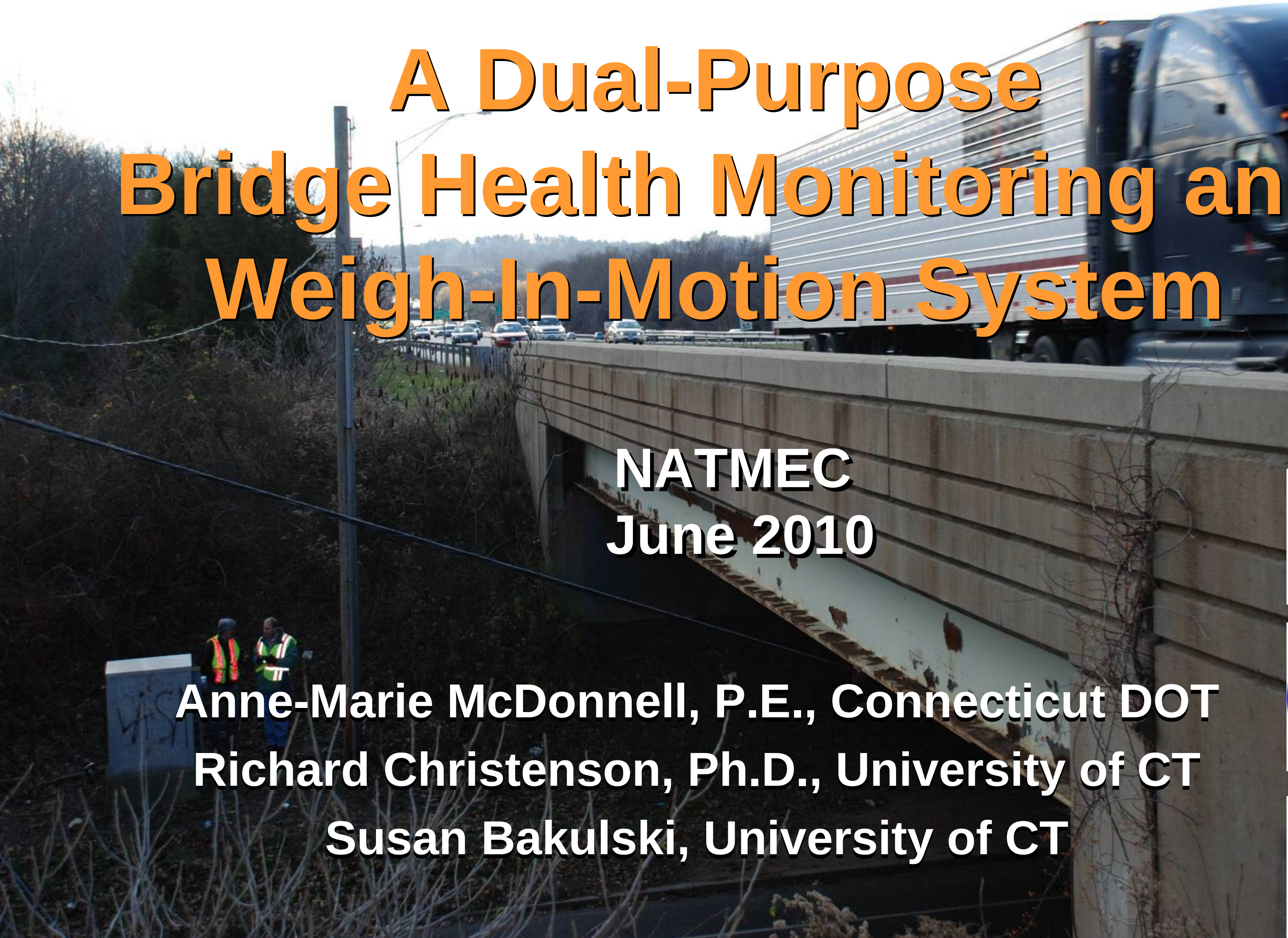

A Dual-Purpose Bridge Health Monitoring and Weigh-In-Motion System

NATMEC
June 2010

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OVERVIEW

- CT History of Bridge Health Monitoring & Weigh-In-Motion Research
  - Preliminary Test – Report NATMEC 2006
  - Short -Term Bridge Monitoring System
- Novel BWIM Method (Dr. Christenson)
- Feasibility Test
  - Field Data Collection, November 2008
  - Data Analysis & Results 2009
- Research Project : CT SPR-2265
  - Scope of Work
  - Status June 2010

Short-Term Bridge Monitoring System

- Wireless Structural Testing System (STS-WiFi)
  - 8 strain gages; 2 nodes; 1 base station

Christenson's BWIM Method Theory

- Given: Area under strain is proportional to GVW (Ojio, ICWIM3)
- 2nd time derivative of strain indicates when axles pass over center of bridge

FEASIBILITY TEST

Test Site

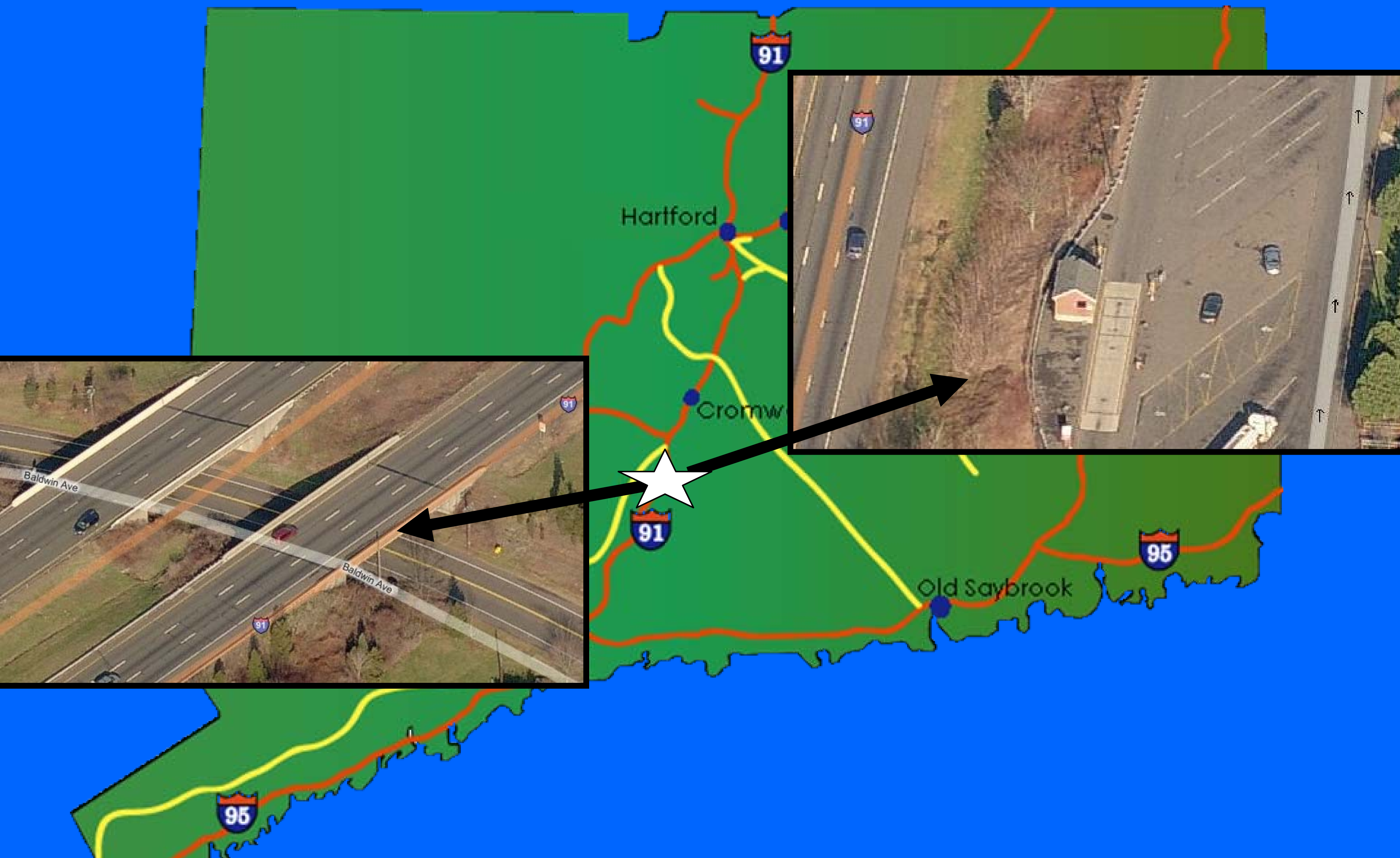
- Typical Highway Bridge in Connecticut
- I-91 Northbound at Exit 19: Meriden, CT

TEST BRIDGE – I-91 (NB)

- Built in 1964: 3 Lanes
- Single-Span, Simply-Supported
- 8 Steel Girders with Composite Deck
- 85 feet in length, skew angle: 12 degrees
- Traffic ADT: 57,000 veh/day & 9% Trucks

Street View

Half-Mile Prior to Weigh Station



Weigh Station

- Operated by CT Department of Public Safety
- Three static-platform scales
  - Scales were calibrated exactly one week prior to testing (± 20 lb)

FIELD DATA COLLECTION

November 20, 2008

Installed Wireless Bridge Monitoring System

- 8 strain gages, mounted at mid-span on the 6 inside girders

Strain Sensors

- 8 strain gages, mounted at mid-span on the 6 inside girders
  - Six – 3” above the bottom flange
  - Two – 3” below the top flange
    (on the two girders under lanes 1 and 2)

Measurements At Bridge

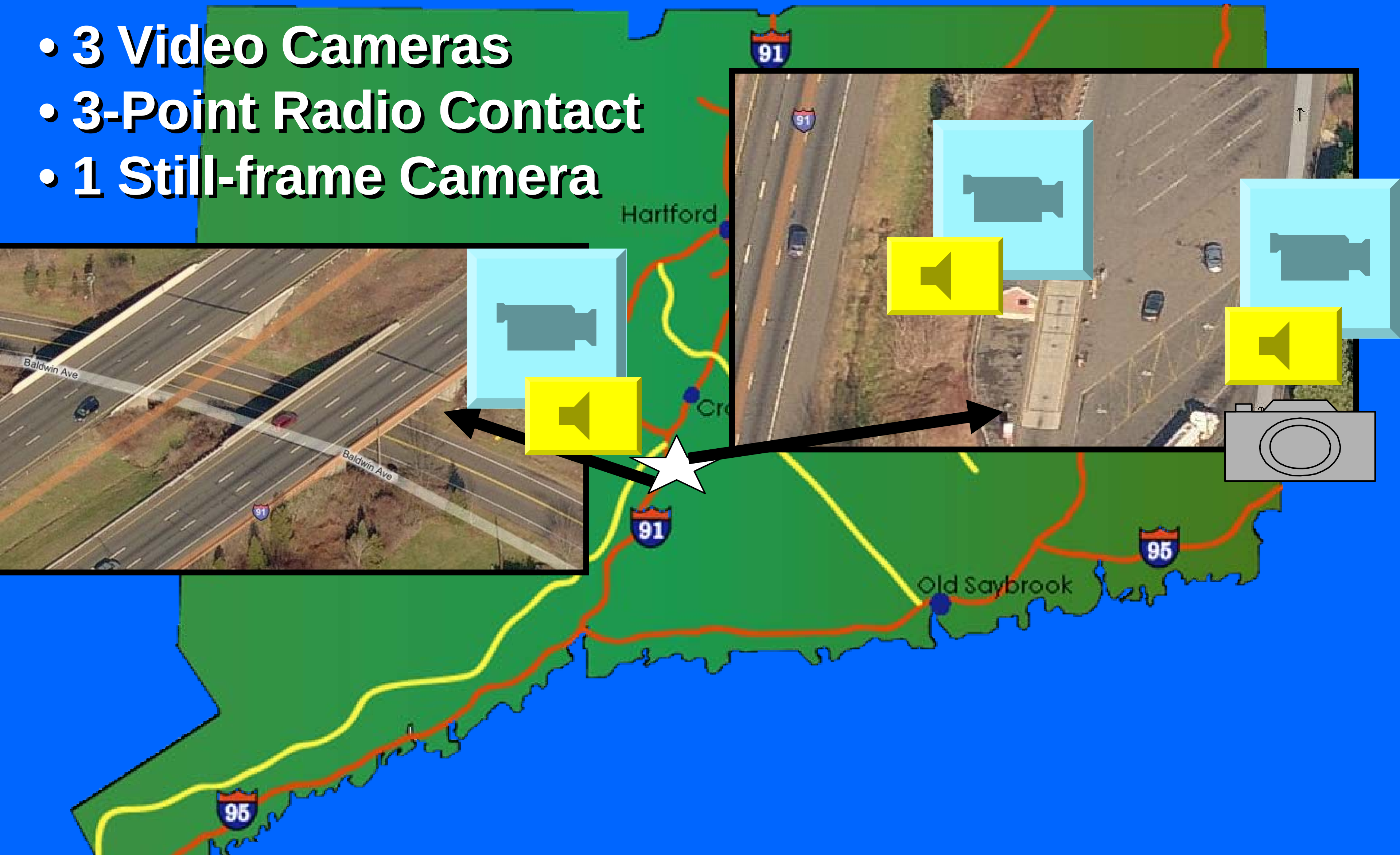
- Strain gages (transducers) used to capture measurements of bridge response to traffic loading at the bridge
- Data captured at 100 Hz sample rate (0.01 sec) for 5 minute intervals
- Traffic stream captured on video at bridge when weigh station “OPEN” sign lighted

Data Acquisition - Bridge

- **Truck passing events were identified manually flagged in data records and synchronized with video**
- **Measured trucks were directed into weigh station (next exit)**

Syncronization

- 3 Video Cameras
- 3-Point Radio Contact
- 1 Still-frame Camera



Data Acquisition – Weigh Station

- **<u>Static Weight Records</u> recorded manually and on video in scale house (GVW and axle weights)**
- **<u>Vehicle Lengths</u> acquired from still-frame photos taken across from scales**
- **Video verification of vehicle sequence acquired across from scale**

Control Vehicle : 5-Axle Truck

Gross Vehicle Weight	67,420 lbs
Axle Weight (1)	10,020 lbs
Axle Group Weight (2 & 3)	27,040 lbs
Axle Group Weight (4 & 5)	30,360 lbs
Length (first to last axle)	44.6 feet
Axle Spacing (1-2)	11.8 feet
Axle Spacing (2-3)	4.4 feet
Axle Spacing (3-4)	24.4 feet
Axle Spacing (4-5)	4.1 feet

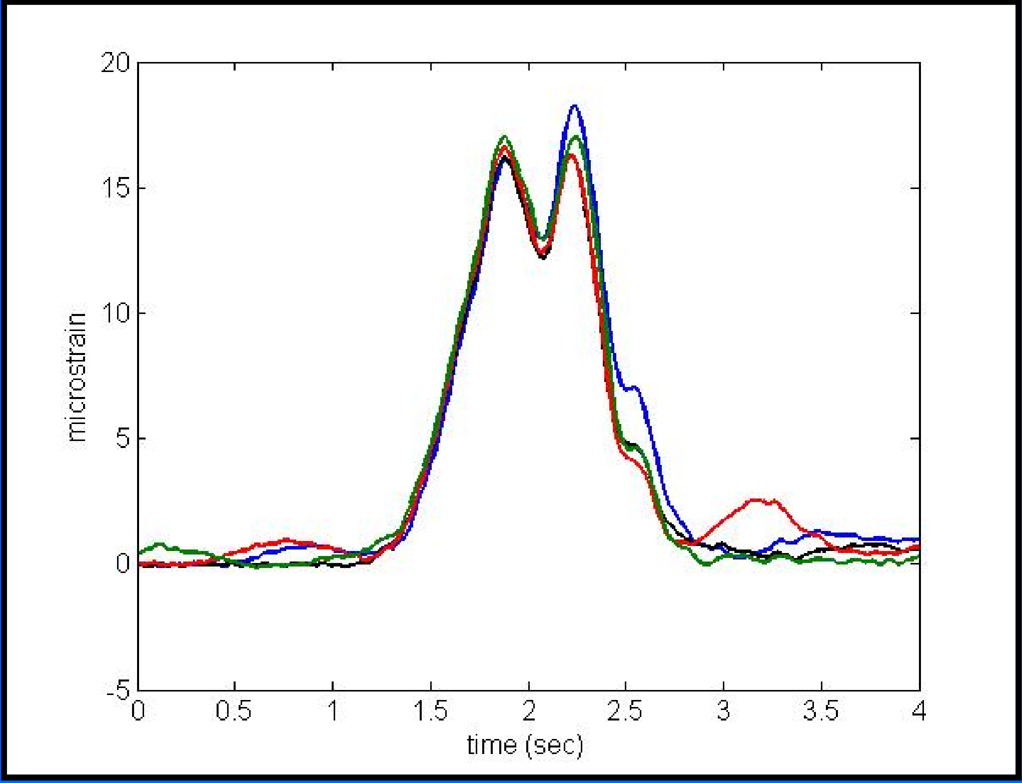
Data Analysis

5-Axle Truck of Known-Weight

- Total of 22 passes over the bridge

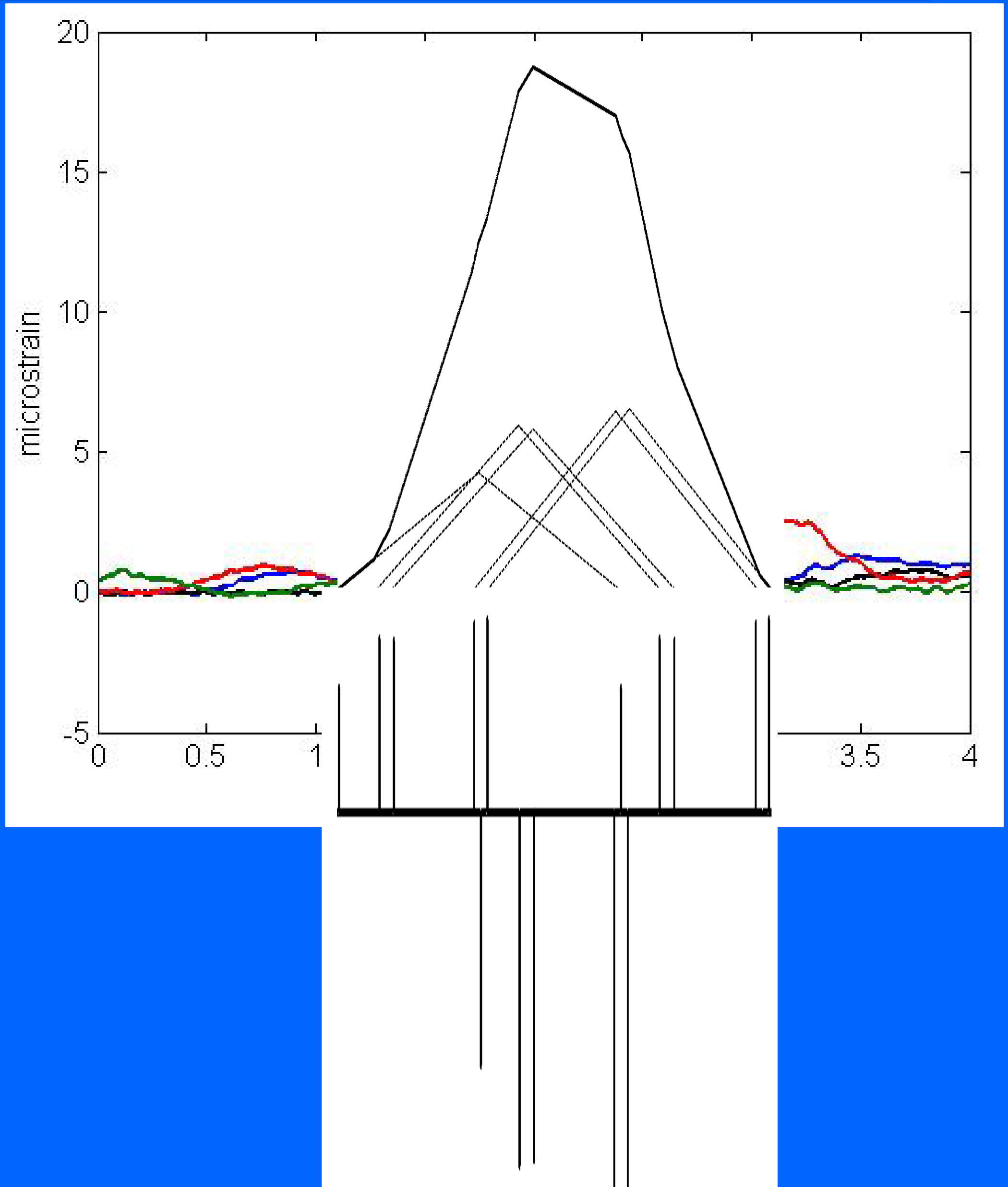
Example Output:

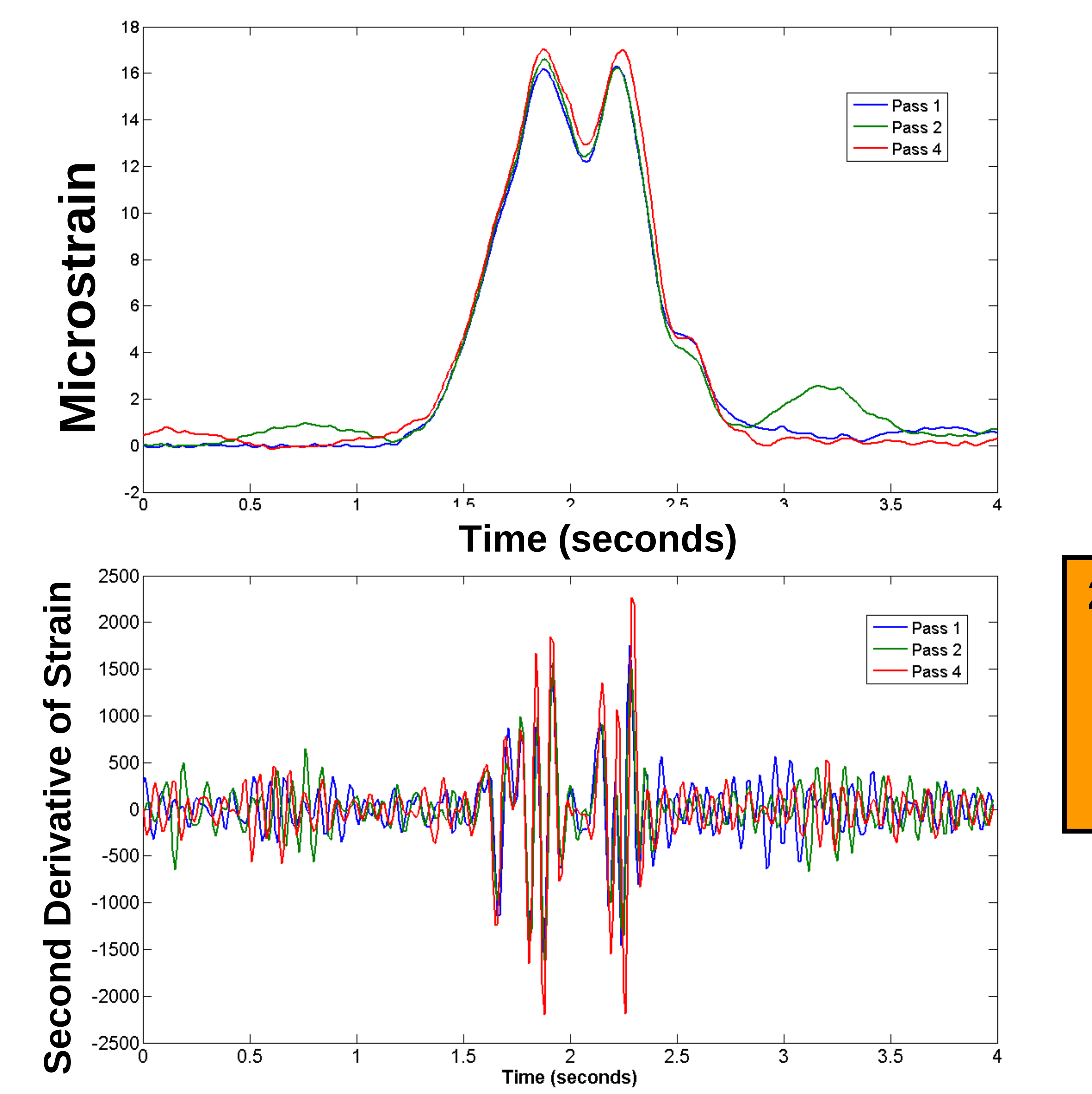
4 passes over lane 1 at 55 mph



Christenson's BWIM Theory

- **Area under strain is proportional to GVW** (Ojio, ICWIM3)
- **2nd time derivative of strain indicates when axles pass over center of bridge**
- **Speed is critical calculation**



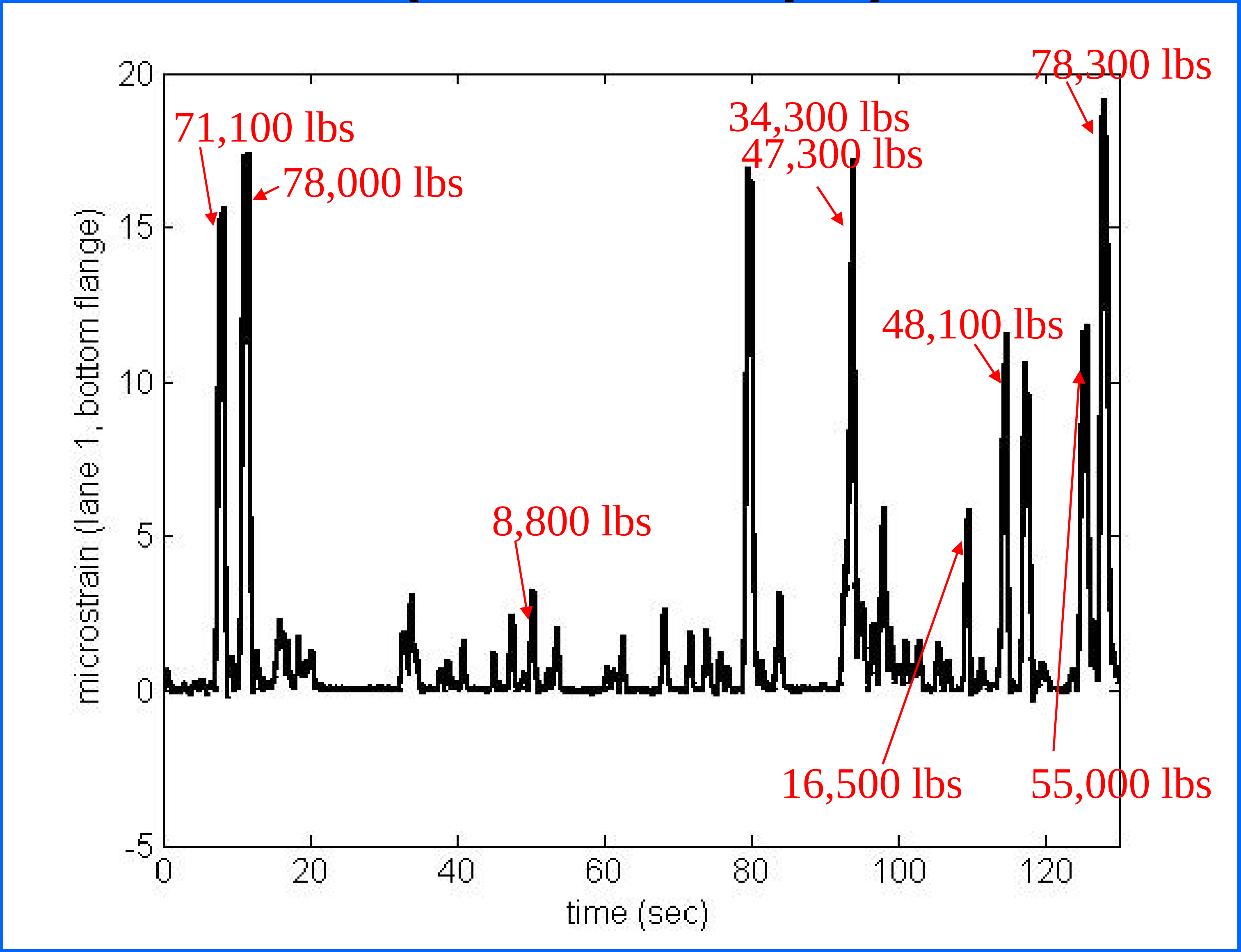


Time (seconds)

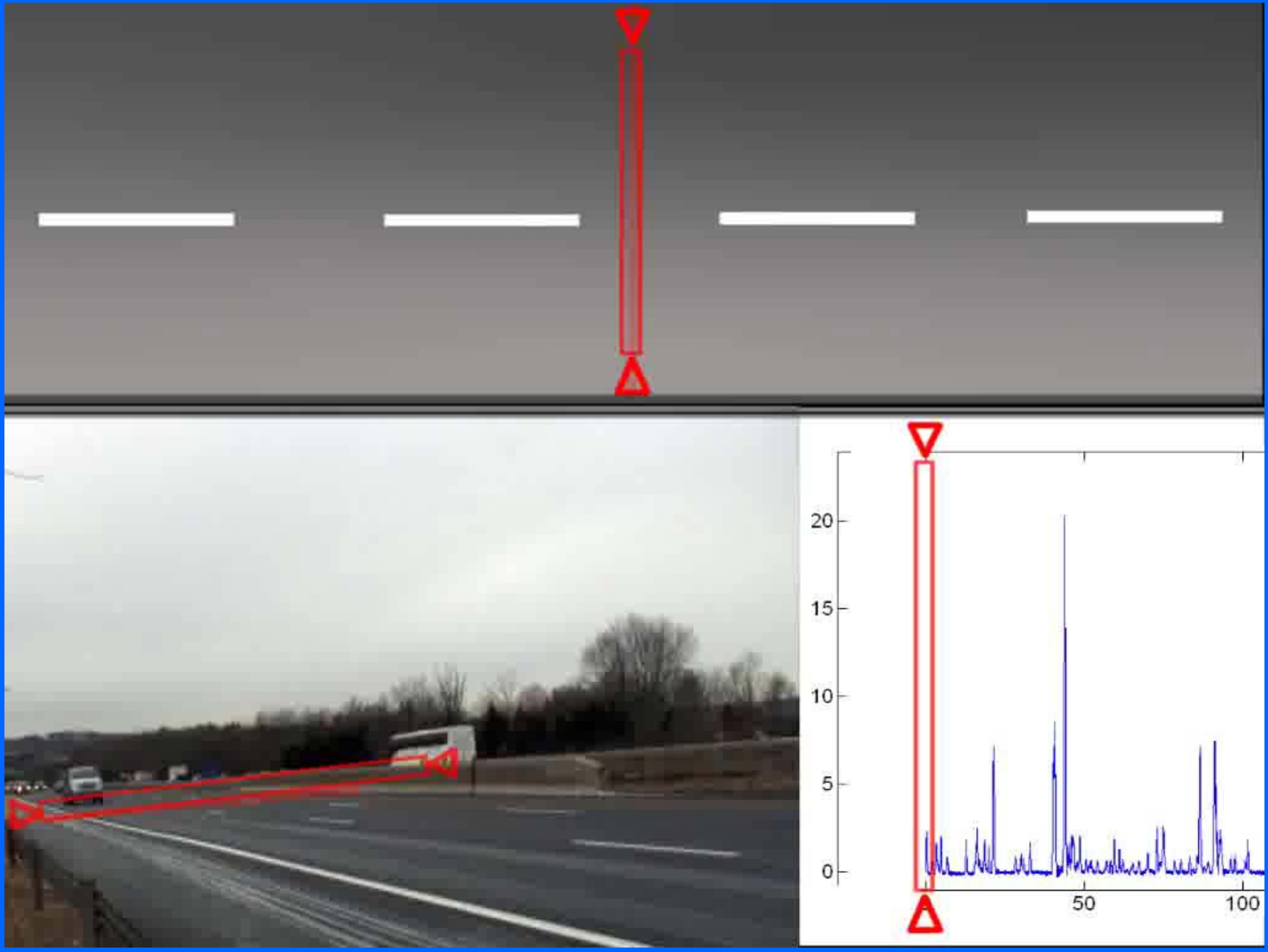
Strain Output: GVW

2nd Derivative of Strain: speed, lengths & axle weights

Actual Truck Traffic
(125 sec sample)



Bridge Weigh-In-Motion (BWIM)



RESULTS

BWIM: Test Truck in Lane 1

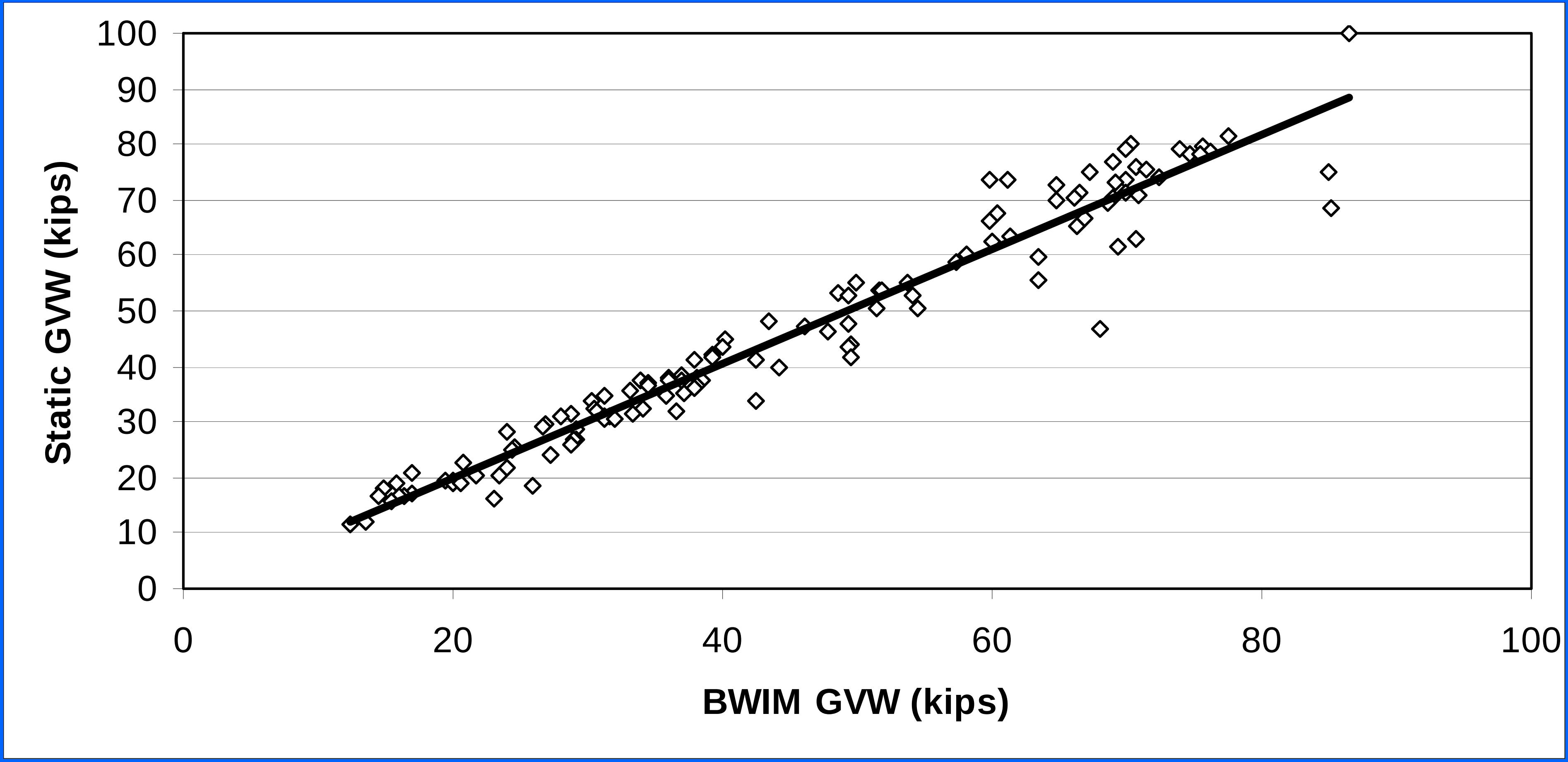
PERCENT DIFFERENCE (Based on 10 Passes)	Mean	Std Dev	$\langle E \rangle_{0.95}$
GVW [%]	0.00*	2.45	[-6.31; 6.31]
Axle Weight (P_1) [%]	31.88	44.91	[-83.59; 147.36]
Axle Group Weight (P_2+ P_3) [%]	13.23	15.90	[-27.64; 54.11]
Axle Group Weight (P_4+ P_5) [%]	-17.79	16.58	[-60.43; 24.85]
Wheelbase (sum of d_i) [ft]	2.49	2.69	[-1.35; 2.88]
Axle Spacing (d_1) [ft]	0.16	1.15	[-0.85; 0.95]
Axle Spacing (d_2) [ft]	1.35	0.79	[-0.22; 1.04]
Axle Spacing (d_3) [ft]	0.52	1.25	[-0.82; 1.14]
Axle Spacing (d_4) [ft]	0.46	2.53	[-1.85; 2.13]

* Test Truck Data Used to Determine Calibration Factor

BWIM: Test Truck in Lane 2

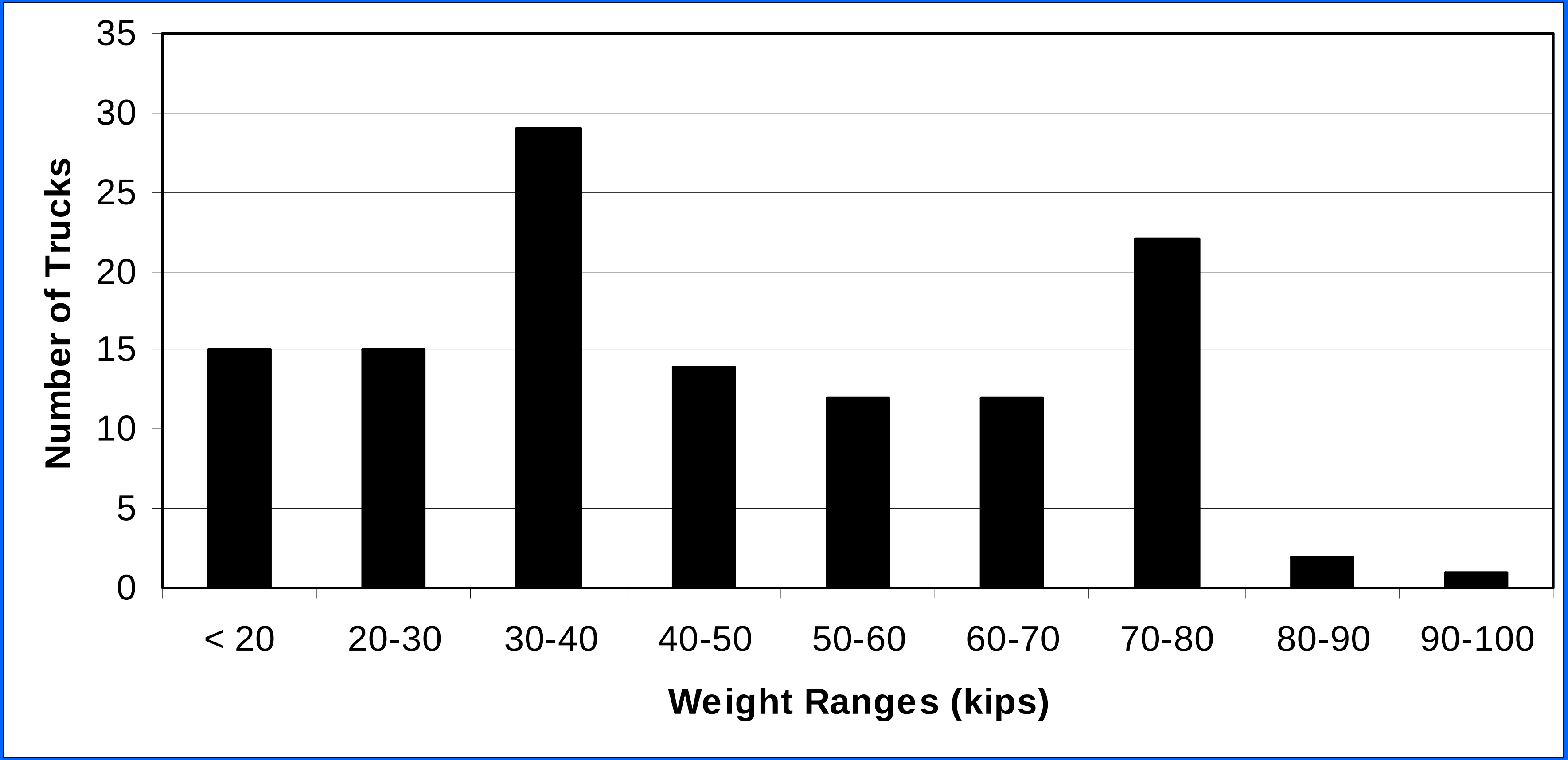
Percent Difference (based on 5 passes)	Mean	StdDev	$<E>_{0.95}$
GVW [%]	0.01*	5.91	[-15.19; 15.20]
Axle Weight (P_1) [%]	9.79	69.83	[–169.75; 189.32]
Axle Group Weight (P_2+ P_3) [%]	-10.62	61.25	[–168.11; 146.86]
Axle Group Weight (P_4+ P_5) [%]	9.27	52.54	[-125.81; 144.35]
Wheelbase (sum of d_i) [ft]	5.91	2.92	[-1.64; 13.45]
Axle Spacing (d_1) [ft]	0.23	0.92	[-2.17; 2.62]
Axle Spacing (d_2) [ft]	1.84	1.02	[-0.82; 4.46]
Axle Spacing (d_3) [ft]	-3.71	8.37	[-25.26; 17.81]
Axle Spacing (d_4) [ft]	0.95	1.84	[-3.77; 5.64]

Results From Traffic Stream



Range of Truck Traffic Weights

- 122 trucks from the traffic stream



BWIM Percent Difference from Static GVW
- Trucks from the Traffic Stream

Lane	# Trucks	Mean	Std Dev	$<E>_{0.95}$
1	109	-1.94	12.78	[-27.28; 23.39]
2	8	6.23	19.72	[-39.23; 51.70]

BWIM Percent Difference from Static GVW

5-Axle Trucks from the Traffic Stream

Lane	# Trucks	Mean	Std Dev	$<E>_{0.95}$
1	64	-1.13	8.22	[-17.52; 15,26]
2	5	14.18	20.31	[-38.03; 66.39]

Feasibility Results

- Applied novel approach to calculate speed and axle spacing and weights.
- Demonstrated Non-Intrusive Bridge Weigh-In-Motion using only Strain Measurements applied to a single-span steel girder bridge can produce gross vehicle weights, axle weights and speed.
- Seek improvements for acquisition of axle weights and speed data.
- Seek improvements for lane and multiple vehicle event configurations.
- Report Available Online

Acknowledgement

Great cooperation from and between ConnDOT, UCONN, CT State Police & FHWA.

CT - State Research Project: SPR- 2265

“Development of a Dual-Purpose Bridge Health Monitoring (BHM) and Bridge Weigh-In-Motion (BWIM) System For A Steel Girder Bridge”

Research Project Key Elements

BHM integrated and focused on BWIM data collection abilities

- System development
- Field Deployment
- Continuous Data Collection
- Periodic Validation
- Assess system robustness and stability over time

Sensors for Meriden Bridge

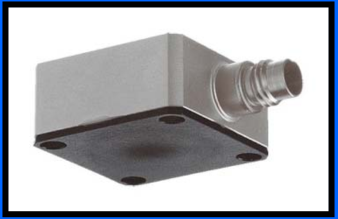
- Strain
  - –Vibrating Wire Strain Gage
  - –Quartz Strain Transducer
- Accelerometer(s)
  - –Integrated Circuit Piezoelectric (ICP)
  - –Variable Capacitance
- Temperature
  - –Surface Mount RTD

Innovative Sensor Technology: Quartz Strain Transducers

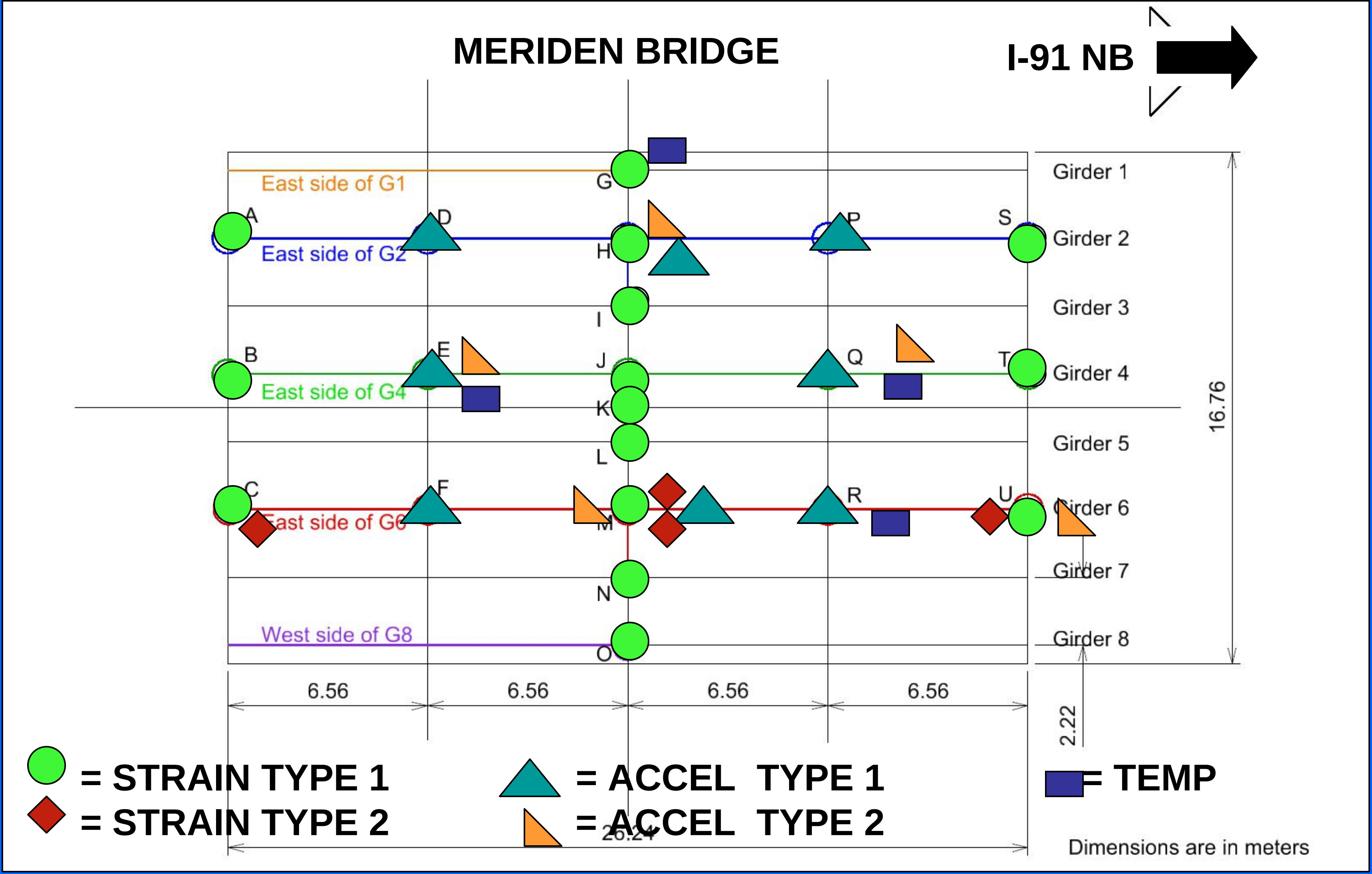
- Will allow for high sensitivity strain measurements
- Frequency range down to 0.1 Hz
- Powered in the field from Compact Data Acquisition (cDAQ) using Range Capacitor and Impedance Converter

Innovative Sensor Technology: Capacitive Accelerometers

- Will allow for constant acceleration measurements
- Frequency Range: 0-250 Hz
- Powered in the field from Compact Data Acquisition Unit using DC power supply module and analog input module



Proposed Sensor Layout



Installation – Summer 2010

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