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Texas A&M Transportation Institute

Workshop Slides

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Bridge Weigh-in-Motion -
An Approach to Measure Truck Loading on Texas Highways

Texas Department of Transportation

Workshop
October 26, 2022

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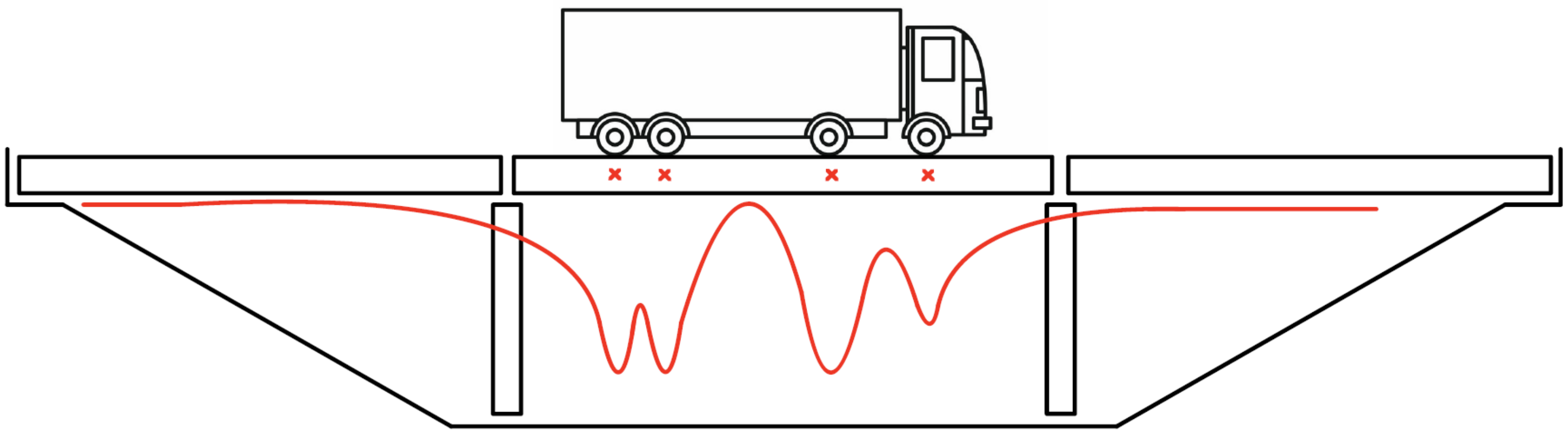
Bridge Weigh-in-Motion (BWIM) Workshop

9:00 AM - Session 1: BWIM Introduction

10:00 AM - Session 2: BWIM case studies - Truck characterization

11:00 AM - Session 3: BWIM case studies – Bridge Evaluation

11:40 AM - Workshop Summary



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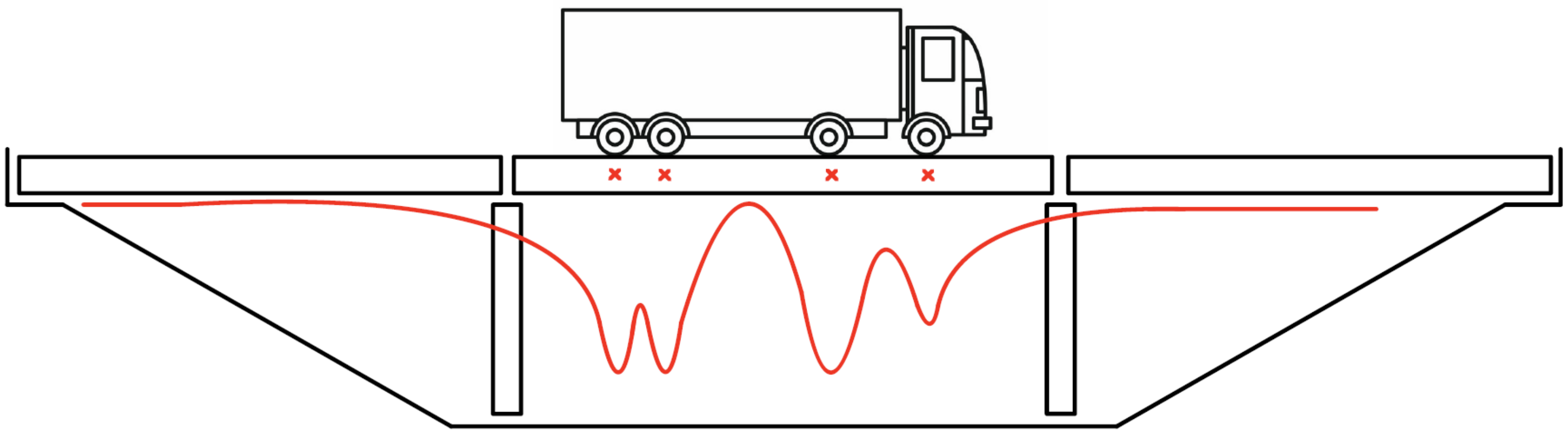
SESSION 1: BWIM INTRODUCTION

Session 1: BWIM Introduction

1. Definition & Objectives
2. Background
3. Components of BWIM
4. TxDOT Study



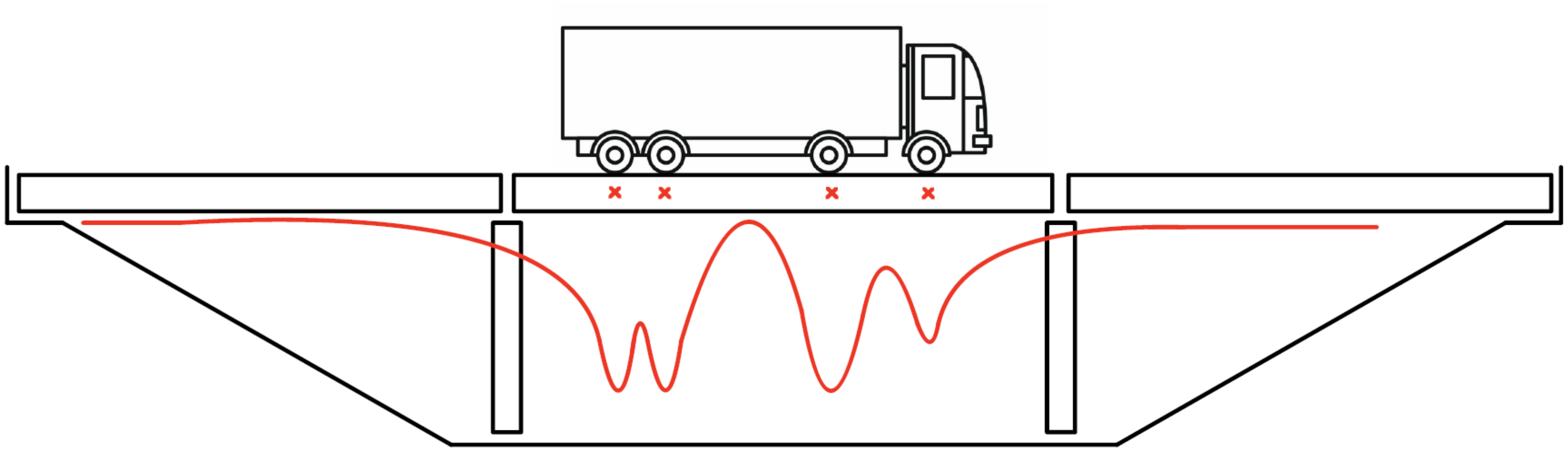
Q1

1.1

DEFINITION & OBJECTIVES

Definition

A BWIM system utilizes physical measurements (e.g., strain) to characterize truck traffic and potentially evaluate the bridge itself.



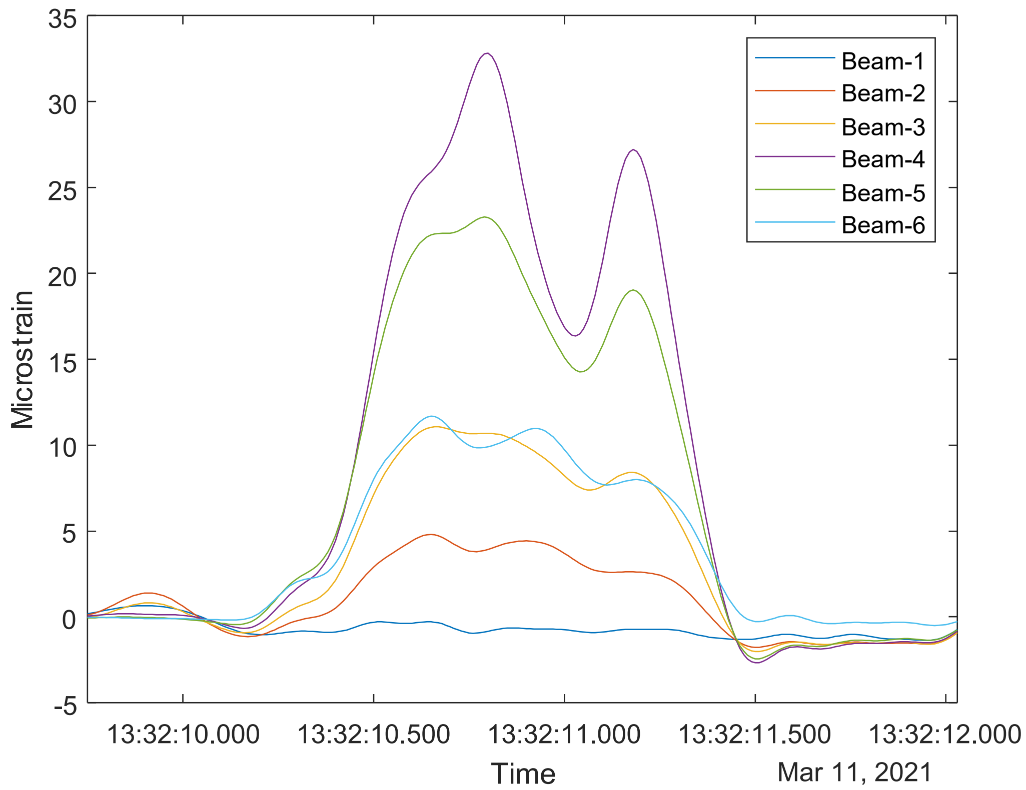
Objectives

Q2 & Q3

1. Characterize truck traffic in a corridor
   - axles (number and spacing)
   - speeds
   - weights (axles and gross)
   - classifications

2. Evaluate the bridge itself
   - distribution factors
   - percent composite action
   - dynamic impact factor
   - site-specific load ratings

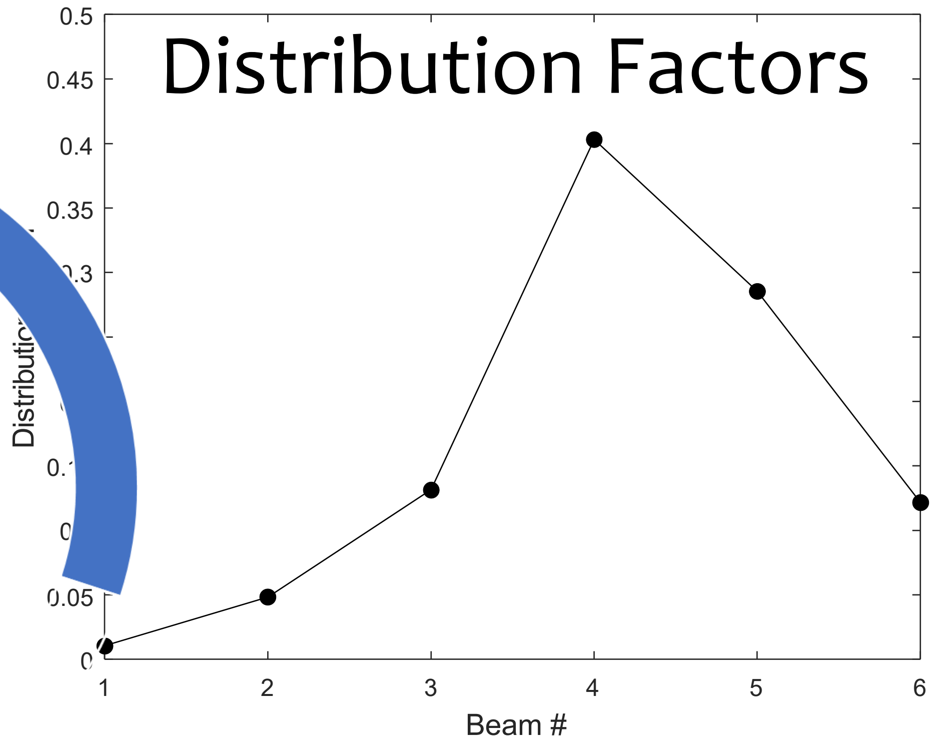
BWIM Illustration



BWIM Illustration

Lane Detection	Outside Lane
Number of Axles	5
Average Speed (mph)	70.2
Axle Spacing (ft)	20.6, 4.7, 34.2, 4.5
GVW (kips)	81
Axle Weight (Kips)	15.3, 17.4, 18.2, 15.7, 14.3
Classification	Class 9

Processing



Load Rating	Inventory	Operating
	2.24	3.74

1.2

BACKGROUND

Weigh-in-Motion (WIM) Systems

1. Permanent Pavement WIM

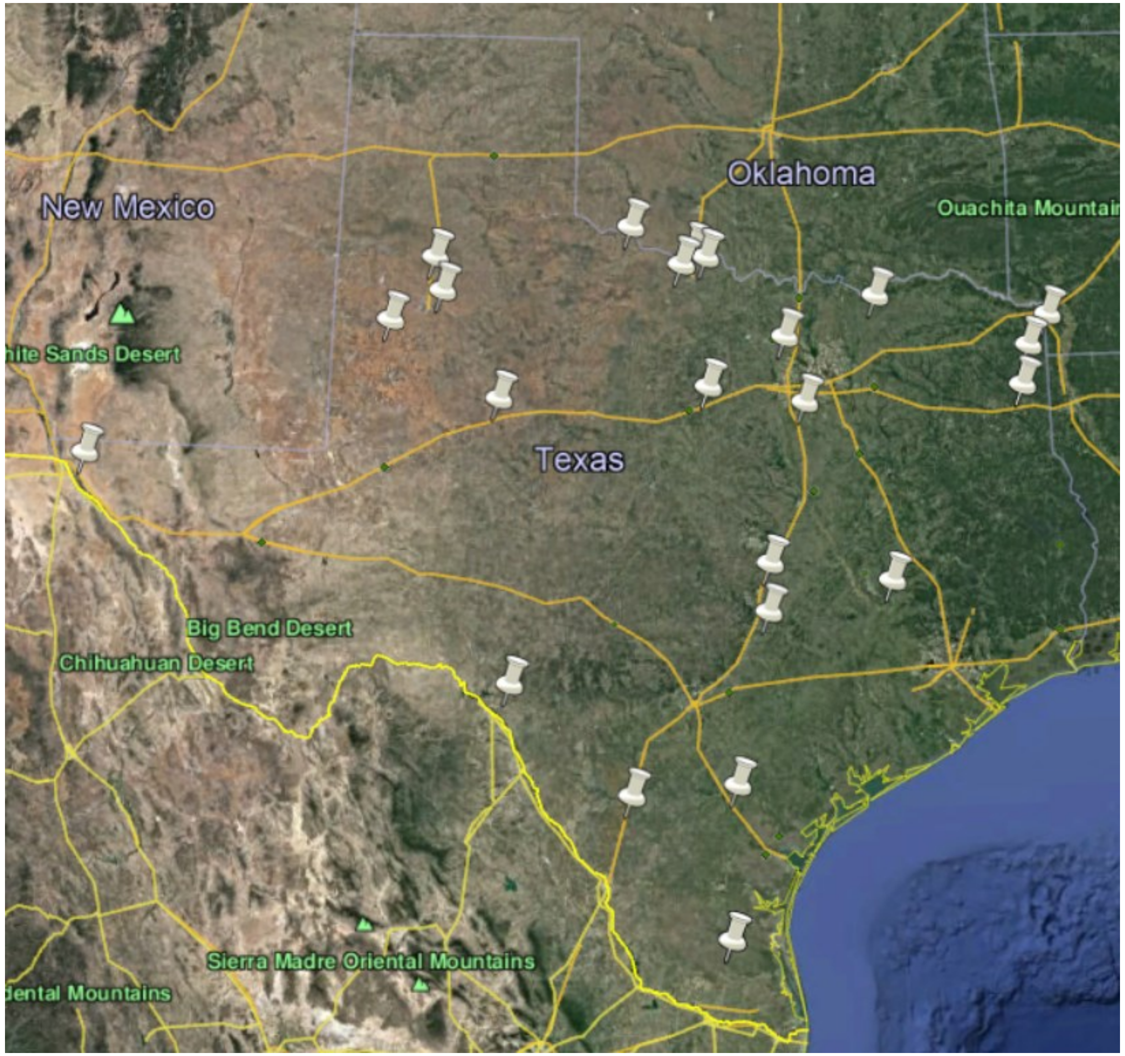
2. Portable Pavement WIM

3. BWIM

Permanent Pavement WIM

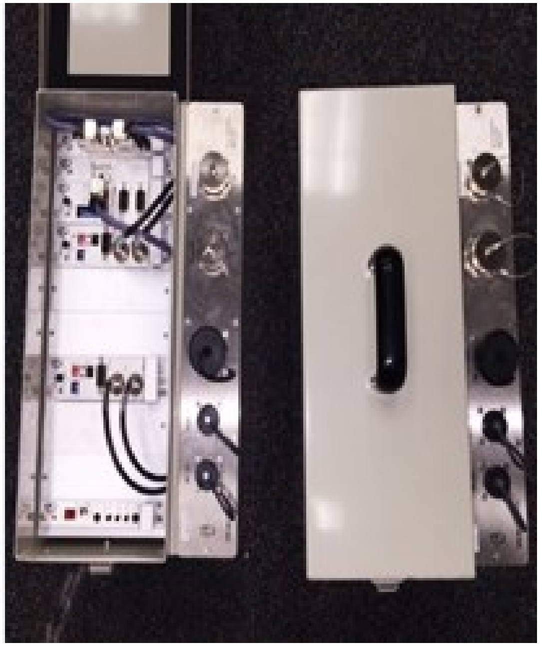
Main types:

- Bending plate
- Load cell
- Piezoelectric



Active Permanent WIM station (as of July 2020)

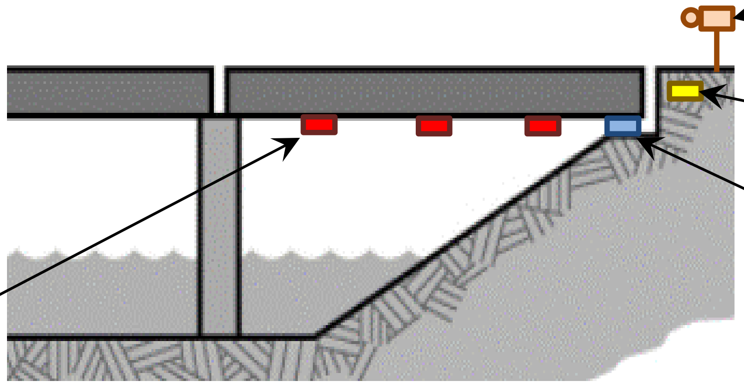
Portable Pavement WIM



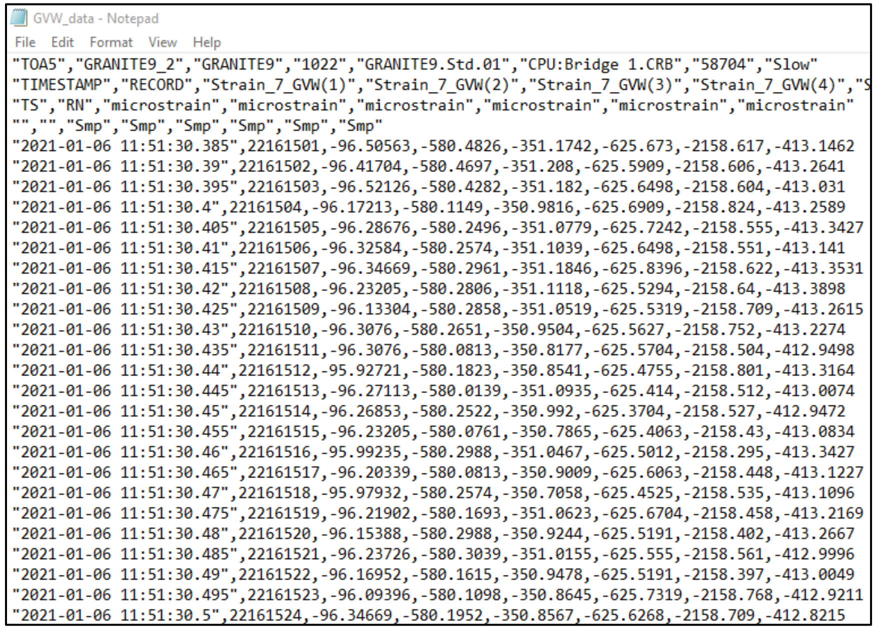
1.3

COMPONENTS OF BWIM

BWIM System



Physical Data


GVW_data - Notepad
File Edit Format View Help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"TS","RN","microstrain","microstrain","microstrain","microstrain","microstrain","microstrain"
"","","Smp","Smp","Smp","Smp","Smp","Smp"
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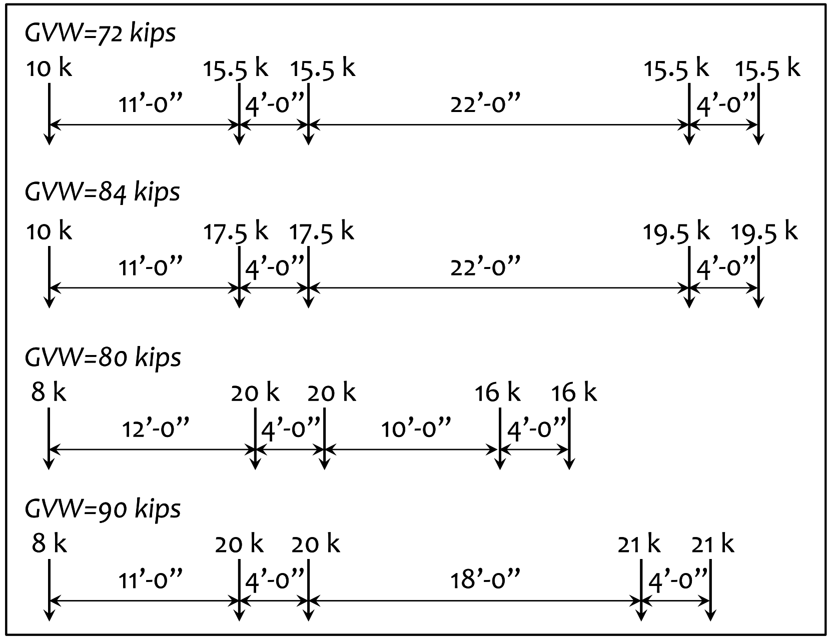
Algorithm

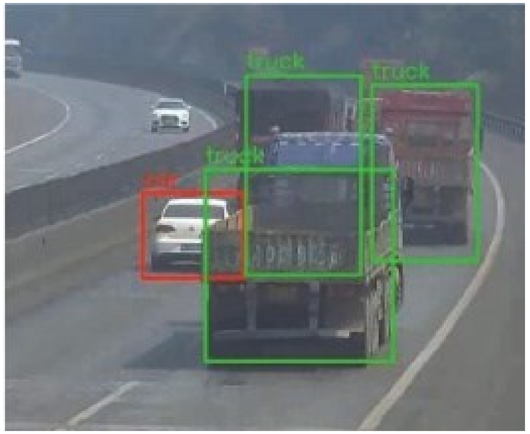


Truck Information

BWIM System

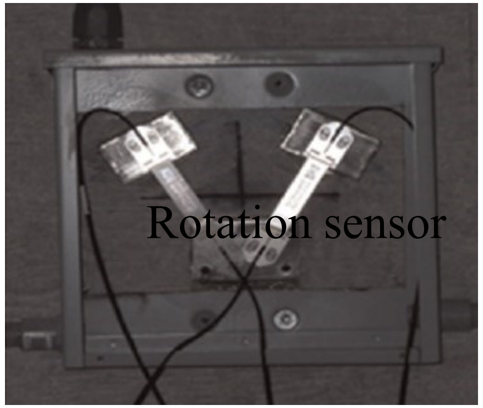
Axle Detection

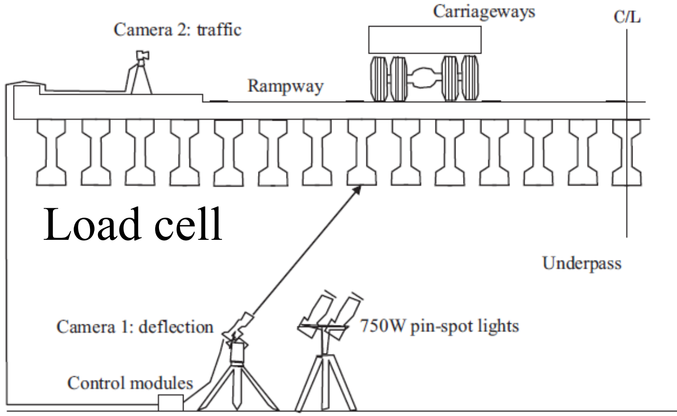
Strain Gauge



Imaging

Weighing





1.4

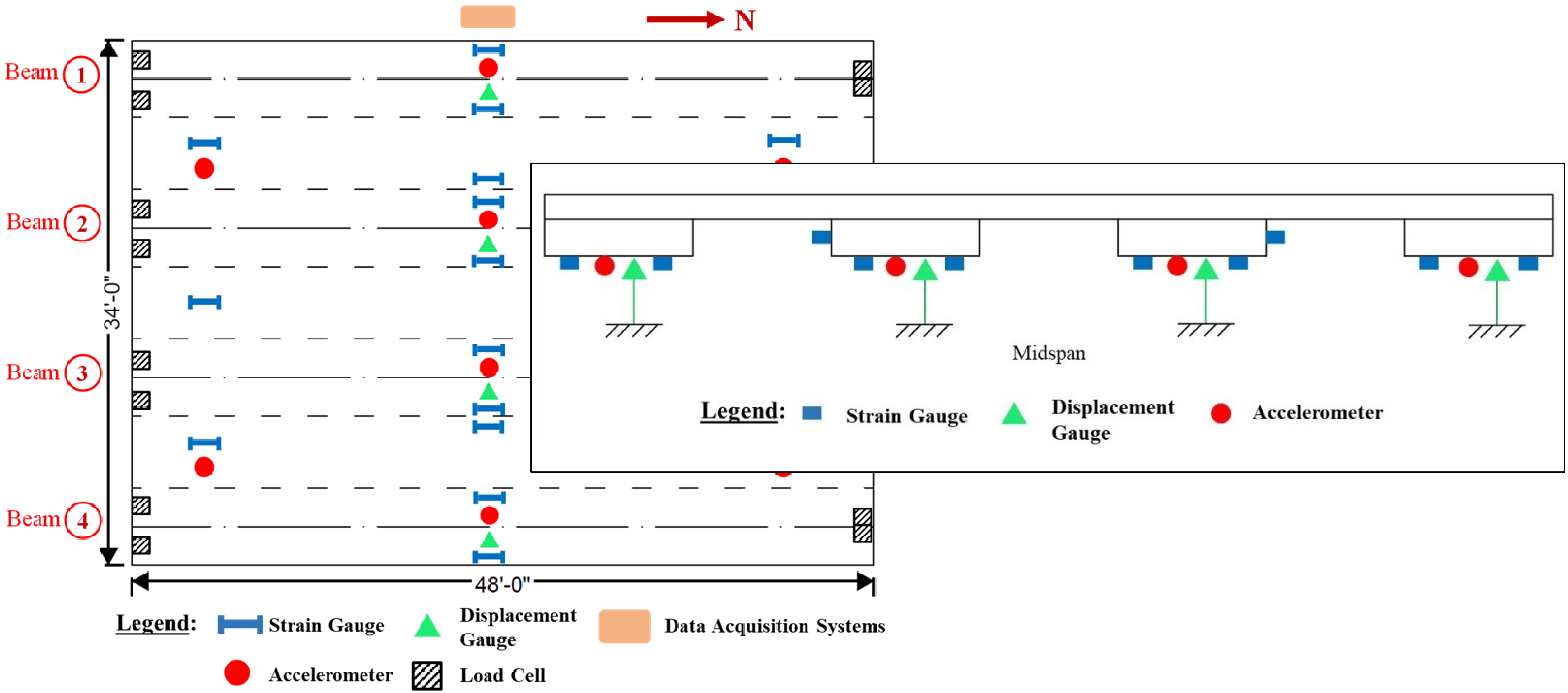
TxDOT STUDY

Scope of Work

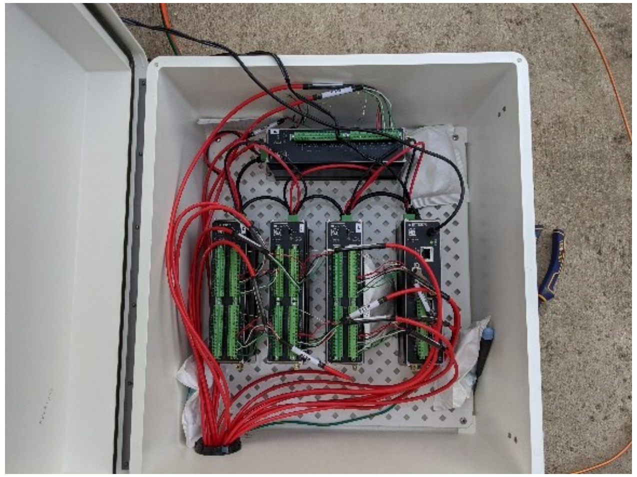
1. Literature review
2. Preliminary study on a full-scale bridge not in-service
3. Three case studies on in-service TxDOT bridges
4. Development of guidelines and recommendations

Preliminary Study – RELLIS Bridge

Preliminary Study – RELLIS Bridge

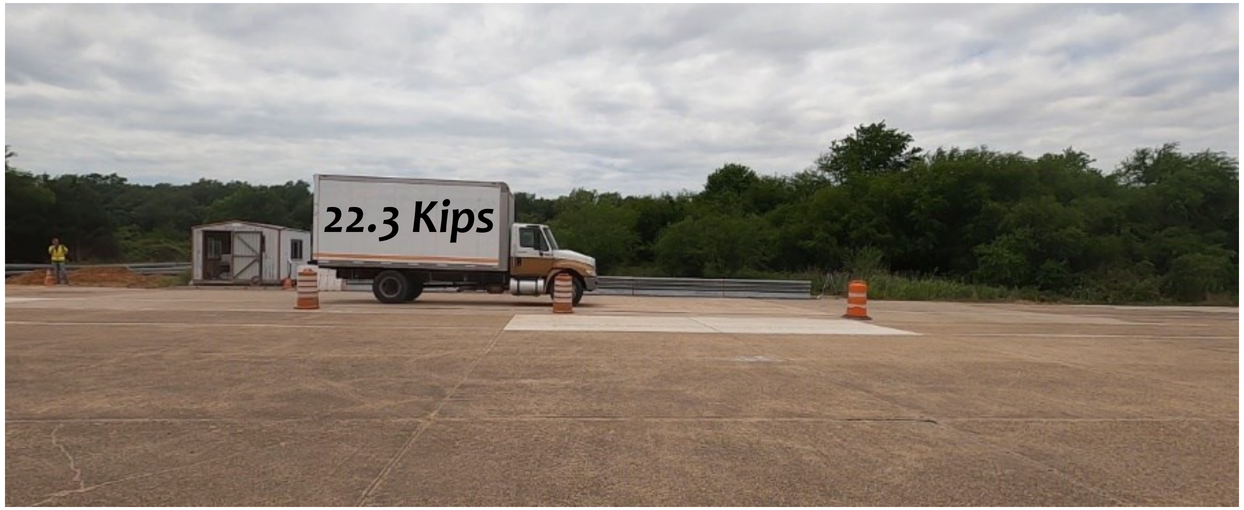


Preliminary Study – RELLIS Bridge

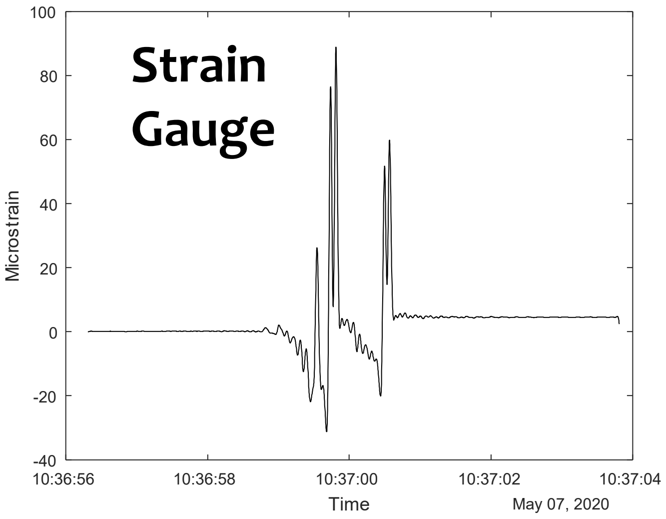


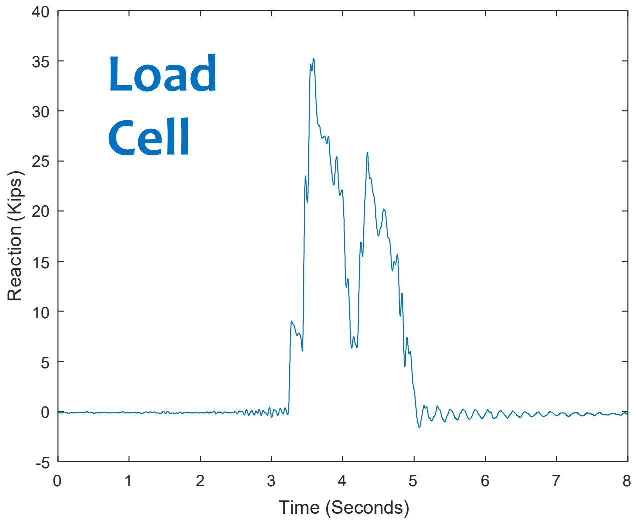
Preliminary Study – RELLIS Bridge

Test Information	
Speed:	10 / 20 / 30 / 40 / 50 mph
Direction:	South→North, North→South
Single Vehicle:	72 runs
Back to Back	6 runs
Side by Side	5 runs
Opposite Direction	4 runs

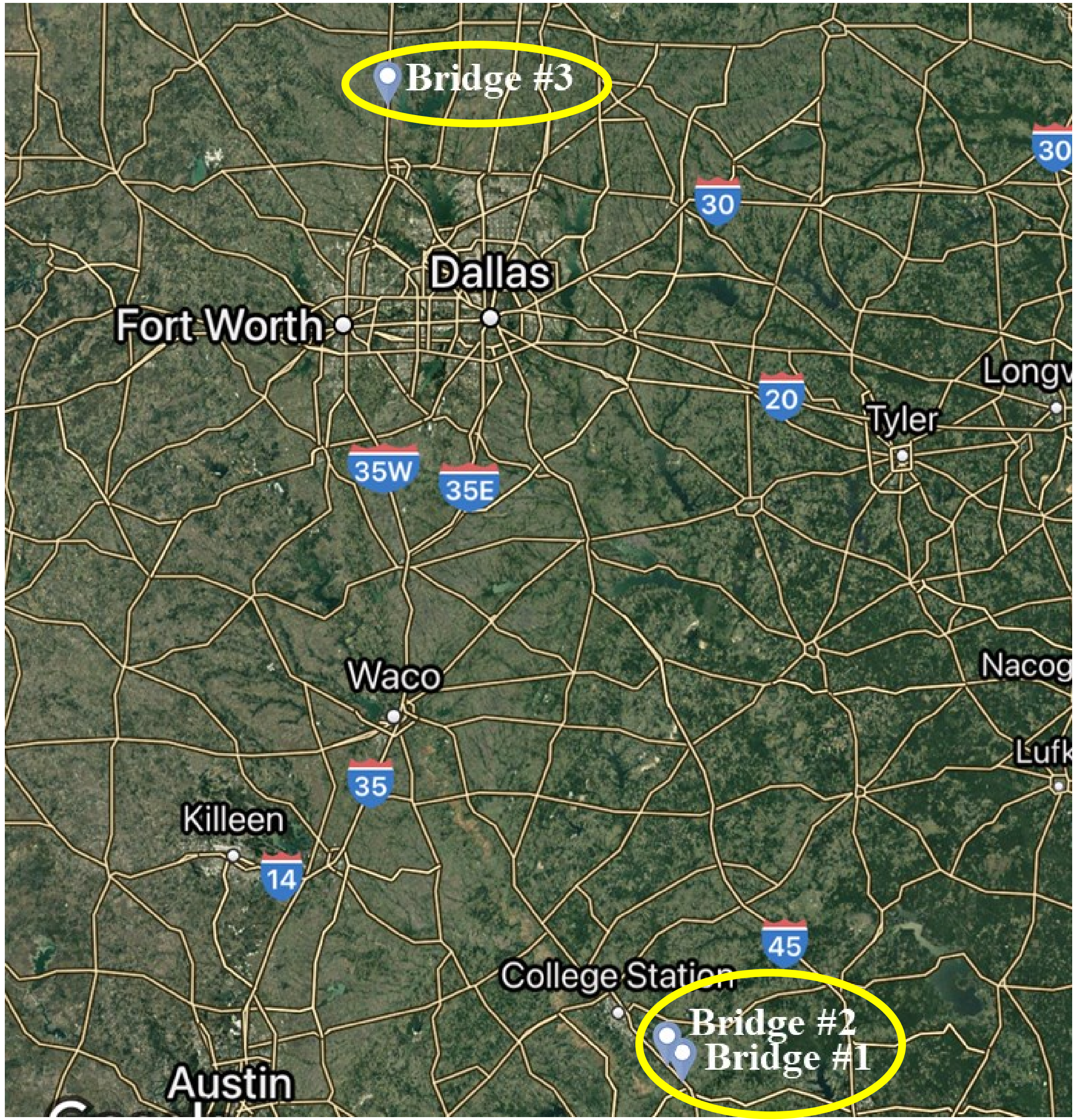


Preliminary Study – RELLIS Bridge





TxDOT In-Service Bridges



Primary Process

A. Instrumentation design

B. System installation

C. Data acquisition & Communication

D. Calibration test

E. Data processing

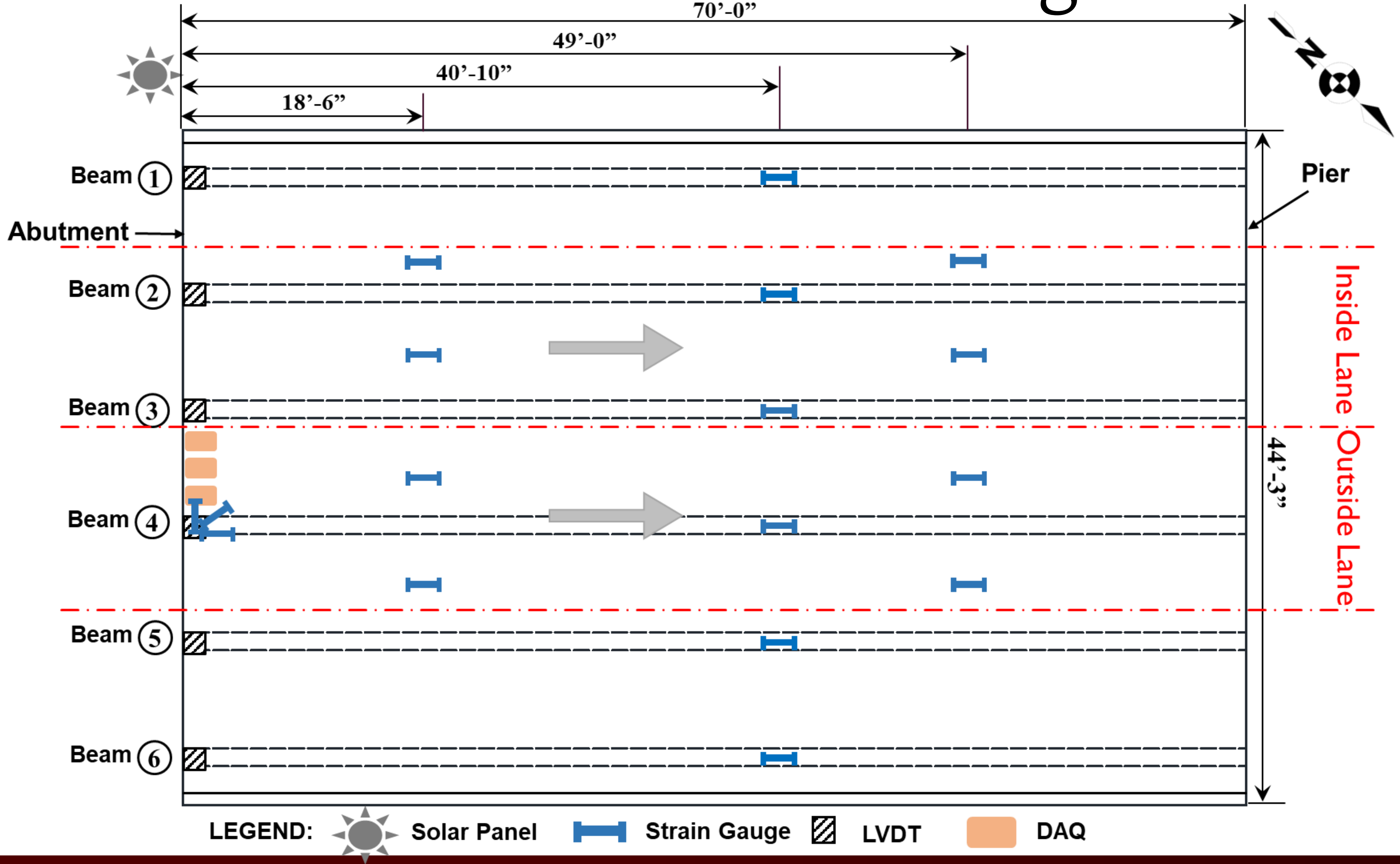
F. Validation study

→ ***Session 2***

G. Bridge assessment → ***Session 3***

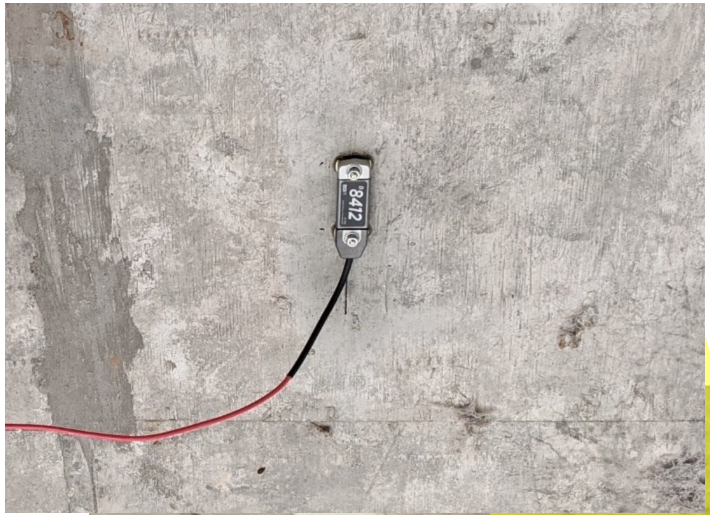
A. Instrumentation Design

Bridge #1



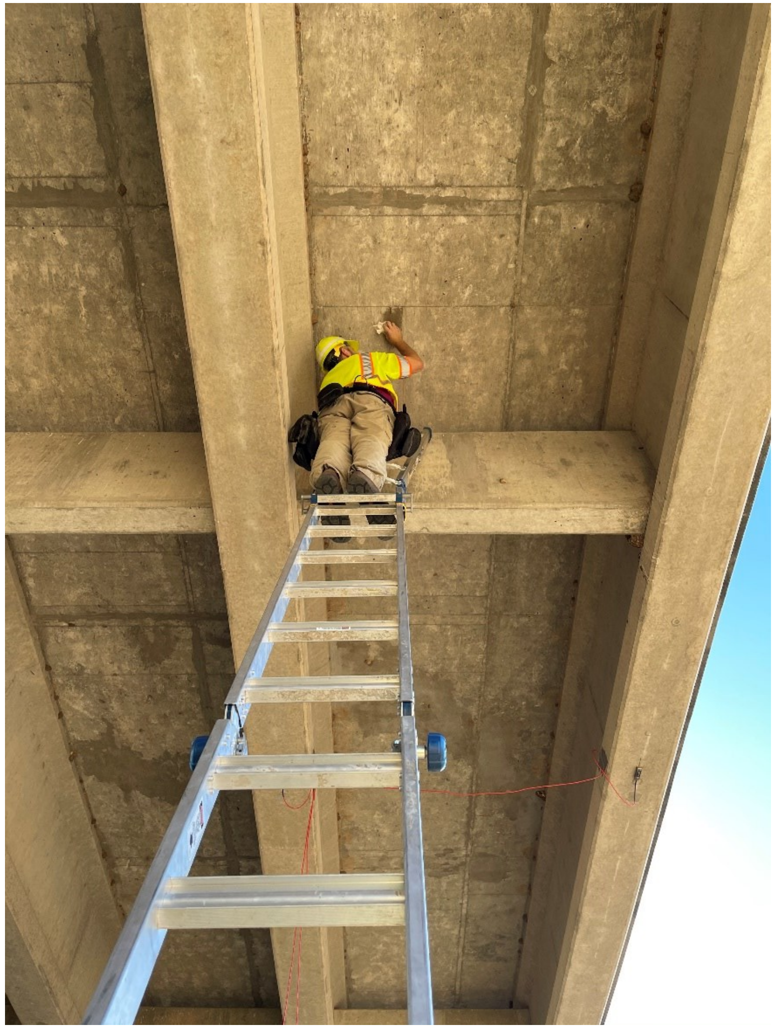
B. System Installation

Bridge #1



B. System Installation

Bridge #1

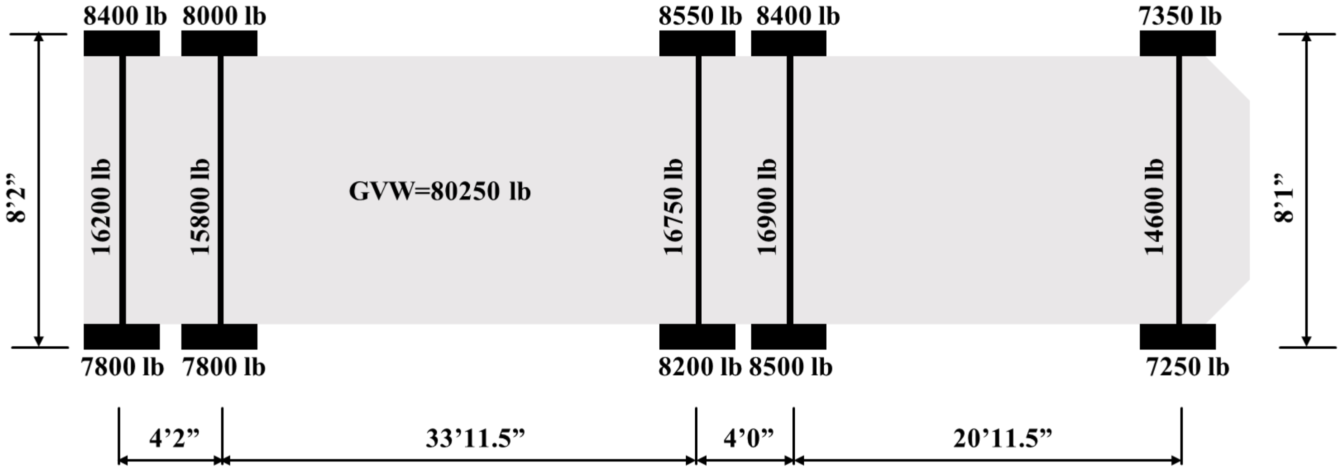


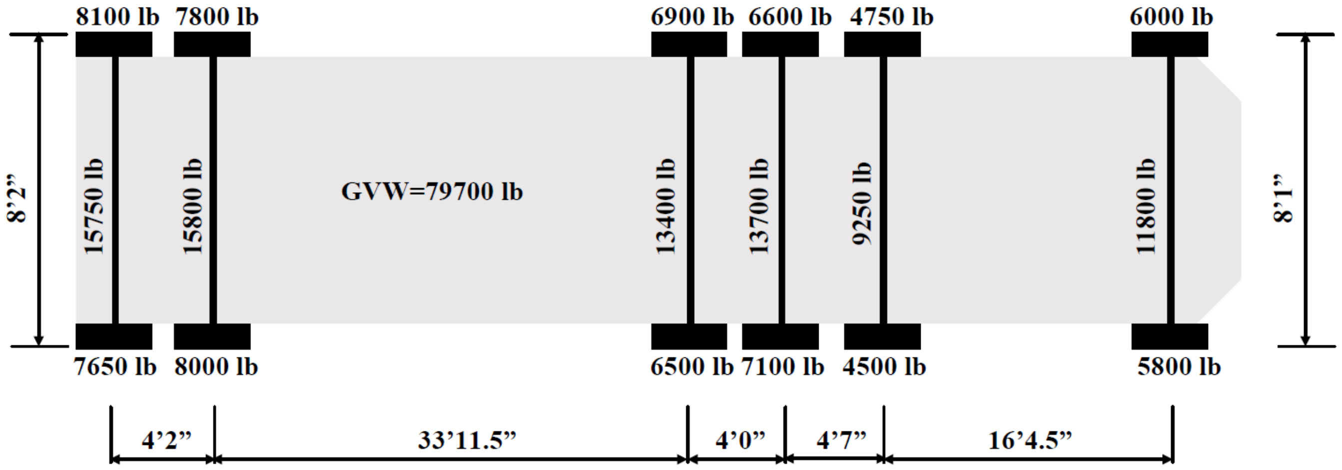
B. System Installation

Bridge #1

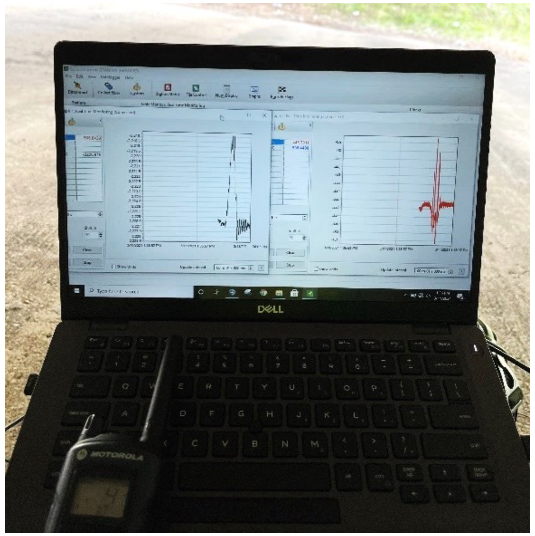
C. Data Acquisition & Communication

D. Calibration Test

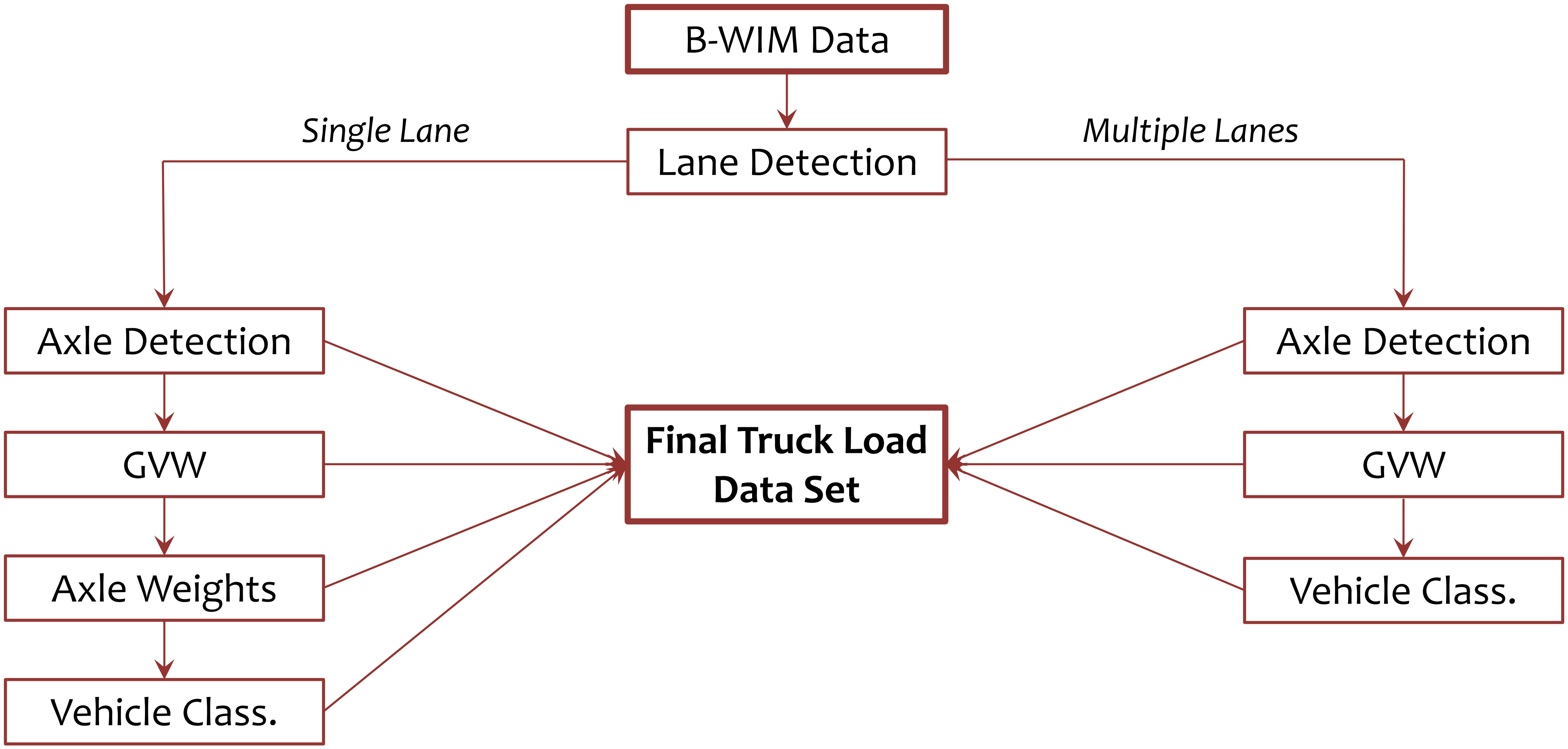




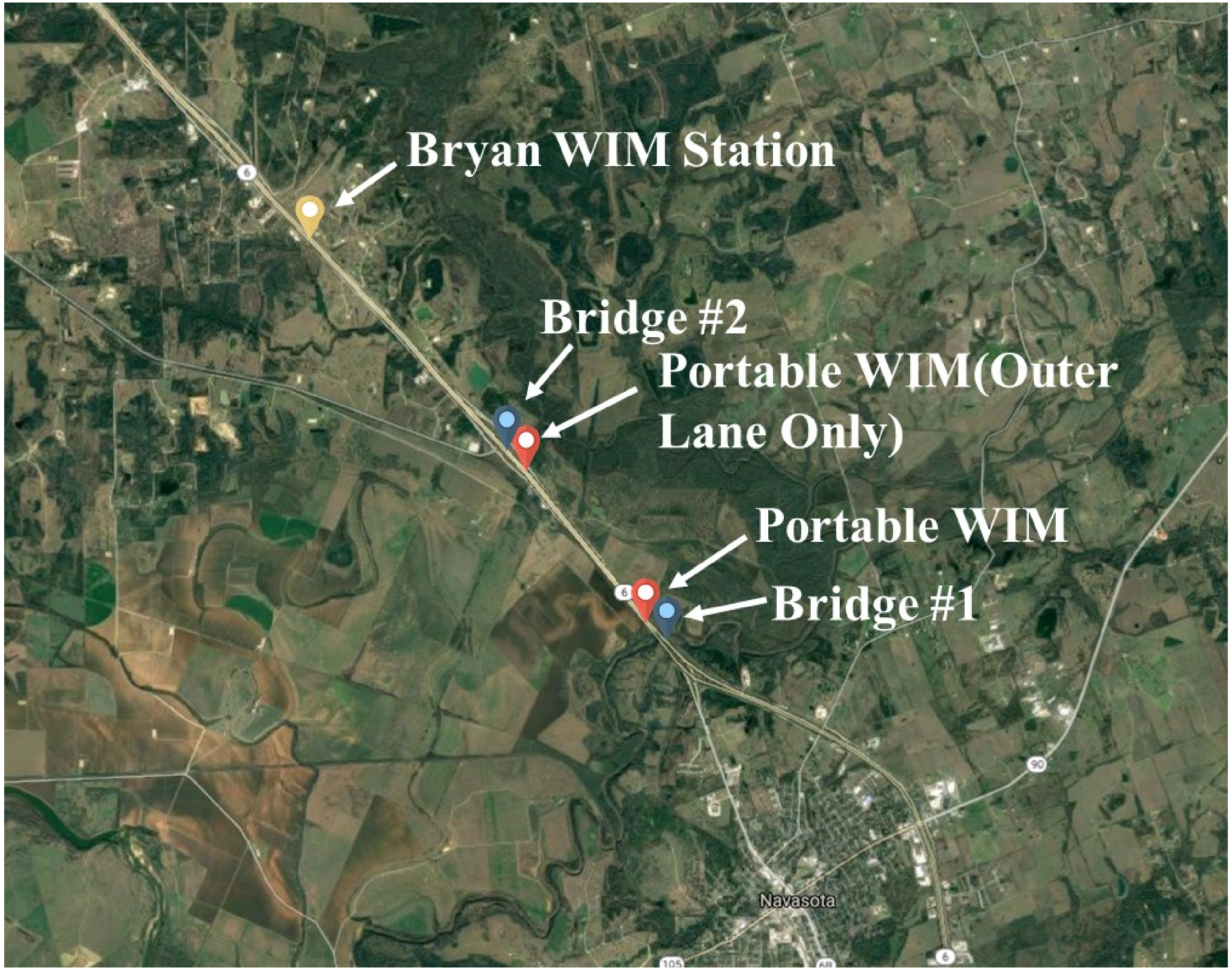
D. Calibration Test



E. Data Processing



F. Validation Study



G. Bridge Evaluation

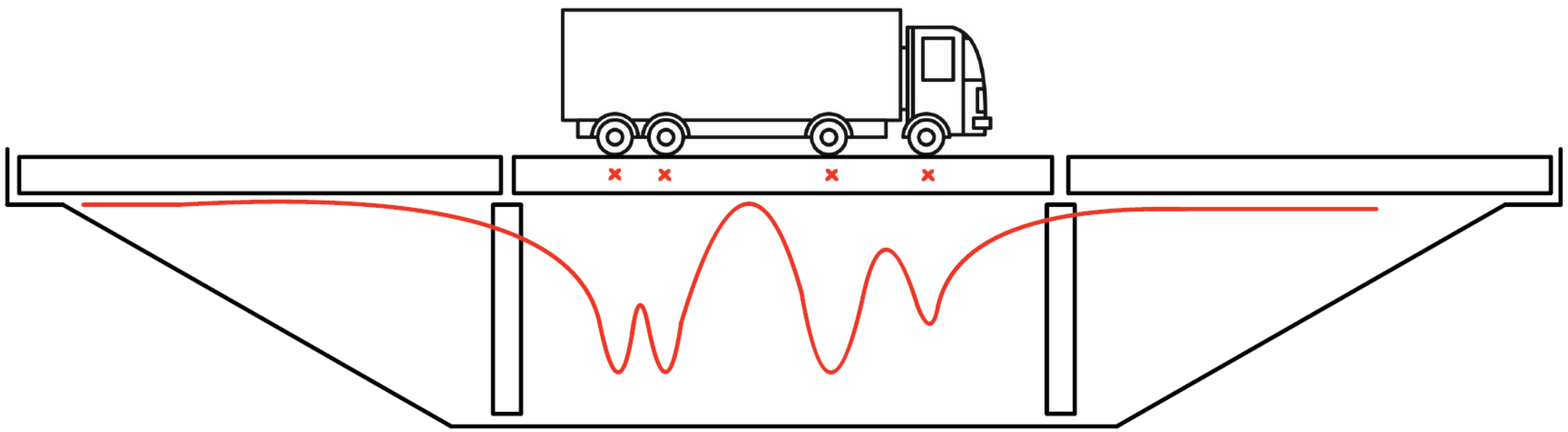
<u>Site-Specific Load Ratings:</u>

- LFR code for prestressed concrete beam and steel girder bridges
- Validated code using TxDOT Load Rating Spreadsheet
- BWIM data processed to identify:
  - Distribution factors
  - Composite behavior
- Calculate load ratings for:
  - Notional trucks
  - Actual trucks

Session 1: BWIM Introduction

1. Definition & Objectives
2. Background
3. Components of BWIM
4. TxDOT Study

QUESTIONS?



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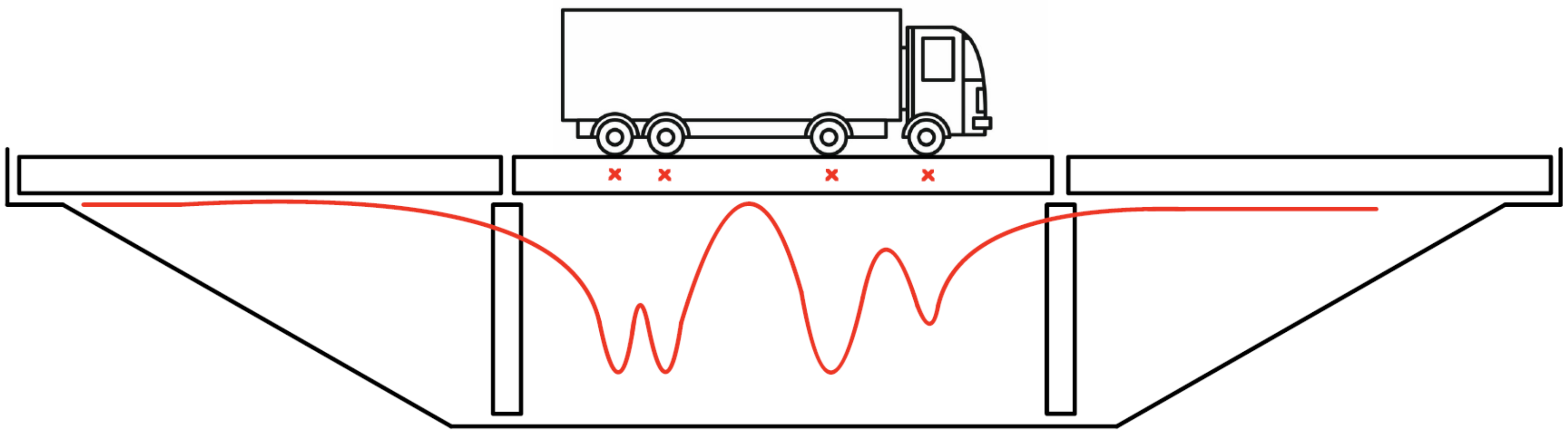
SESSION 2: BWIM CASE STUDIES TRUCK CHARACTERIZATION

Session 2: BWIM Case Studies-Truck Characterization

1. Data Processing
2. Validation Study



Primary Process

A. Instrumentation design

B. System installation

C. Data acquisition & Communication

D. Calibration test

E. Data processing

F. Validation study

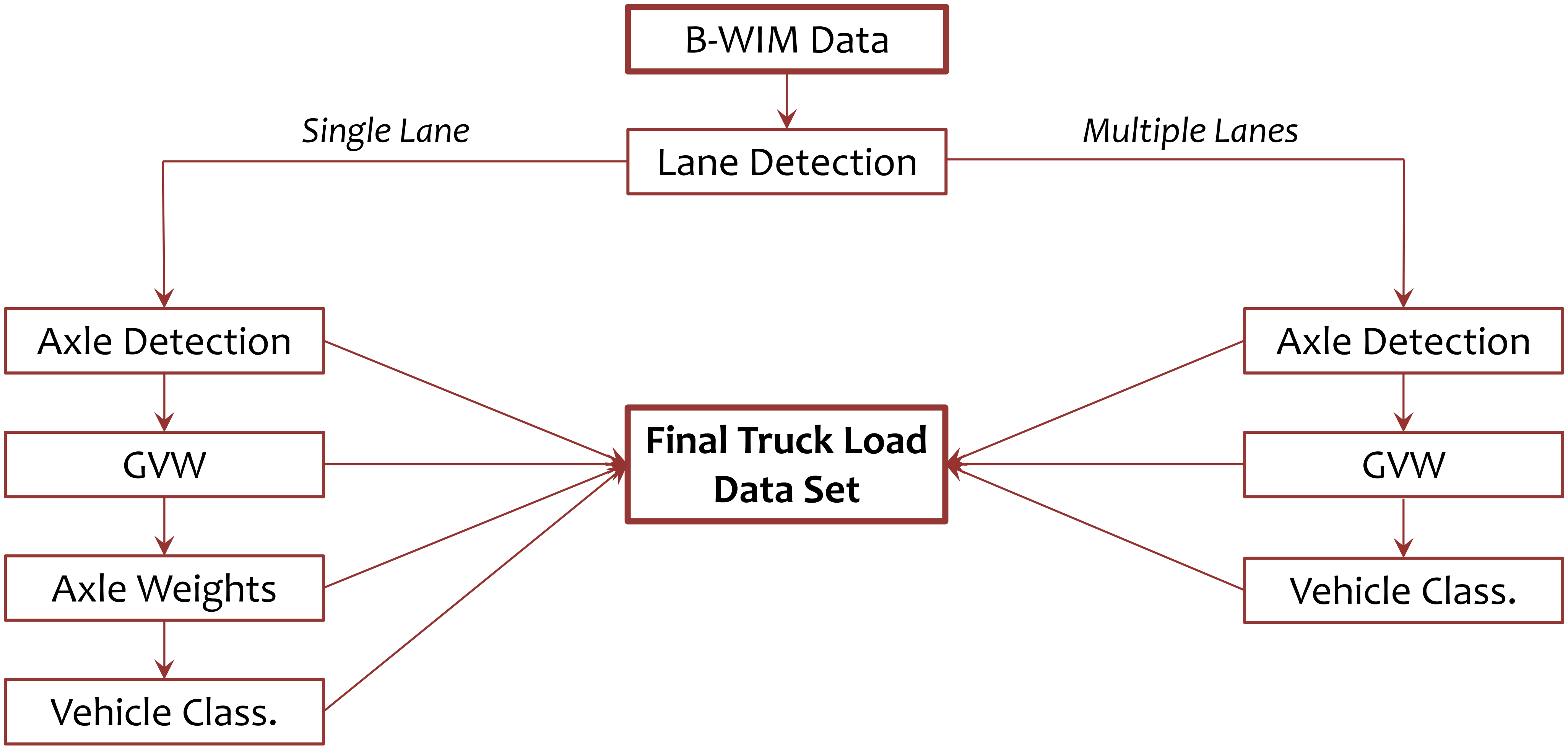
→ ***Session 2***

G. Bridge assessment

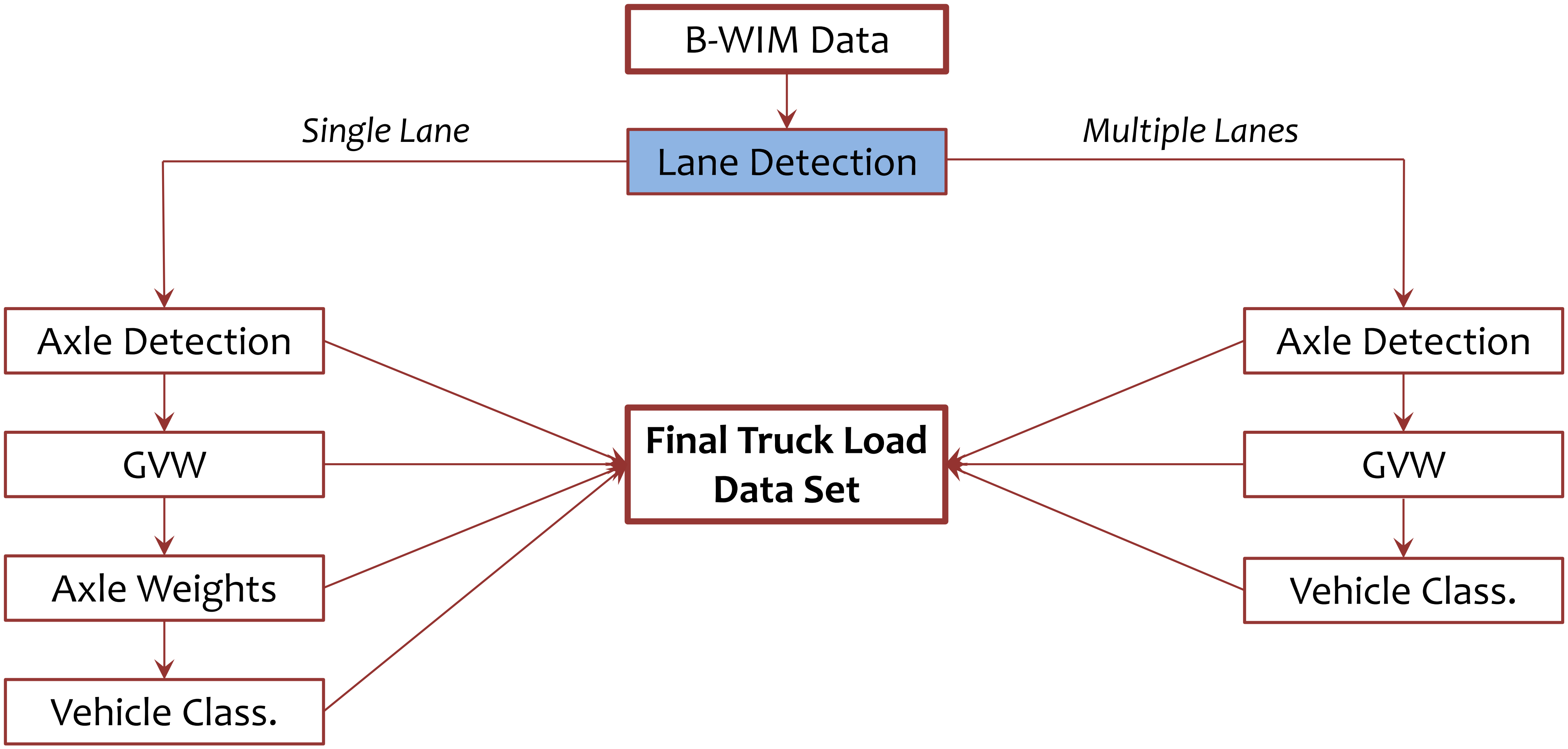
2.1

DATA PROCESSING

Data Processing

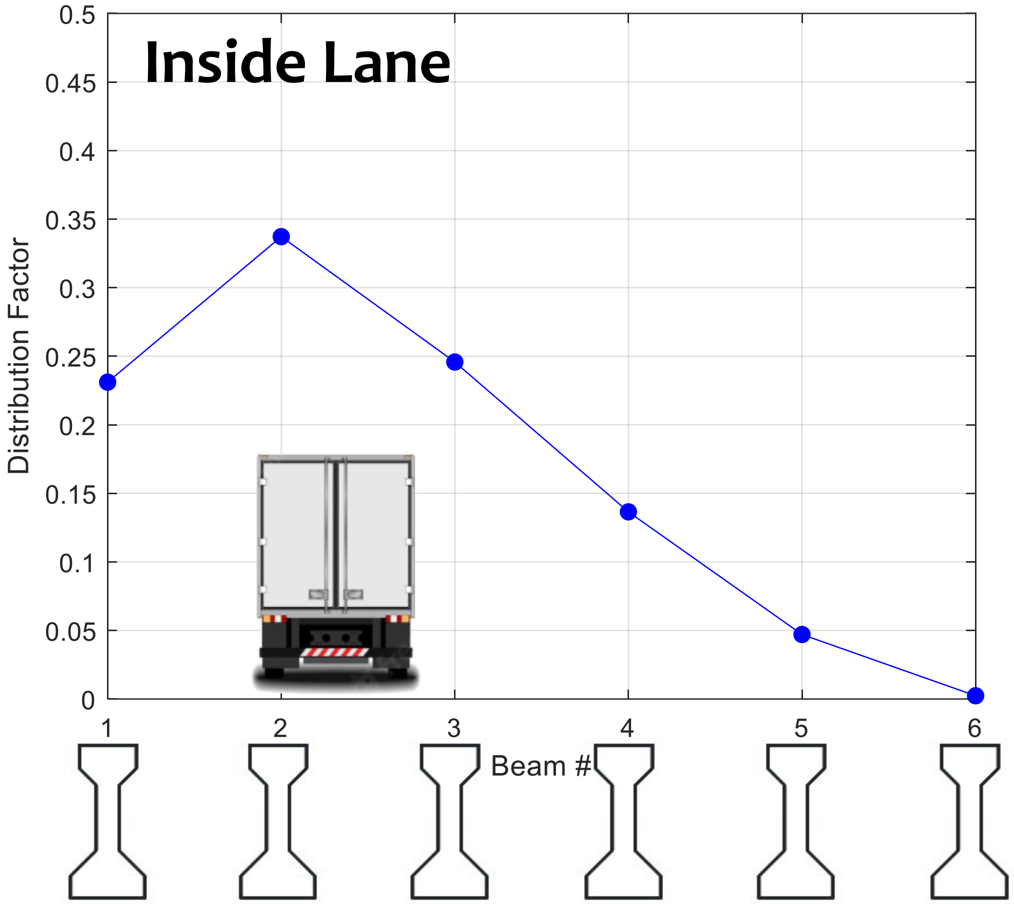


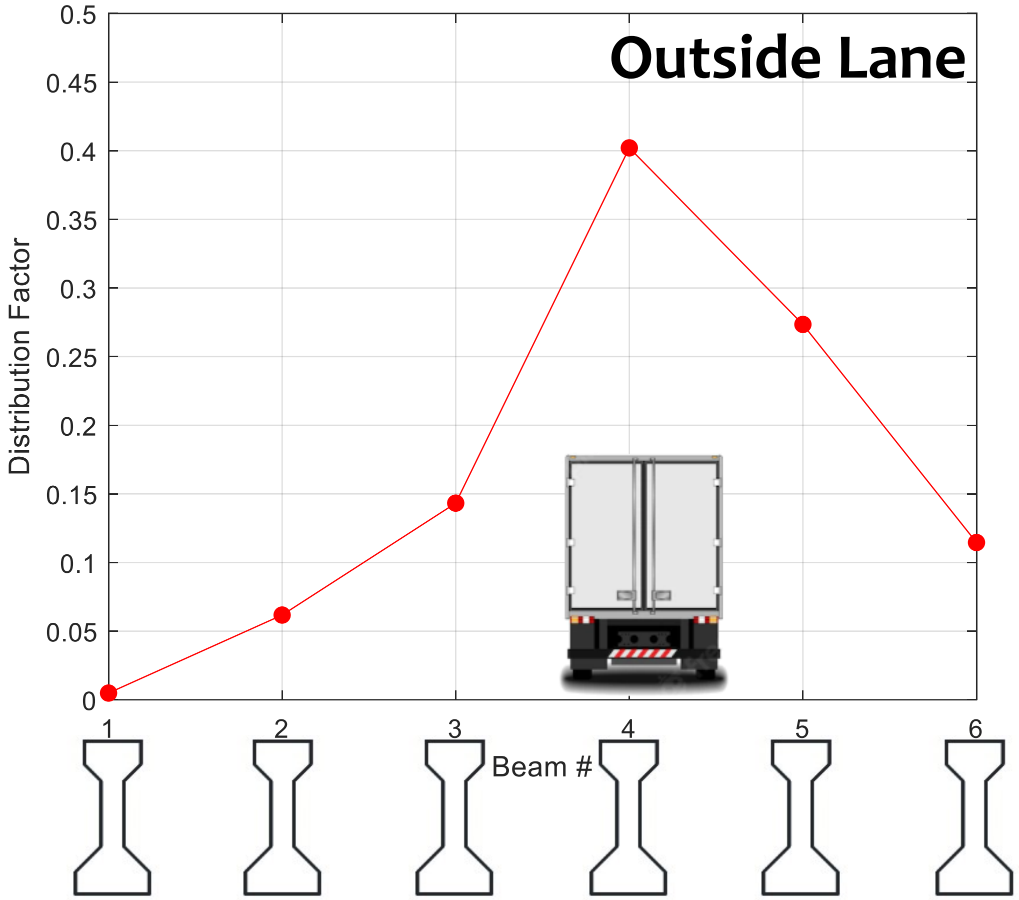
Data Processing



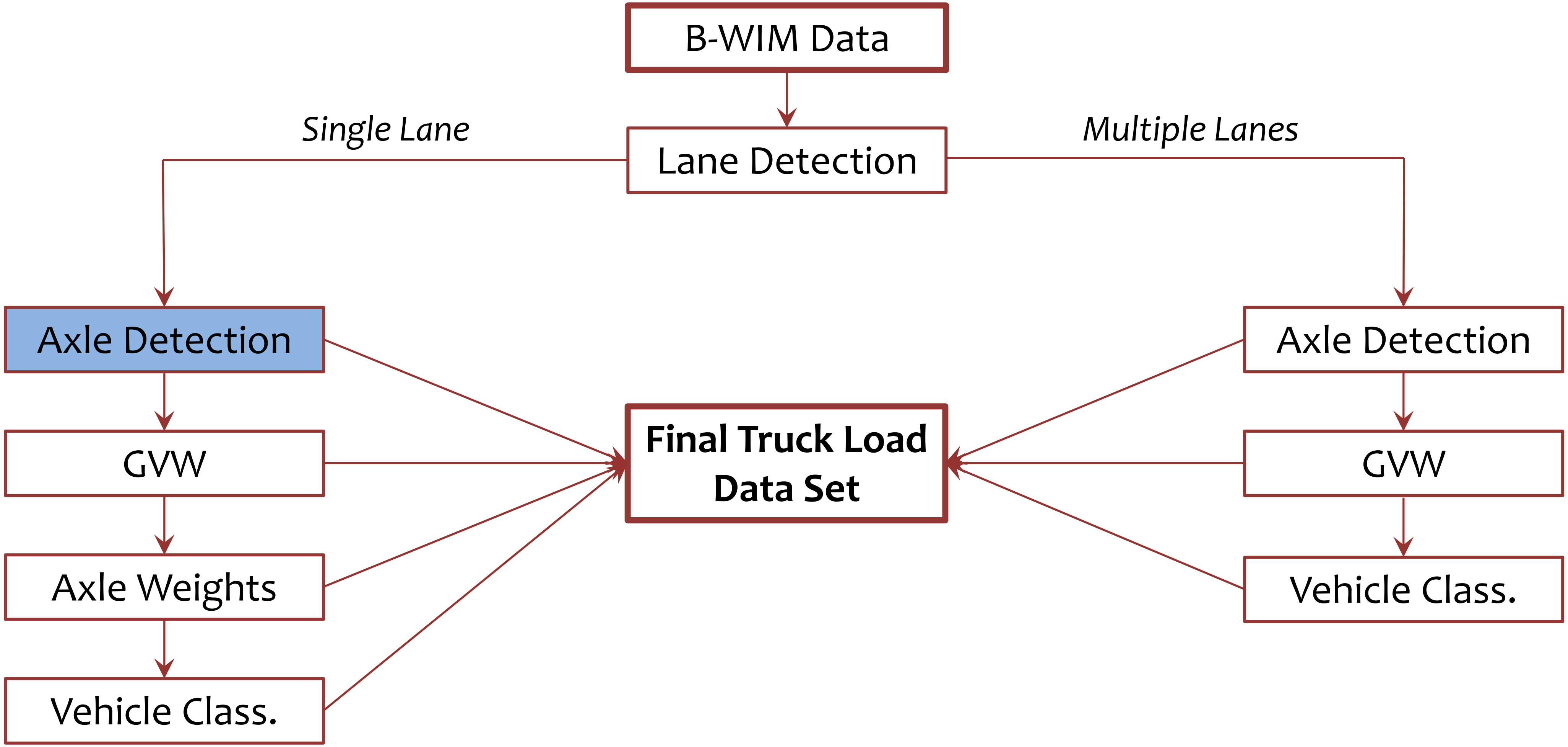
Data Processing

Lane Detection





Data Processing



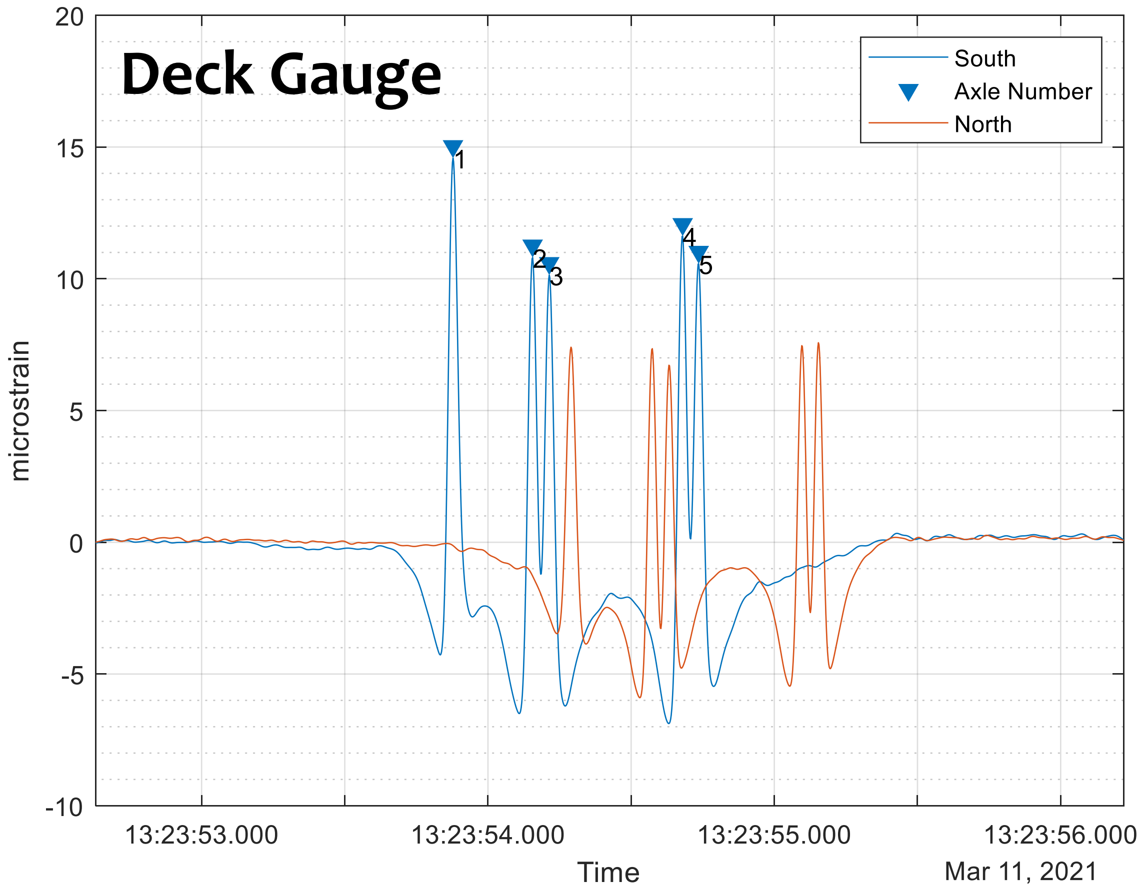
Data Processing

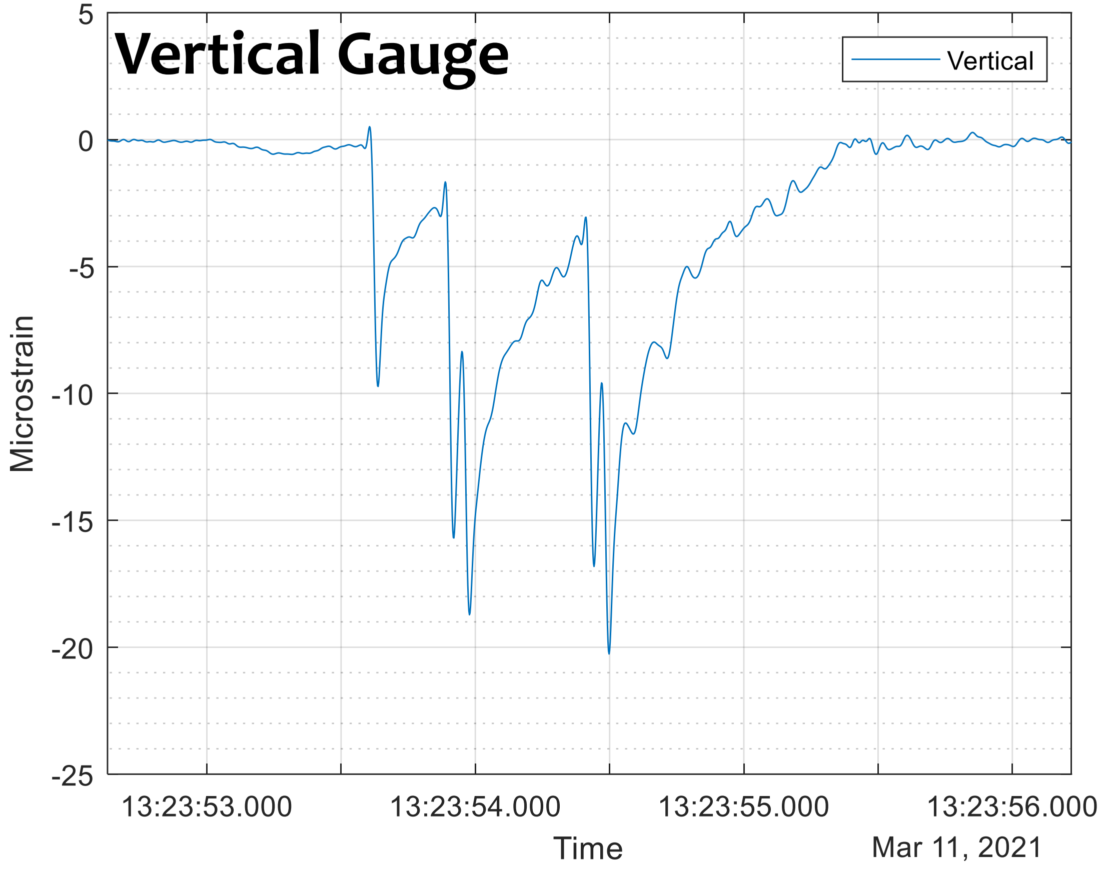
Axle Detection

- Objective to identify precise axle times at specific locations, which provides:
  - Number of axles
  - Vehicle speed
  - Axle spacing
- Methods:
  1. Deck strain gauges (1/4 span)
  2. Beam vertical strain gauges near the bearings
  3. LVDTs measuring vertical bearing deformation

Data Processing

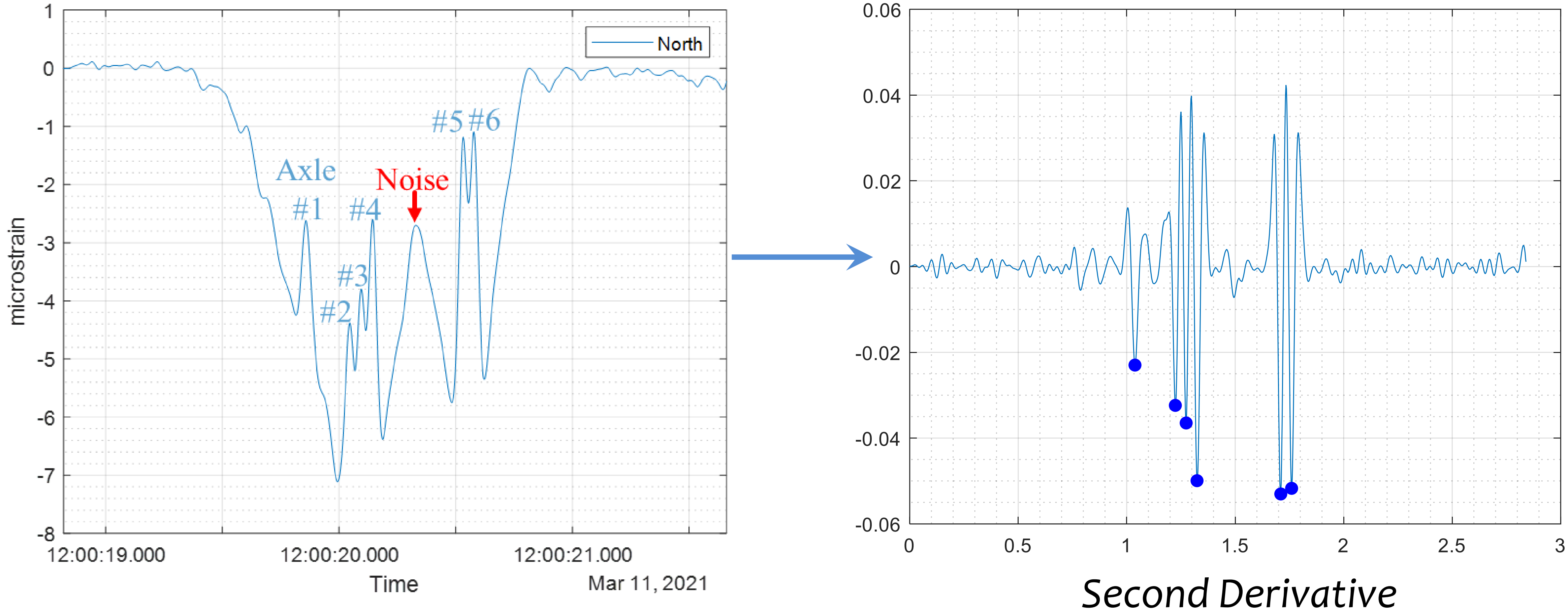
Axle Detection – Number of Axles





Data Processing

Axle Detection - Number of Axles (Second Derivative)

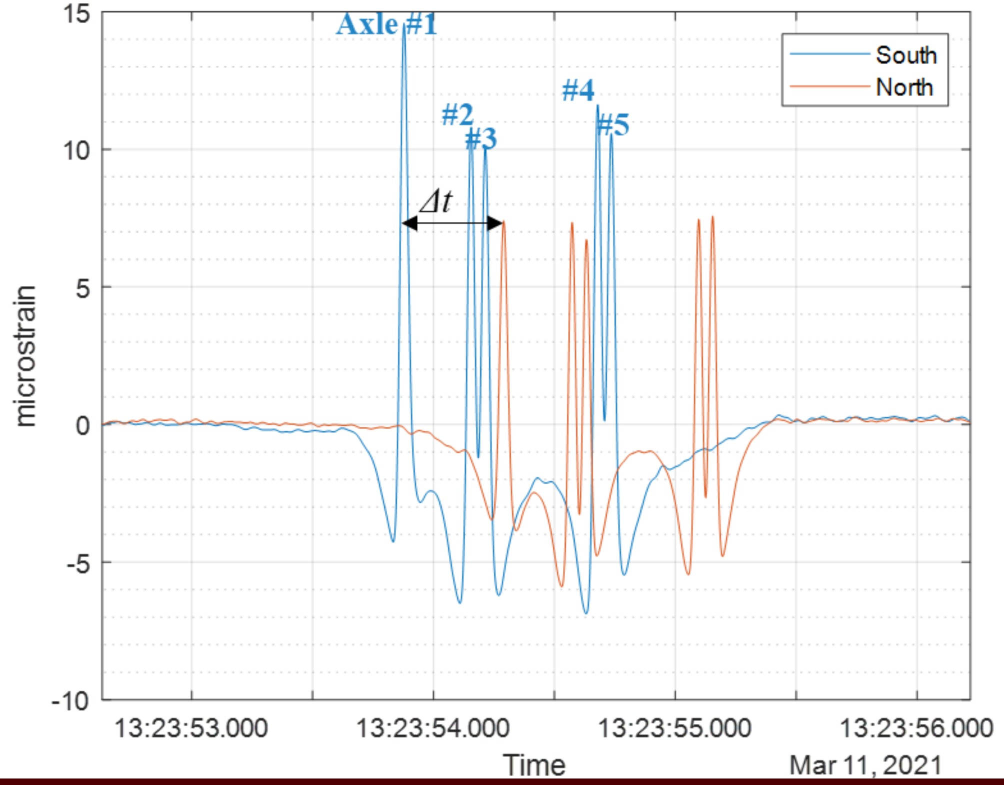


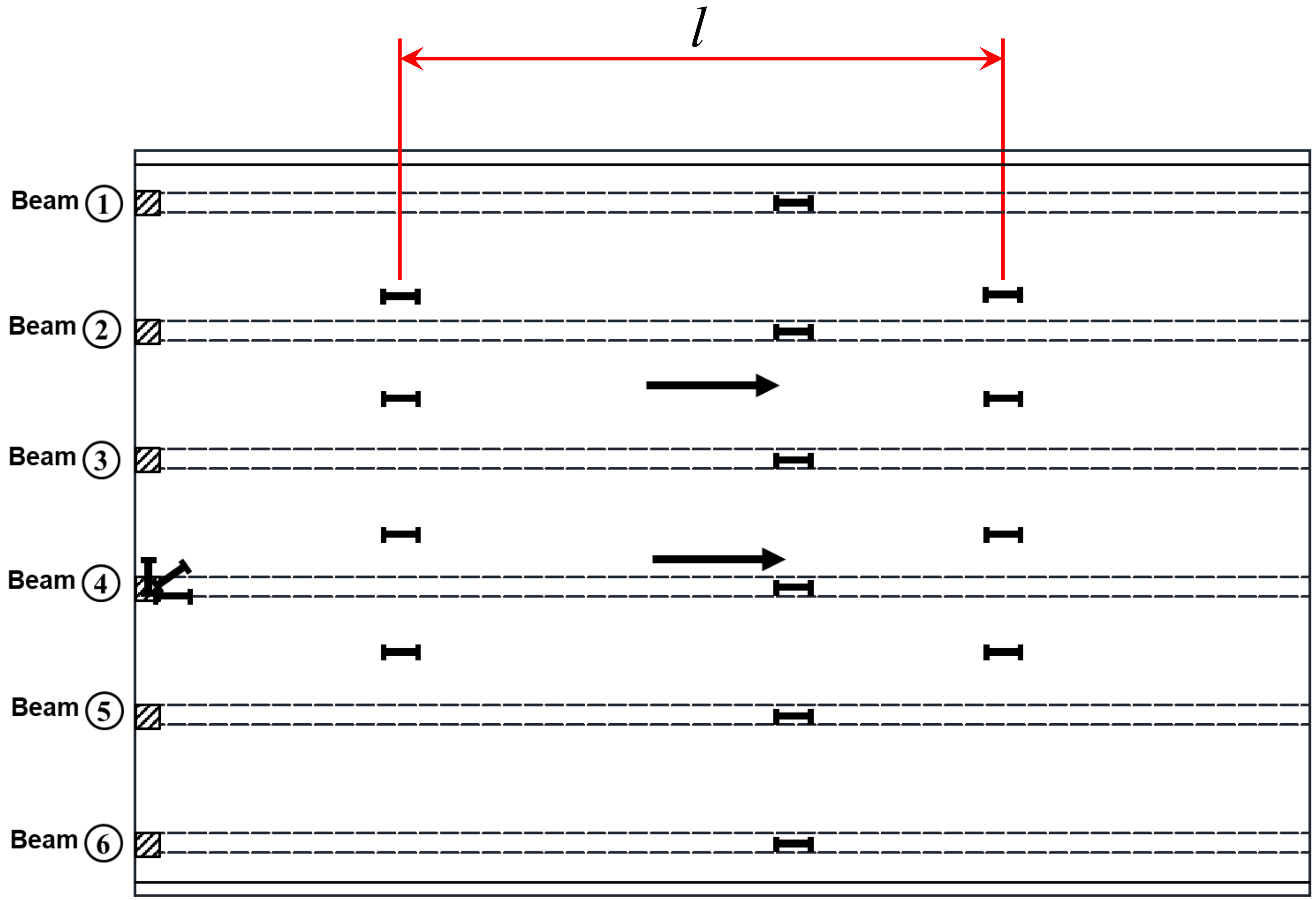
Second Derivative

Data Processing

Axle Detection - Speed

$$v = \frac{l}{\Delta t}$$

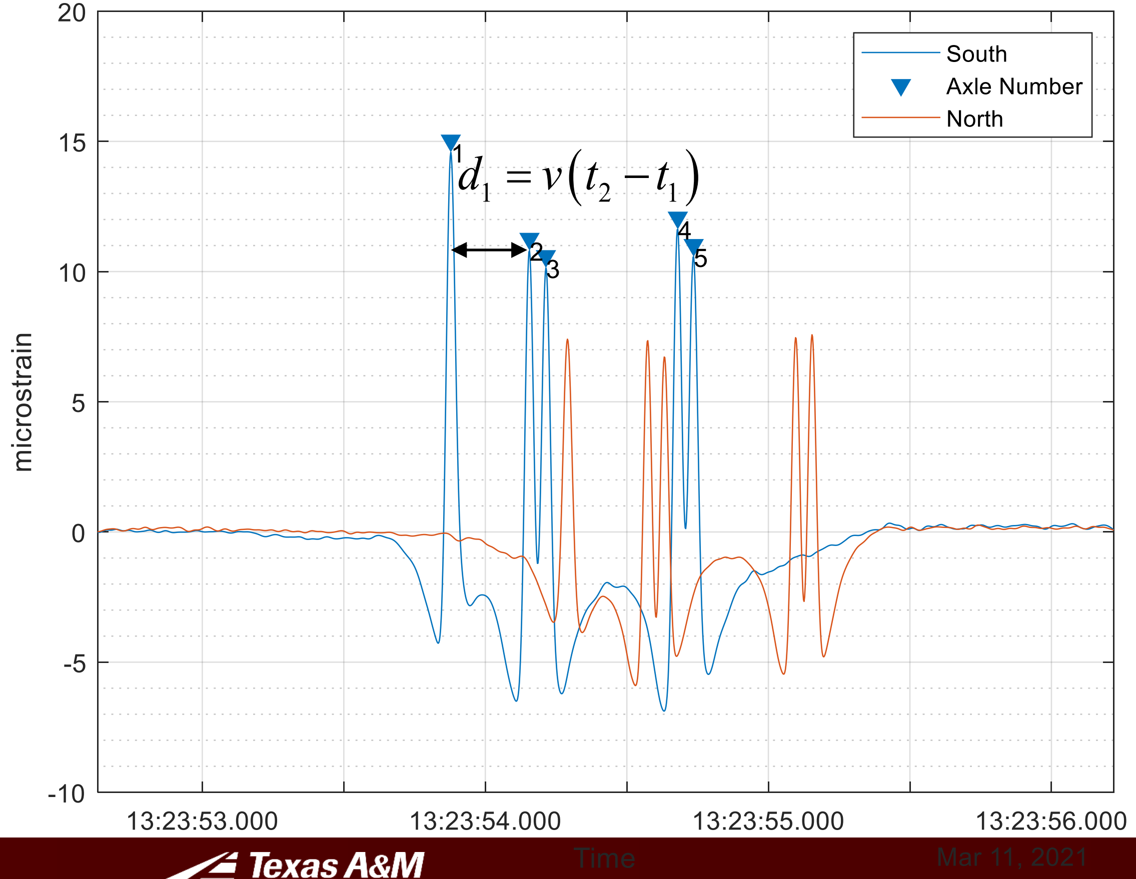




Data Processing

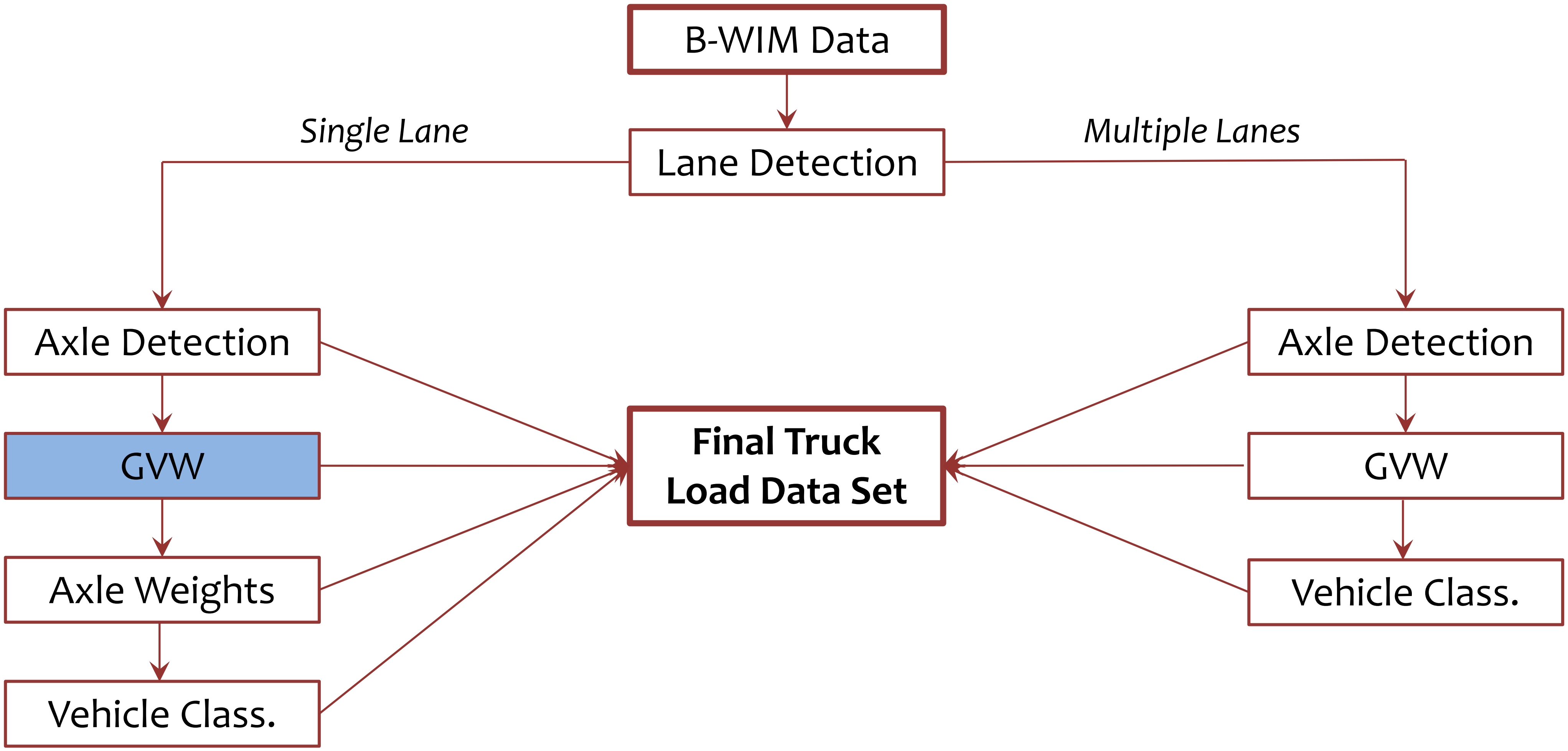
Axle Detection - Spacing

$$d_n = v\left(t_{n+1} - t_n\right), \quad n = 1, 2, 3, \cdots, n-1$$



Example – Measuring axle spacings of a test vehicle

Data Processing

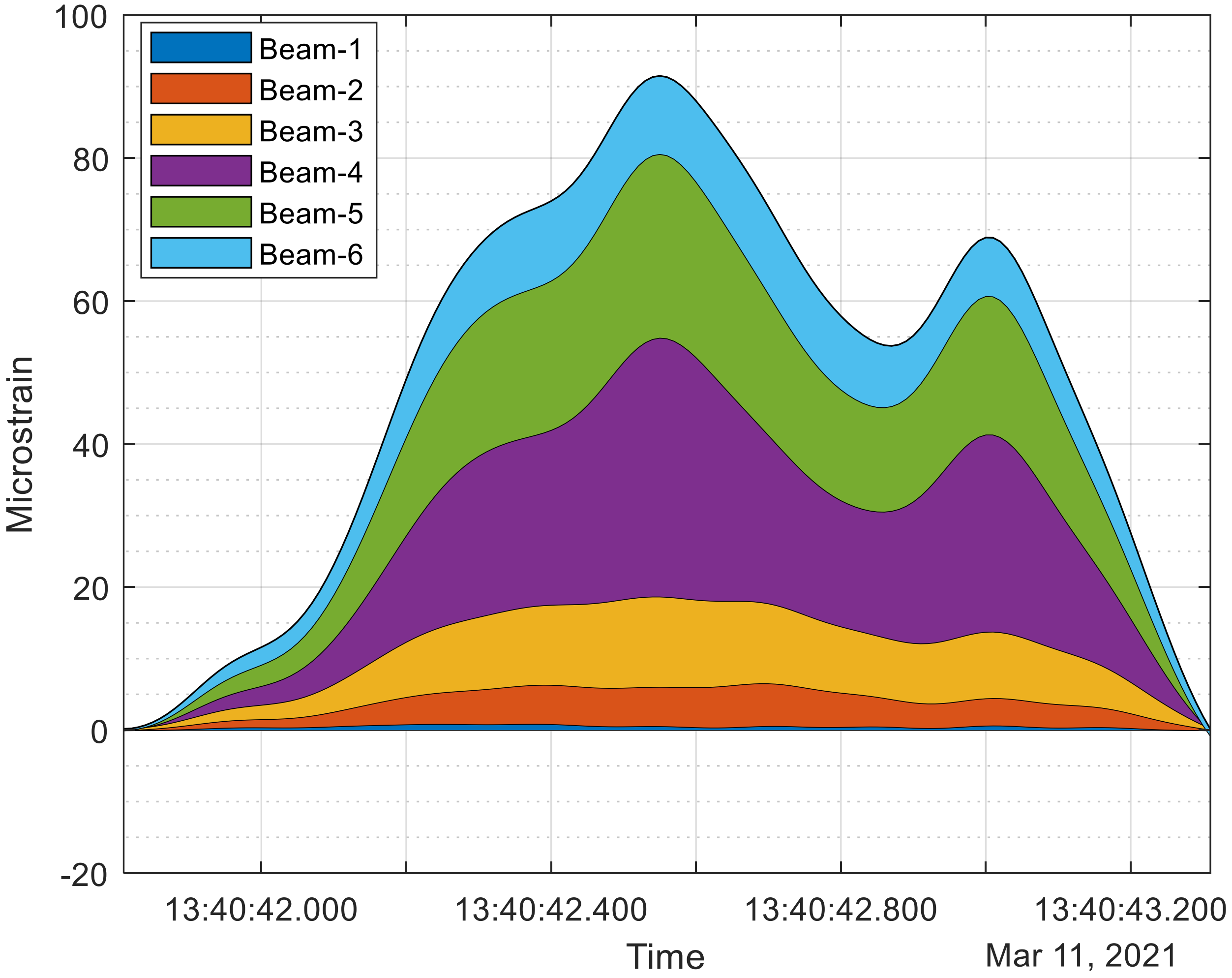


Data Processing

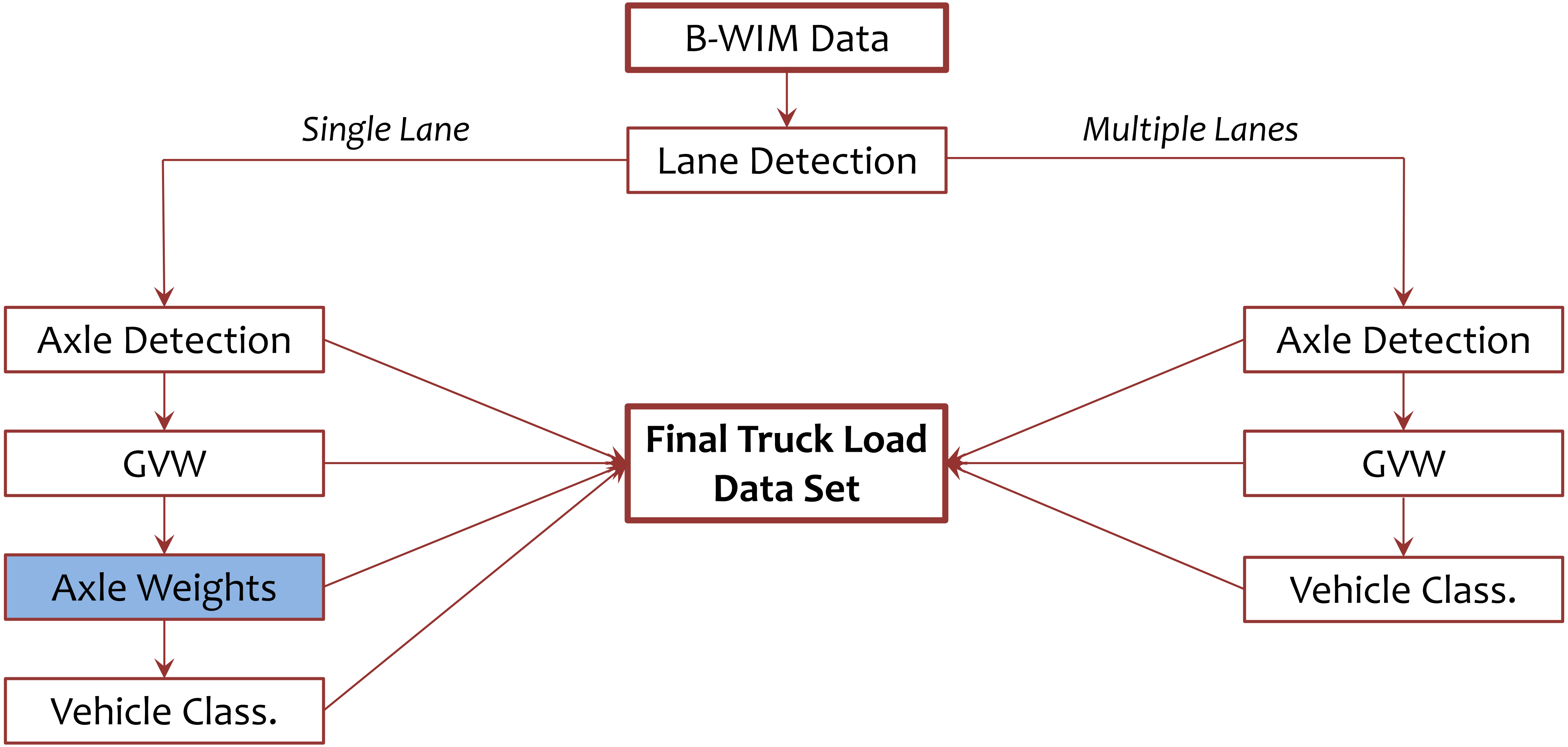
GVW – Area Method shown

- Midspan strain gauges

$$GVW_u = A_u \frac{GVW_c}{A_c} \frac{v_u}{v_c}$$



Data Processing

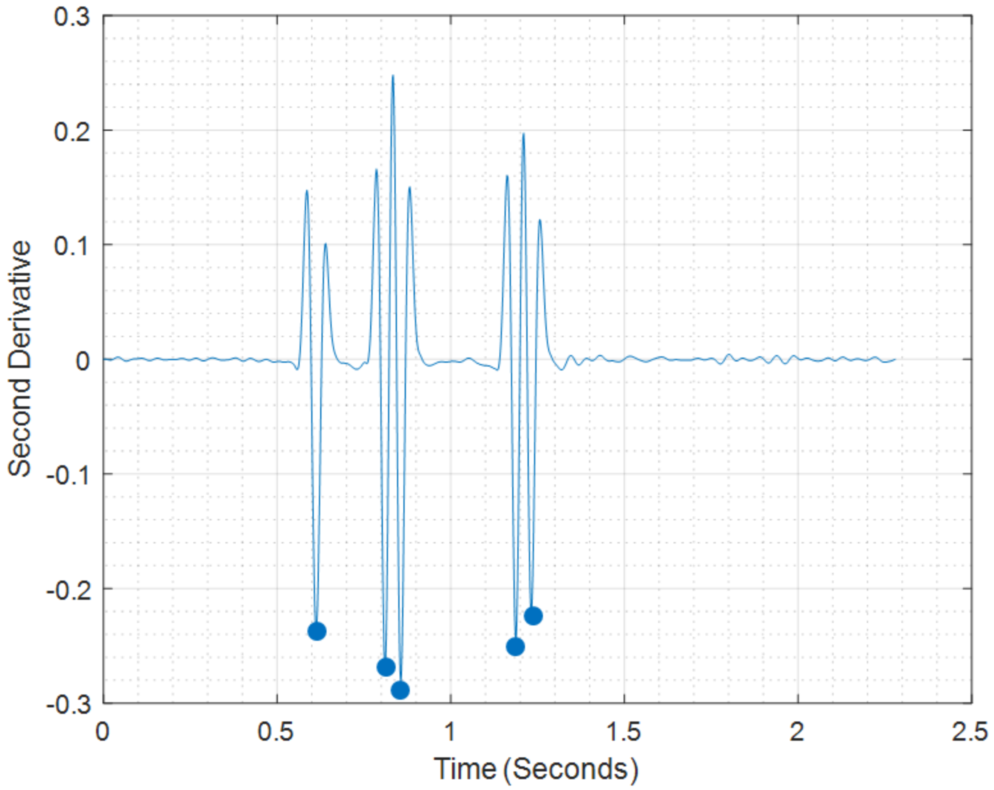


Data Processing

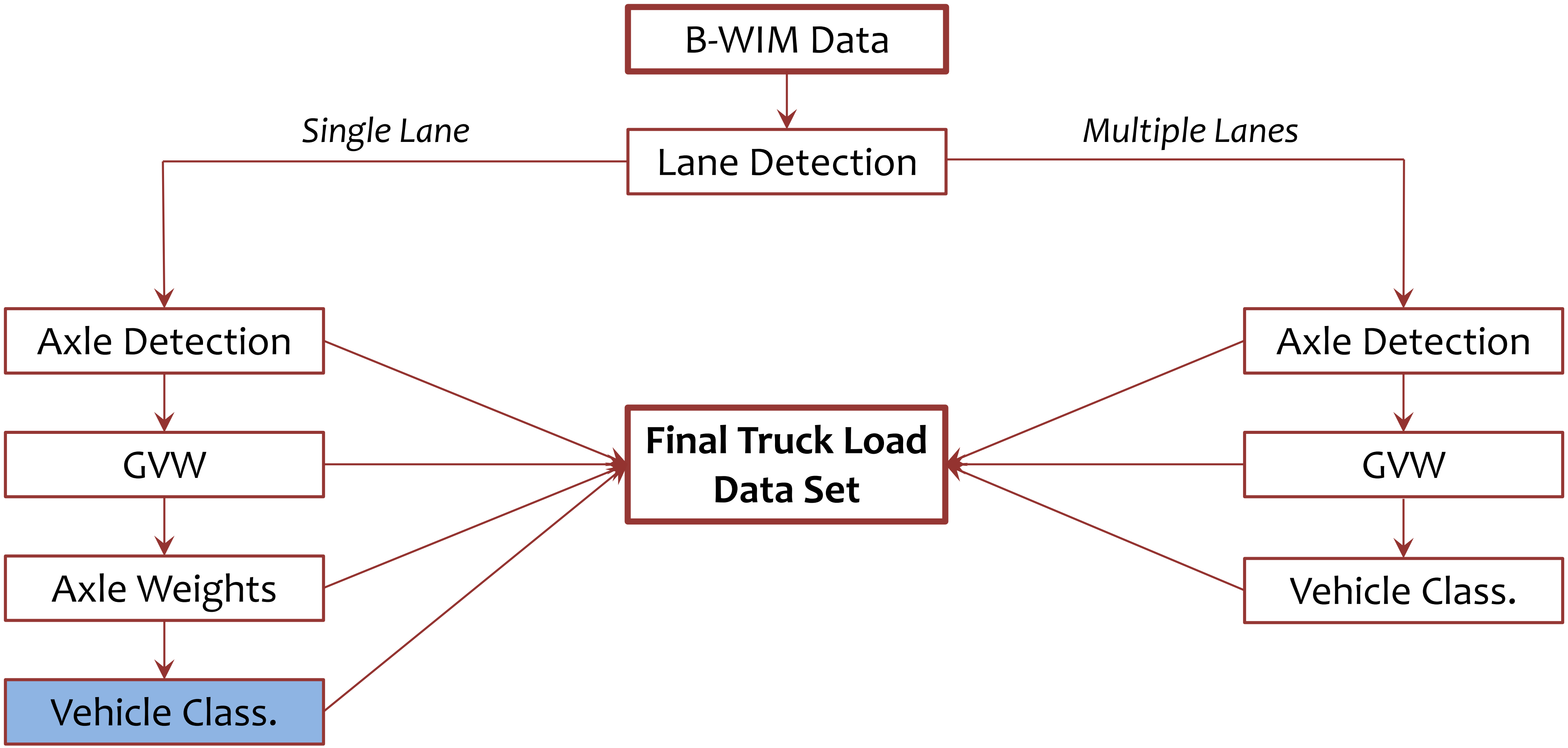
Axle Weights

- Calibrate the GVW by area method
- Axle weights are calculated by distribute the GVW according to peak values in second derivative data

$$P_n = \left[\frac{\frac{d^2\varepsilon}{dt^2}(n)}{\sum_{i=1}^{n} \frac{d^2\varepsilon}{dt^2}(i)} \right] \times GVW$$



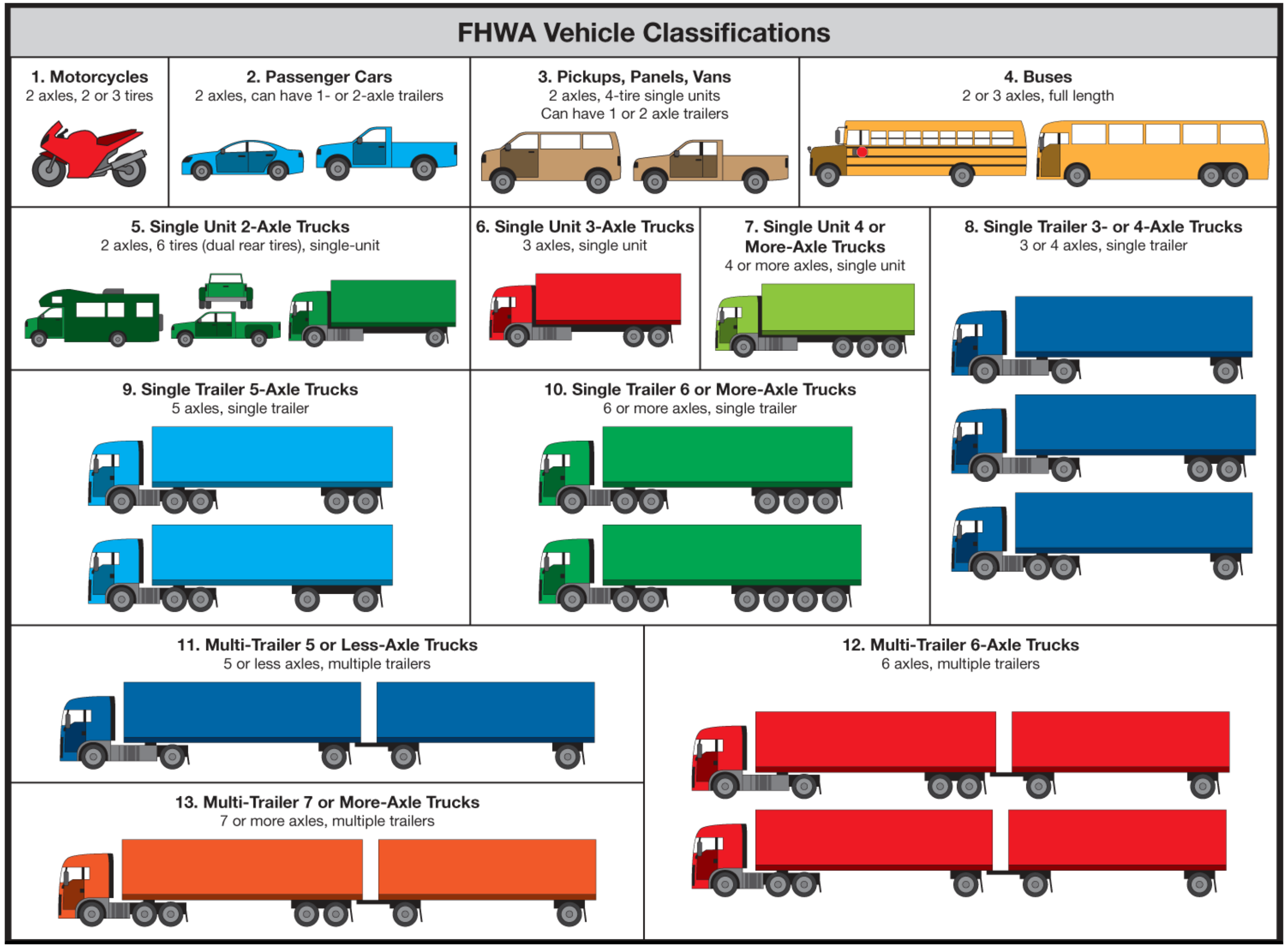
Data Processing



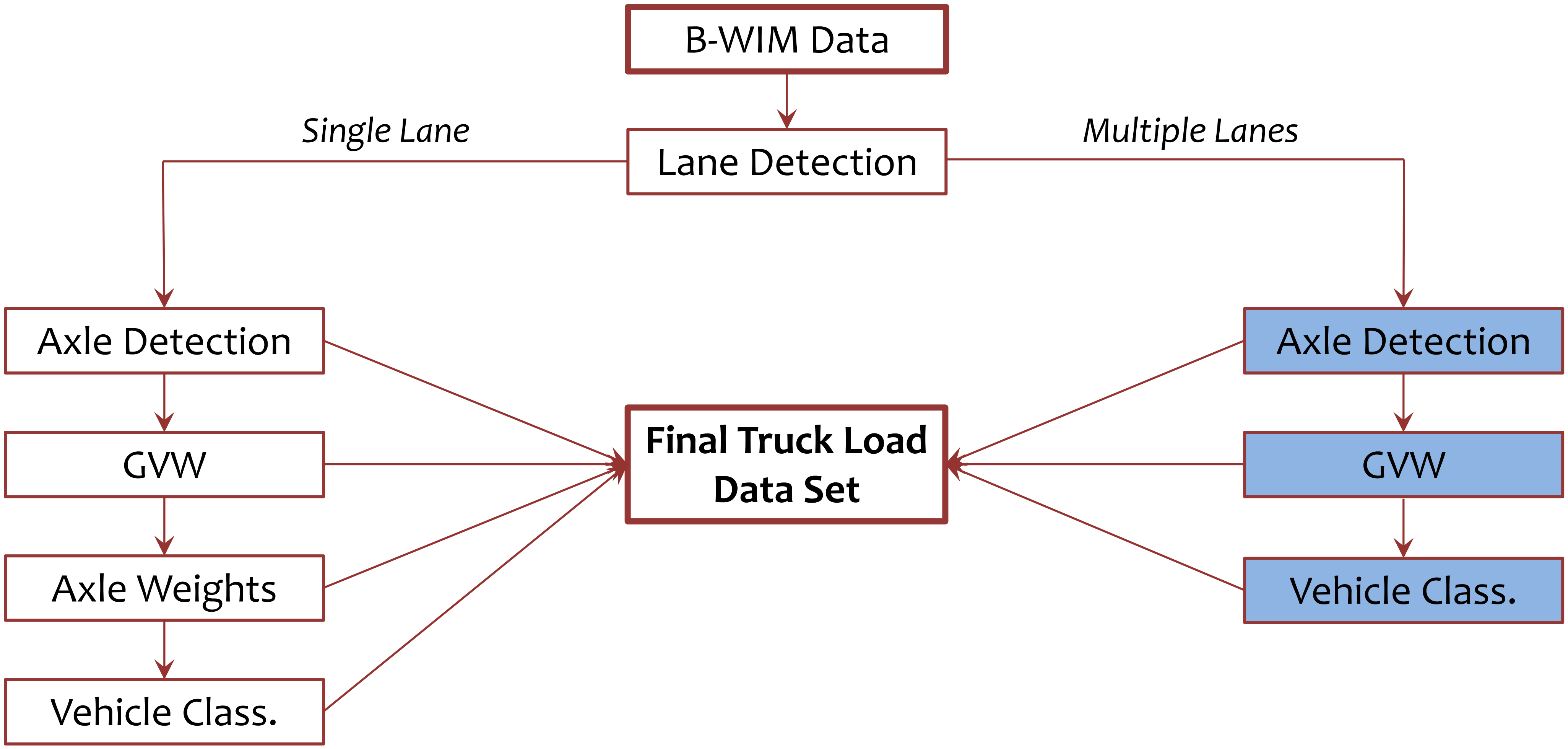
Data Processing

Classification

- Number of axles
- Spacing of axles
- Gross Vehicle Weight



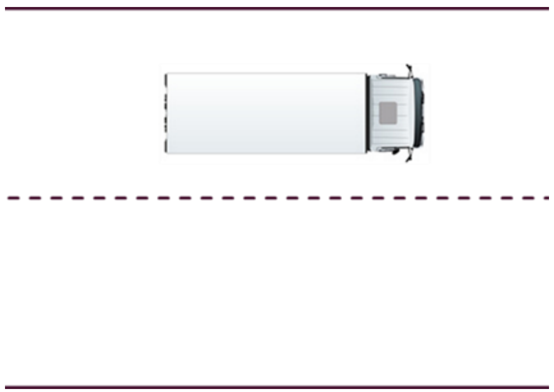
Data Processing

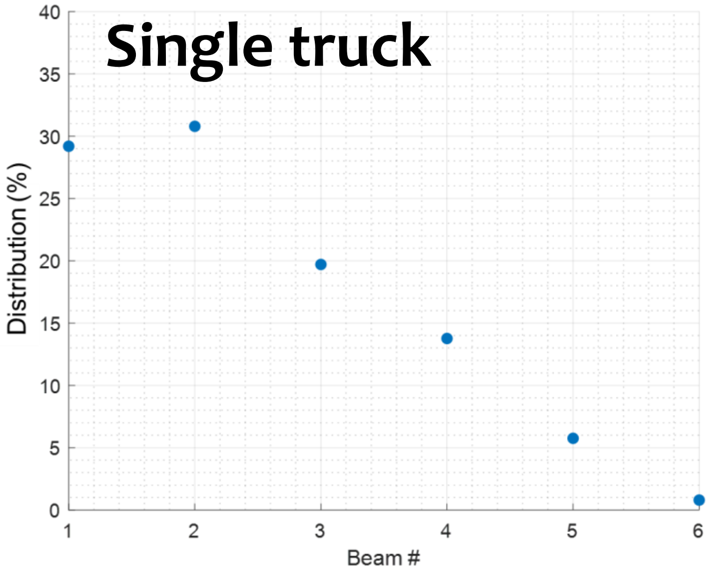


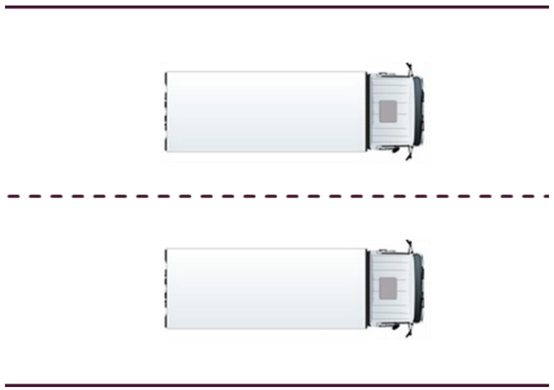
Data Processing

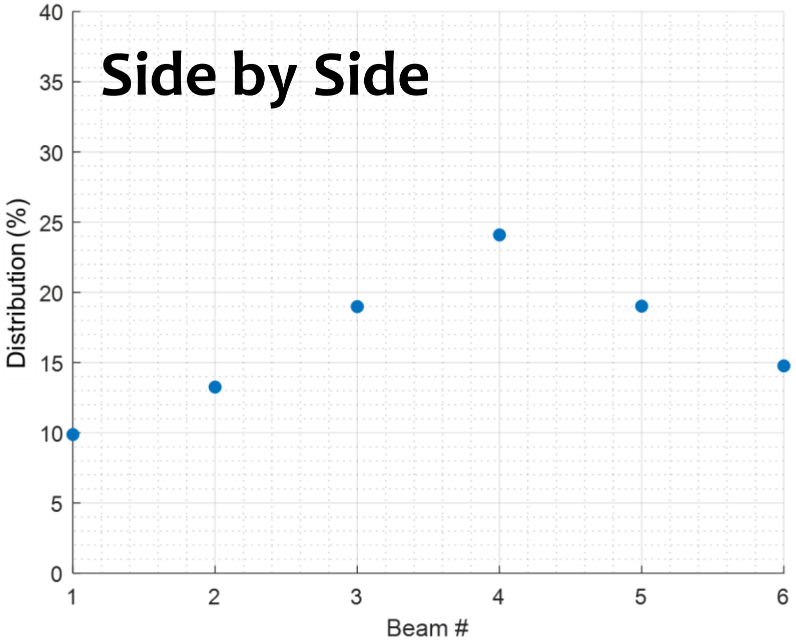
Side-by-Side Detection and GVW Calculation

- Identified using distribution factors
- GVW calculated using the distribution factors with the Area Method

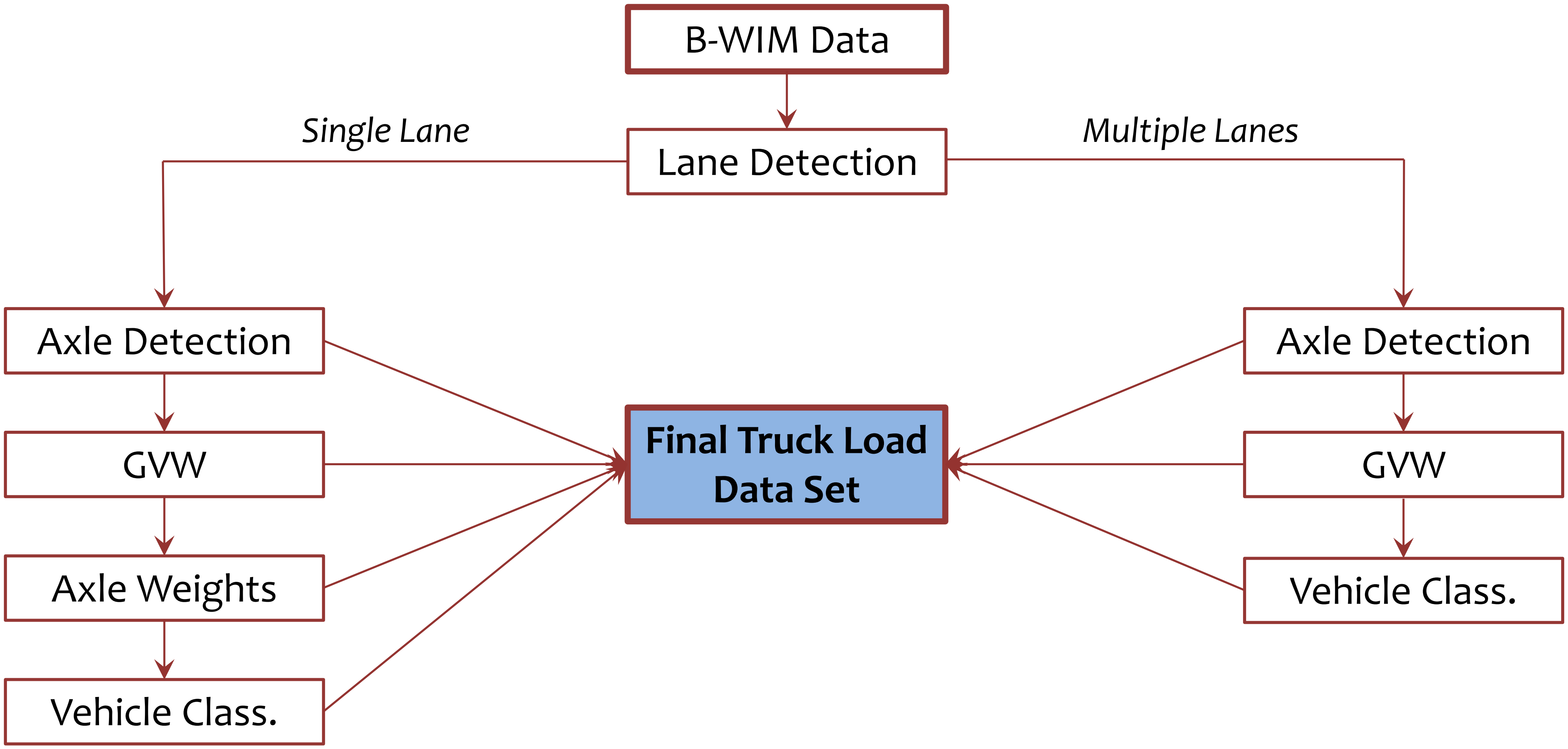








Data Processing

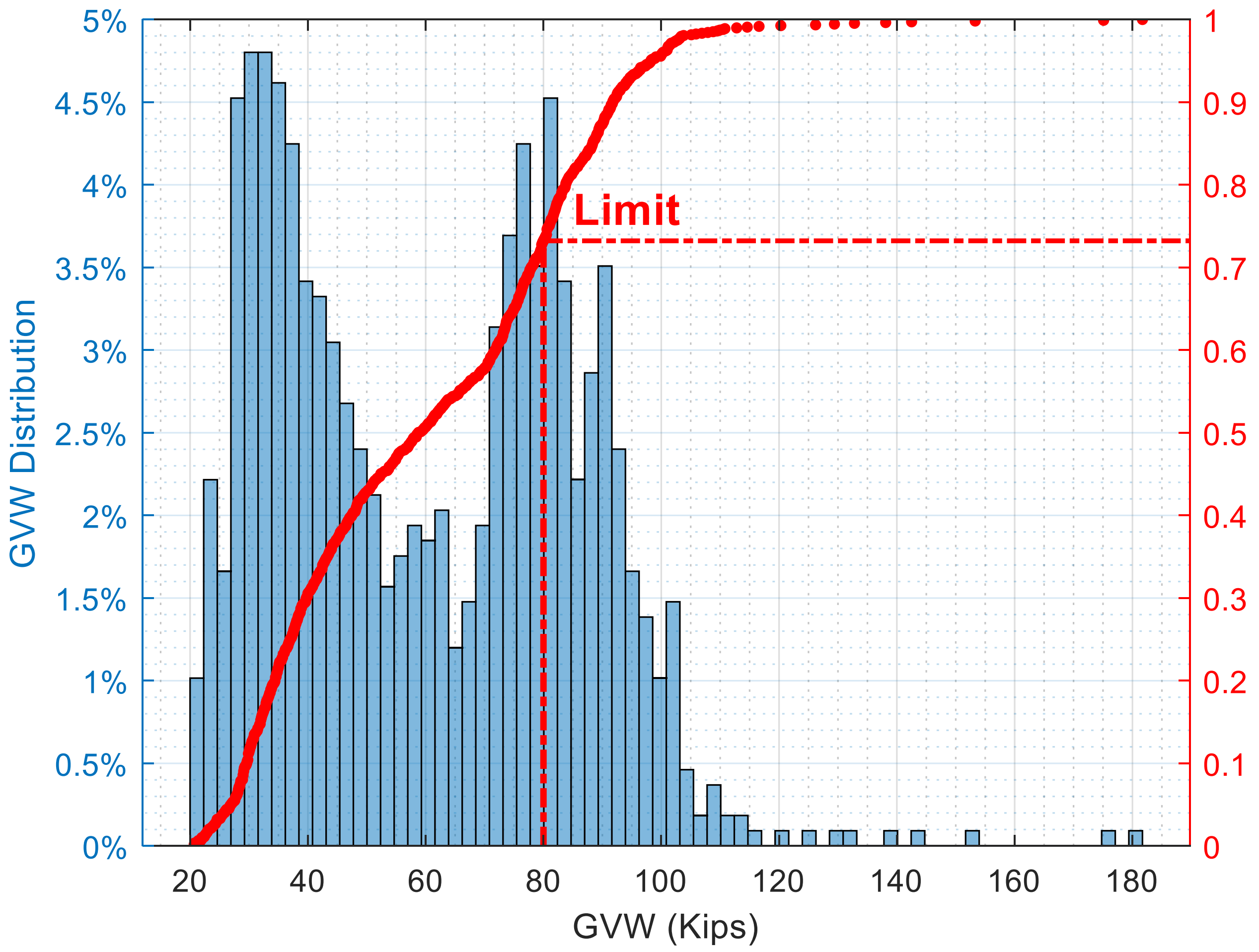


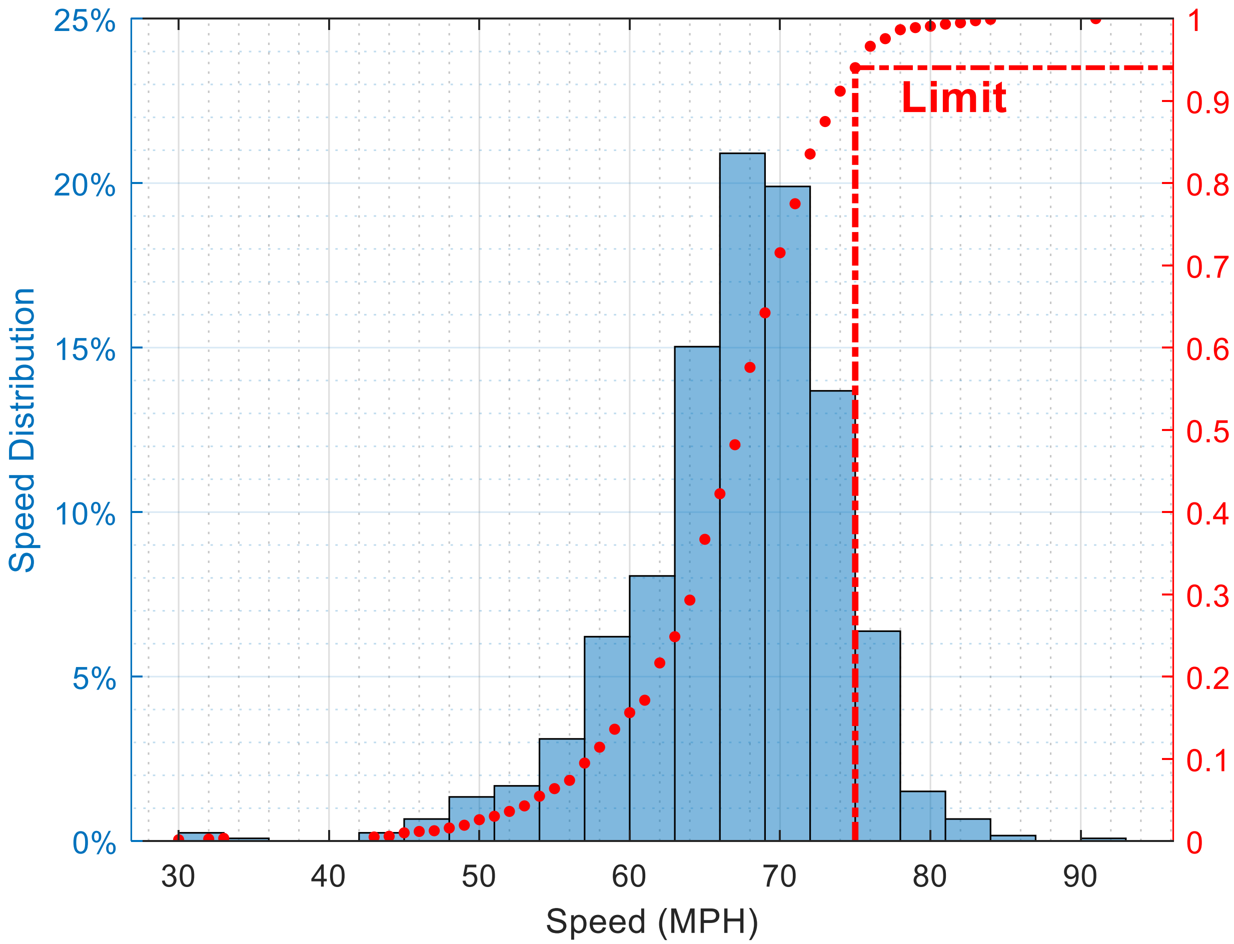
Data Processing

Bridge #1

Q4

Sample Results



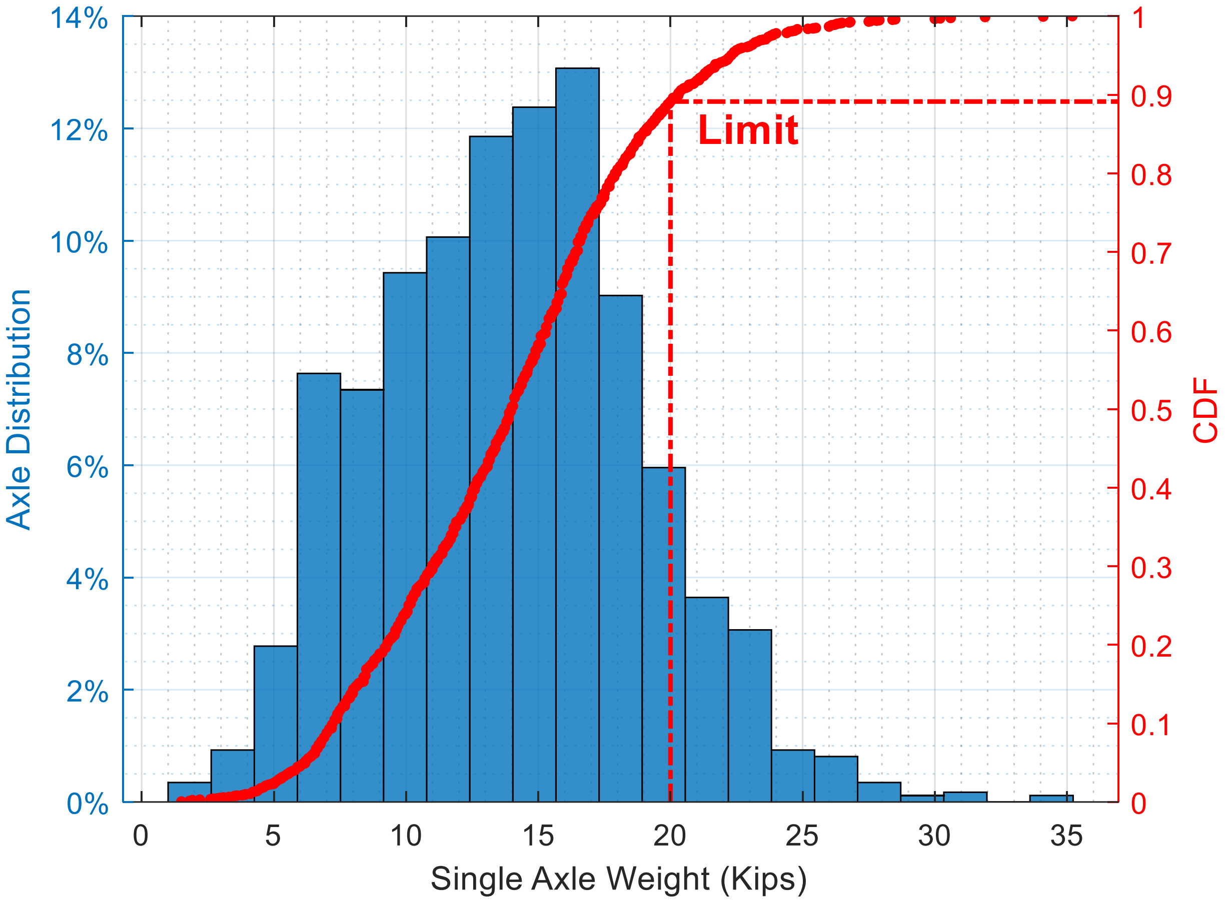


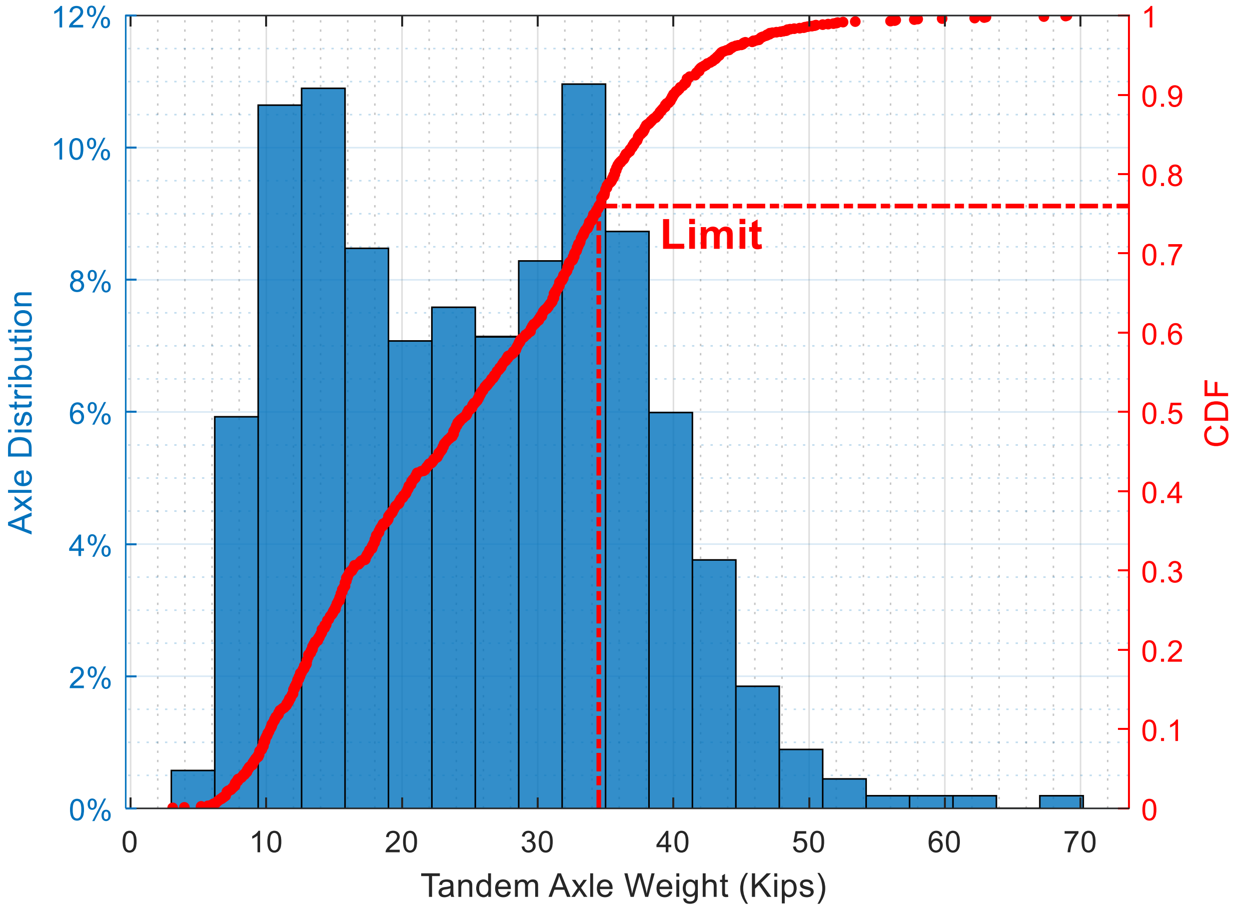
Data Processing

Bridge #1

Q5

Sample Results



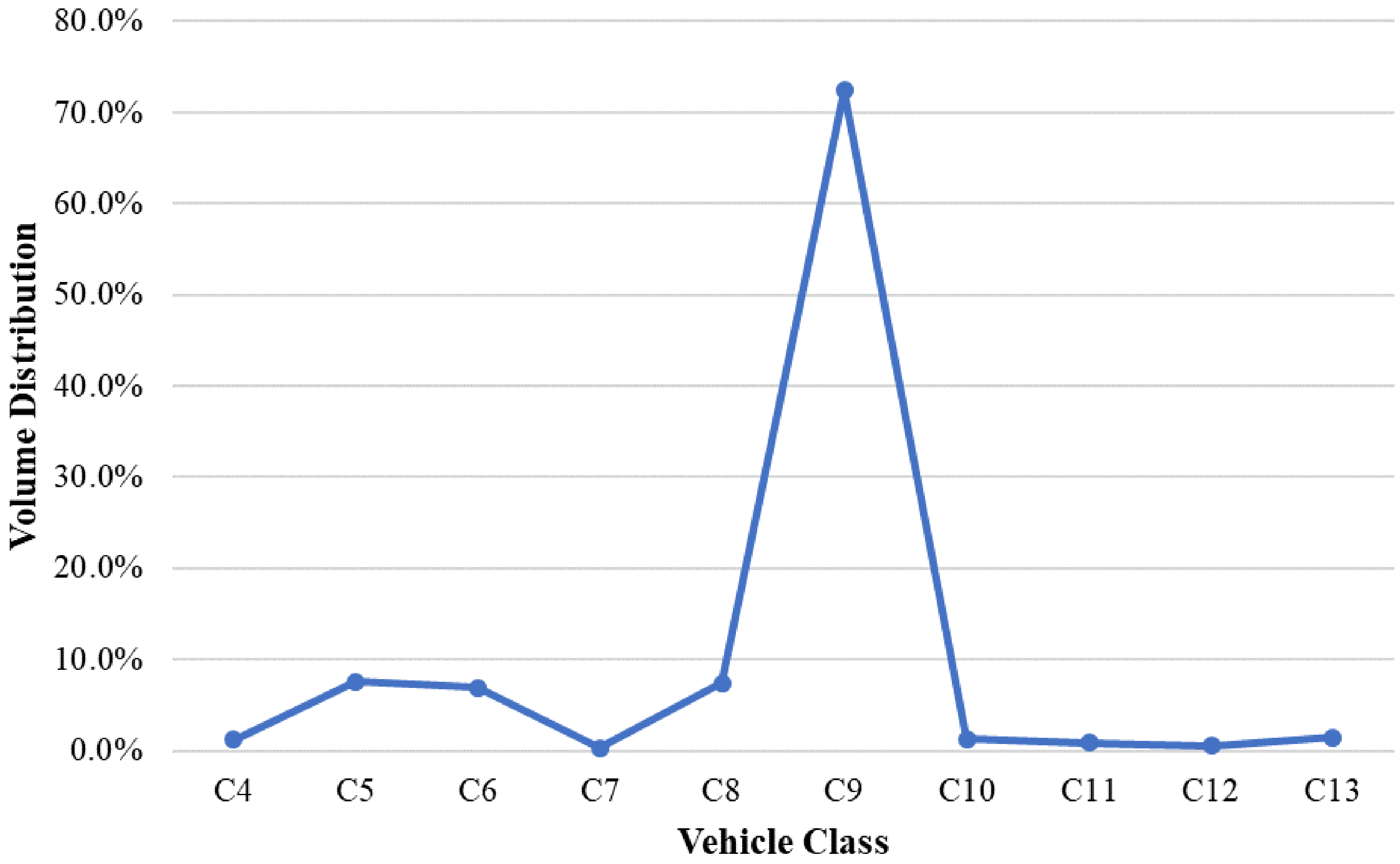


Texas A&M Transportation Institute

Data Processing

Bridge #1

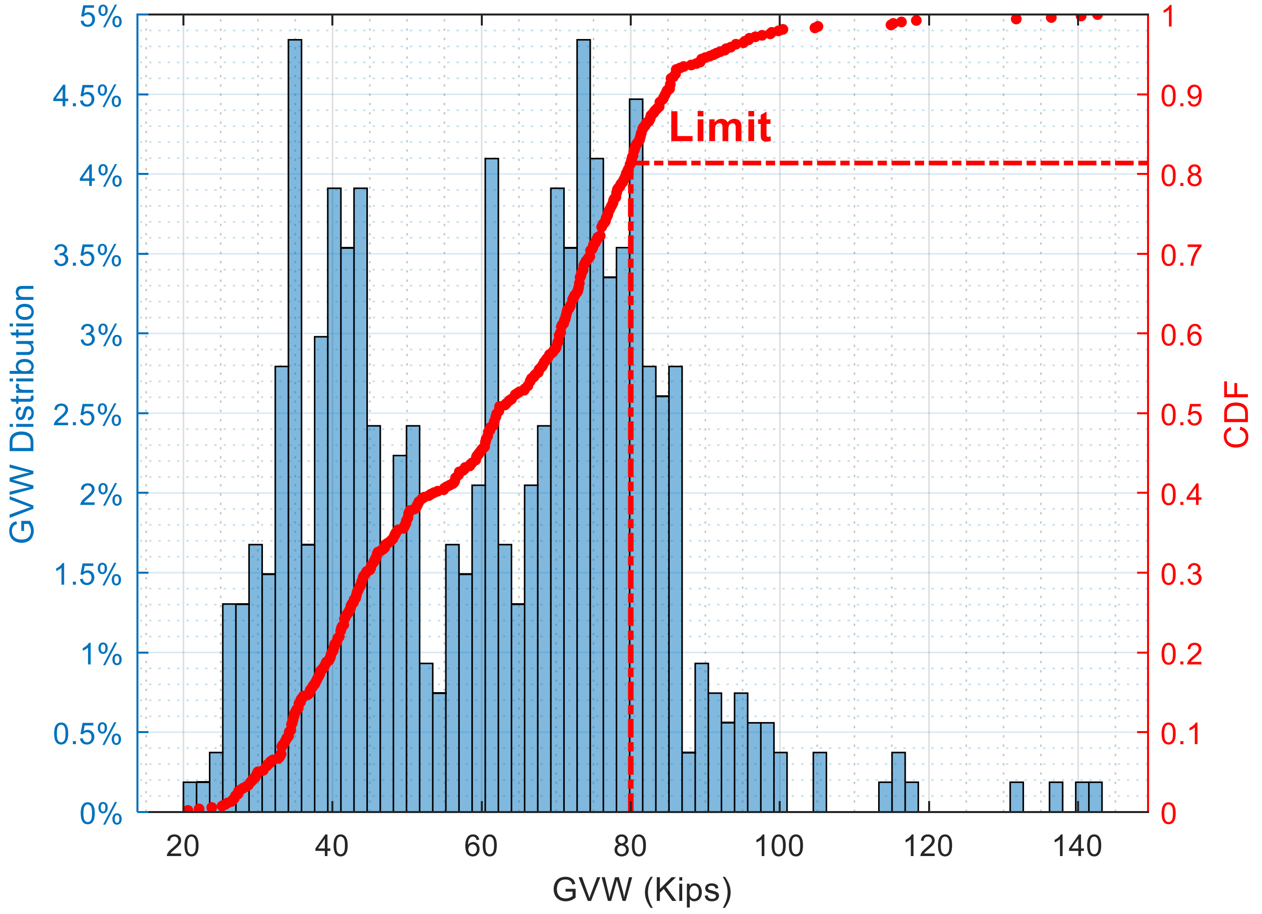
Sample Results

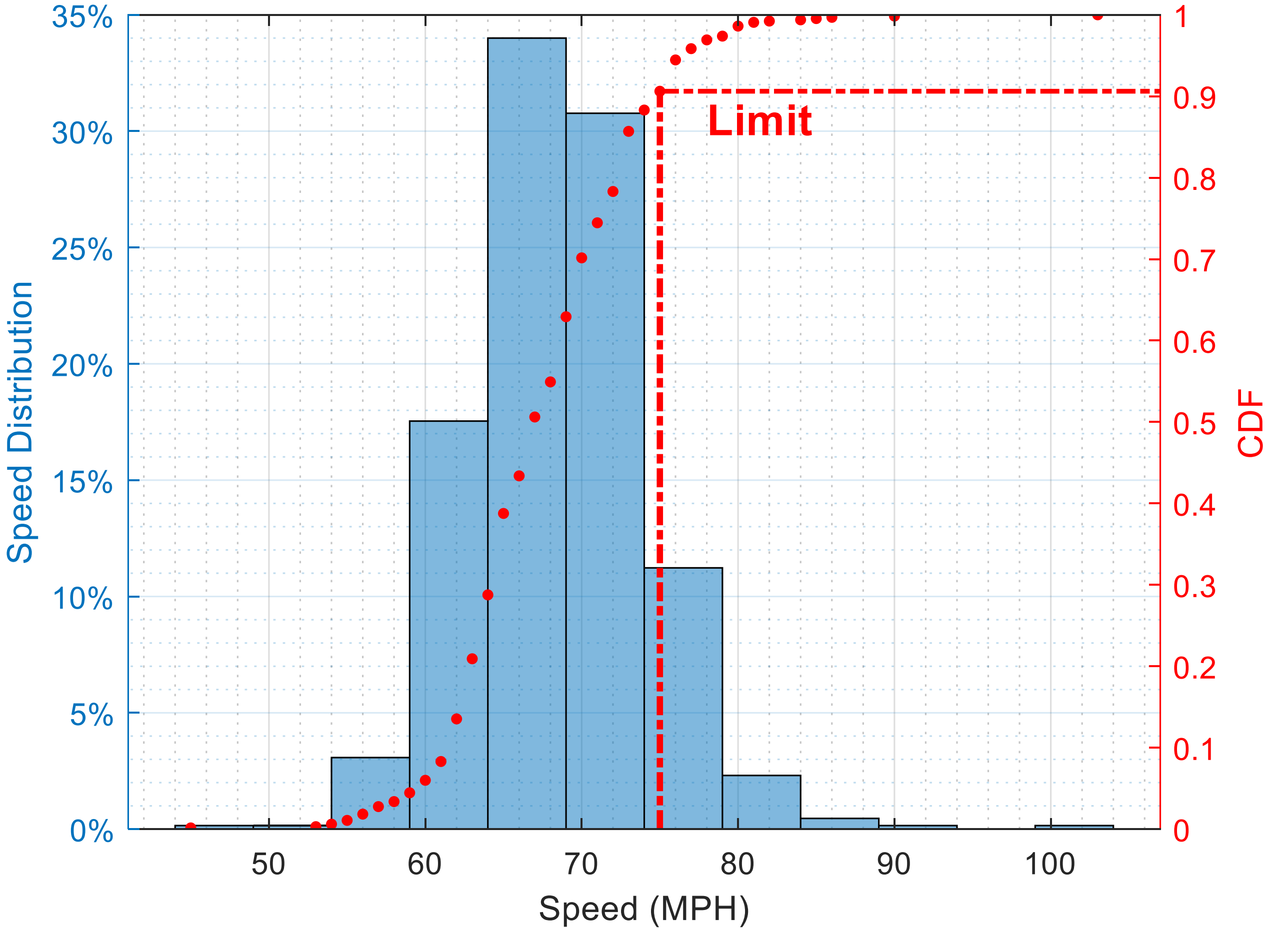


Data Processing

Bridge #2

Sample Results

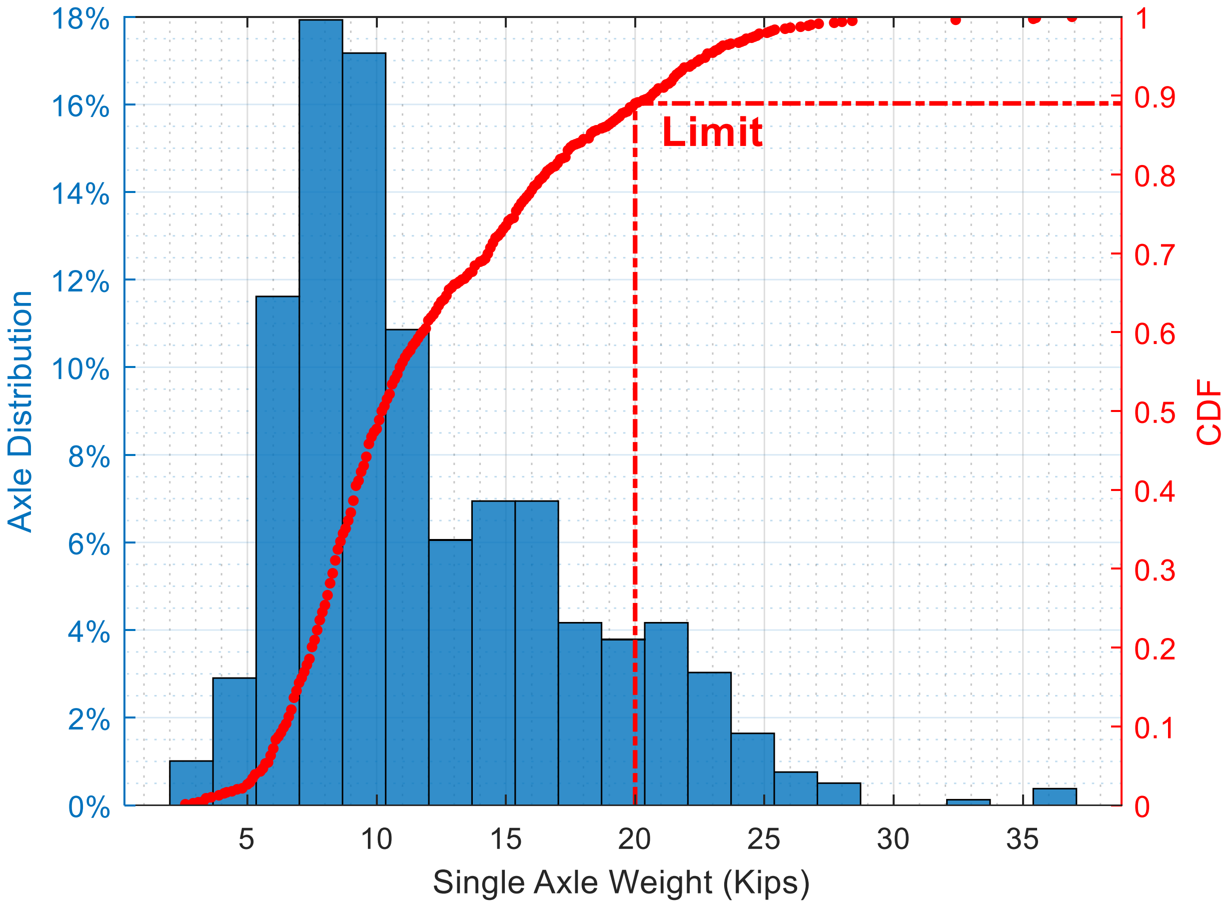


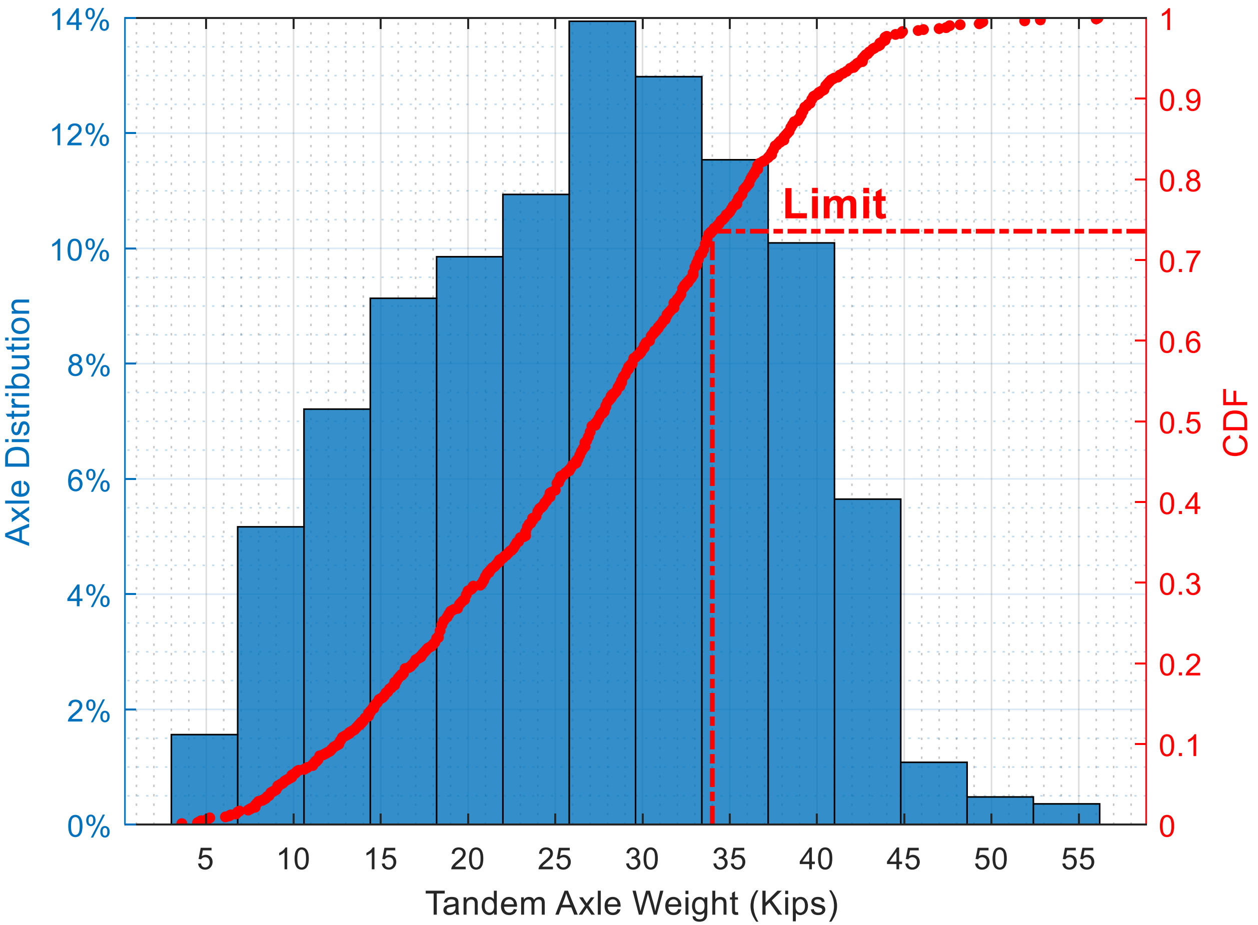


Data Processing

Bridge #2

Sample Results

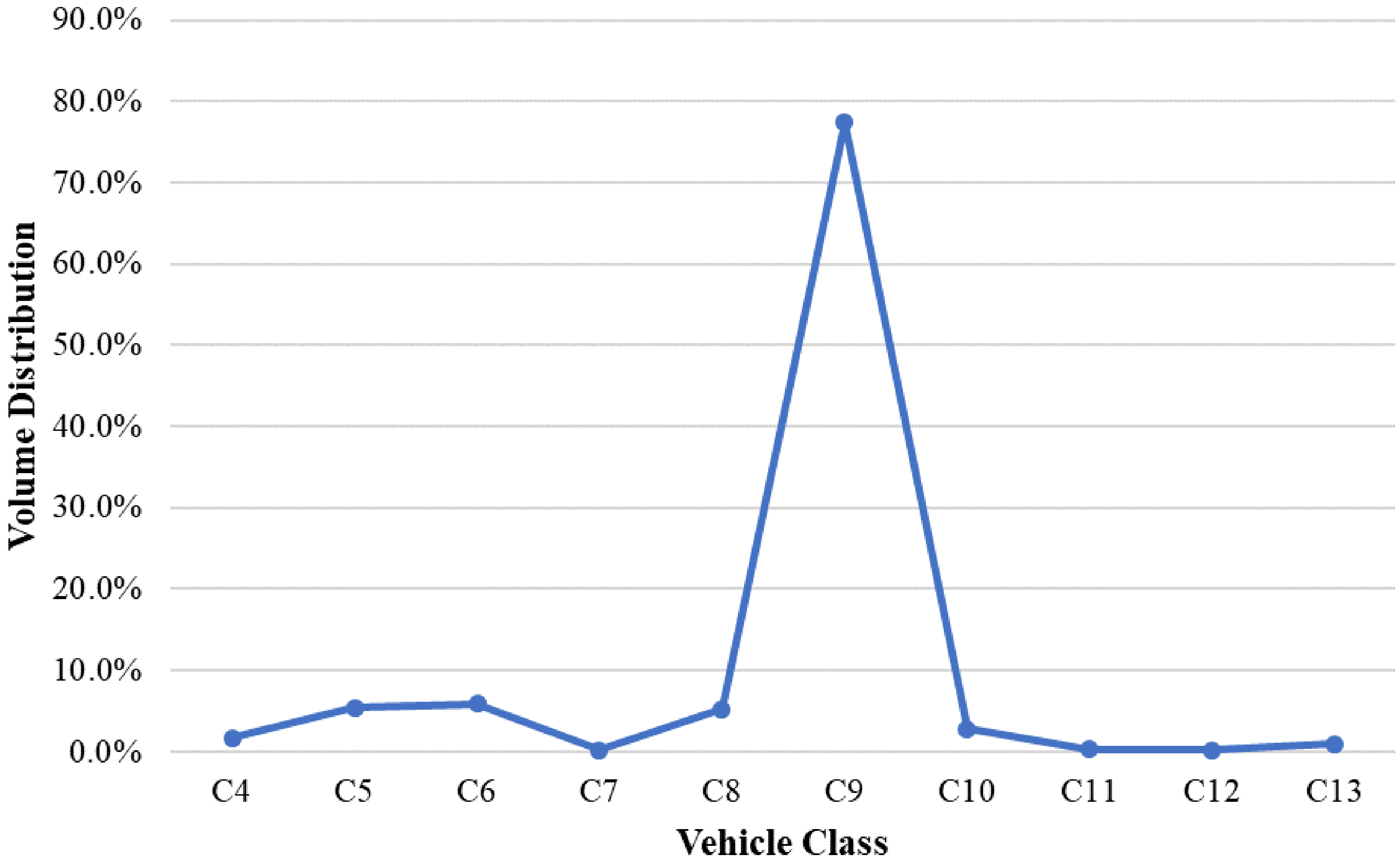




Data Processing

Bridge #2

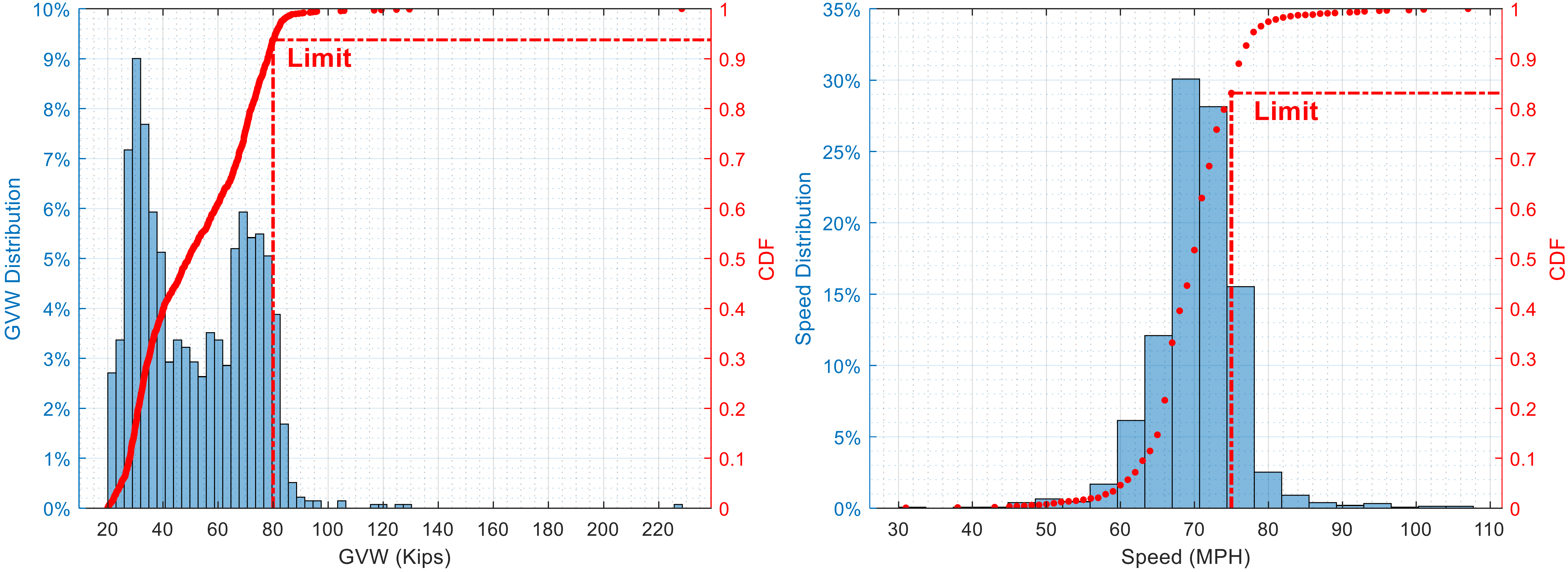
Sample Results



Texas A&M Transportation Institute

Data Processing

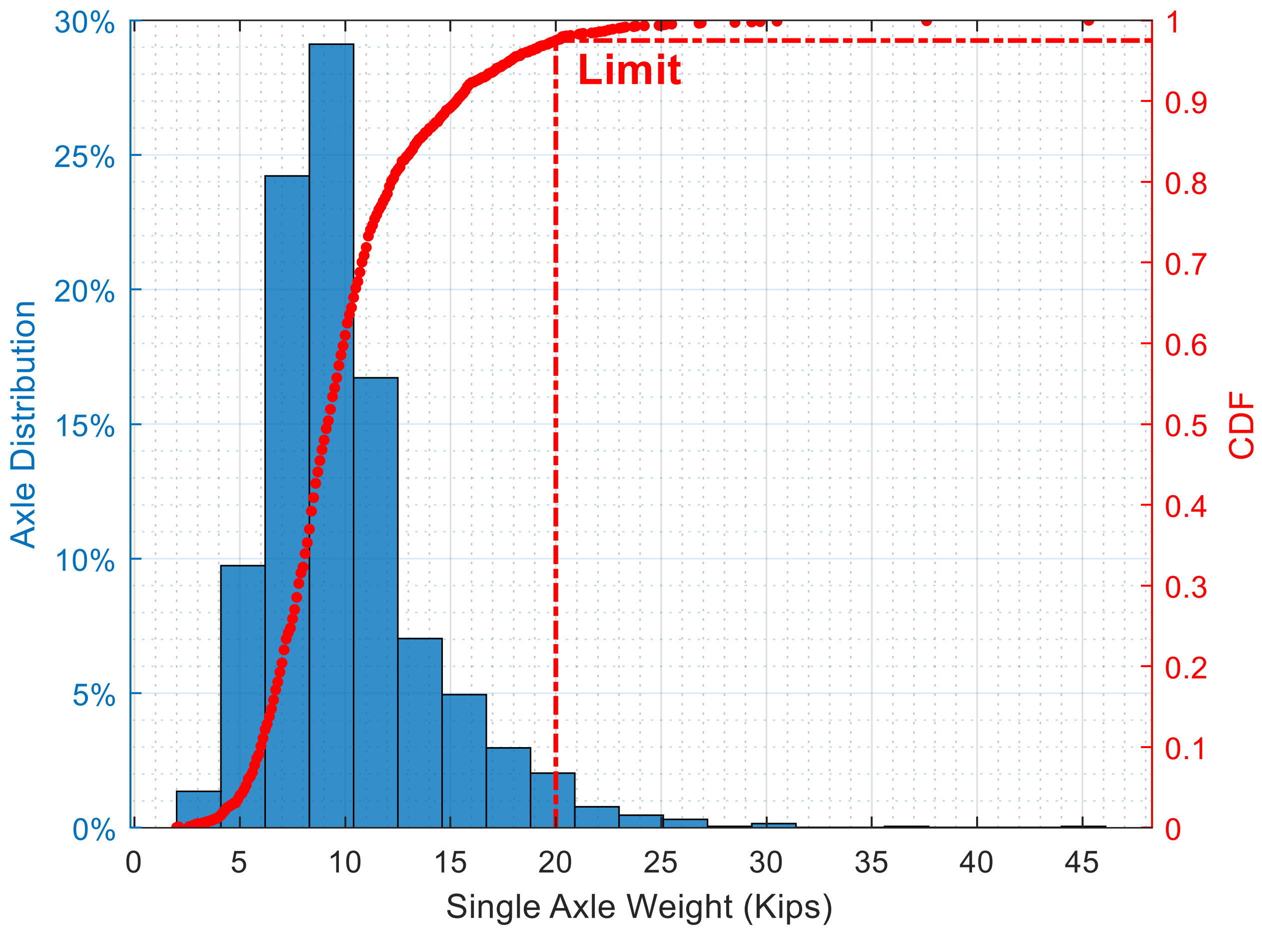
Sample Results

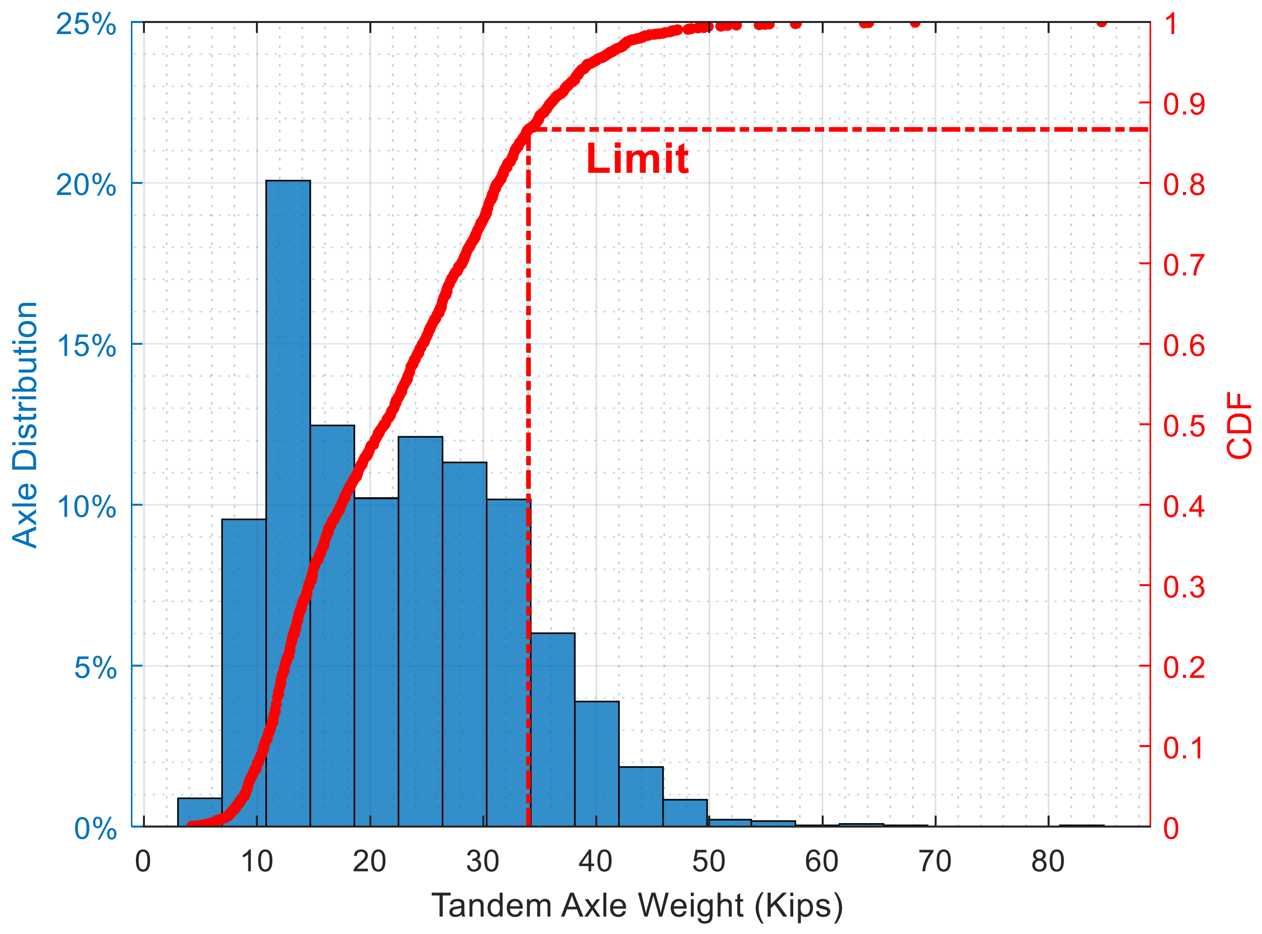


Data Processing

Bridge #3

Sample Results



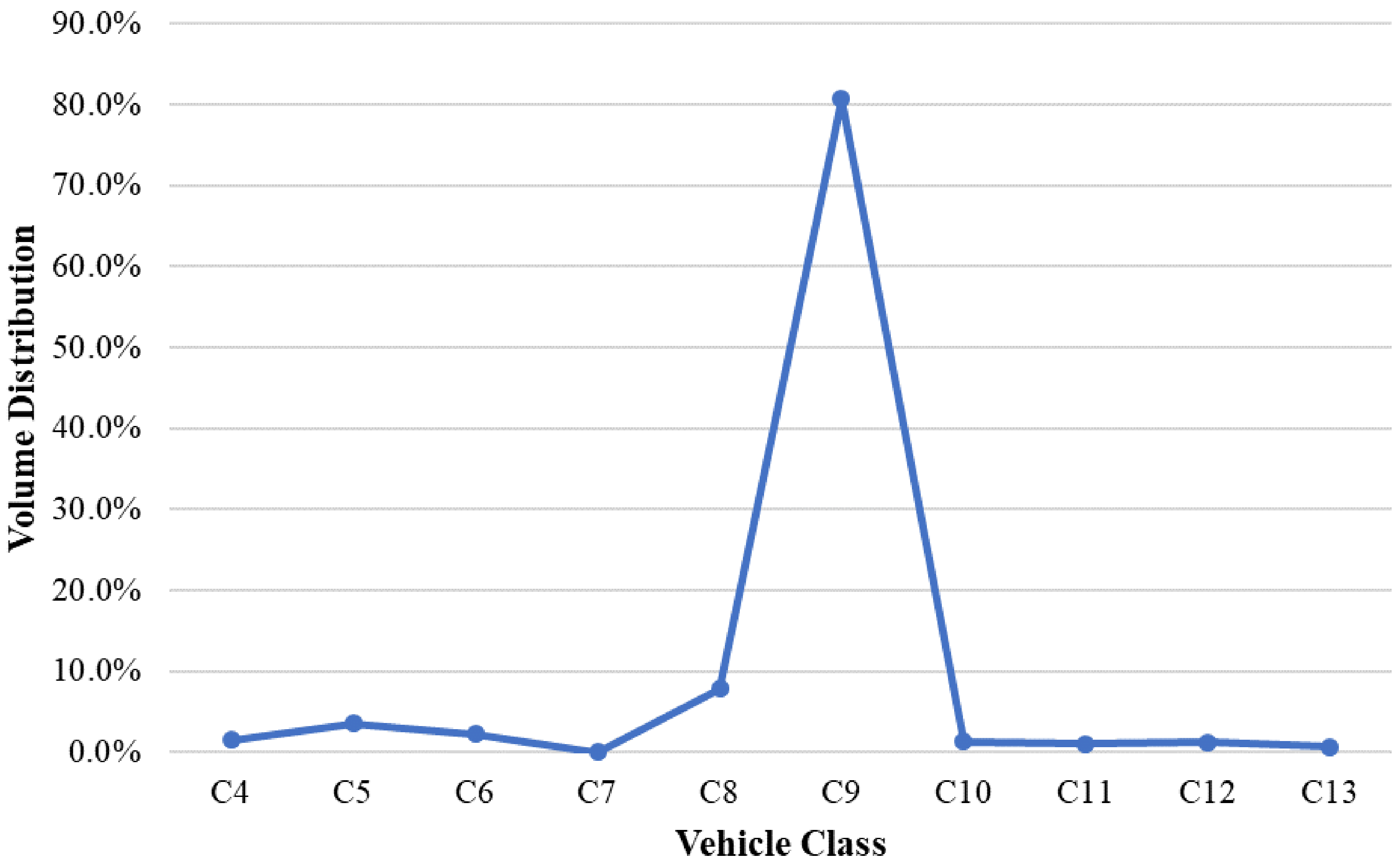


Data Processing

Bridge #3

Q6

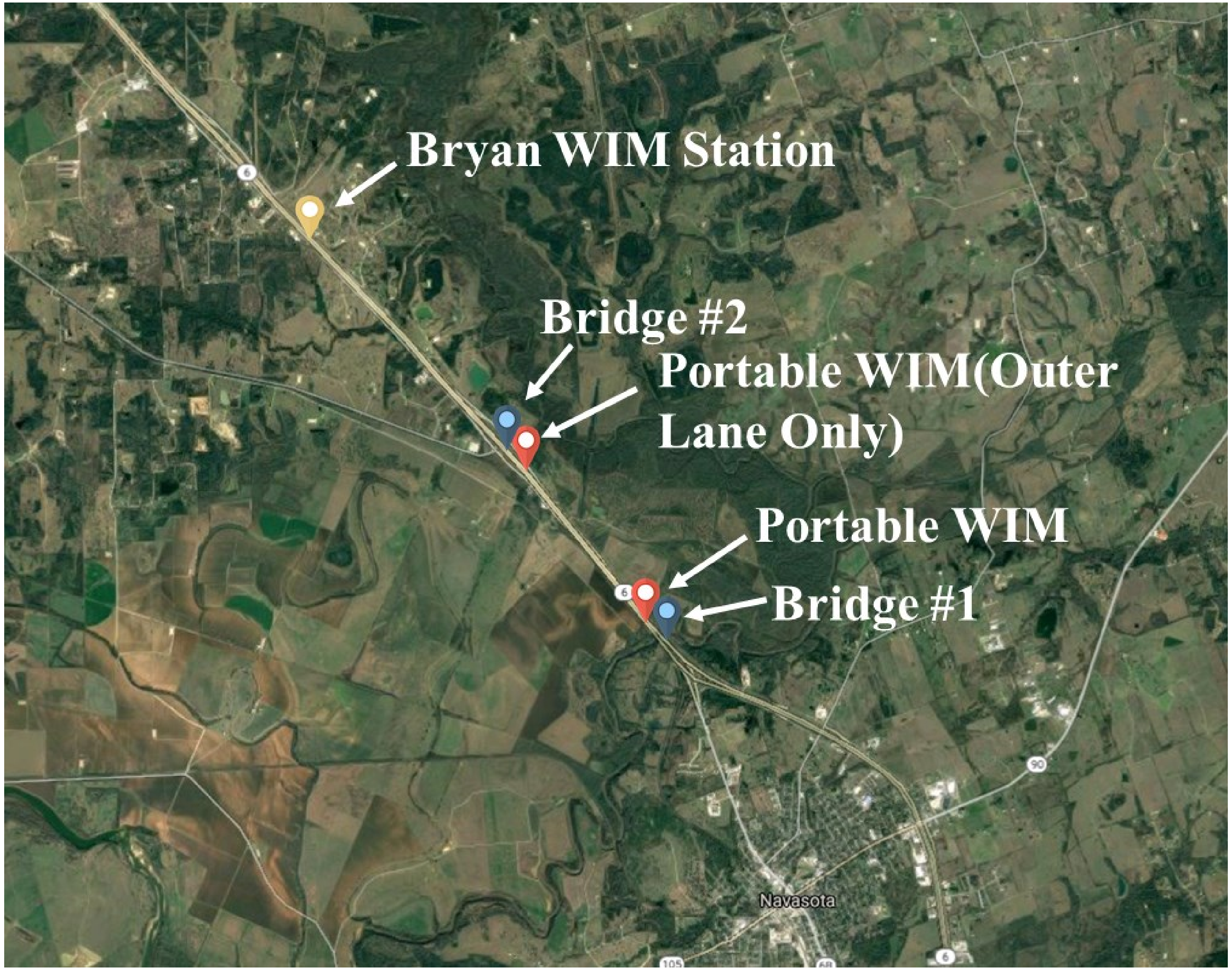
Sample Results



2.2

VALIDATION STUDY

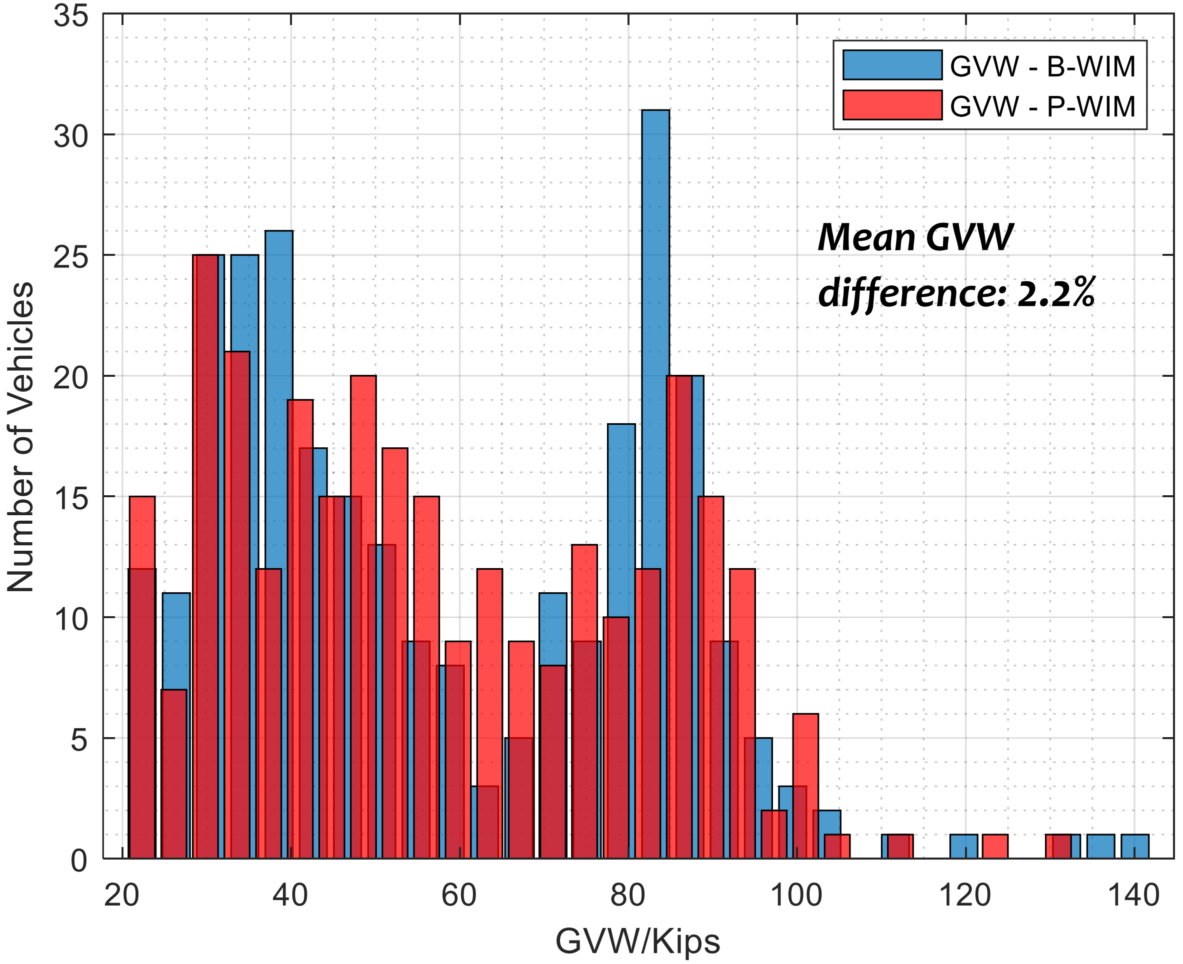
Validation Study

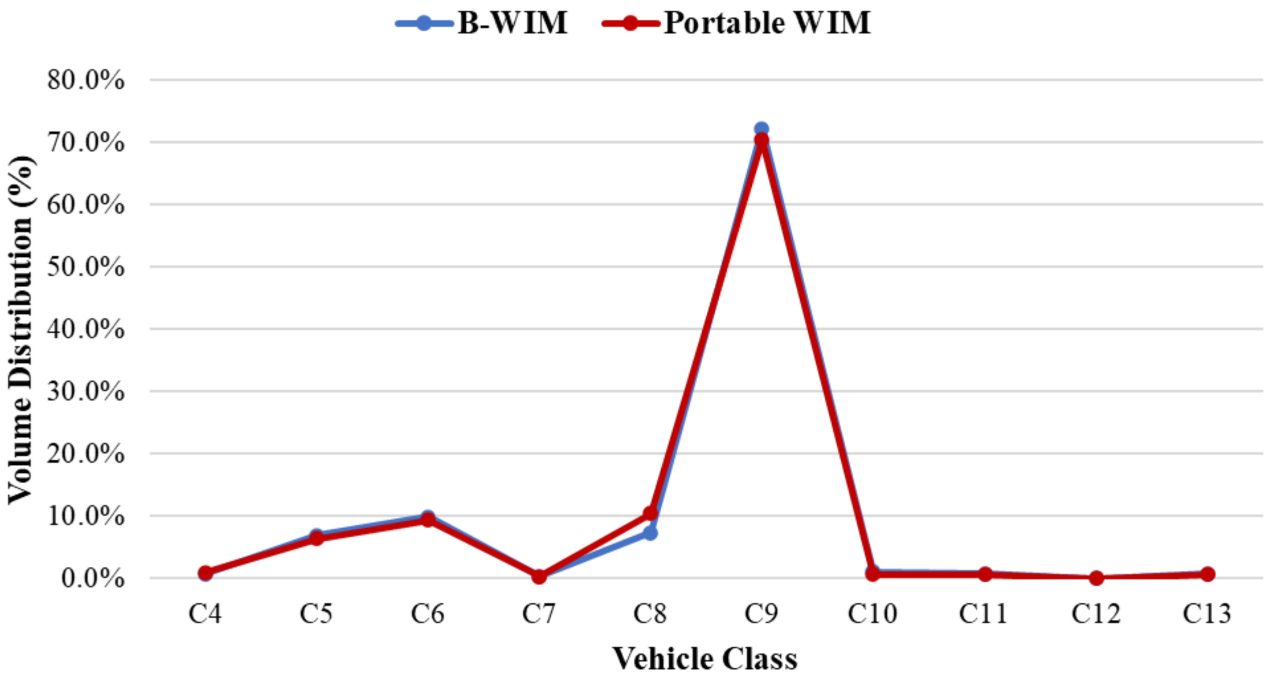


Validation Study

Bridge #1

BWIM vs Portable Pavement WIM





Validation Study

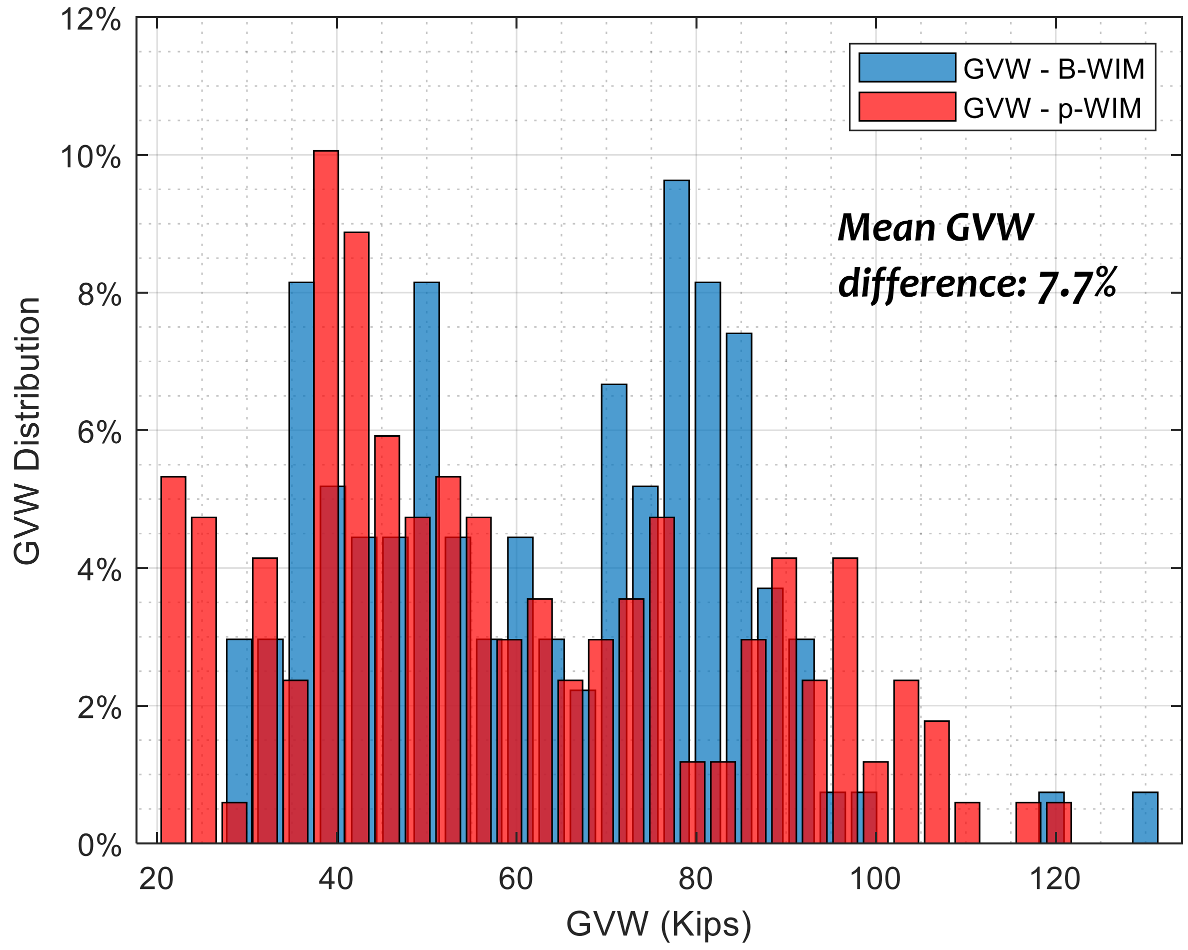
Bridge #1

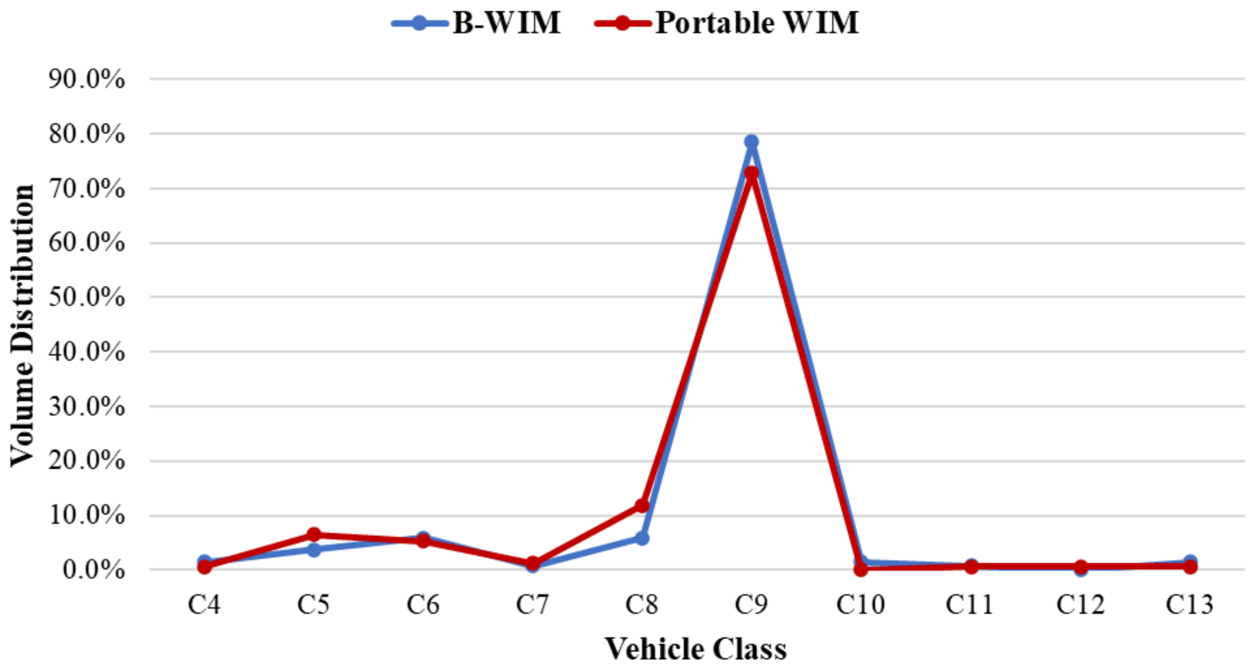
BWIM vs Portable Pavement WIM

System	GVW (kips)		Average Speed (mph)		Number of Axles		Wheelbase (ft)		Front Axle (Kips)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
B-WIM	59.2	25.6	69.8	4.3	4.5	1.0	54.4	24.6	13.4	3.3
P-WIM	57.9	23.7	70.8	4.5	4.5	1.0	51.2	14.7	10.4	2.6
Percentage Difference	**2.2%**		**1.4%**		**1.1%**		**5.8%**		**22.3%**	

Validation Study

BWIM vs Portable Pavement WIM





Validation Study

Bridge #2

Q7

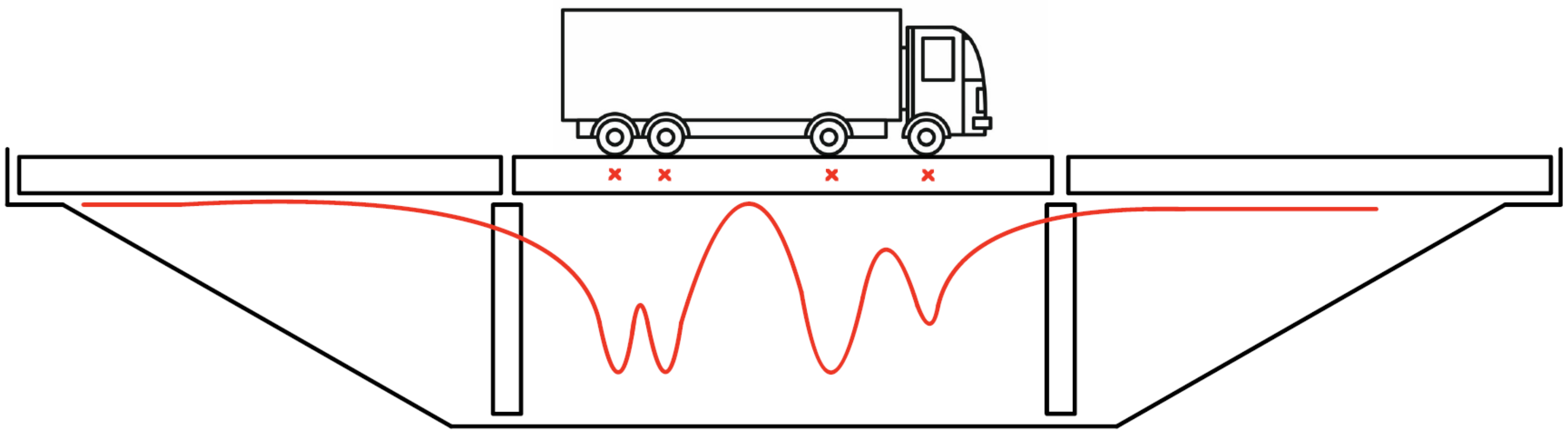
BWIM vs Portable Pavement WIM

System	GVW (kips)		Average Speed (mph)		Number of Axles		Wheelbase (ft)		Front Axle (kips)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
B-WIM	63.4	21.0	66.8	4.6	4.7	0.9	53.6	13.5	9.9	2.9
p-WIM	58.5	24.7	69.7	4.4	4.6	0.9	51.4	13.9	10.1	3.3
Percentage Difference	**7.7%**		**4.2%**		**2.1%**		**4.1%**		**1.9%**	

Session 2: BWIM Case Studies-Truck Characterization

1. Data Processing
2. Validation Study

QUESTIONS?

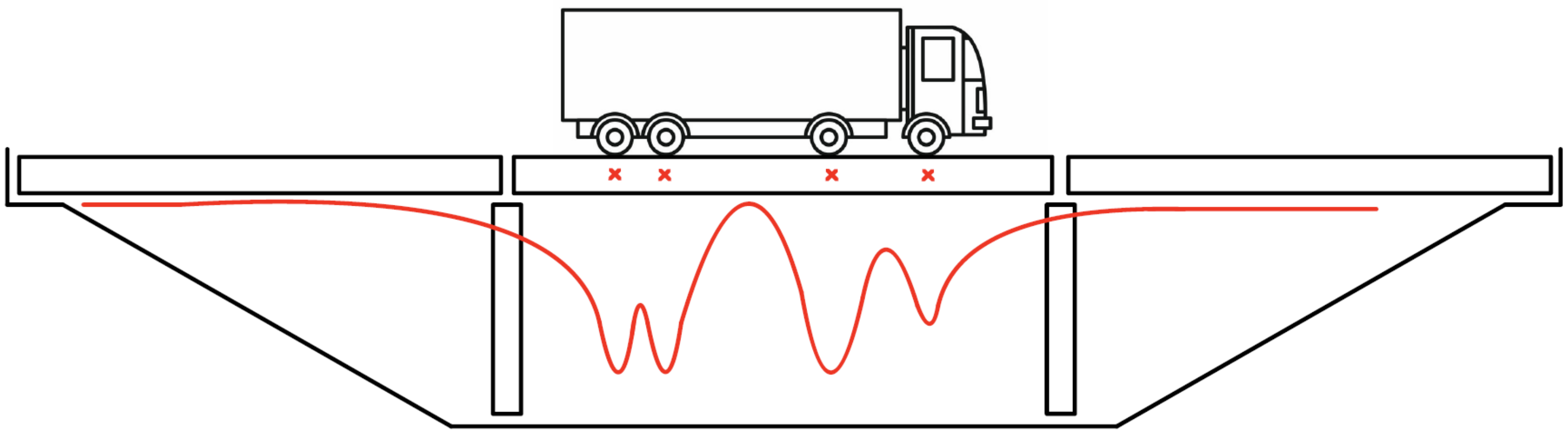


3

SESSION 3: BWIM CASE STUDIES BRIDGE EVALUATION

Session 3: BWIM Case Studies-Bridge Evaluation

1. Bridge #1 – SH6 over Navasota River (Prestressed Concrete)
2. Bridge #3 – IH35 over Spring Creek Relief (Steel)



Primary Process

A. Instrumentation design
B. System installation
C. Data acquisition & Communication
D. Calibration test
E. Data processing
F. Validation study
G. Bridge assessment → ***Session 3***

Bridge Assessment

Q8

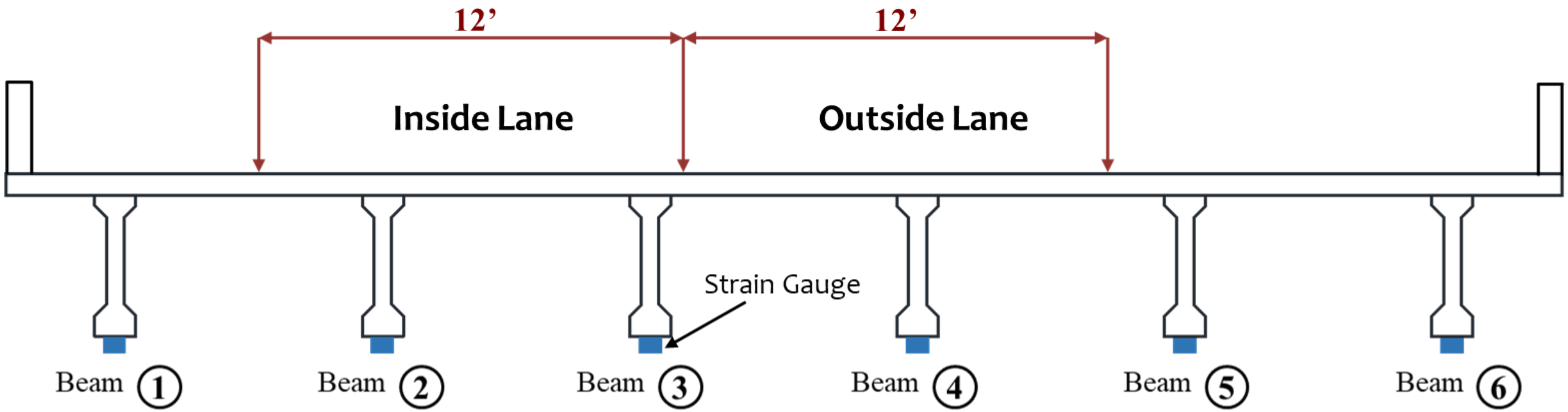
Site-Specific Load Ratings:

- LFR (Load Factor Ratings)
- Line girder analysis
- Field determined:
  - Distribution factors
  - Composite action
- Rating trucks:
  - Notional
  - Actual

3.1

BRIDGE #1

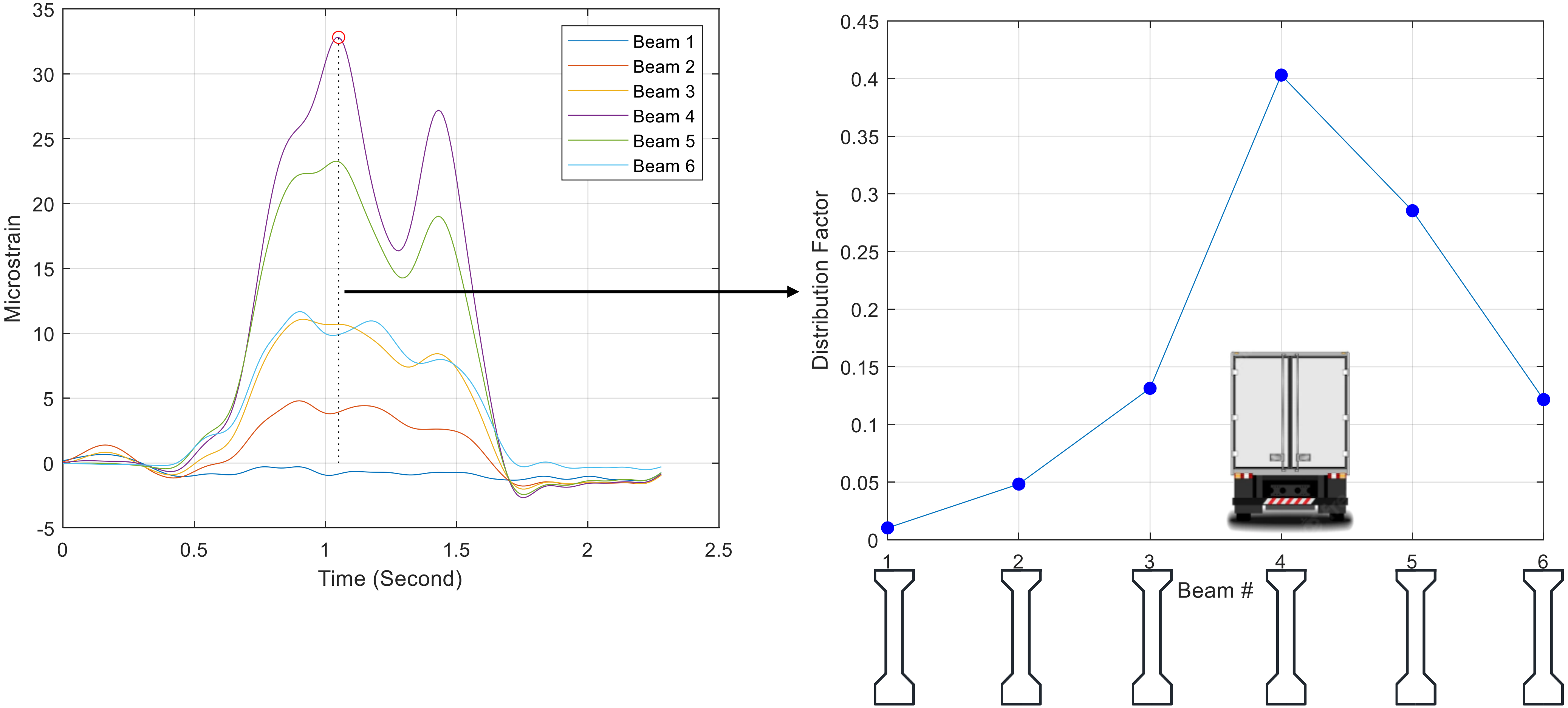
Bridge Assessment



Bridge Assessment

Bridge #1

Distribution Factors - Single Lane Loaded

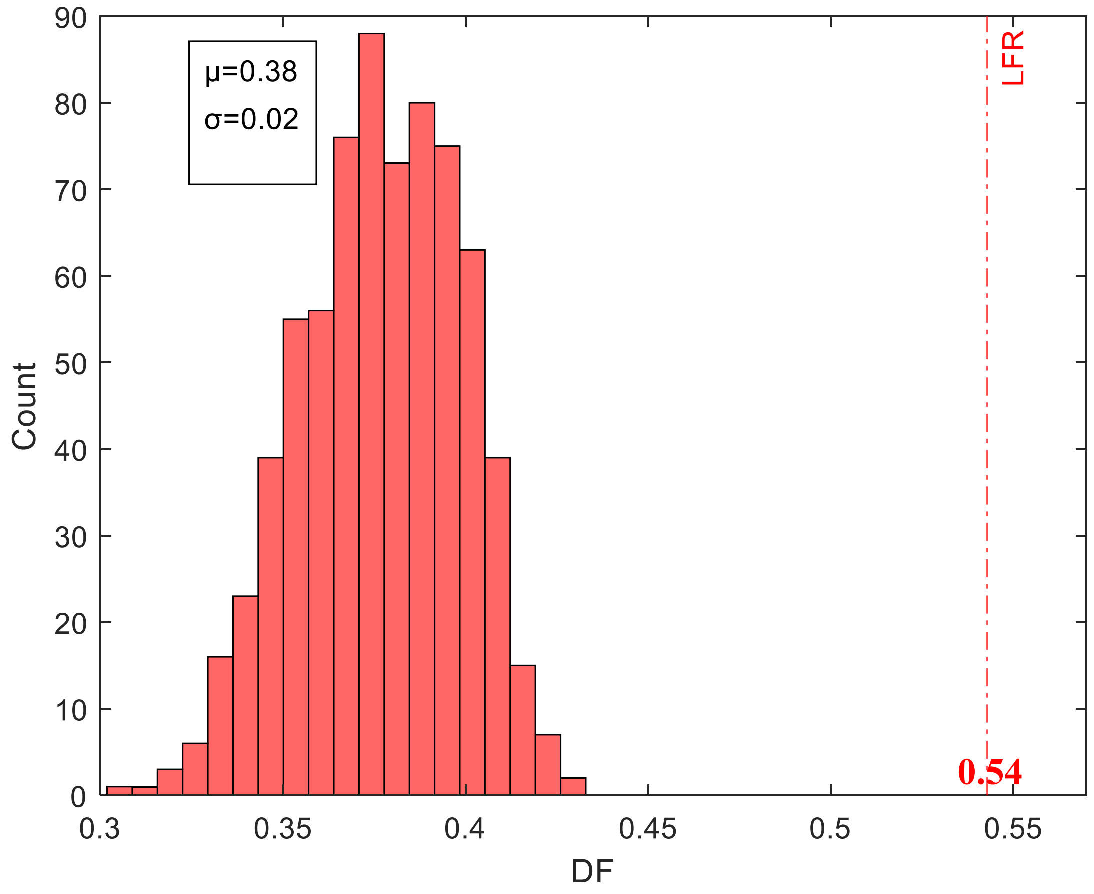


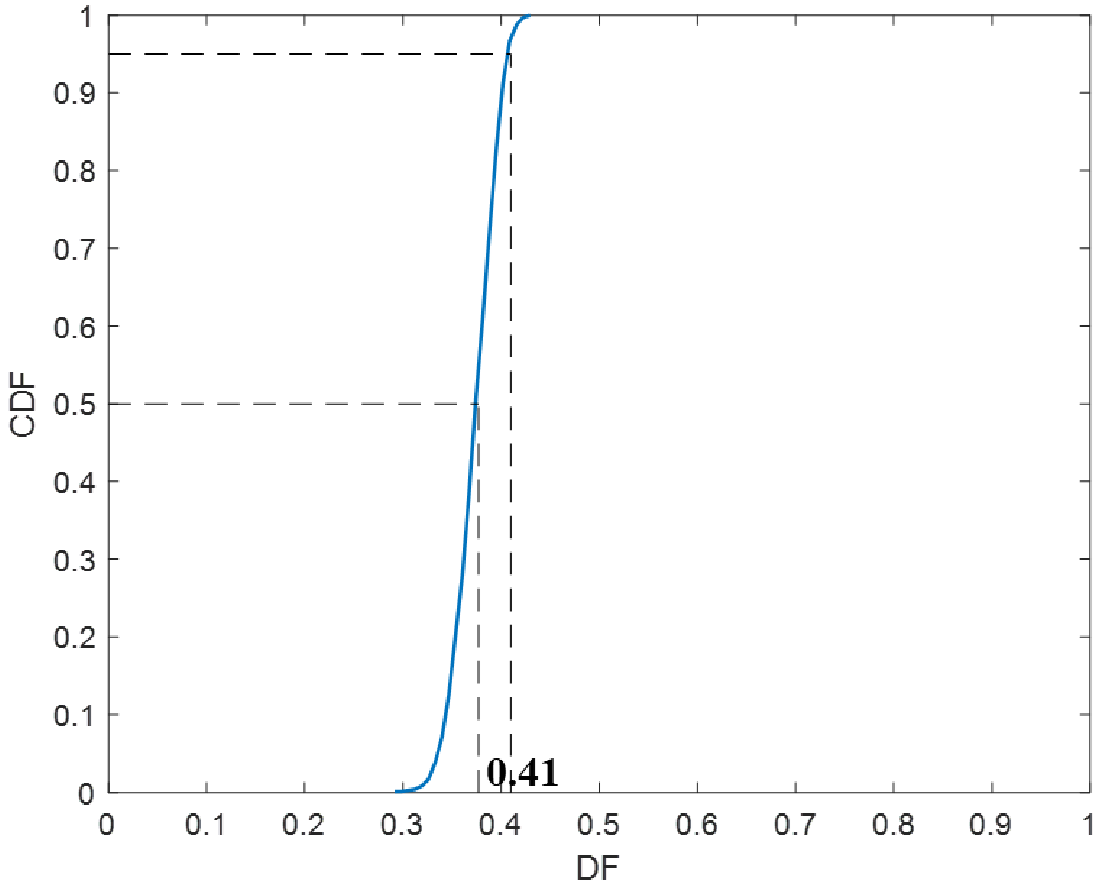
$$g = \frac{\varepsilon_i}{\sum_1^n \varepsilon_i}$$

Bridge Assessment

Bridge #1

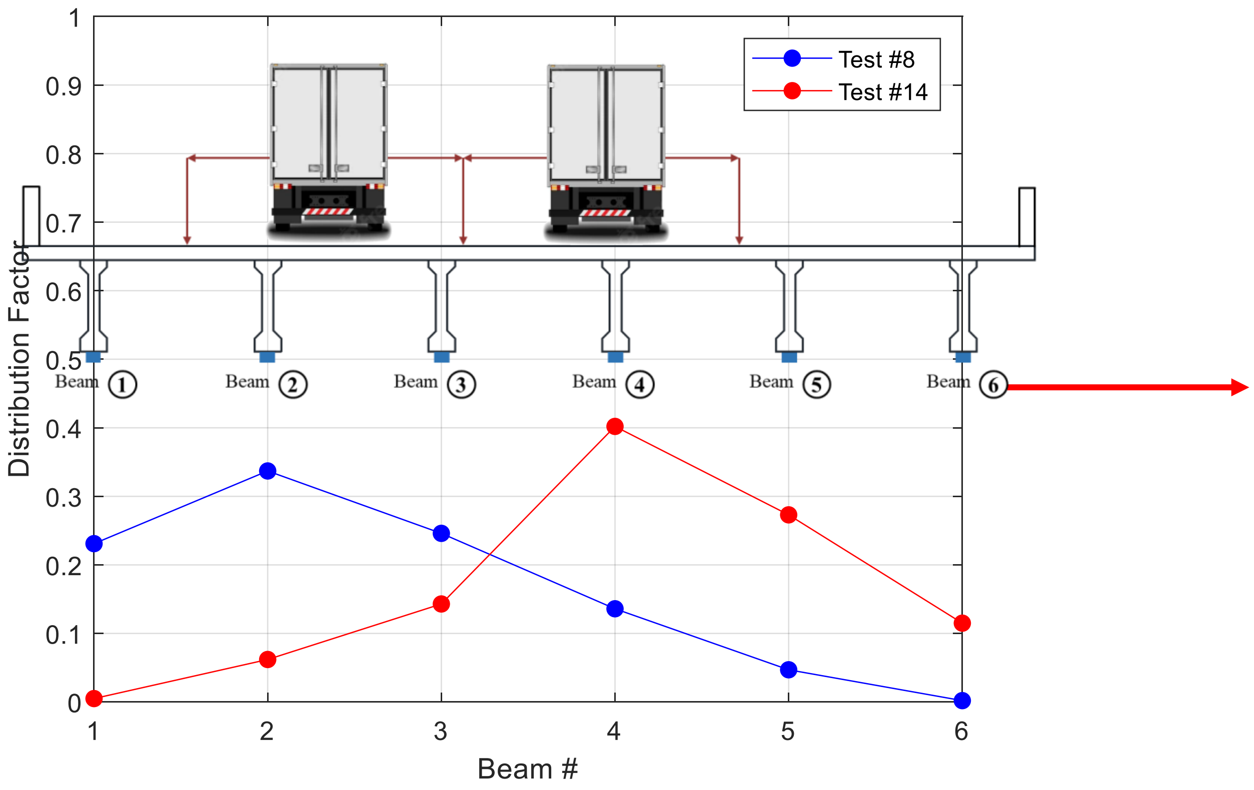
Distribution Factors - Single Lane Loaded

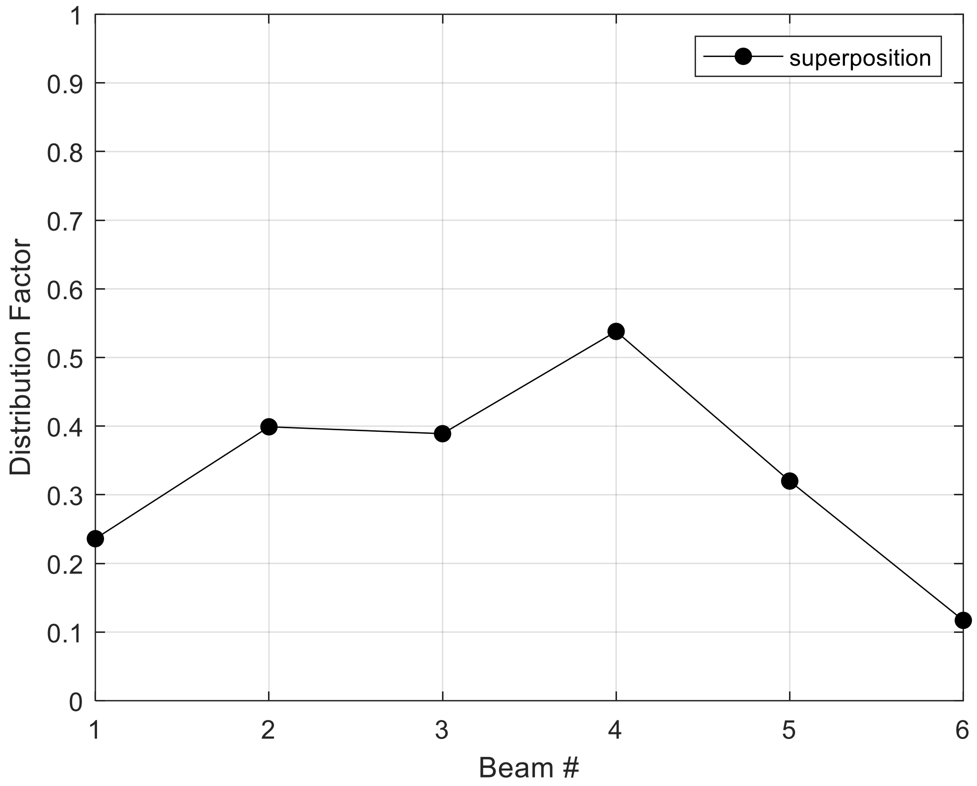




Bridge Assessment

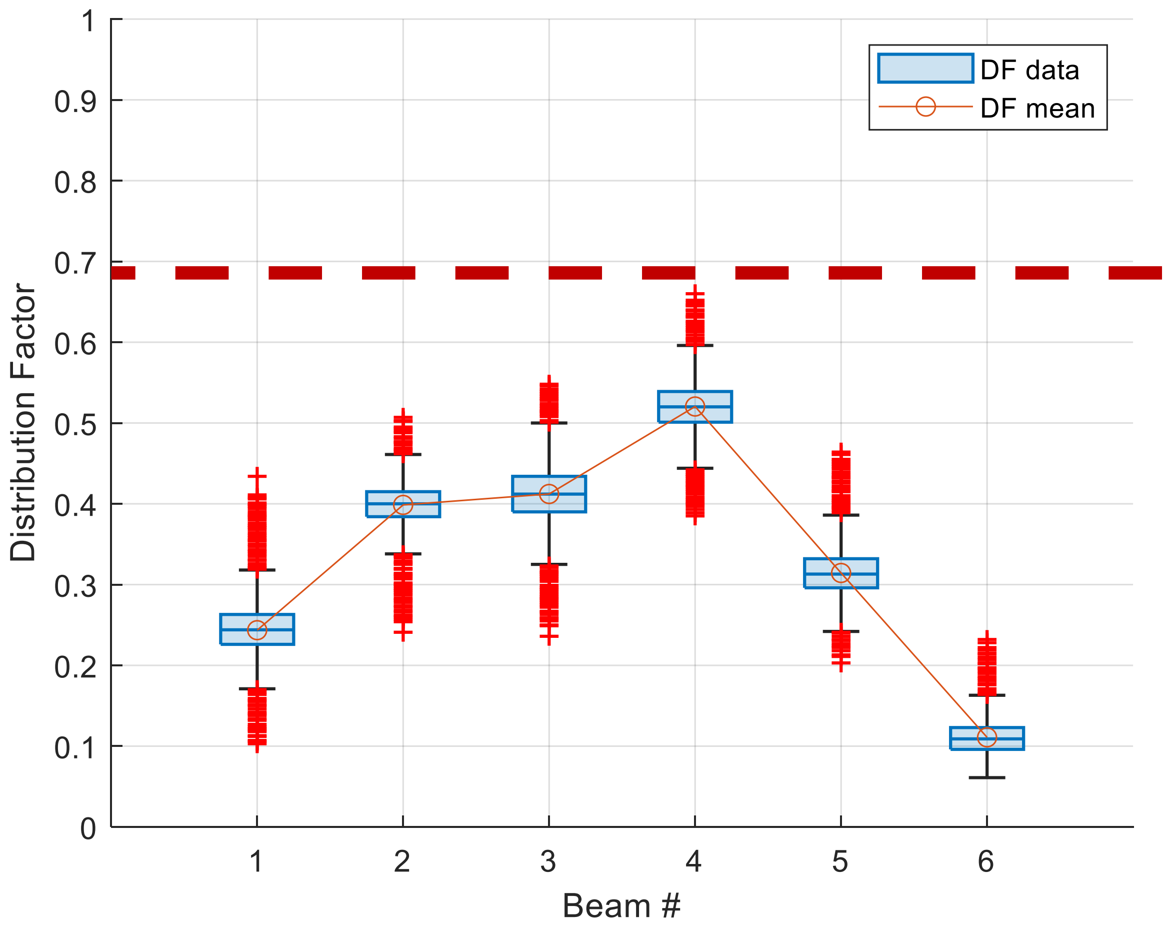
Distribution Factors - Two Lanes Loaded

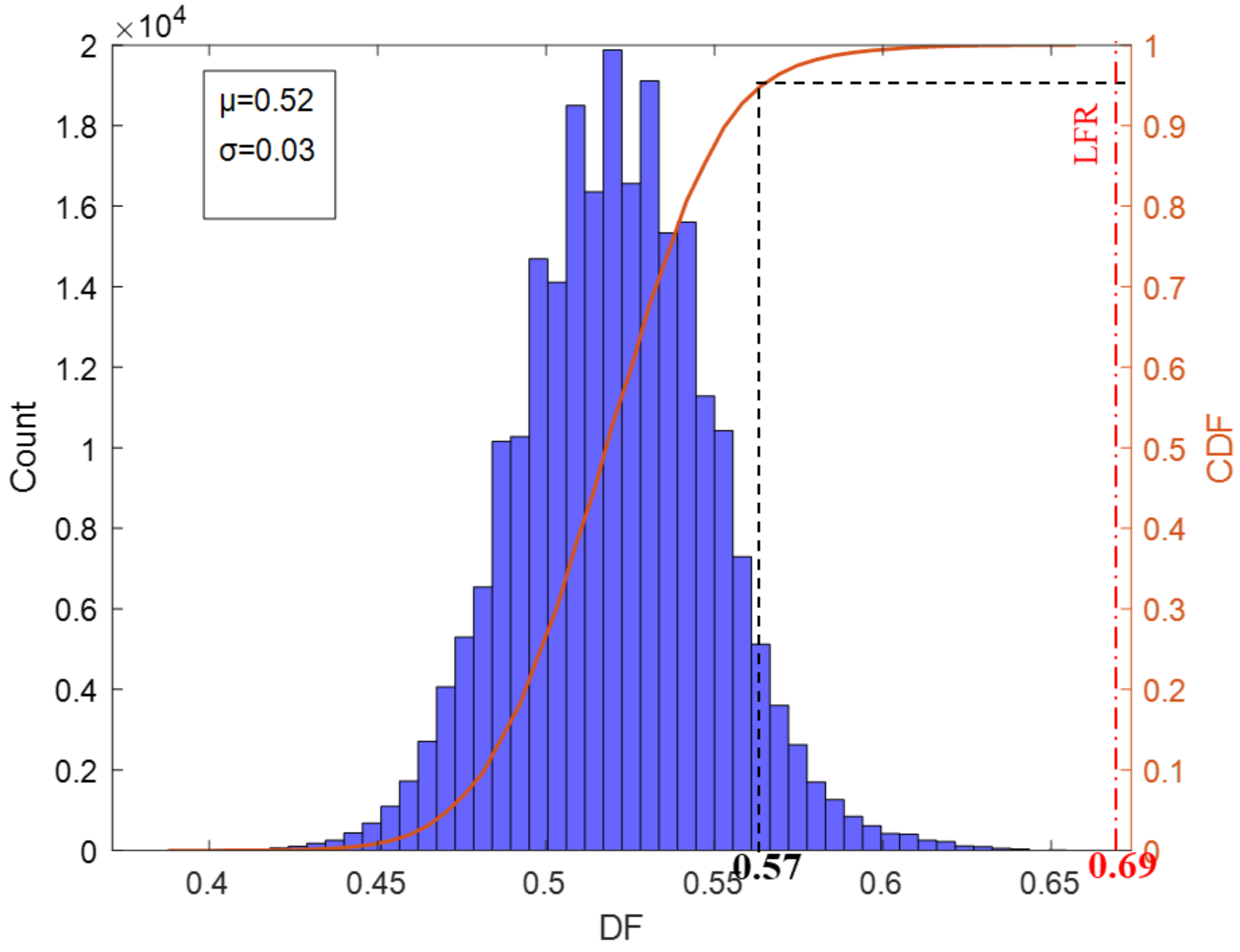




Bridge Assessment

Distribution Factors - Two Lanes Loaded





Bridge Assessment

Bridge #1

Output Load Ratings:

Inventory

Truck	Without B-WIM	B-WIM with refined DF
HS20	1.34	1.60
H20	1.87	2.23
SU4	1.64	1.93
SU5	1.48	1.74
SU6	1.33	1.57
SU7	1.22	1.44

20% increase

Operating

Truck	Without B-WIM	B-WIM with refined DF
HS20	2.24	2.68
H20	3.12	3.74
SU4	2.75	3.23
SU5	2.49	2.92
SU6	2.23	2.62
SU7	2.05	2.41
EV2	2.68	3.15
EV3	1.76	2.07

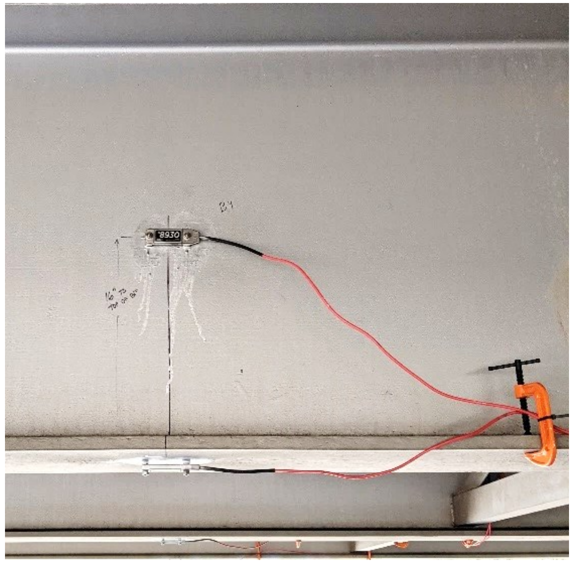
3.2

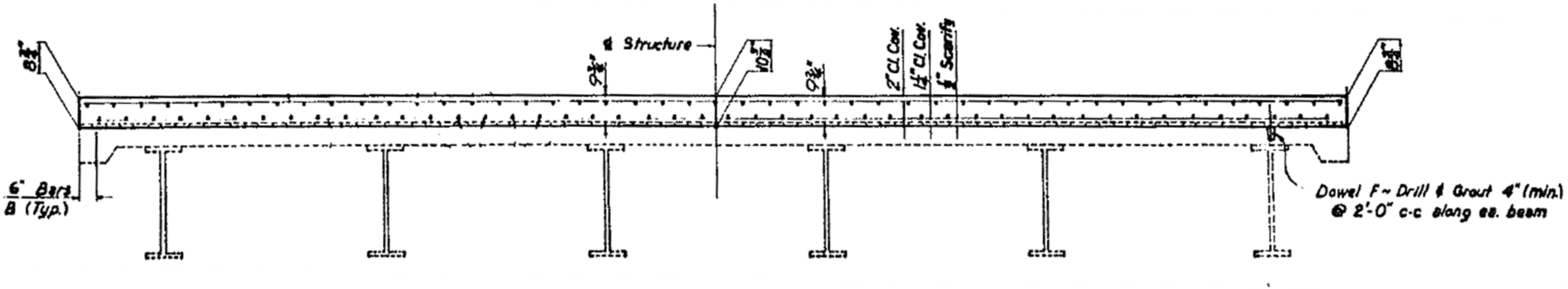
BRIDGE #3

Bridge Assessment

Bridge #3

Q10

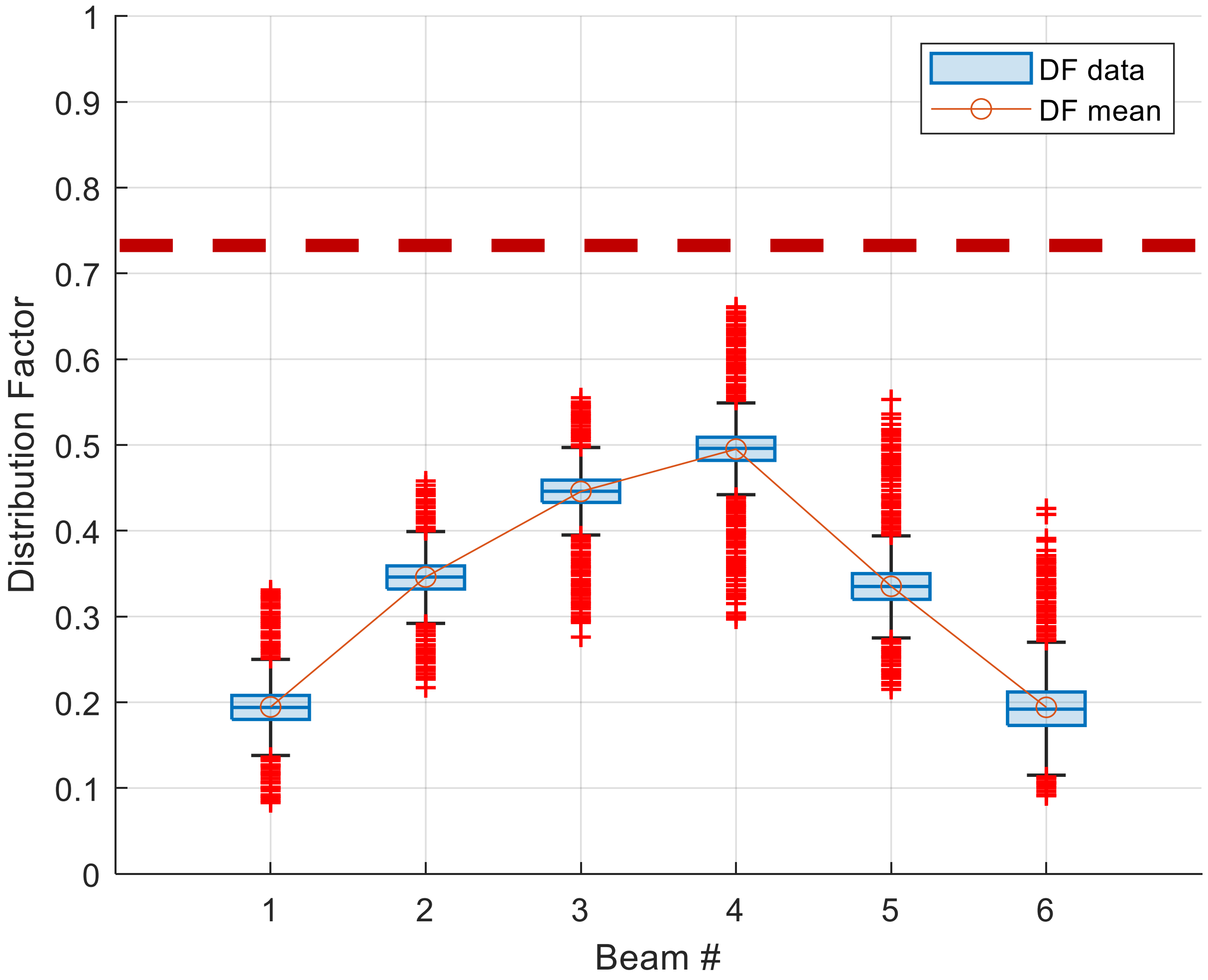


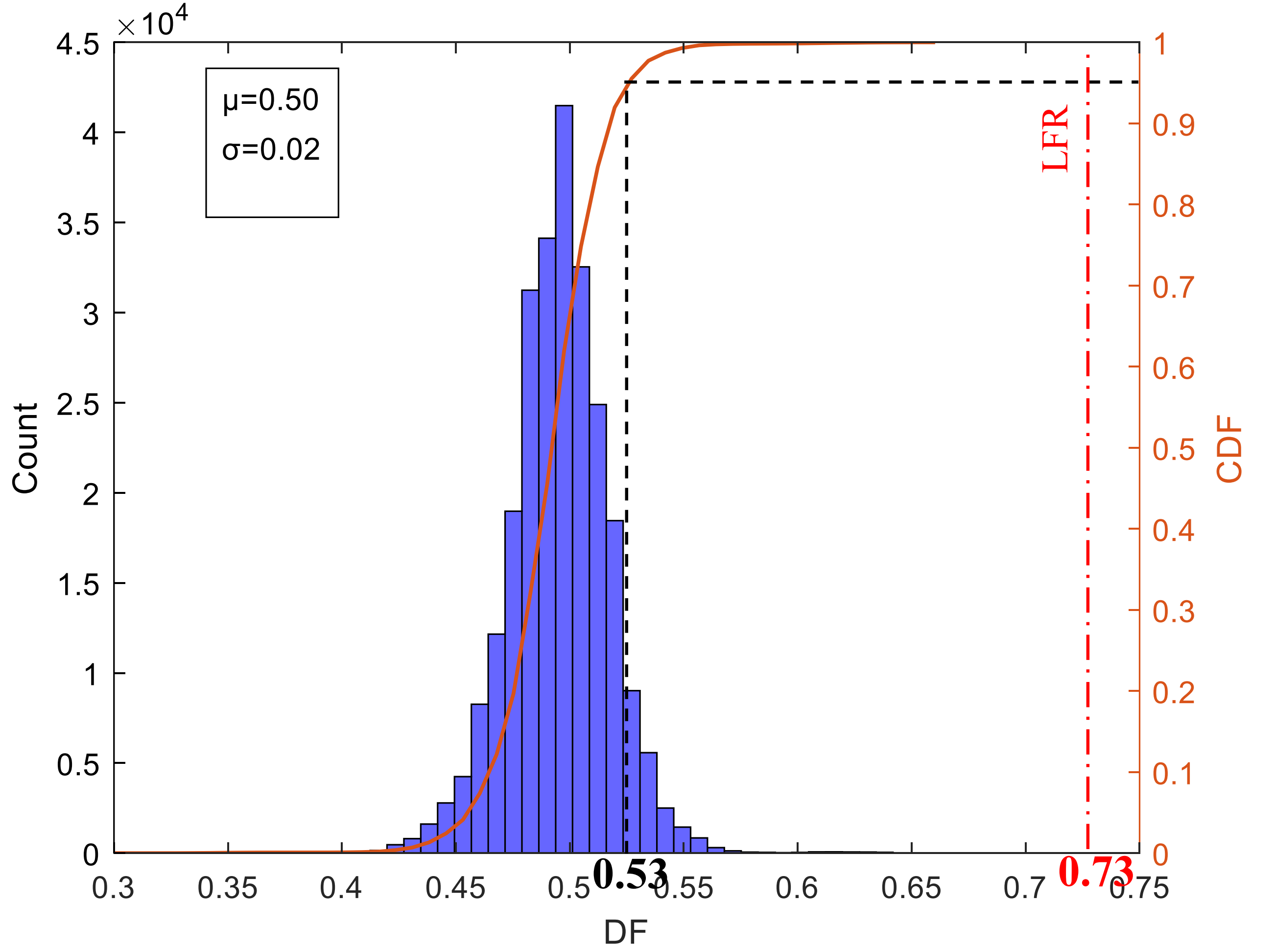


Bridge Assessment

Bridge #3

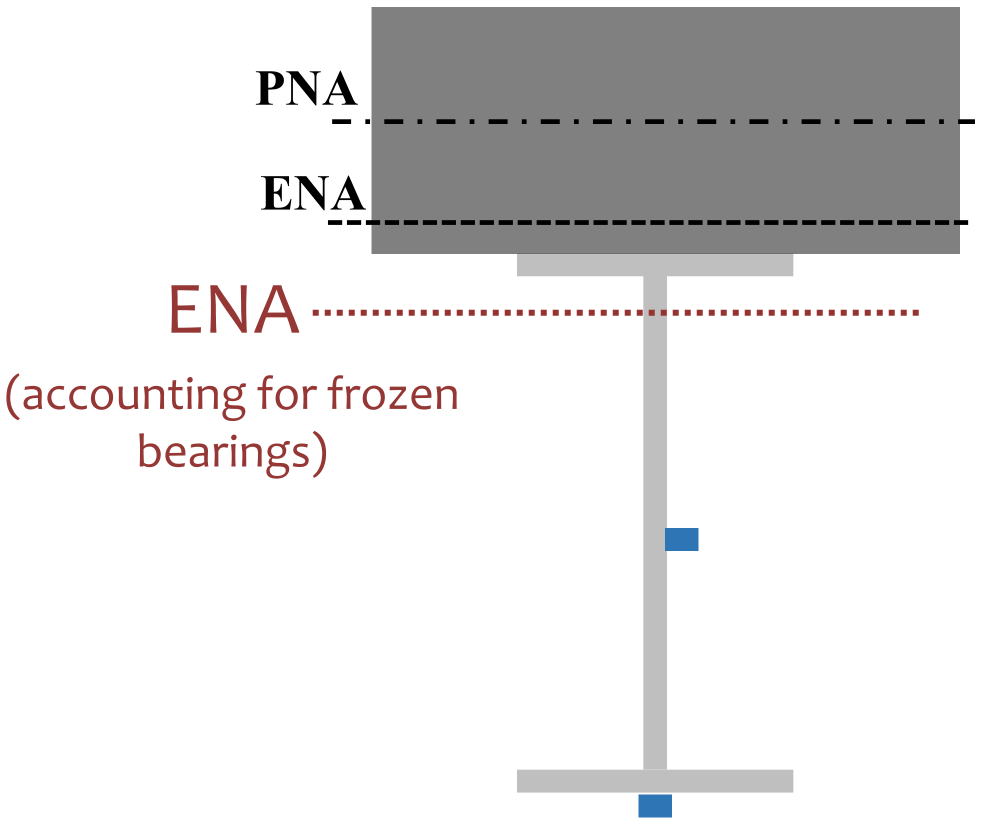
Distribution Factors





Bridge Assessment

Composite Action



Bridge Assessment

Load Ratings (Operating) – Notional Trucks

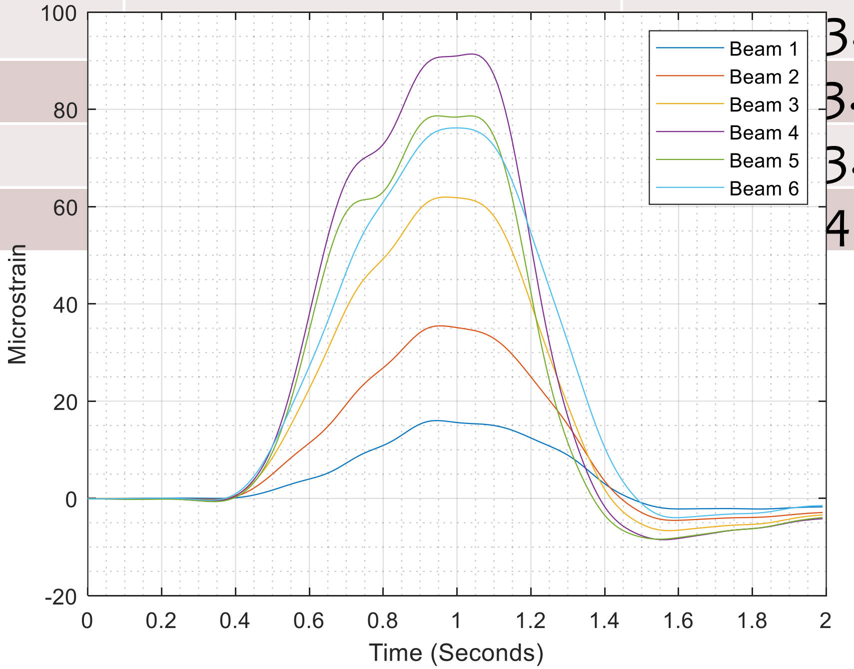
Truck	Without B-WIM	B-WIM with refined DF
HS20	1.22	1.83
H20	1.69	2.54
SU4	1.39	2.08
SU5	1.28	1.92
SU6	1.15	1.73
SU7	1.07	1.61
EV2	1.37	2.05
EV3	0.90	1.35

50% increase

Bridge Assessment

Load Ratings – Actual Trucks (with refined DFs)

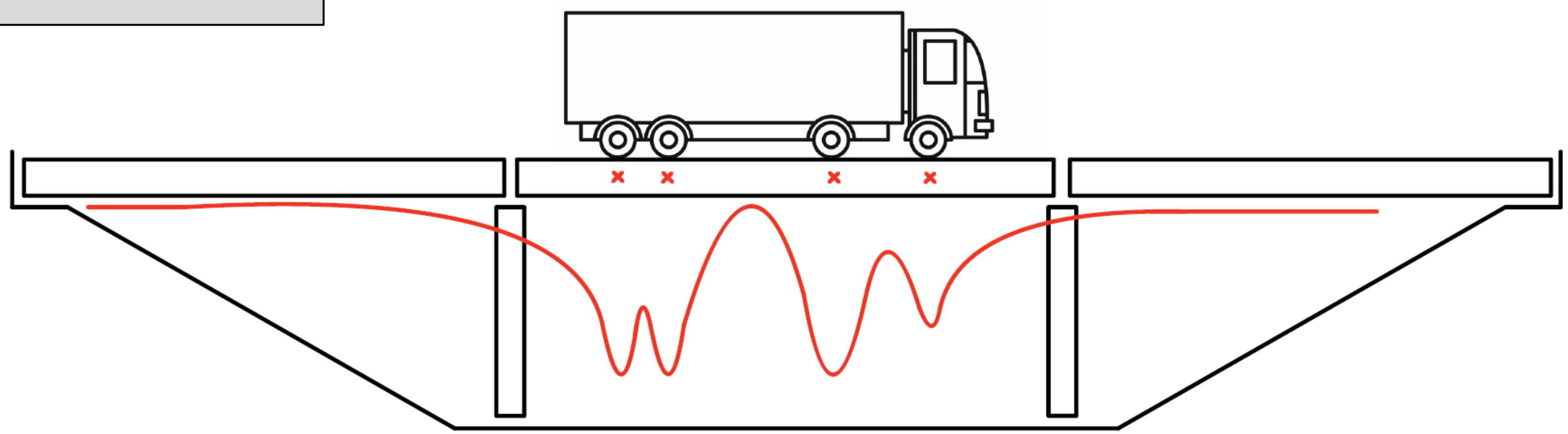
Truck	Number of Axles	GVW (kips)	Moment (kip-ft)	Operating LFR - Non-Composite	Operating LFR - Composite
1	7	130	655	1.67	4.14
2	**7**	**228**	**1538**	**0.71**	**1.76**
3	6	105	597	1.83	4.54
4					3.29
5					3.68
6					3.59
7					4.82



Session 3: BWIM Case Studies-Bridge Evaluation

1. Bridge #1 – SH6 over Navasota River (Prestressed Concrete)
2. Bridge #3 – IH35 over Spring Creek Relief (Steel)

QUESTIONS?



4

WORKSHOP SUMMARY

Takeaways

1. Algorithms and Sensors
2. Bridge selection criteria
3. Accuracies
4. Comparison of BWIM to other WIM systems
5. Potential BWIM applications

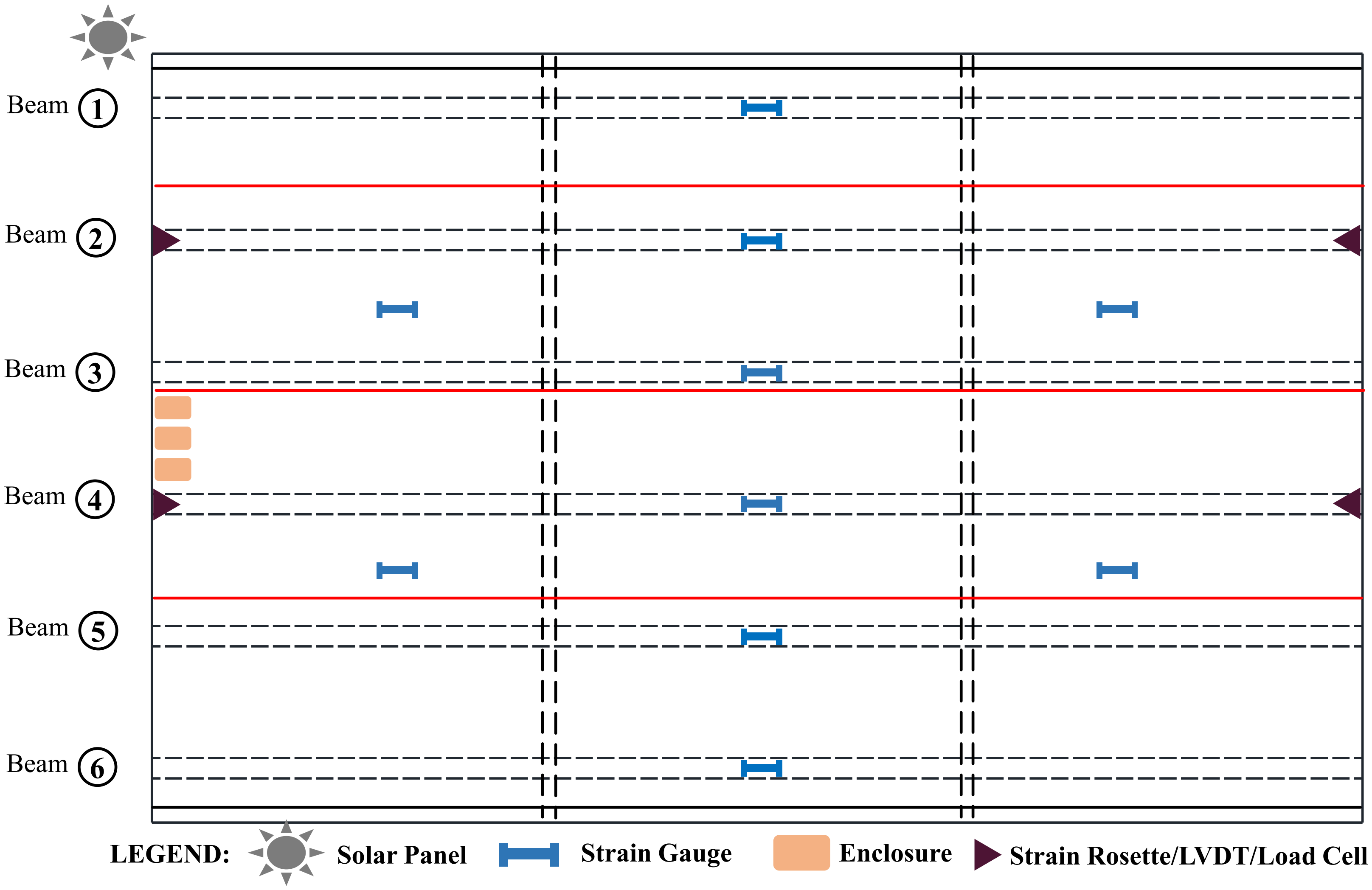
Algorithms and Sensors

<u>Axle Detection</u>:

- Sample 500 Hz
- Second derivative method with peak picking

<u>Weight Calculation</u>:

- Area method for GVW
- Axle weights from second derivative distribution



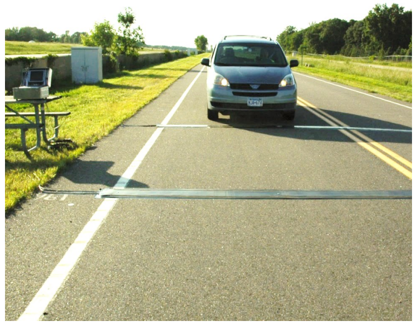
Bridge Selection Criteria

Selection Criteria	Recommendation
Bridge Type	Straight spread multi-girder bridges (no skew)
Span Type	Simple span
Length	30 to 80 ft (can go up to 125 ft if needed)
Traffic Direction	One-way with minimal lanes
Traffic Speed	Greater than 15 mph
Pavement Roughness	Even and smooth
Underside Access	Favorable

Accuracies

Truck Information	Qualitative Accuracies	Validation Study Results (Percent Differences)
Axles (number and spacing)	High	1% - 6%
Speed	High	1% - 4%
Axle weight	Moderate	2% - 23%
Gross weight	High	2% - 13%
Classification	High	<5%

Comparison of BWIM to other WIM Systems



Advantages	• High accuracy • Consistent weight measurements • Many commercial systems	• High accuracy • Consistent weight measurements • Portable/cost-effective	• **High accuracy (axle detection and GVW)** • **Durable/cost-effective** • **Reusable** • **Bridge evaluation**
Challenges	• High installation cost • High maintenance • Limited to certain highways	• Dynamic effects can influence results • Less durable	• **Lower axle weight accuracy** • **Limited expertise** • **Only measures trucks (Class 4-13)**

Potential BWIM Applications

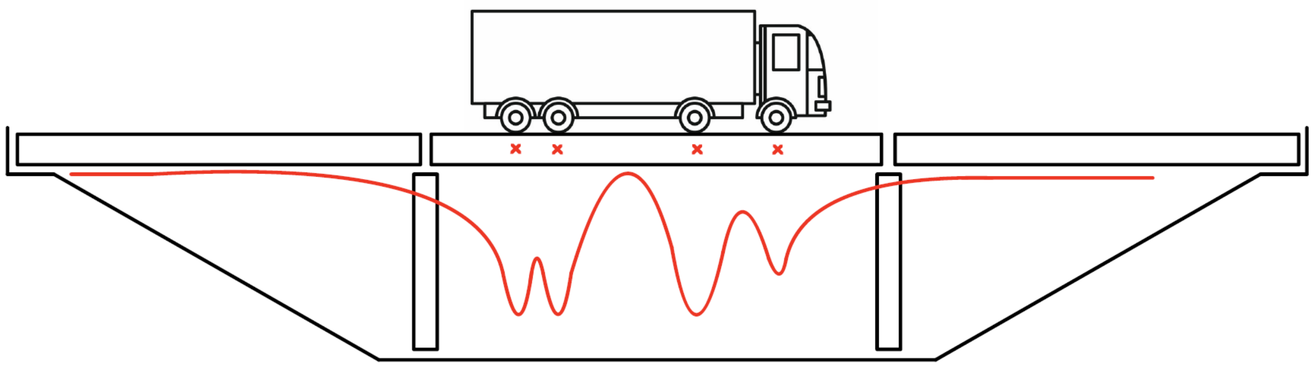
Q12

- Prescreening for weigh stations
- Weight enforcement
- Bridge evaluation
  - Bridges without plans
  - Change in loading
- Corridor where truck information is needed
  - Traffic planning
  - Pavement assessment

Thank you to TxDOT!

- Martin Dassi

- Bernie Carrasco
- Biniam Aregawi
- David Fish
- David Freidenfeld
- Drake Builta
- Mark Wallace
- Yi Qiu



Bridge Weigh-in-Motion - An Approach to Measure Truck Loading on Texas Highways

<u>TxDOT – 0-7038</u>

Contact: Matthew Yarnold, Ph.D., P.E.
Email: myarnold@tamu.edu
Cell: 484-547-1500

Texas Department of Transportation