Enriched Sensor Data for Enhanced Bridge Weigh-in-Motion (eBWIM) Applications

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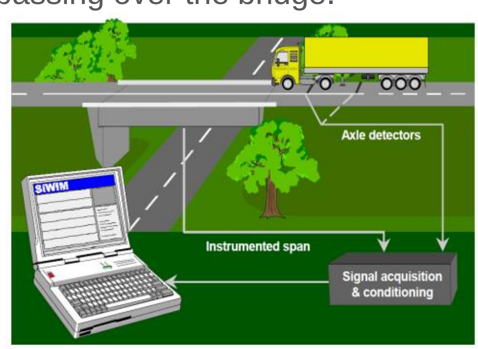
What's a Bridge-weigh-in-motion (BWIM) ?

- The system uses the entire bridge as a weighing device, and analysis of the bridge provides the gross weight of the vehicle passing over the bridge.

- Main elements:
- Strain sensors
- Axle detectors
- Signal processing

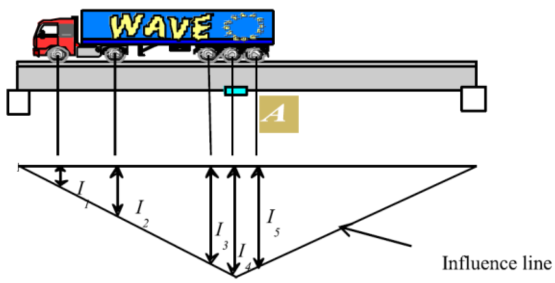


(O'Brien, E. J., Znidaric, A., Baumgartner, W., Gonzalez, A., & McNulty, P. (2001). Weighing-In-Motion of Axles and Vehicles for Europe (WAVE) WP1. 2: Bridge WIM Systems. University College, Dublin, Ireland.)

How does it work?

- IL Concept: Bending is proportional to product of moving load magnitude and influence line ordinate.
- Predicted moment:

$$M_{predicted} = W_1 \times I_1 + W_2 \times I_2 \dots \dots ..$$



(Lydon, M., Taylor, S. E., Robinson, D., Mufti, A., & O'Brien, E. J. (2015). Recent developments in bridge weigh in motion (BWIM). Journal of Civil Structural Health Monitoring, 6(1), 69–81.)

How does it work?

- Moses algorithm: The change in strain is related to the bending moment caused by the load.

$$M_{measured} = E \times S \sum_{i}^{N_{girders}} (\varepsilon_i)$$

- *E* & *S* is obtained through calibration.

(Lydon, M., Taylor, S. E., Robinson, D., Mufti, A., & O'Brien, E. J. (2015). Recent developments in bridge weigh in motion (BWIM). Journal of Civil Structural Health Monitoring, 6(1), 69–81.)

How does it work?

- Moses' algorithm determines axle weights by minimizing difference between measured and predicted bridge responses (moments).

$$Error = \sum_{k}^{No.of\ Scans} [M_{measured}^{k} - M_{predicted}^{k}]^2$$

- Weight of the vehicles for which predicted moment is equal to measured moment is calculated by solving an inverse problem.
- $A = F^{-1} \times M$ $\qquad GVW = \sum_{j}^{No\ of\ Axles} A_j$

BWIM Advantages

- Track vehicle loads to enforce bridge limits for overweight vehicles
- Facilitates load rating of older bridges and provides better estimation of bridge capacity for permit loading
- Enhances knowledge of truck movement in a region enabling better scheduling of bridge monitoring and maintenance
- Assists in bridge health monitoring

Conventional BWIMs' Limitations

- Use strain gauges for axle detection
- Poor accuracy with multiple vehicle passage on a bridge, either in tandem or side-by-side
- aptur

(http://vunukozo.top/insurance-for-semi-trucks.html)

(https://www.123rf.com/photo_32564053_two-big-trucks-traveling-side-by-side.html)

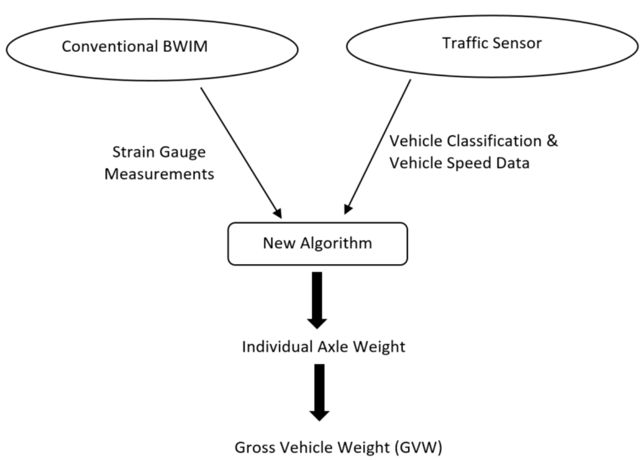
Other limitations

- Dynamic effect (bridge vibration) causes measured response to deviate from predicted response thus reduces accuracy.
- Ignoring transverse position of vehicle could lead to significant errors in identified axle weights
- Derived system equations are usually ill-conditioned, especially for rough road surfaces, vehicles with closely spaced axles & multiple vehicles
- These limitations have been or are being investigated by other researchers.
- Current study seeks to improve accuracy via better vehicle classification and speed detection.

Objective of the project

- Review the literature on
  - performance of BWIM systems and
  - vehicle classification performance of traffic sensors
- Determine if any traffic sensors could enable development of more accurate BWIM → eBWIM
- Propose a potential eBWIM system and how to evaluate it.

eBWIM Components



Some improvements so far.

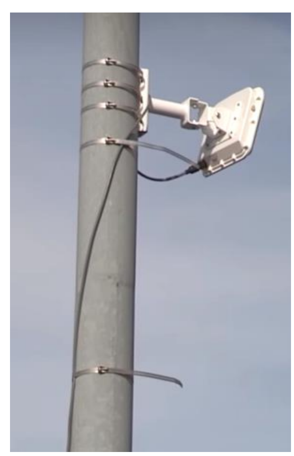
- Wavelet theory to improve axle detection (2006)
- Moving force identification (MFI) theory and Tikhonov regularization (2009) to remove the dynamic effects of vehicle
- Strip Method to overcome the multiple-presence problem – use specific sensors (2012)
- Contactless BWIM using video cameras (2016)
- Portable BWIM using accelerometers (2017)
- Free-of-axle detectors (FAD) (2001)

But these improvements have not overcome all of the limitations on BWIM.

Traffic Sensors with Potential

Microwave Radar Sensors

- Very low disruption
- High mounting ease
- Very high insensitivity to lighting and inclement weather
- High Accuracy
- Lower cost

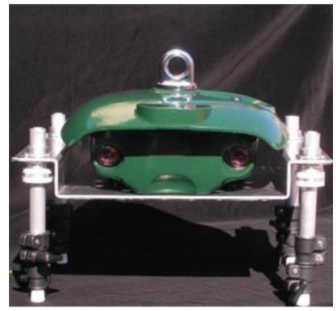


(Wavetronix LLC. (n.d.). SmartSensor HD. Retrieved April 25, 2018 from https://www.wavetronix.com/en/products/3-smartsensor-hd)

Traffic Sensors with Potential

Active Infrared Detectors

- Low/high disruption
- Moderate/low mounting ease
- Very high insensitivity to lighting and moderate insensitivity to inclement weather
- High Accuracy
- High cost



The infra-red traffic logger

(Minge, E., Kotzenmacher, J., & Peterson, S. (2010). Evaluation of non-intrusive technologies for traffic detection (No. MN/RC 2010-36). Minnesota Department of Transportation, Research Services Section, St. Paul, MN.)

Traffic Sensors with Potential

Video Image Vehicle Detection Systems

- Very low disruption
- High mounting ease
- Low insensitivity to lighting and inclement weather
- Moderate Accuracy
- Medium cost

(http://mysite.myhostcenter.com/s0096b13/Cameras_Installation.html.)

Traffic Sensors with Potential

Magnetic Sensors

(https://www.fhwa.dot.gov/policyinformation/pubs/vdstits2007/04pt2.cfm)
(https://partners.sigfox.com/products/magnetic-detector-model-type-dm-217cs-and-dm-218cs)

- High disruption
- High insensitivity to lighting and inclement weather
- Low Accuracy
- Low cost
- Sensor development not fully mature

Need for Algorithms

1) Data from microwave radar must be processed to obtain number of axles and their spacing

2) Coupling of BWIM system data and radar data will require algorithm modification or another algorithm

3) Proposed as future work

How to Evaluate eBWIM Effectiveness?

- Select a local/accessible bridge as testbed
- Procure a BWIM system (e.g. SiWIM®) & microwave radar sensors (e.g. Wavetronix)
- Develop algorithm for combining BWIM data with microwave radar sensor data → eBWIM
- Install eBWIM system on selected bridge and collect data on passing vehicles
- Obtain independent verification of vehicle data
- Assess effectiveness of eBWIM system
- Make modifications to algorithm if needed

Proposed Testbed Plan

- Instrumented highway bridges in the Twin Cities – instrumentation found to be unsuitable
- An appealing option: Bridges along U of M Transitway
- Campus Connector buses (known vehicle)
- Expedite permission process
- Easier instrumentation and equipment maintenance
- Proximity to the CEGE Department

(Google Maps)

Summary

- eBWIM data enrichment using microwave radar sensor promises to enhance accuracy of existing BWIM system.
- Algorithms/simulations required to couple data from microwave radar sensors with BWIM data.
- Deploy SiWIM® and Wavetronix microwave radar sensor on a testbed bridge for evaluation.

Thank You!

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