# Corridor-based Monitoring of Highway Bridge Health Condition and Truck Loads using a Cyber-Physical System Framework

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## MOTIVATION

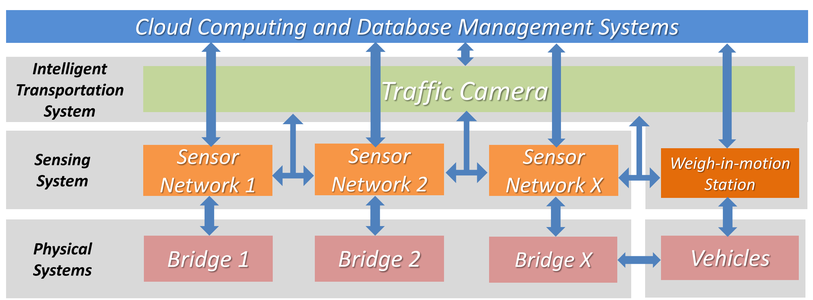
Highway bridges are vital highway elements upon which cars and heavy trucks travel daily. Over time, the condition of bridges deteriorate requiring visual inspections and other means of assessing structural conditions. Structural health monitoring (SHM) systems can be used to collect measurements from bridges to characterize the condition of the bridge and to aid the owner in making their asset management decisions. Unfortunately, most SHM systems only record the response of the bridge and lack any measurement of the loads inducing the measured response. Furthermore, an SHM system on one bridge lacks knowledge of how other bridges respond to the same load. Data pertaining to truck loads and how other bridges respond to the same load could offer unprecedented insight to bridge behavior and health.

## OBJECTIVES

This project advances a cyber-physical system (CPS) architecture that integrates bridge SHM systems with other data sources including cameras and weigh-in-motion systems to track truck loads along a highway corridor. The key objectives of the research project are to:

- Establish a corridor-based CPS that triggers data collection activities based on heavy trucks, and tracks trucks loads along the entire corridor;
- Correlates different bridge structural responses to the same truck and use correlations between bridges to identify unhealthy bridges;
- Conduct bridge load rating using information extracted from matched data sets;
- Predict truck loads using a learning-based model trained with collected bridge system input-output data sets;

## CYBER-PHYSICAL SYSTEM FRAMEWORK




**Cyber-Physical System (CPS) Framework for SHM**

CPS framework includes the following functional elements:

- Wireless sensor networks deployed as SHM systems measuring bridge responses to passing trucks;
- Weigh-in-motion stations used to measure axle weight information of trucks;
- Traffic camera array used to identify vehicles and match vehicles measured by WIMS and those on bridges;
- Advanced cloud computing and database system for secure storage, curation and automated interrogation of data in real-time.

## CPS TESTING ENVIRONMENT: I-275 HIGHWAY CORRIDOR

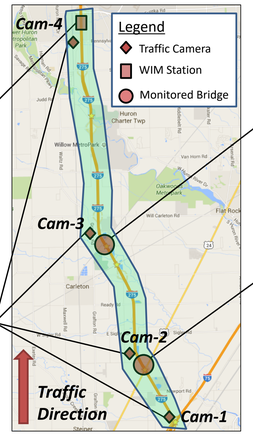
A CPS test-bed has been set-up on the 20-mile northbound I-275 corridor between I-94 (Romulus, MI) and I-75 (Monroe, MI). Three major data sources are used: two bridges with wireless monitoring systems installed, one weigh-in-motion (WIM) station measuring truck traffic, and a network of traffic cameras. Data is collected and pushed to a cloud-based NoSQL databases for secure storage and real-time processing.

### Weigh-in-Motion (WIM) Station


WIMS stations measure the curb weight of trucks on a per axle basis; they also record truck speeds and their lane assignment. WIMS stations are sparsely distributed in a network and typically are not collocated with a bridge (as is the case in I-275).

### Intelligent Traffic Camera System

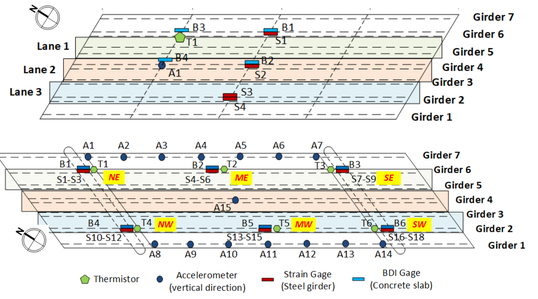
A network of four traffic cameras have been installed along the I-275 corridor providing a real-time stream of traffic conditions and trucks. Camera feeds are installed at the bridges and WIMS; feeds are recorded at 10 Hz. All camera feeds are processed by a GPU-enabled computer (Nvidia TX2) in real-time using convolutional neural networks (CNN) to identify truck events.




### Wireless SHM System for Highway Bridges

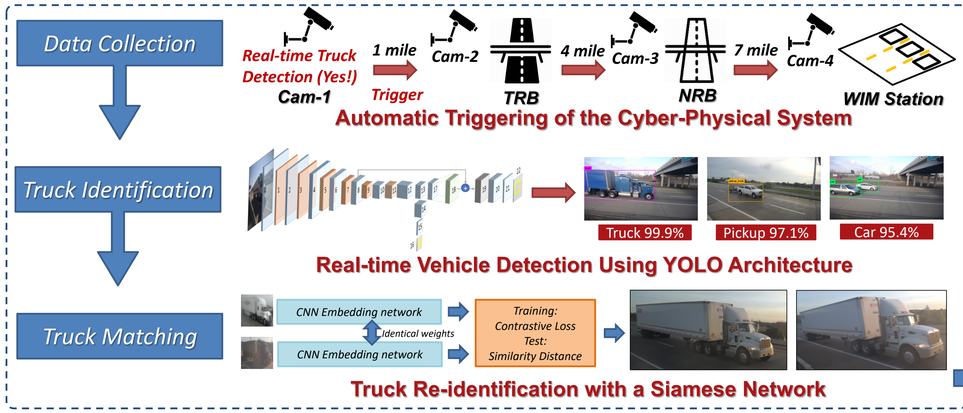
Newburg Road Bridge

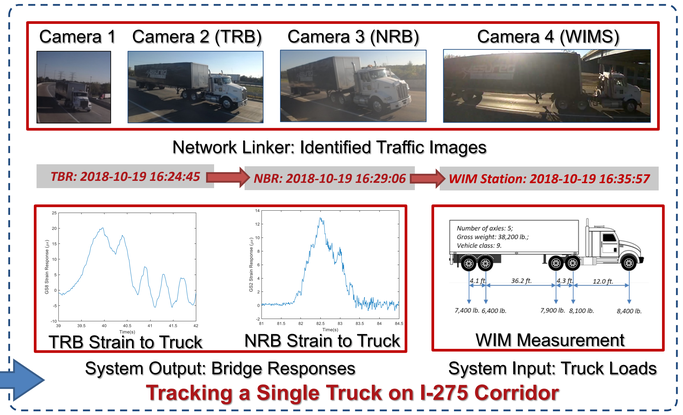
Telegraph Road Bridge




Wireless SHM systems are installed on the northbound Telegraph Road Bridge (TRB) and the Newburg Road Bridge (NRB). Both systems consist of accelerometers, strain gages, and thermistors to record the response of the bridges to truck loads.

## TRUCK RE-IDENTIFICATION AND LOAD CORRELATIONS

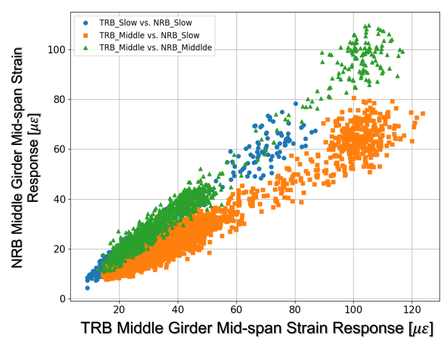


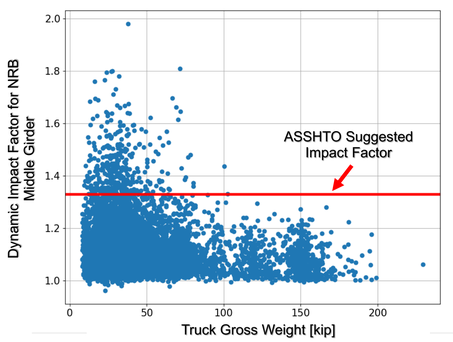




- The CPS system is triggered by Cam-1 which performs real-time truck detection using an embedded YOLO detector. To capture the same truck, Cam-1 triggers the data collection activities for the corridor in a cascading fashion based on the travel time from Cam-1 to each subsystem;
- After collecting data, it is uploaded to the cloud database. The cloud-based computing platform conducts truck detection on collected bridge response data (through peak detection) and traffic images (through CNN-based object detection) to time synchronize these two sources;
- After truck events are identified at each subsystem, a similarity-based match algorithm is developed based on the Siamese CNN architecture to re-identify the truck along the corridor so as to correlate measured bridge responses with truck load information measured at the WIM station.

## CPS-ASSISTED BRIDGE MANAGEMENT STRATEGIES

1. Baseline SHM by linking bridge responses:
   - Utilizing the data collected by the CPS architecture, the responses of different bridges to the same truck loads can be correlated and used as a regression model for detecting normal and abnormal behavior.
2. Data-driven bridge load rating analysis:
   - The matched input-output (i.e., truck load & bridge response) data for each bridge can be used to calculate parameters needed for load rating including dynamic impact factor, influence line, and load distribution factors, leading to less uncertainty and more accurate load rating.

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