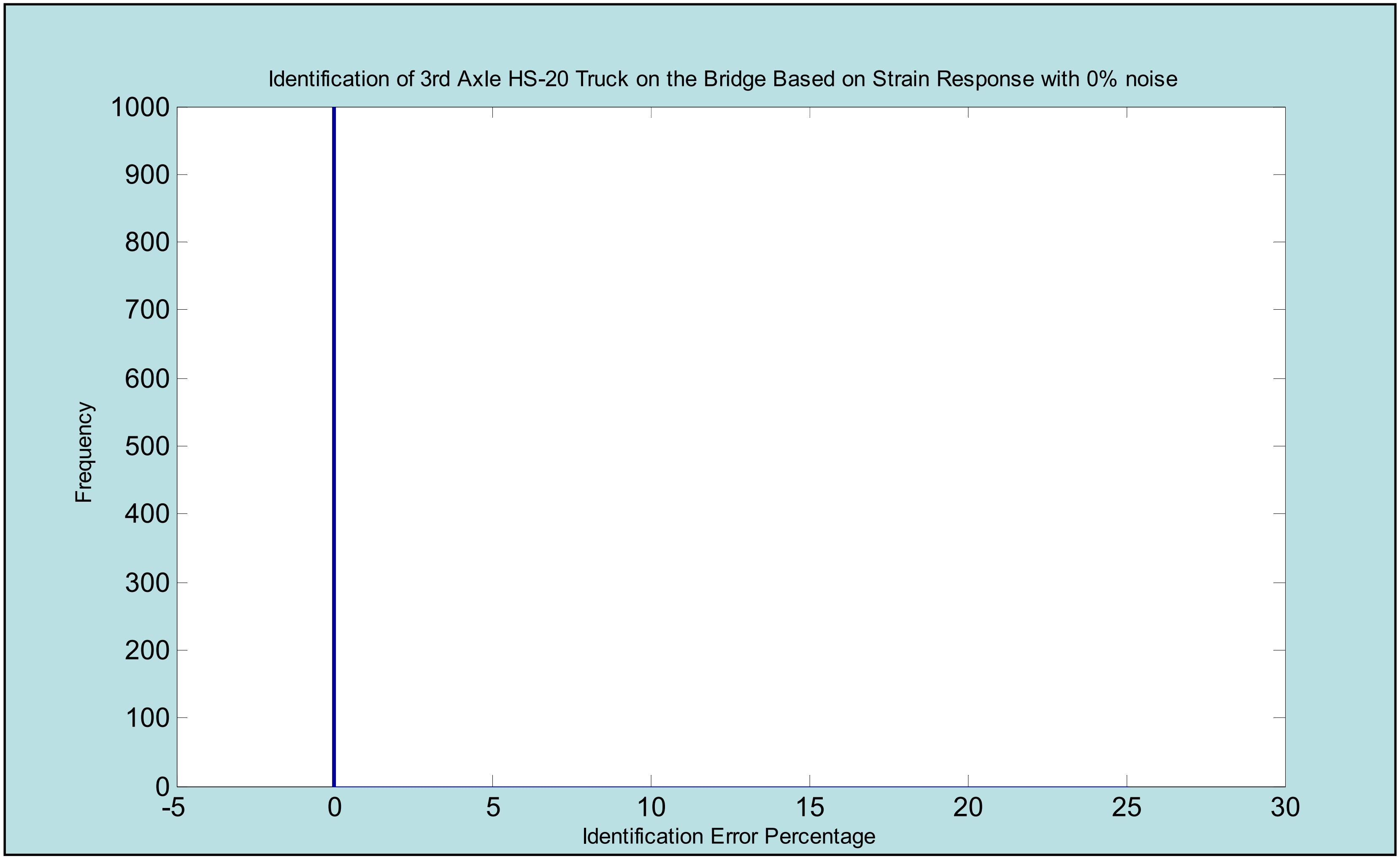
Vehicle models







Histogram of the identified load with recorded data without noise



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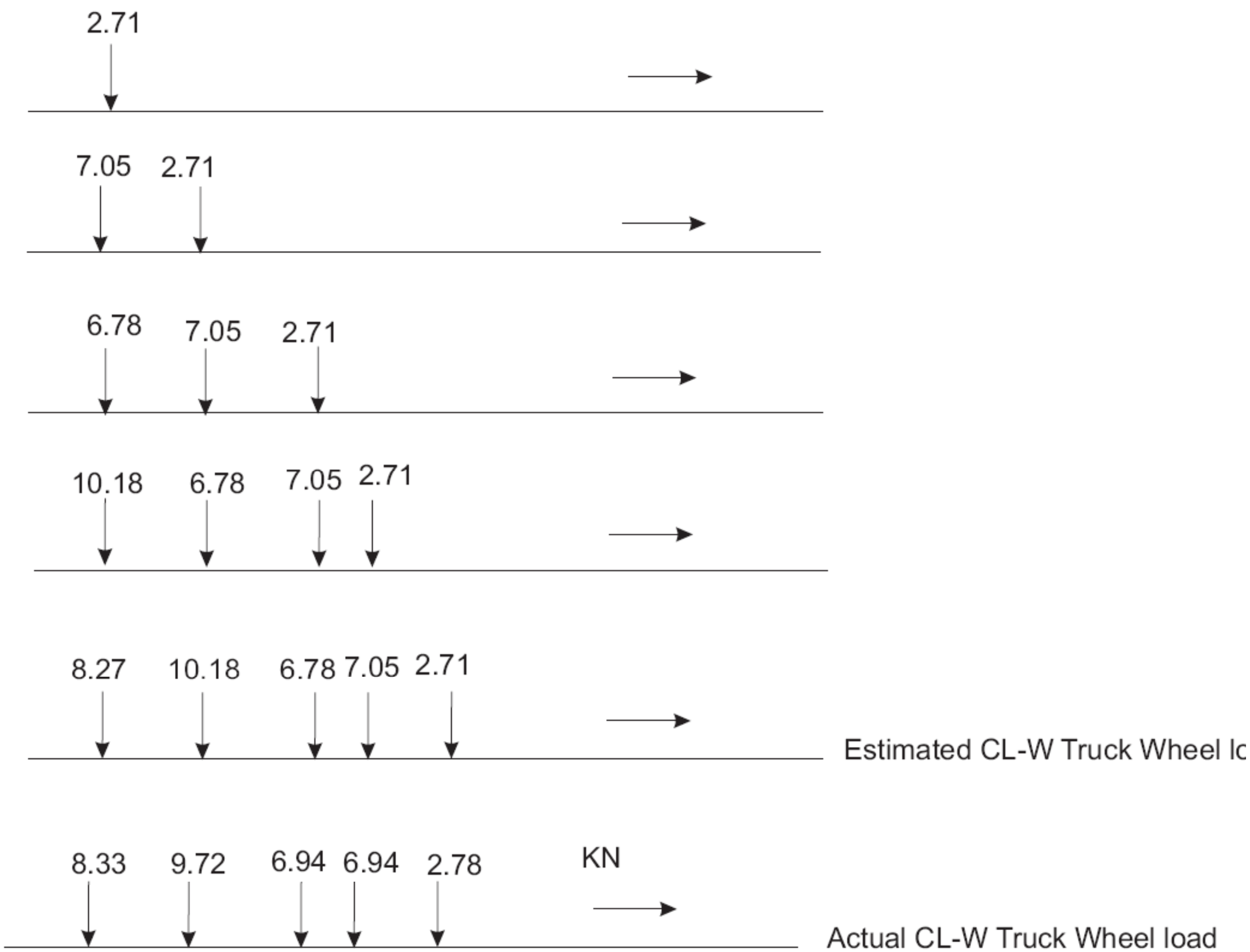
Truck wheel load estimation on the bridge

10% noise, Displacement recording using Pattern Search, Load are in KN



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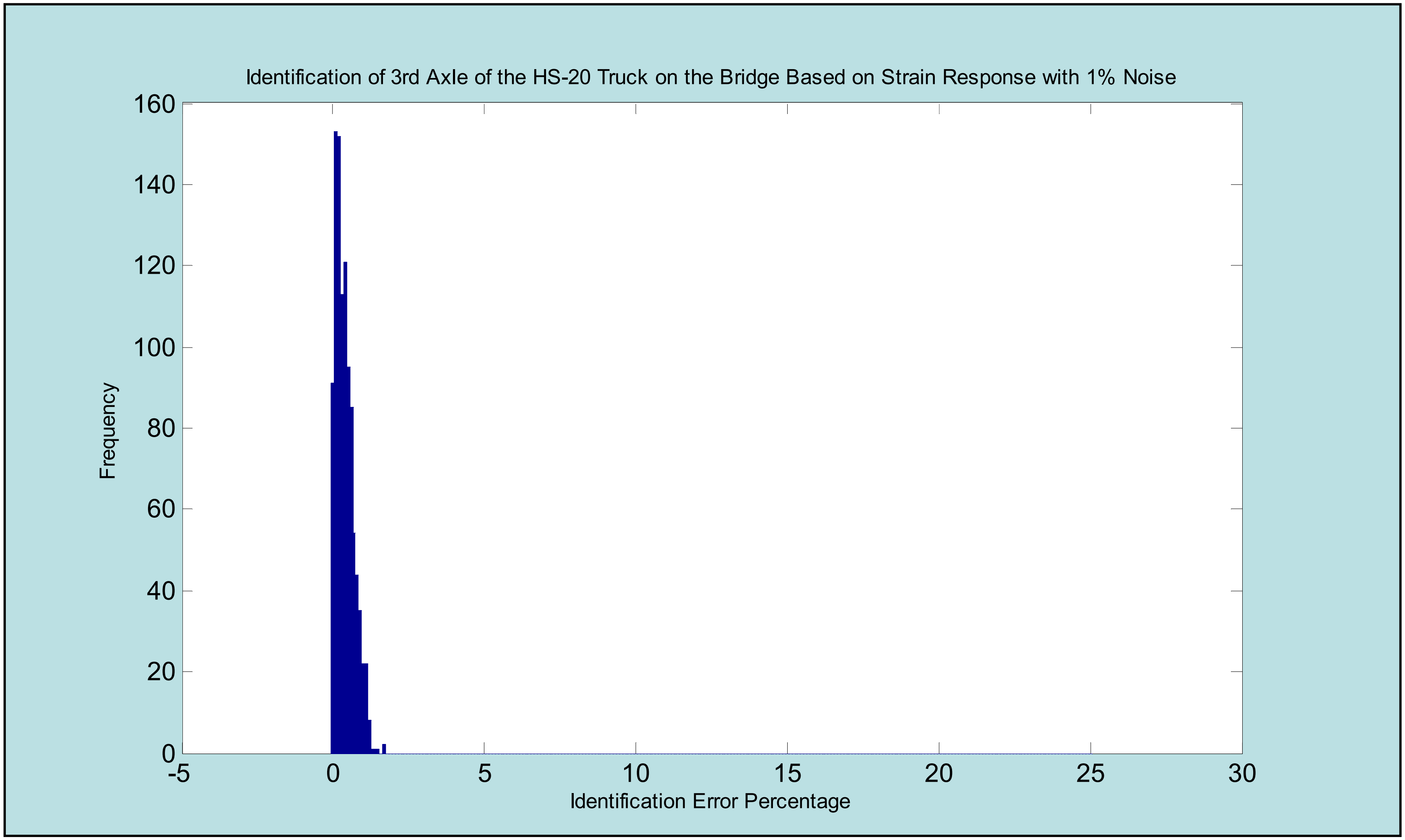
Histogram of the identified load with recorded data with 1% noise



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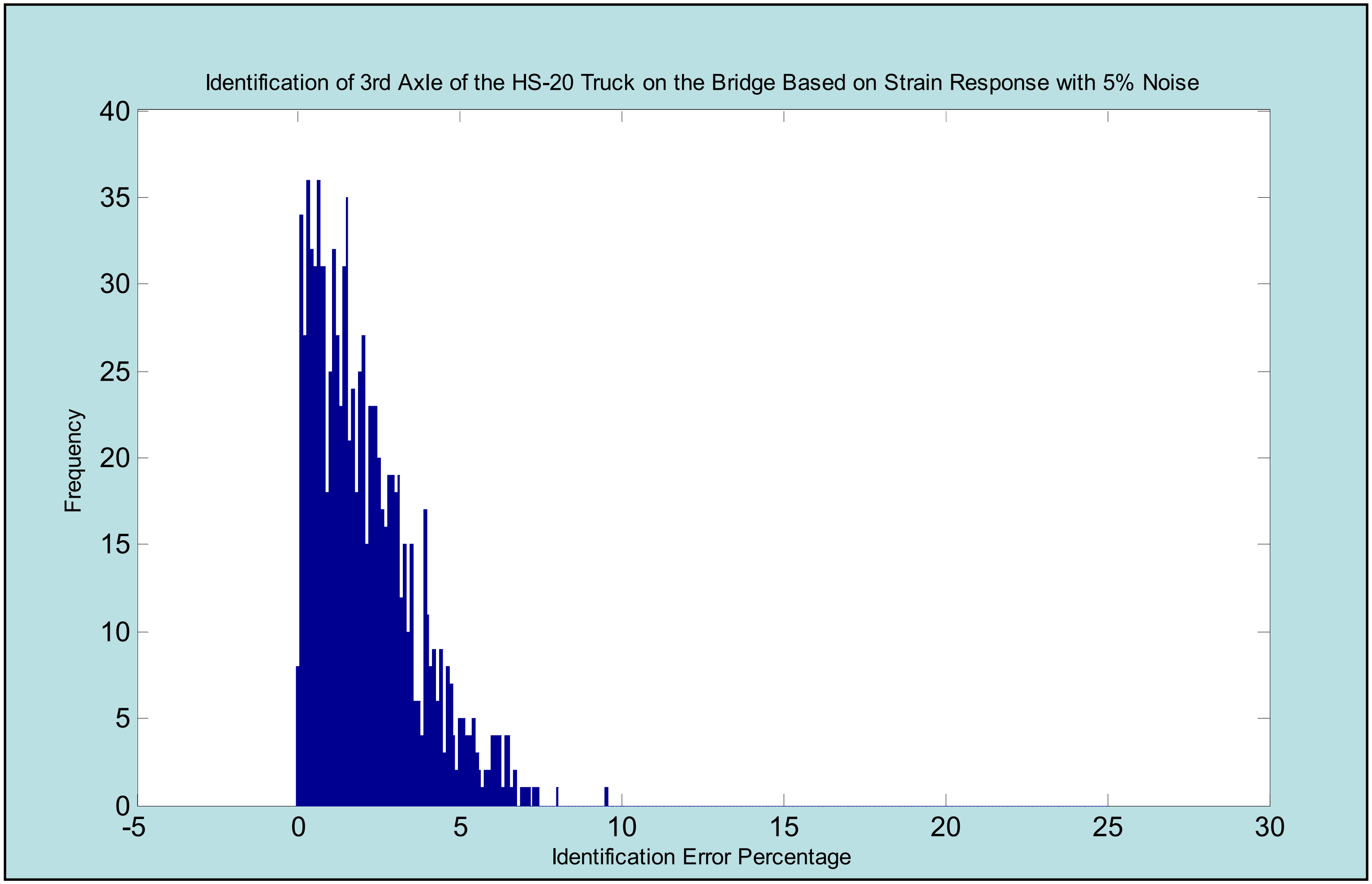
Histogram of the identified load with recorded data with 5% noise



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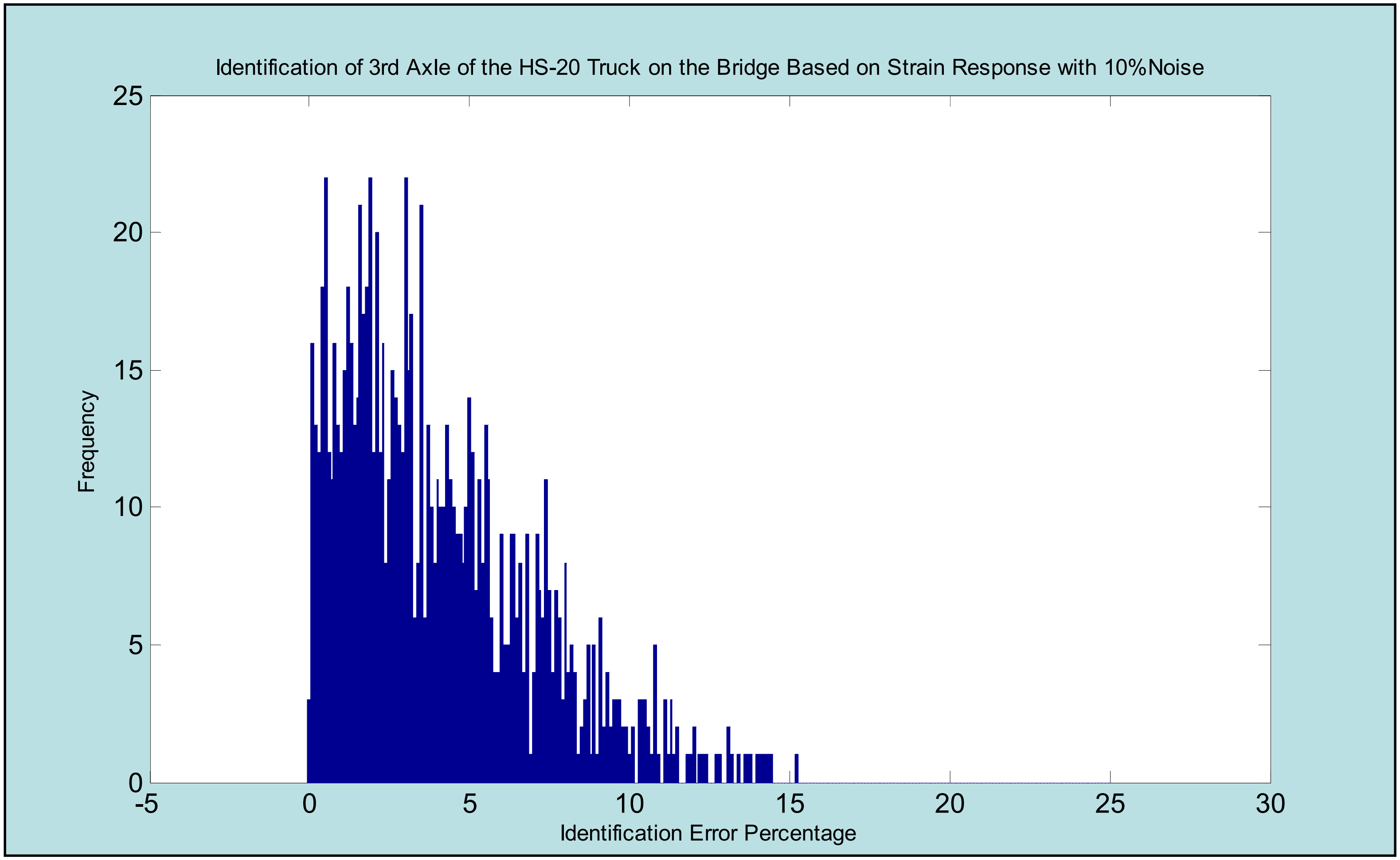
Histogram of the identified load with recorded data with 10% noise



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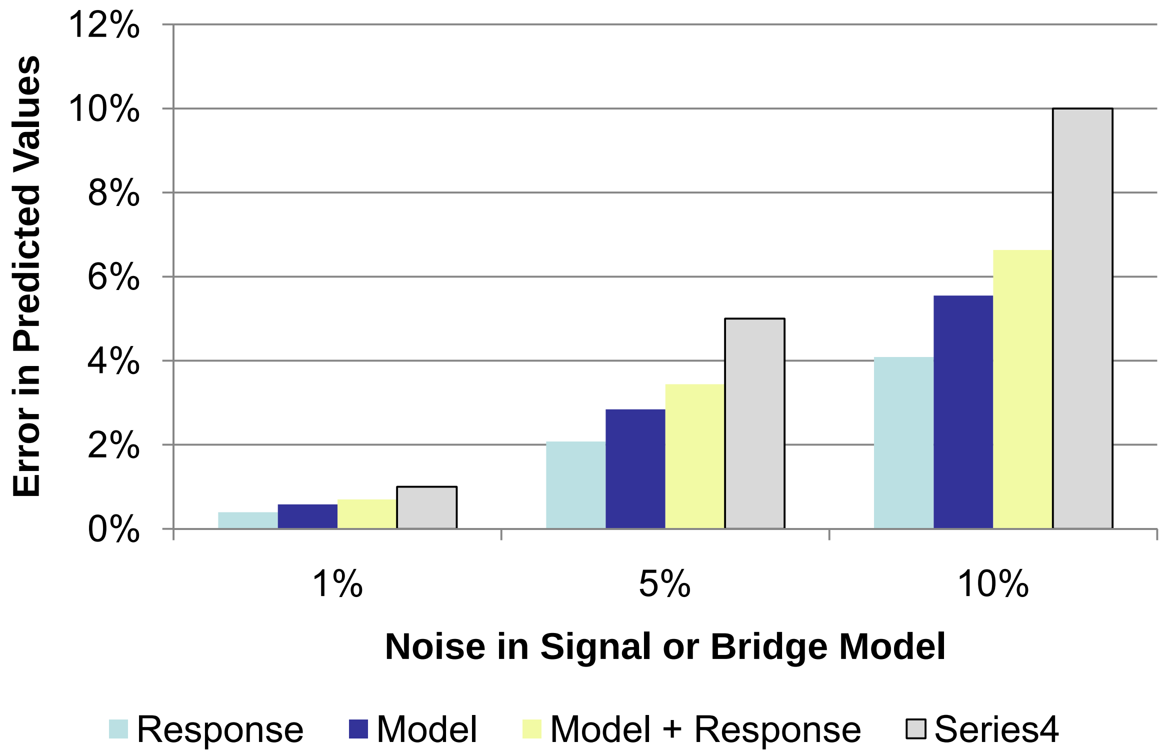
The recorded data, strain vector is noisy

HS-20 Truck on the Bridge using Pattern Search Method

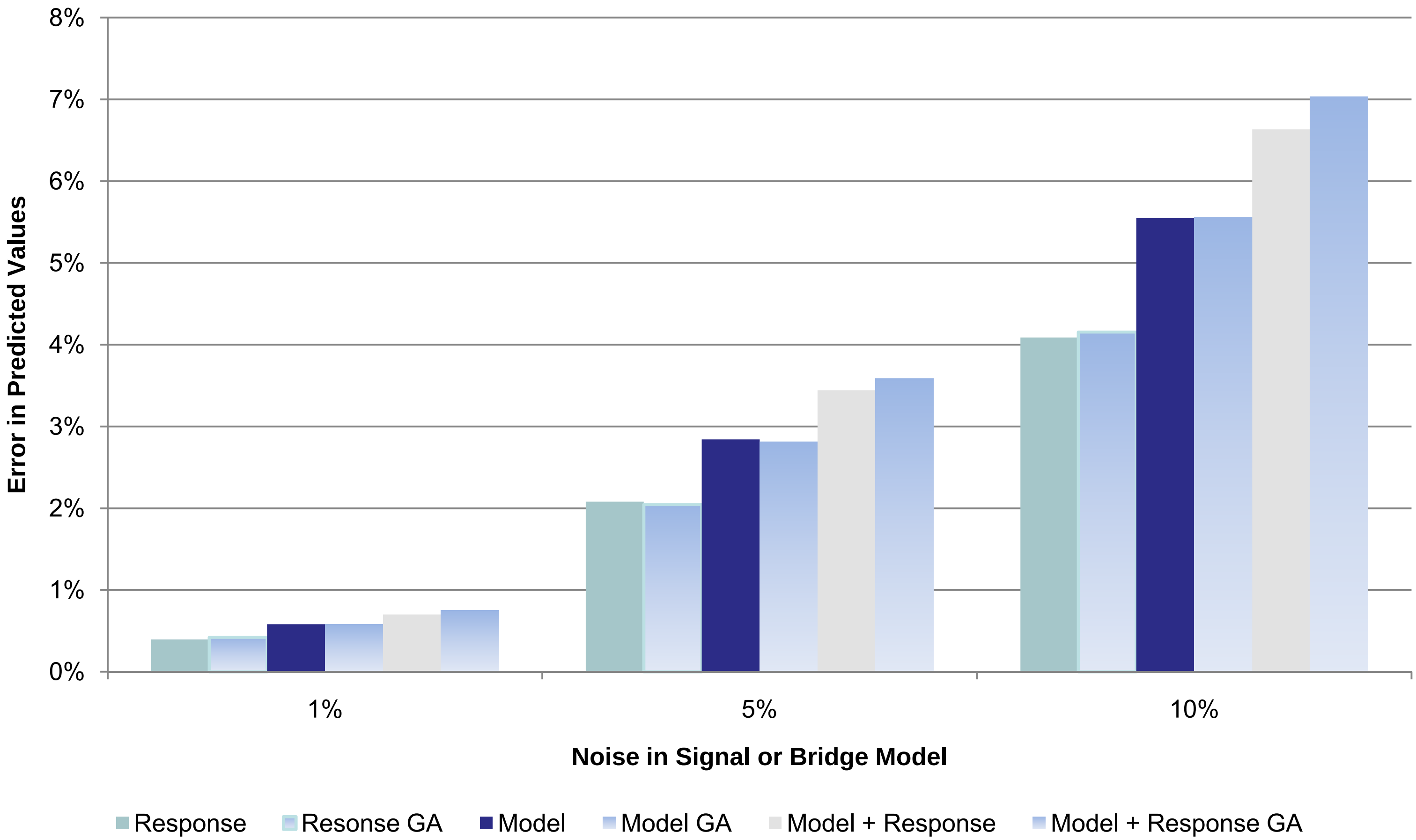
Statistical Data on Prediction Error (%)						
Noise Level	Mean	Variance	Standard Deviation	coefficient of variation	Skewness	Kurtosis
0	0.00047	1.03E-38	1.02E-19	2.16E-16	1.00	1.00
1%	0.3951	0.0904	0.3007	0.7611	0.8893	3.4746
5%	2.0797	2.5078	1.5836	0.7615	1.0182	3.8341
10%	4.0888	9.3384	3.0559	0.7475	0.9436	3.477

Evaluate Sources of Error



$$[A] = [I]^{-1} \times [B]$$

Pattern Search versus GA



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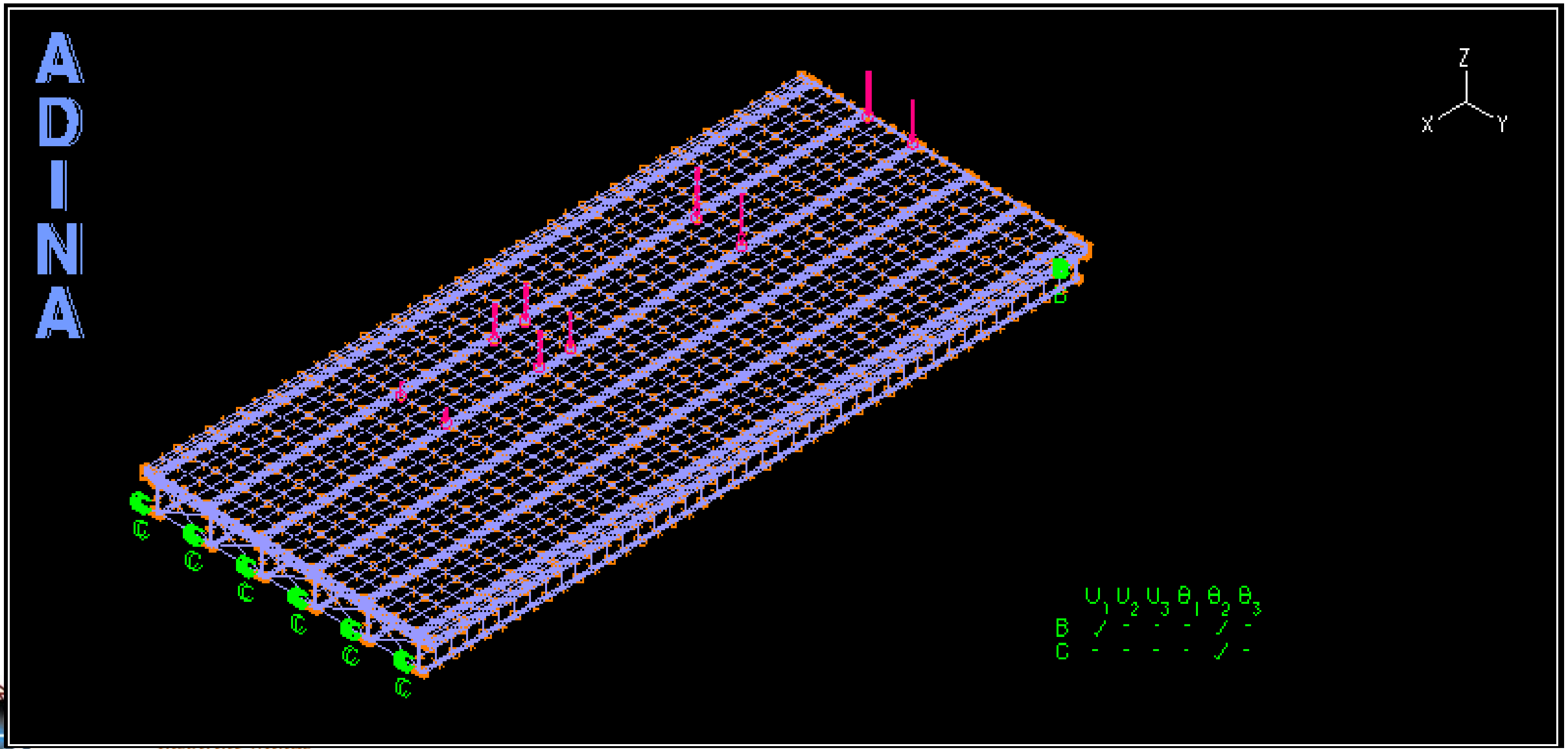
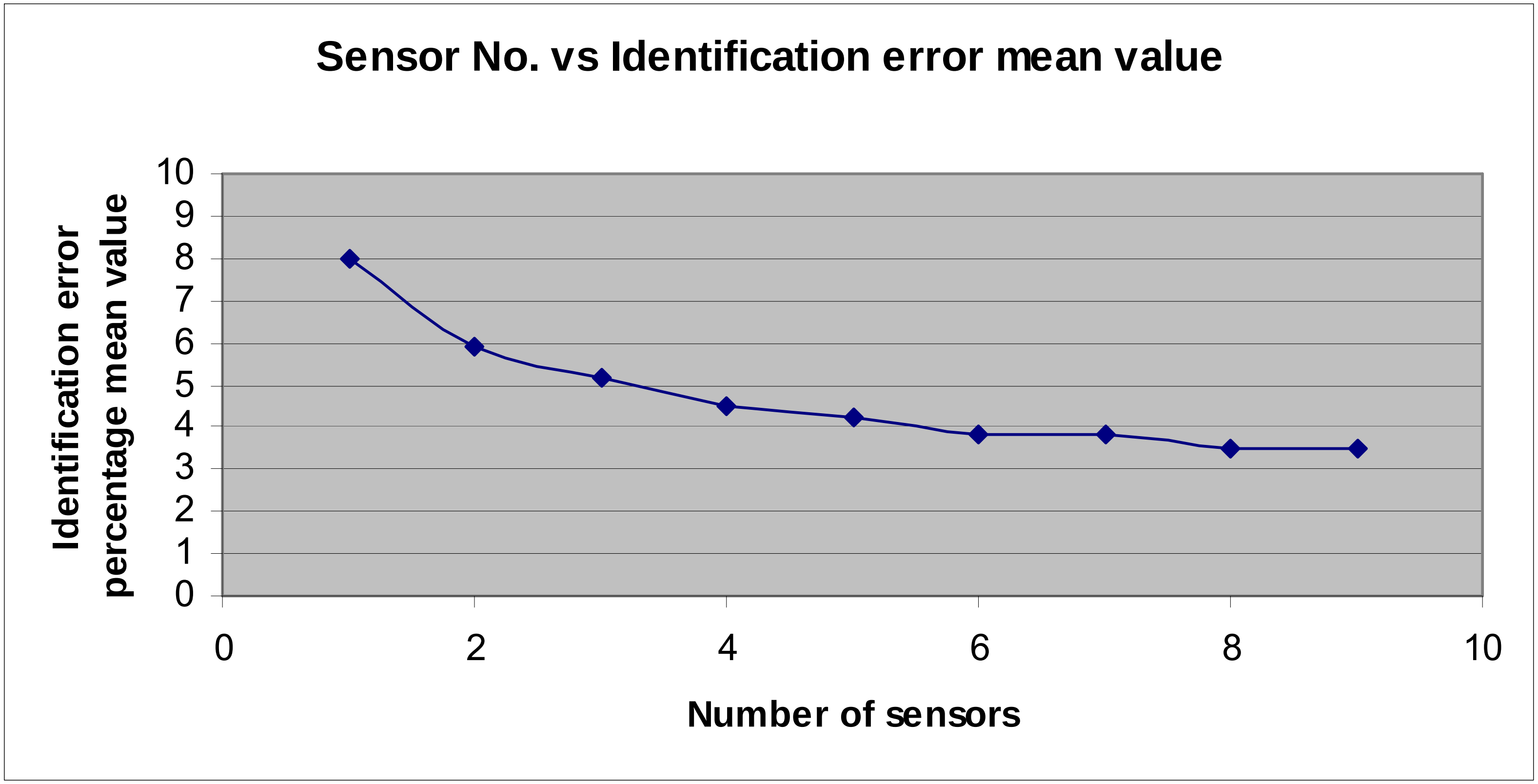
Additional Tools

- Determine How Many Sensors
- Average Multiple Predictions
- Determine Lateral Position
- Vehicle Speed and Longitudinal Locations



The variation of identification error mean value vs number of sensors

Beam model under CL-W truck with 10% noise
Using Pattern Search Method and moment responses



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Effect of quantity of averaging locations

Beam model under HS-20 truck with 5% noise
Using Pattern Search Method and moment responses

Number of averaging points	Mean	Variance	Standard deviation	Skewness	kurtosis	Coefficient of variation
1	3.5033	7.3888	2.7182	1.0357	3.9328	0.7759
2	3.4184	3.2402	1.8000	0.7295	3.4802	0.5266
3	3.5163	2.4343	1.5602	0.6281	3.5177	0.4437

Analysis of lateral location of HS-20 first axle on the bridge

Bridge under first axle of HS-20 truck using strain data and pattern search method with 5% noise

Number of lane	axle load estimation	identification error	objective function value
1	-1.6301	1.419	285.3286
2	3.89	1.57E-07	0.0095
3	1.1836	0.6957	262.7739
4	-2.3122	1.5944	199.2252
5	1.0839	0.7214	302.2422

Analysis of actual speed of HS-15 on the bridge

Bridge under first axle of HS-20 truck using strain data and pattern search method

location (mm)	axle load estimation	identification error	objective function value
425	0	1	456600
1225	6.5219	6.02E-02	18.1969
1625	9.0291	0.301	80247
2225	11.3989	0.6425	53115

Actual Position

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Conclusion

- Pattern Search Method Developed for WIM
- Simulations show promise
- Field Testing is Required
- Integrate with SHM System

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Questions