ISWIM

Practitioners' Guides

WIM Data for Bridge Engineering

WHAT SHOULD I KNOW, WHAT SHOULD I DO?

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WIM DATA FOR BRIDGE ENGINEERING: What Should I Know, What Should I Do?

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The **International Society for Weigh-In-Motion** (ISWIM) is a global non-profit organization, bringing together all stakeholders with an interest in Weigh-In-Motion (WIM) technology, its application, data it collects and information it generates. Our members are users, researchers and vendors of WIM systems including systems in or under the road pavement, bridges, rail tracks and on-board vehicles.

The **International Society for Weigh-In-Motion** has produced and is disseminating this publication to make the information contained herein available for use by ISWIM members. The information in this publication was reviewed by the ISWIM Editorial Board. This document does not circumvent any available standard Weigh-In-Motion (WIM) specifications, international standards, or other official WIM documentation.

Preface

This document is part of the publication series "ISWIM Practitioners' Guides" produced by the International Society for Weigh-In-Motion (ISWIM). The aim of this publication series is to provide WIM practitioners, technicians, and end-users with a series of guides illustrating "best practices" concerning the various aspects of WIM technology and its applications. This document does not circumvent any available standard WIM specifications.

On behalf of ISWIM, I would like to acknowledge and thank Olga Selezneva for taking the lead in championing the development of the ISWIM Practitioners' Guides Series, and the support of the individual Editorial Board members. Specific to this guide, I would like to thank the members of the working group and authors, namely Eugene OBrien, Aleš Žnidarič, Bernard Jacob, Jonathan Regehr, Chul-Woo Kim, Rish Malhotra, Andrzej Nowak, Matija Mavrič and Gérard Barons.

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Foreword

This guide is developed by ISWIM volunteers to assist bridge engineers and inspectors interested in using truck weight and size data collecting by WIM systems. It describes what is considered a good practice in the use of weigh-in-motion (WIM) data for bridge-related applications and assumes no prior knowledge of WIM. The guide focuses on the use of WIM data rather than on the data collection process itself.

There are many ways in which WIM data can be exploited in the bridge community to protect structures, to assess the loading on structures or to estimate the health of structures. Therefore, the guide provides guidance on use of WIM data for (a) bridge design and assessment loading; (b) bridge overload protection; and (c) bridge health monitoring. WIM data quality management is another important aspect covered in this guide.

Any comments or questions for this guide could be provided by email to: *info@is-wim.net*.

Olga Selezneva, Ph.D.
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Introduction

Weigh-In-Motion (WIM) is the process of measuring the properties of trucks, especially weights, while they are in motion. The most common forms of WIM are pavement-based technologies – pressure or force sensitive sensors are embedded in road pavement. The resulting data on axle weights or masses is widely used for the design or assessment of pavements. However, WIM data can also be a valuable tool for a number of bridge applications. Bridge WIM (B-WIM) is a particular WIM technology that uses an existing bridge as a weigh scale instead of using a pressure-sensitive sensor in the road pavement. For bridge applications, this has some advantages, but it should be emphasized that all WIM data, regardless of the technology, can be used in bridge applications.

WIM data provides information on axle (and vehicle) weights, speeds, and axle spacings, and it can be used to calculate load effects (e.g. bending moment, shear force) due to passing vehicles or combinations of vehicles. With some reasonably simple statistics, this can be used to calculate design values for load effects. This in turn, can be used to assess the conservatism of the design code or to propose customized values for bridges in particular locations. Most bridge loading standards use a notional load model, which provides a conservative estimate of the design load effects on the network, and a statistical study using WIM data can provide more accurate site-specific values. These kinds of statistical studies have applications in code development but also in the assessment of bridge safety, as load is just as important as load carrying capacity in a bridge safety assessment.

WIM is also used for bridge protection. WIM data can be used to inform policies on posting weight limits on bridges, balancing the need to protect the bridge against the economic cost of restrictions on vehicle weights. In recent years, WIM and B-WIM have also been used for bridge health monitoring. Pavement strip sensors can provide information on applied load, which greatly enhances any measurement of the bridge's response to that load. B-WIM can do this, but there are other advantages – it can measure actual bridge performance under traffic loading and provide information on the load sharing between girders and on the dynamic amplification.

Bridge Design and Assessment Loading

WIM data can be used to calculate characteristic maximum load effects such as bending moment, shear force, cable force and reaction on a bridge. These can be scaled up with load factors to provide design or assessment values or the information can be incorporated into a reliability analysis. For shorter spans, the critical load effect is the result of one extreme vehicle or perhaps an overtaking or meeting event involving a few vehicles. For longer spans, except for local effects, the critical event is more likely to be a large combination of vehicles as would be expected in congested traffic conditions. In general, shorter spans involve an allowance for dynamic amplification as the vehicles may be moving at speed. Whether the spans are long or short, fatigue loading is different, as damage results from an accumulation of stresses due to many different loading events.

Short-span Bridges (One or a Few Heavy Vehicles)

The influence line (IL) is defined as the load effect (LE) due to a unit axle load, expressed as a function of its location on the bridge. The LE due to several axles is found from the influence line – it is simply the sum of the effects due to each axle.

Generally, the data of interest is the 'block maximum' value, typically maximum-per-day, for all loading events that happened in that block of time. As not many trucks travel during the weekend or on holidays, people often discard that data, resulting in a year made up of about 250 working days. The block maximum values can be plotted in order of magnitude to form the cumulative distribution function. So if, for example, there are 500 days of WIM data, the smallest value, corresponding to a probability of 1/500, is plotted first, the 2nd smallest (probability of 2/500) next and so forth – see Figure 1. The data can be hard to see at the ends, so they are often plotted to a double-log or 'Gumbel' scale on the Y-axis and are known as Probability Paper plots – Figure 2.

Bridges are designed for a specific return period. While this is given in units of time, it is a level of probability or safety, not a design life. For example, with maximum-per-day data and 250 working days per year, a 75-year return period corresponds to a probability of 1 in 75x250. This level of loading has a probability of being exceeded of 1 in 18,750 (or a probability of not being exceeded of 1 – 1/18,750 = 0.999947). The corresponding value of LE, the 75-year characteristic maximum, can be read directly from the Probability Paper plot – see Figure 2.

The design life relates to the period of time for which the bridge is expected to remain in service and is unrelated to the level of safety. The AASHTO standard specifies a 75-year design life and a 75-year return period. The Eurocode, on the other hand, specifies a 100-year design working life and a 1000-year return period (a level of loading corresponding to about 10% probability of being exceeded in the 100-year life).

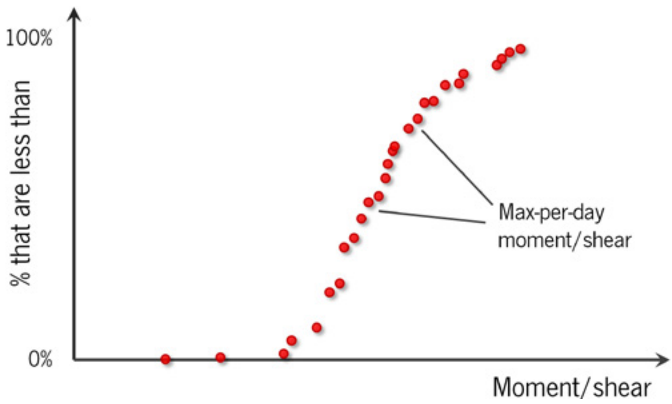

Figure 1: Cumulative distribution function of Load Effect

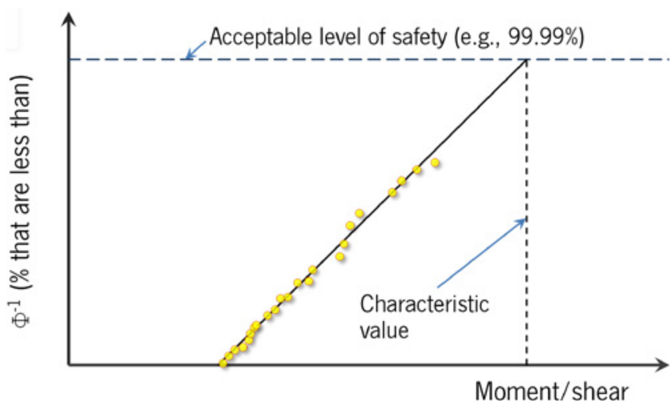

Figure 2: Probability paper plot

Much of the challenge in calculating characteristic maximum LEs comes from a shortage of WIM data. Even with years of data, there is a considerable extrapolation from the data to the return period level [Zhou et al., 2012; 2016]. Some engineers use simulation to artificially generate more WIM data. Once the statistical distribution of weights is known from WIM data, further 'typical' weights can be generated in a process known as Monte Carlo simulation. This allows for many more possible combinations of vehicle meeting and overtaking events to be investigated.

Most countries have a system for issuing permits for trucks heavier (or longer) than the standard rules allow. In the United States, some vehicles outside the standard rules are permitted because of 'grandfathered rights', i.e., vehicles of that type were present in the state before the legislation was introduced (see Figure 3). In many countries, there are 'routine permits', i.e., vehicles outside the standard rules that require permits but are permitted to travel with few restrictions. Finally, there are special permit vehicles that are subject to restrictions such as speed limits and escort vehicles. Notional load models used for bridge design such as HL-93 and the Eurocode, tend to cover all types of vehicle except the special permit ones.

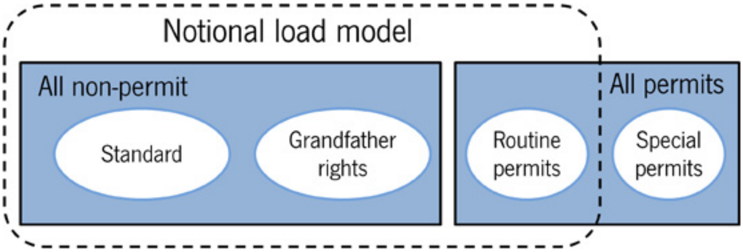

Figure 3:
Vehicle permit classes

When calculating characteristic maximum load effects, special permit vehicles are usually treated separately, and routine permit vehicles may or may not be included in the data. Unfortunately, many WIM systems do not have the ability to separate permit from non-permit vehicles. Some researchers have addressed this problem by estimating the vehicle permit status from its length or number of axles [Enright et al., 2016].

There is some guidance in the literature [O'Connor & OBrien, 2005; Žnidarič et al., 2018] on the minimum quantity of WIM data for a calculation of characteristic maximum LE. What is clear is that more data is better and that data should be representative of what is present. For example, the period of data collection should cover all seasons if there is the possibility of seasonal variation (e.g. harvesting season in an agricultural area). While early work was based on very small databases, recent studies typically use years of WIM data.

Calculations of characteristic maximum LE are generally based on the static weights of vehicles and do not account for dynamic amplification of the effect. Standards generally specify a system of rules to allow for dynamic effects for loading due to free flowing traffic. These rules are often quite conservative and may be the result of combining extremes of vehicle weights with extremes of dynamic amplification factor (DAF). In recent years, B-WIM systems allow the evaluation of DAF values for vehicle loading events, thus allowing the calculation of more realistic characteristic DAF values for specific bridges [Kalin et al., 2021].

Some approximate methods have been proposed which can be used to convert WIM data into an indication of 'bridge friendliness' [OBrien & Enright, 2013; Getachew & OBrien, 2007]. These can be used to provide a quick answer on whether or not a particular site is heavily loaded from a bridge perspective.

Long-span Bridges (Many Vehicles)

For longer span bridges, congested traffic loading events, involving many vehicles moving slowly, tend to govern. In these conditions, no allowance for dynamics is used. What constitutes long in this context is not generally known, i.e. when many vehicles in congested conditions become more critical than a loading event with a small number of vehicles travelling at speed. However, a threshold span length in the region of 50 m has been suggested. Where WIM data is available, it can be used to generate trains of vehicles on the bridge. With influence lines, this can be used to generate load effects and, as described above, to calculate characteristic maximum and design/assessment values [Flint & Jacob, 1996; Zhou et al., 2014].

Unfortunately, most WIM technologies do not function well when traffic is congested so the challenge is to use WIM data during free-flowing traffic conditions to represent congested or jammed conditions on the bridge. There are many studies, including the work done during the derivation of the Eurocode load model, where gaps in free-flowing WIM data are simply 'collapsed' to minimum values to generate congested traffic. There is much discussion in the literature as to what constitutes a reasonable minimum gap between vehicles [OBrien & Caprani, 2005]. One of the more popular values is a minimum axle-to-axle gap of 5 m and this seems to give conservative results.

Another challenge with long span bridges is the issue of cars. Some WIM systems do not record cars so data will only be available for heavier vehicles. Cars play an important role in long span bridges. As they are much lighter than trucks, they generate zones between trucks where the loading is considerably less. Hence, if a site-specific design/assessment load effect is calculated without any consideration of cars, the results are likely to be quite conservative. Even if cars are recorded in the data, simply collapsing all the gaps between vehicles in multi-lane traffic changes the relative positions of vehicles in adjacent lanes. Heavy trucks tend to use the overtaking lane only to overtake another heavy vehicle. These kinds of features in the traffic will be lost if gaps are collapsed in each lane independently.

Fatigue Loading of Bridges

Fatigue is a progressive damage process affecting mainly steel and metallic structures. Repeated stress variations (cycles), particularly on welded details, result in the initiation and then the propagation of cracks, resulting in a loss of stiffness and ultimately in failure. Steel bridges or steel parts of composite bridges, cable (stayed or suspended) bridges and reinforcement and prestressing strands and cables in concrete bridges may be affected by fatigue. Repeated axle loads may also cause fatigue problems in the reinforced concrete deck slabs of bridges. In some cases, fatigue may lead to bridge collapse.

The most common actions leading to fatigue in road bridges are traffic loads. Each heavy vehicle crossing a bridge induces one or a few stress cycles, which contribute to crack propagation. It is widely assumed that the initiation of cracks in steel bridges occurs during construction. It is important to know the stress variation history in a bridge to design its details against fatigue, and to monitor its remaining life, in order to prevent severe damage or failure. It is important to note that crack propagation is not linear (Figure 4) but increases exponentially, which may lead to sudden failure before the detection of cracks. It is generally assessed that 80% of the damage occurs during the last 15 to 20% of the lifetime.

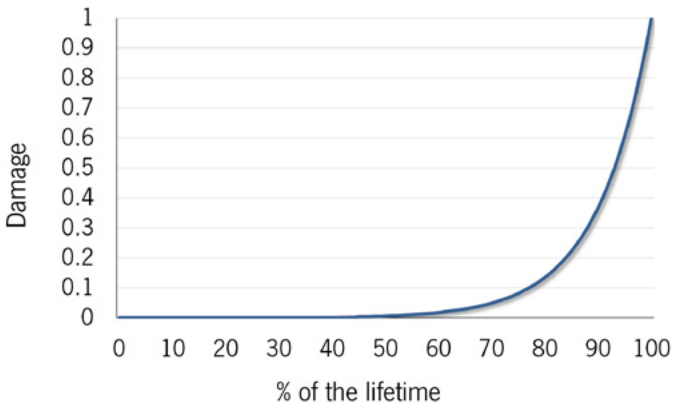

Figure 4:
Crack propagation in fatigue

To assess the fatigue lifetime of bridge details, and the residual lifetime, it is necessary to know the time history of the bridge loading, including axle and vehicle weights, spacings, lateral location, etc. WIM data are the main source of this information, both for the design of a new structure and the assessment of an existing structure [Jacob & Kretz, 1996]. WIM data in accuracy class B(10), or at least C(15) (COST323) is recommended for fatigue assessment. It is important to collect WIM data over a long time period (one year or more), because of the extrapolation over the whole bridge lifetime to assess cumulative damage. Any trend in the traffic density should either be included in the WIM data, or incorporated into the load model for fatigue assessment, using sensible assumptions.

Using a Bridge WIM system for fatigue assessment may be a plus because it would allow the measurement of traffic loads and some strains simultaneously, therefore taking into account the dynamic effects and any other structural effects. However, the measured strains may not be the most critical ones for fatigue damage. Further, a road sensor WIM system can provide all the necessary data for fatigue assessment. In this case, a good bridge model (influence lines and/or influence surfaces) should be available.

Bridge Protection

The protection of bridge infrastructure assets is a critical activity for bridge owners. WIM systems can support bridge protection efforts by providing the truck traffic and loading data needed for bridge posting and by rerouting trucks away for bridges with limited structural capacity.

WIM data for bridge posting

Infrastructure owners post bridges to limit the maximum gross and/or axle loads allowed to traverse the structure, as has been done for the bridge in Figure 5. Bridge posting may be necessary if its capacity has decreased as a result of normal deterioration or unexpected damage, or if its capacity is inconsistent with network-wide truck mass limits. Regardless of the cause, the challenge of posting is to ensure that bridges can be used safely, while recognizing that an overly restrictive limit has economic consequences for road users.

Bridge posting decisions rely on both condition inspections and detailed and current characterization of expected truck traffic loads. As for design, bridge evaluation techniques—including posting—benefit from knowledge of numerous truck traffic data characteristics produced by WIM systems. These include: truck gross weight, axle weights, axle configuration, the lateral position of a truck on the bridge, frequency of multiple presence, and speed. A refined spatial and temporal characterization of these data helps owners to ensure safety and to understand the economic consequences of posting decisions.

Figure 5: Bridge posted with 19 t limit and not more than one truck. It collapsed when crossed by a 51 t truck.

WIM systems to help manage posted bridges

Once a bridge has been identified as needing protection, WIM systems can be configured as part of technology solutions to help manage the posting. Several potential configurations can be deployed.

- **Automated warning systems:** WIM data can help protect bridges from damage using systems that automatically direct overweight vehicles to take another route. These systems are similar to over-height warning systems located in advance of low bridges or overpasses. Heavy vehicles that exceed posted weight limits are alerted by variable message signs that they must not use the bridge. In the future, these systems may be integrated with onboard devices that provide information to drivers through their dash-mounted displays.
- **Virtual weigh stations and enforcement:** A WIM system located a few kilometres in advance of a bridge can interface with other technologies such as overview cameras and license plate readers so that overweight trucks can easily be identified – Figure 6. This kind of system is known as a Virtual Weigh Station (VWS) or Video WIM system, a commercial vehicle enforcement location that does not require a staffed facility and may be monitored over the internet. Enforcement personnel can then monitor traffic from a remote location in real time, observing vehicle weights associated with vehicle identification and photographs for visual reference. This makes it easy to select vehicles for weight enforcement either at the roadside or at a designated inspection facility.

  Company profiling, or the use of WIM data to encourage carriers and operators with a history of overloading to change their behavior, is another use case for virtual systems [Van Loo & Jacob, 2011]. Integration with government databases can assist in the identification of carriers that are not keeping their vehicles within capacity limits. Agencies can then notify operators to discontinue this activity or face penalties.

Figure 6: WIM system in advance of the Goethals Bridge in New York, U.S.A.

The Zoo Interchange in Milwaukee, Wisconsin is an example of how a VWS can be used to manage bridge infrastructure. Enforcement and data collection efforts provided bridge protection and information required to prolong the service life of the bridge and identify when bridge remediation would be required. In the case of the Zoo Interchange, the data from the site indicated that vehicle volumes and weights greatly exceeded the original bridge design criteria. This led to a complete bridge assessment that found structural damage that affected safety, warranting closure of the bridge and ultimately replacement.

- **Road charging and road access based on bridge criteria:** WIM data can be used to develop Performance-Based Standards (PBS) based on bridge criteria. PBS can be used as a basis for road charging. An example of this is the Australian Intelligent Access Programme (IAP). The IAP allows participating commercial vehicle operators access, or improved access, to the road network in return for agreeing to be monitored and complying with access conditions imposed by road authorities or road managers. Commercial vehicles enrolled in the program are monitored using an in-vehicle unit. Satellite tracking and wireless communication are used to remotely monitor the vehicles' use of the road network. Under the IAP program, operators are granted access to certain bridges, can operate at greater masses, or can operate certain larger and heavier vehicles, than would normally be permitted.

Bridge Health Monitoring

Bridge structural health monitoring (SHM) is the process of appraising the structure of a bridge, its behavior in various situations and using this information for maintenance planning. Different technologies are used for SHM, depending on the element of the bridge to be analyzed, the data needed for the analysis and the timeframe of monitoring. Essential information about a bridge from the perspective of SHM is the intensity of loading due to vehicles passing over it – loading and capacity to carry load are equally important from the perspective of safety. Traffic loading, specific to a particular site, can be measured with the help of a weigh-in-motion system. Further, these systems can, through long-term measurements, offer the user direct information about the condition of the bridge.

What data about bridges do we get from all WIM data?

The data from all types of WIM systems, whether pavement based or Bridge WIM (B-WIM), can be used to find the traffic load effects on the bridge. These can be used in turn to provide a site-specific safety assessment appropriate to the level of loading that is actually present. This true loading can vary considerably from the notional load model for which the bridge was originally designed.

What data about bridges do we get from B-WIM systems?

B-WIM systems are particular WIM systems that use existing bridges or culverts as weighing platforms. Since the sensors are installed directly on the underside of the bridge, these systems can give users additional information about the structural condition and performance.

B-WIM systems require actual, not theoretical bending influence lines (IL) to calculate accurate axle loads. The differences between the two can be substantial. Figure 7 compares the theoretical mid-span ILs of a 27-m long simply supported bridge, composed of steel girders and reinforced concrete deck, with the measured one generated by the B-WIM system and the IL modelled with finite-element software. In the model, springs were added to the supports to match their rotations, and the cap of the IL was rounded as a result of the superstructure's depth. Such differences between theoretical and actual bridge performance are common and can increase substantially when the bearings of a bridge seize and begin to restrict rotations. Consequently, the IL shape changes, which can be monitored through long-term B-WIM measurements [Žnidarič & Kalin, 2020].

In a B-WIM system, weights are determined on the basis of strain measurements secured by transducers. If a bridge girder is damaged, the distribution of strain generated by a truck on the bridge is changed. While further research is needed, there is clearly potential to use the data collected to detect such changes in bridge behavior/condition.

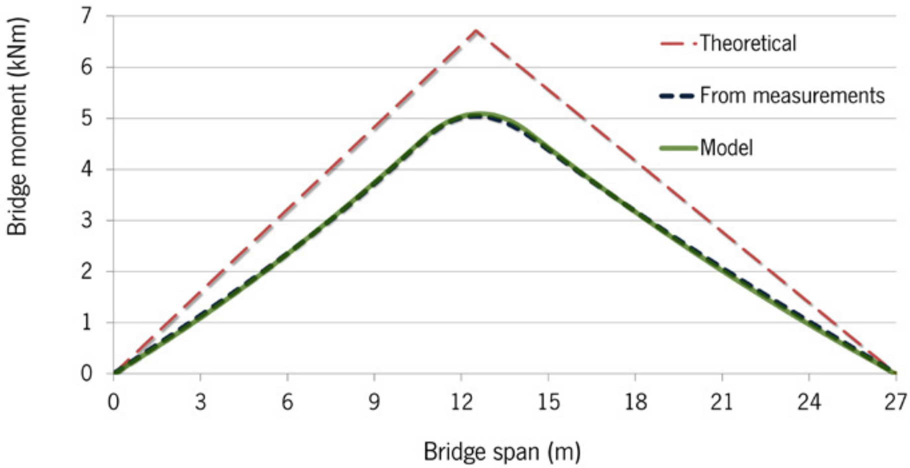

Figure 7: A real-life example of theoretical, measured and modelled influence lines

B-WIM systems can also detect the lateral position of heavy vehicles on the bridge. This, together with direct strain measurements, allows to measure the percentage of load individual girders or deck sections take. If vehicles exert higher or lower traffic loads than assumed in the model, this can significantly affect the safety assessment result of that structural member. For example, Figure 8 shows the girder distribution factor (GDF) results, calculated from 4,550 strain records, recorded on a 40-m long motorway bridge with four prestressed concrete beams and carrying a shoulder and two lanes of traffic. The graph displays the mean values and the ± 1 standard deviation intervals of GDF values for traffic in the slow and fast lanes.

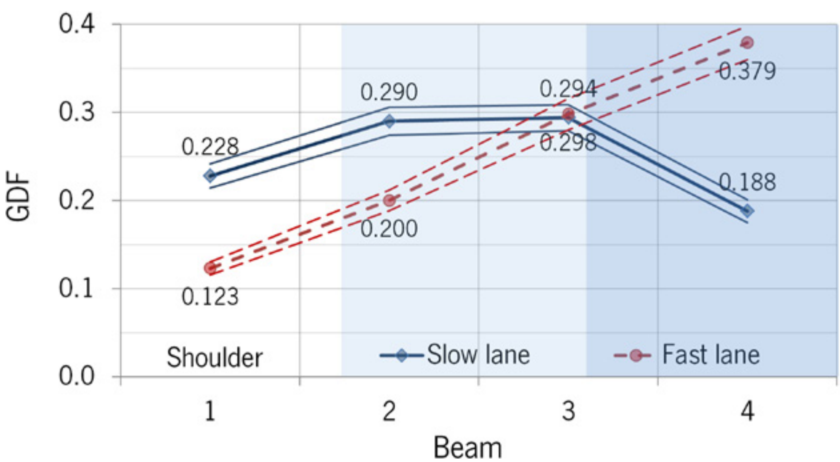

Figure 8: Girder distribution factor from an analysis of a four-girder bridge

Practical examples

In its early stages of development, B-WIM was mostly used on short span steel structures. In the 1990s, it was extended to longer spans and concrete bridges. A preliminary study was carried out on an orthotropic bridge in the 1990s [Dempsey et al., 1998]. This was extended in 2006, with the instrumentation of the Millau viaduct (Figure 9) [Jacob et al., 2010]. The gross weight accuracy in Millau B-WIM system was high enough for pre-selection of overloaded vehicles for enforcement.

Figure 9: B-WIM sensor installed on one of the spans of the Millau viaduct

With advances in technology, higher accuracy, comparable to pavement WIM systems, is reported [Richardson et al., 2014]. Bridge condition add-ons to B-WIM installations have also moved forward. For example, a highway viaduct in Slovenia was equipped with a B-WIM system in 2018, as a part of a permanent monitoring system that correlated B-WIM data with strain and acceleration measurements. The viaduct is nearly half a century old, and the combined loading and structural response data were used to calibrate a numerical model of the bridge. It was determined that the load effects on the structure due to heavy traffic were considerably lower than expected from the theoretical bridge model, which was beneficial for its life expectancy.

For several years a bridge on the A10 in France has been instrumented with a B-WIM system and other sensors – Figure 10. It provides deformation data as well as traffic load data from the B-WIM system. Within the results is some information on the number and weights of special permit overloaded trucks. It was concluded that the risk of overload was at an acceptable level for the short term future.

Several long-span steel bridges in the Netherland have been successfully equipped with WIM and other sensors to re-evaluate fatigue conditions. These projects demonstrate the interest in combining WIM with structural monitoring using some of the same sensors to appraise the effects of traffic loads on bridges and evaluate their remaining life.

Figure 10: B-WIM sensors on A10 bridge (France)

Data Quality for Bridge Applications

The collected raw WIM data may include errors resulting from many issues. These include a malfunctioning processing system, sensor failure, faulty calibration, changes in temperature or weather conditions, detours, accidents, road closures and roadworks. Inadequate quality of the traffic data can lead to misinterpretation and/or incorrect estimation of the traffic-induced load effects.

It is important to maintain the required quality of data in bridge design by applying quality control (QC) procedures to identify and eliminate questionable records [Henny, 1999; Ghosn et al., 2011; Sivakumar et al., 2008]. There are two types of error in WIM data: (1) random errors usually affecting individual vehicles and (2) systematic errors that affect groups of records. In bridge application, systematic errors are critical, as they can impact the assessment of characteristic maximum load effects. Important documents that provide guidelines for QC of WIM data include the WP3.2 report of the WAVE project [WAVE, 2000], the Traffic Monitoring Guide [FHWA, 2016a], AASHTO Guidelines for Traffic Data Programs [Vandervalk-Ostrander, 2009], and the Highway Performance Monitoring System Field Manual [FHWA, 2016].

Many studies related to quality checks of traffic data have been conducted [Elkins & Higgins, 2008; Kulicki et al., 2015; Nichols & Bullock, 2004; Qu et al., 1997; Ramachandran et al., 2011; Anjan Babu et al., 2019]. However, there is no universal documented Quality Control procedure.

A traffic data QC procedure is presented in Figure 11. The QC includes various data checks, including completeness, logical, statistical, and traffic-specific checks. A completeness check identifies missing records. Probable causes of missing data may be communication failures or system malfunction. Logical checks include verification of records with zero weight and spacings and an inconsistent number of axles. Statistical checks are applied to identify anomalies in the traffic patterns and possible reasons causing the abnormality. Checks can be applied to accumulated data on a monthly basis to detect possible malfunctions and their reasons, such as communication failures or operational problems with the sensor. Traffic-specific checks determine possible errors in vehicle configurations, classes, and weights that use the specific threshold values.

Examples of specific filtering criteria are shown in Table 1. The QC procedure checks WIM system description, timestamps, duplicated or null records, and vehicle configurations. The QC procedure begins with WIM station ID, traffic lane, and trip direction detection. If the data record does not pass the data description check, it is flagged. WIM data is validated for the correct year, month, day, and time. It is also checked for duplicated records with identical vehicle weights and configurations. Duplicated and null records are discarded. From WIM data analysis experience, it was observed that data duplication or null records are standard errors. After WIM data is checked for description, time, nulls, and duplicates, there is generally an analysis of the gross vehicle weight (GVW) data and axle weights and spacings. All data with zero weight recorded is eliminated. The number of axles and axle spacings are checked to determine if the vehicle was recorded correctly. The sum of axle weights is also compared with the GVW, typically with +/- 10% tolerance. The WIM records are checked for the minimum first axle spacing and minimum axle spacing based on a literature review and traffic analysis. Also, the threshold limit is verified for steering axle weight and for a single, tandem, and tridem axle weight.

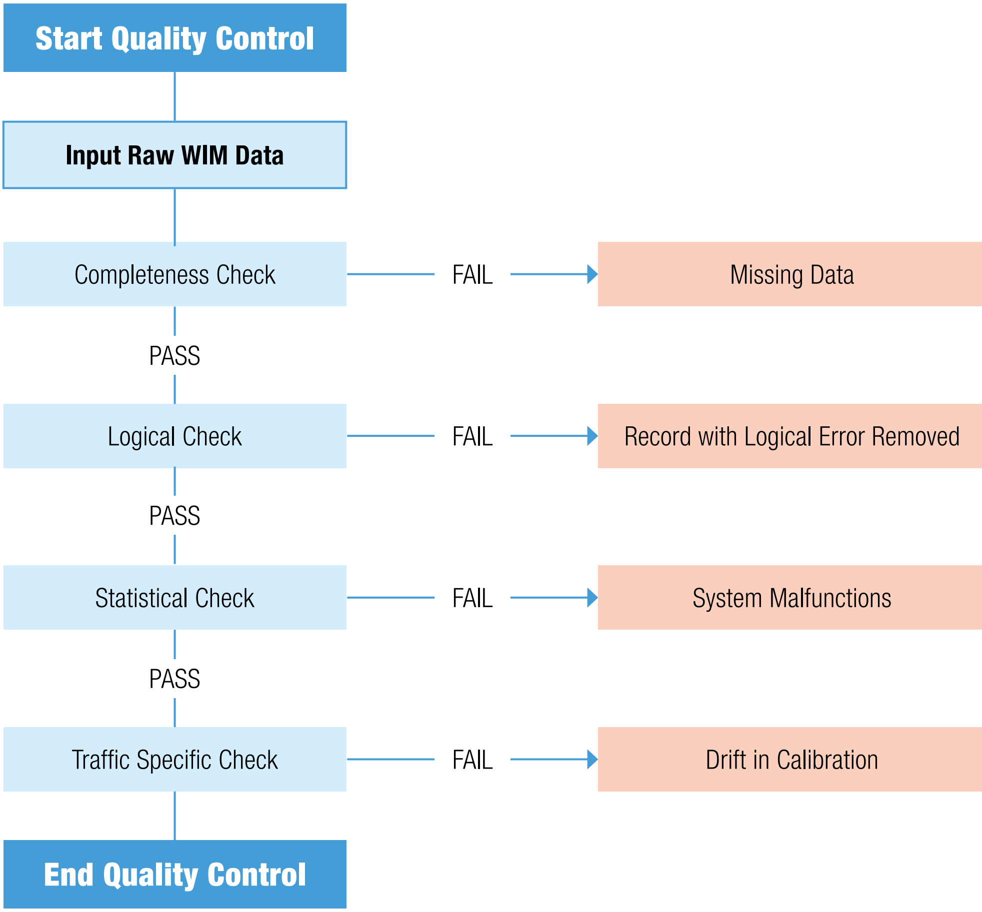

Figure 11: Data Quality Control Procedure Flowchart

Type	Filtering criteria	Example of threshold limits
Description	Station ID	Invalid ID
	Lane of travel	≠ (0-9)
Timestamp	Invalid year	Null or irrespective year
	Invalid month	≠ (1-12)
	Invalid day	≠ (1-31)
	Invalid time	≠ (0-86399) sec.
Duplicates	Identical records	Exact copy
	Same weights for consecutive axles or consecutive groups of axles	Exact copy
Vehicle configuration	Invalid vehicle class	≠ (set of vehicle classes)
	Negative or abnormally small GVW	1 tonne (2.2 kips)
	Abnormally small axle spacings	0.3 m (0.98 ft)
	Number of axles vs. axle weights	Number of axles = number of axle weights
	The number of axles versus the number of axle spacings	Number of axles ≠ number of axles spacing +1
	Sum of axle weights is equal to GVW	± 10% of GVW
	Axle weight	≠ 0.5 – 27 tonnes (1.1-60 kips)
Speed limits	Vehicle speed	≠ 15* – 145 km/h (10-90 mph)

* Less for low-speed WIM

Table 1: Example of Quality Control filtering criteria (thresholds may vary considerably between countries)

Inadequate QC may result in over-estimation or under-estimation of the load effects, and hence inaccurate prediction and assessments of traffic loads on bridges and roads. Understanding vehicle classification systems and processing raw WIM data are vital since the heaviest vehicles, which contribute significantly to the upper tail of the traffic load distribution, can be mistakenly eliminated. The QC procedure can help to identify malfunctioning systems and record poor-quality traffic WIM data. It can also serve as a basis in prioritization when considering upgrades and maintenance of WIM systems. Reliable WIM traffic data can serve as a basis to develop traffic load models for the design of new bridges and it can predict traffic-induced load effects when evaluating existing structures. Quality traffic data is important in the development of statistical parameters that reflect the uncertainty in traffic-induced load effects.

Conclusions

This document provides an introduction to the bridge applications of WIM. There is a brief discussion on data quality – for bridge applications, the focus is on having no bias in the data rather than on the accuracy of individual vehicle records. It is also important for some bridge applications to have accurate time stamps.

All WIM data has applications in bridge engineering, whatever the technology used to secure it. Perhaps the most important application is in traffic load. With some statistical calculations, WIM data can be used to determine the characteristic maximum load effects on bridges and hence the design values. This has applications in the development of traffic load models for countries and for the finding of site-specific design loading for a particular bridge.

WIM data can also be used in the protection of bridges that have lower load carrying capacity. It can be used to inform posting policy or to issue a warning to heavy vehicles using a variable message sign. WIM and particularly Bridge WIM can also be used for bridge health monitoring. Having load as well as condition (performance under load) data greatly improves the quality of the information on the overall safety of a bridge structure. This in turn can be used to extend the safe working life of a bridge and ultimately to reduce its carbon footprint.

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