DETERMINING BRIDGE LOADING FROM SOUTH AFRICAN WIM DATA

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ABSTRACT

WIM data is in abundance in South Africa, mainly due to toll concessions operating in the Northern parts of the country. Most Weigh-in-Motion sensors are considered to be well calibrated to international norms, but still suffer some shortcomings. Raw WIM data still contains inherent measurement errors, and some post calibration still needs to be performed before the data is usable to determine bridge load effects. Over the years, some studies have suggested cleaning techniques and post calibration techniques for South African WIM data. This paper investigates errors, systematic and random, as well as other uncertainties that are inherent to WIM systems, which influence bridge load effects to show how local WIM data can be used to calculate bridge load effects.

1. INTRODUCTION AND MOTIVATION

Weigh-in-Motion (WIM) data is in abundance in South Africa, mainly due to toll concessions operating in the Northern parts of the country. WIM systems enable authorities to collect large amounts of data undetected and the data is therefore unbiased. To derive a load model for bridge design it is important to capture the heaviest vehicles along with their frequencies. This is captured by continuous WIM measurement.

Most Weigh-in-Motion sensors in South Africa are considered to be well calibrated to international norms, but still suffer some shortcomings. Raw WIM data contains inherent measurement errors, and some post calibration needs to be performed before the data is usable to determine bridge load effects. Over the years, some studies have suggested cleaning techniques and post calibration techniques for South African WIM.

This paper investigates errors, systematic and random, as well as other uncertainties that are inherent to WIM systems, which influence bridge load effects to show how local WIM data can be used to calculate bridge load effects.

2. WEIGH-IN-MOTION DATA IN SOUTH AFRICA

Figure 1 below shows some of the Weigh-in-Motion (WIM) sensors currently installed in South Africa. The most sensors are located on the N3 between Durban and Johannesburg and on the N4 between Maputo and Pretoria. These are the heaviest freight routes, which transport import and export freight between the ports of Richard's Bay, Durban and Maputo to the Gauteng province and back.

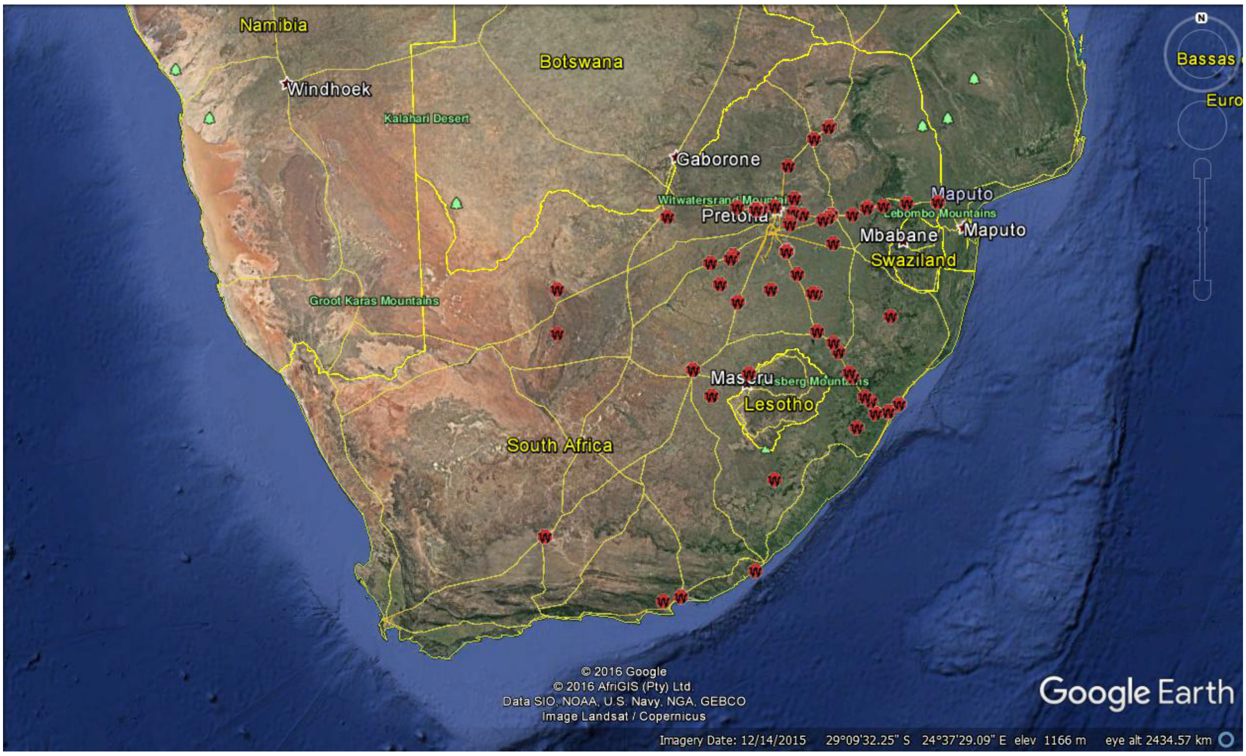

Figure 1: WIM sensors installed across South Africa

In 2007 it was reported that there were 56 permanent WIM stations on national and provincial roads in South Africa (Slavik, 2007). In 2010 it was reported that approximately 100 WIM sensors were installed in South Africa (de Wet, 2010a). It is fair to say that enough WIM data is available in South Africa to evaluate the bridge loading critically.

2.1 WIM Data Collection Regulation and Formats

The collection of WIM data in South Africa is governed by three specifications. TMH3 specifies the provision of WIM services (COTO, 2016), whereas TMH8 sets procedures for how traffic and axle load monitoring should be conducted (COTO, 2014). TMH14 specifies the data collection format and output. The format is known as the South African Standard Data Collection Format (COTO, 2013).

Although there are some stations where more than one lane is measured in each direction, the majority of WIMs have a single sensor in the outer lane. This sensor is also only half a lane wide and only collects data from the outer row of wheels of vehicles (Slavik, 2007). Wheel loads are typically multiplied by a factor of 2.0 to determine the axle weights. This is known as Data Record 13 in the South African system and presents some inaccuracies due to the cross fall of roads. Table 1 shows a typical record obtained from a WIM sensor in South Africa.

Table 1: Example of Record Type 13

Record Type	Date	Time	No of axles	Weight 1	Space 1	Weight 2	Space 2	Weight 3	Space 3	Weight 4	Space 4	Weight 5	Space 5	Weight 6	Space 6	Weight 7
13	150101	00011680	7	59	305	66	139	64	566	80	137	83	672	68	137	56

2.2 Cleaning of WIM Data in South Africa

During WIM measurements, gross errors occur that must be addressed. This is done by correcting values through calibration and by removing false recordings from the records (Enright & OBrien, 2011). Although the derivation of the method is undocumented, Slavik developed a technique named Golem to specifically address sources of false recordings for South African data and according to the South African Standard Data Collection Format discussed in the previous section. Golem’s rejection criteria are as follows:

- Any vehicle travelling at less than 5 km/h or more than 150 km/h.
- Any truck length less than 4 m or greater than 26 m.
- Any vehicle with fewer than two axles.
- Vehicles with GVM less than 3.5 t.
- Any vehicle with an individual axle mass more than 16 t.
- Any vehicle with an axle spacing less than 0.53 m or more than 10 m.

2.3 Calibrating WIM Data in South Africa

Static and dynamic effects are typically treated separately in bridge live load models (Nowak & Hong, 1991). It is typical to apply a dynamic amplification factor (DAF) to the static loads to account for dynamic effects (Croce, Sanpaolesi & Bruls, 1996; Caprani et al., 2011; OBrien, O’Connor & Arrigan, 2012). WIM systems invariably measure a certain degree of dynamic effects due to vehicle dynamics and road surface irregularities (Ghosn & Moses, 1986; Nowak, 1993; Nowak & Szerszen, 1998, 2000; Slavik, 1998; Sivakumar, Moses & Ghosn, 2008). These dynamic effects should not be confused with the DAF applied to bridges. This can be observed by comparing the GVW at a static weigh station with the GVW recorded by the WIM sensors (Sivakumar, Moses & Ghosn, 2008). To remove the dynamic component, WIM systems are calibrated to remove possible bias due to dynamic effects (OBrien & Enright, 2013).

In South Africa, De Wet and Slavik developed the Truck Tractor (TT) method which provides corrections for the systematic errors in WIM data (de Wet, 2010a,b). Systematic errors refer to the calibration of the WIM data. The application of this method results in a k-factor by which all axle weights are multiplied to suppress the systematic WIM error.

The systematic error causes a shift in the distribution of measured axle loads and the random error enlarges the dispersion of the distribution (Slavik, 1998). It is vital that the errors are addressed before using the data to determine a bridge load model. The TT method uses a sub population of six and seven axle trucks with a single steering axle and a double driving axle, called “eligible trucks.” It was found that the monthly average of TT loads is 21.8 t with a Coefficient of Variation (COV) of 1.7%. Measured “eligible trucks” are compared to the 21.8 t weight to calibrate the WIM data. The TT method is used in this study to correct the systematic WIM error. The method has been accepted by the South African National Roads Agency Limited (SANRAL) and is included in Technical Methods for Highways 3 (TMH3) (Committee of Transport Officials South Africa, 2016).

3. CONVOYS AND LOAD EFFECTS

3.1 Assembling Convoys from WIM Data

By using the time stamps and speeds, it is possible to calculate the distance between vehicles and to assemble a convoy of axles for each day by using the date stamps. The distance between the rear axle of the front vehicle and the front axle on the following vehicle is calculated by using time difference and speed.

Table 2 and Figure 2 show an example of how two vehicles are placed in a convoy by using WIM data. The difference in time between the recordings and the speed of the front vehicle is used to calculate inter vehicle spacing between the front wheels of following vehicles.

Table 2: Example of two following vehicles from a WIM file

	Vehicle 1	Vehicle 2	Units
Date	170101	170101	yymmdd
Time	00:06:38.60	00:12:20.70	hhmmss.ss
Speed	93	68	km/h
No of axles	2	7	[]
Axle 1 Weight	27	48	kN
Spacing 1	608	298	cm
Axle 2 Weight	33	52	kN
Spacing 2	N/A	137	cm
Axle 3 Weight	N/A	51	kN
Spacing 3	N/A	706	cm
Axle 4 Weight	N/A	41	kN

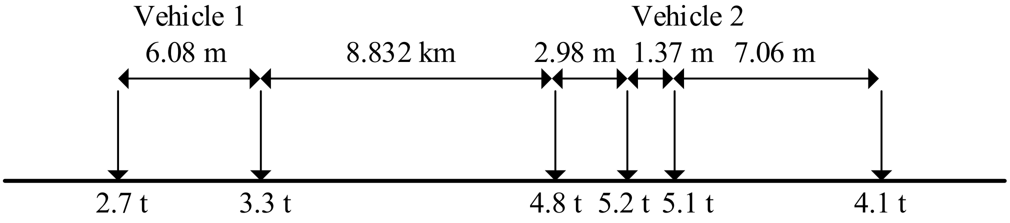

Figure 2: Spatial arrangement of example WIM vehicles

3.2 Calculating Load Effects

Simplified studies of bridge load effects utilise a single vehicle analysis (Nowak & Hong, 1991; Nowak, 1994; Anderson, 2006), but continuous convoys of vehicles should be passed over varying span lengths for the different load effects while recording the daily maximum values for each load effect and span length. The convoys contain all observed vehicles after cleaning of the data has been performed. This makes it possible to capture load effects resulting from multiple presence of heavy trucks in the same lane travelling at close distance. This provides more accurate results at longer span lengths.

When deriving traffic load models for bridges, it is common to investigate hogging moments for two span structures as well as sagging moments and shear forces for single span structures (Caprani, 2005; Enright & OBrien, 2012; Lenner, 2014; Lenner, Keuser & Sykora, 2014). These are simply calculated using influence lines or explicit analytical expressions, provided in Van der Spuy (2020).

4. CONCLUSION

This paper shows how WIM data, in the South African format, can be used to calculate bridge traffic load effects. Cleaning and calibration procedures specific to South Africa are described, and it is shown how convoys of vehicles can be assembled from cleaned and calibrated WIM data to calculate bending moments and shear forces for bridge design.

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