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Evaluation of Accuracy of Weigh-In-Motion Systems in Alberta

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Abstract: Weigh-In-Motion (WIM) systems can collect a variety of traffic data for moving vehicles. The accuracy of six piezoelectric WIM systems installed in Asphalt Concrete (AC) pavements at six highway locations in Alberta was investigated in a five-year verification experiment, which compared the WIM measurements to predetermined axle weights of a test truck. While the WIM systems accurately characterized the speed and dimensions of the test truck, 56, 43, 37, and 34 percent of their weight measurements for single steering, tandem drive and load axles, and Gross Vehicle Weight (GVW), respectively did not comply with the American Society for Testing and Materials (ASTM) E1318 requirements. Outlier analysis revealed that an error limit of 50 percent can be considered as the threshold for the WIM random errors. Mechanistic Empirical Pavement Deign Guide (MEPDG) was used to investigate the effect of the WIM errors in measuring the test truck's axle weights on flexible pavement design for a typical section in Alberta. While WIM errors in the range of ±20 and ±30 (corresponding to the majority of WIM errors in Alberta) did not affect the AC design, error magnitudes of ±50 and ±100 percent affected the AC thickness by more than 100 percent.

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Key words*: Asphalt; gross vehicle weight; Mechanistic-Empirical Pavement Design Guide (MEPDG); pavement; piezoelectric; quartz; Weigh-In-Motion.*

Introduction

Weigh-In-Motion (WIM) is a sensing technology installed in the pavement to establish various traffic parameters, such as vehicle classification and speed, as well as axle-load spectra. WIM can provide continuous, safe, and quick traffic data collection. Highway agencies can use WIM data for several applications, such as road and pavement design, transportation operation, and management and truck overload enforcement. WIM data is essential for the new Mechanistic Empirical Pavement Design Guide (MEPDG), which implements full truck traffic characteristics for pavement design [1]. Traffic parameters, such as vehicle class distribution in the Annual Average Daily Traffic (AADT) and monthly and hourly variations in the AADT, as well as axle load spectra are considered in pavement analysis using the MEPDG [1].

WIM systems, although promising a convenient method of traffic and axle-load spectra data collection, can be associated with inaccuracies and variability in weight measurements when compared to a static scale. Percent divergence of the WIM weight measurements from those of a static scale (hereafter referred to as "WIM_{error}") is established using Eq. (1):

$$WIM_{error} = \frac{Weight_{WIM} - Weight_{Static}}{Weight_{Static}} \quad (1)$$

WIM errors are inevitable due to the dynamic nature of their measurement compared to that of a static scale. The American Society for Testing and Materials (ASTM) has set the acceptable tolerance limits for errors associated with WIM for different weight functions of axle load, axle group load, and Gross Vehicle Weight (GVW) at 95 percent compliance, see Table 1 [2].

Table 1. Acceptable Tolerances According to ASTM E1318.

Weight Function	Tolerance at 95% Compliance
Axle Load	±20%
Axle-Group Load	±15%
GVW	±10%

Unacceptable errors (higher than the ASTM thresholds) can be caused by various groups of parameters: 1) system characteristics: sensor type, algorithm, and software; 2) pavement type and road conditions: smoothness and geometry; 3) environmental variables: precipitation and temperature; and 4) vehicle static and dynamic specifics: speed, suspension system, and tire pressure [3]. Several studies have focused on evaluating the accuracy of various types of WIM systems. A study performed in Texas evaluated the accuracy of two Kistler quartz piezoelectric WIM sensors installed in Portland Cement Concrete (PCC) pavements at two different sites. The researchers indicated that the quartz sensors were durable and produced accurate weight measurements, when installed in a pavement section with minimal longitudinal roughness and sufficient structural support. The WIM measurements for calibration trucks with predetermined static weights for 245 observations met the criteria set by the ASTM for all the weight functions [4]. Another study conducted at the University of Waterloo investigated the accuracy of four Piezoelectric (PE) WIM systems installed at a test site in Waterloo, Ontario. Researchers found that the quartz PE is more accurate in terms of weight measurements, less sensitive to temperature change, and better at overall performance in comparison to ceramic, polymer, and polarized Polyvinylidene Fluoride (PVDF) PE WIM systems [5]. Another recent study conducted by Nichols *et al*. in Indiana proposed a new approach to evaluate the WIM accuracy based on a left-right wheel weight differential for each axle. The researchers identified a relationship between the left-right differential and the minimum ambient

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temperature records for the load cell WIM [6]. In 2001, Papagiannakis *et al*. evaluated the performance of PE WIM systems from two different manufacturers: Vibracoax (VC) and Measurements Specialties Incorporated (MSI). Sixteen PE WIM sensors, including two sensor types from each manufacturer (one bare and one factory-encapsulated) were installed in Asphalt Concrete (AC) using various grout types. Another ten PE WIM sensors from the two manufacturers were installed in PCC. The measurements from the sensors installed in the AC pavement showed temperature dependency. Sensor-grout type affected the measurements of only the WIM sensors in the PCC pavement. Further, a portion of the inaccuracy in the measurements was found to be due to the load calculation algorithm used for the system. None of the sensors showed fatigue failure under the increasing load cycles [7]. In 1999, Zhi *et al*. evaluated the accuracy of a WIM system in Manitoba, Canada through a previous field survey conducted at two truck weigh stations in August 1997. Researchers found that the WIM systems underestimated approximately 90 percent of the truck weights during the survey period by 50 percent of the corresponding static weights [8]. In another study, Ott and Papagiannakis (1999) examined the quality of the WIM measurements for the steering axle of a five-axle semi-trailer truck and established the confidence intervals for the measurements based on the mean static loads. The authors concluded that confidence limits were a function of the pavement roughness and vehicle speed at the site [9]. In Oregon, Ali *et al*. [10] measured the axle weights of five-axle tractor semi-trailer trucks using a PE WIM system and compared the values with static axle weight measurements. They concluded that no statistically significant difference existed between the WIM and static weight measurements for the steering and tandem axle weights; however, there was a significant difference for the trailing tandem axle [10]. Haider *et al*. categorized the WIM errors into two groups of random errors (depending on the technology used) and systematic errors (associated with equipment calibration). The researchers then established the effect of systematic errors on the MEPDG-predicted pavement distresses for both flexible and rigid pavements. Their research showed that cracking for both types of pavements is significantly affected by the negative measurement bias in axle loads [11].

The current study focuses on evaluating the accuracy of the weight measurements of the WIM systems installed in AC pavements at six highway locations (total of 20 lanes) in Alberta. A five-axle semi-trailer test truck with predetermined axle loads made 10 successive passes over the WIM systems on one day of every month from 2006 to 2008 and one day of every other month in 2009 and 2010. WIM axle-load measurements for the single steering, tandem drive, and tandem load axles of the truck were evaluated in the present study. The impact of the WIM errors in characterizing the axle loads on the MEPDG-predicted flexible pavement performance and thickness design was also investigated.

Description of Weigh-In-Motion Systems in Alberta

In summer 2004, Alberta Transportation commissioned the installation of WIM systems in six highways located in Edson, Leduc, Leduc VIS, Red Deer, and Villeneuve. Geographical locations of the six WIM sites are projected on the map of Alberta in

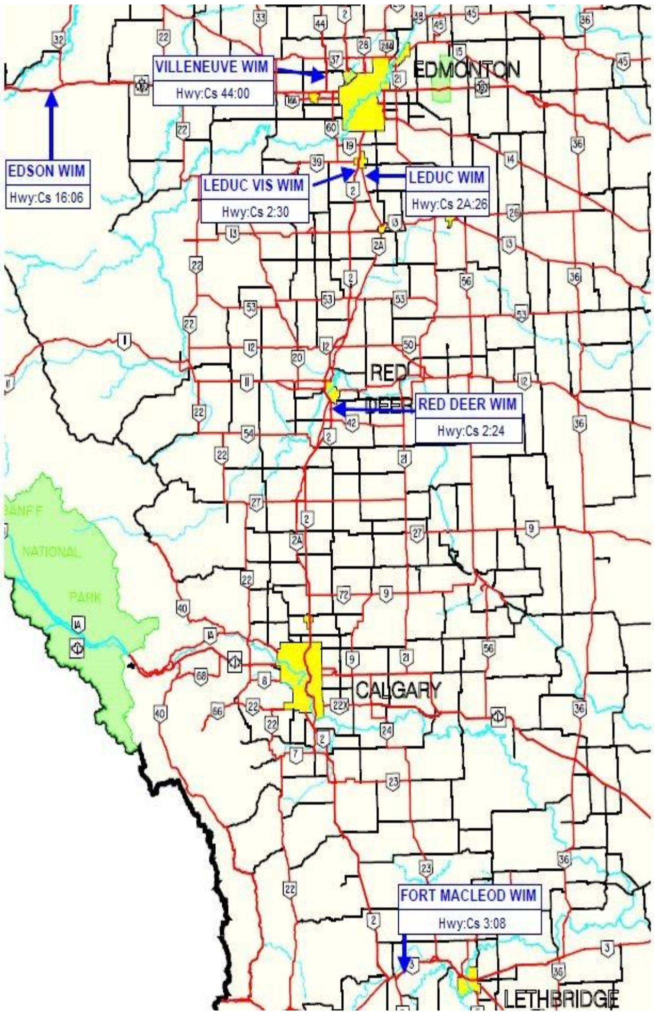


Fig. 1. Geographical Location of Six WIM sites in Alberta [14].

Fig. 1. Other information regarding each WIM site's highway number, kilometer, and posted speed is provided in Table 2. Based on the literature review provided in the "Introduction" section, WIM systems best perform in smooth and level pavement sections [4, 8]. Therefore, information regarding each WIM site's pavement rehabilitation history, rutting depth, and International Roughness Index (IRI) as reported in Alberta Transportation's 2011 Pavement Management System (PMS) as well as their Annual Average Daily Traffic (AADT) is provided in Table 2 [12]. It is important to note that the rutting and IRI records in the PMS are average values for the control section containing the WIM sensors and do not necessarily reflect the conditions of the WIM sensors' location. The installation crew's description of the road section conditions was also acquired and used in the analysis in addition to the information presented in Table 2. It should be noted that Highway 2A in Leduc and Highway 44 in Villeneuve are undivided, single-lane highways with a posted speed of 100 km/h, while the remaining four sites are divided, double-lane highways with a posted speed of 110 km/h.

Sensor Specification and Calibration

In 2004, Hestia Type P ceramic WIMs by Electronique Contrôle Mesure (E.C.M.) were installed at all six locations using the E.C.M.

Table 2. Location, Pavement Structure, AADT, IRI and Rut Depth for WIM Sites in Alberta [13-14].

WIM Sensor Type	Highway No.	Control Section No.	Lane	Location	Posted Speed	Highway km	Original Pavement Construction Year	Overlay Construction Year	Overlay Thickness Range (mm)	Total AC Layer Thickness (mm)	AADT	IRI (m/km)	Rut (mm)
E.C.M.[1] Ceramic PE	2	24	NB[3]	Red Deer	110	18	1958	1992	90-109	325	30,900	1.7	6
			SB[4]					1990	70-89	230	30,881	1.6	7
		30	NB	Leduc VIS	110	32	1965	1996	90-109	335	24,848	1.6	9
			SB					2010	70-89	295	24,340	0.85	3
MSI BL[2] PE	2A	26	SB	Leduc	100	27	1945	2002	70-89	280	7,190	1.1	2
	3	08	EB[4]	MacLeod	110	18	1995	1995	None	150	7,260	0.8	6
			WB[5]				1985	1997	90-109	250	7,260	0.9	8
	16	06	EB	Edson	110	39	1989	2006	110-129	250	8,130	0.9	3
			WB				1976	2006	50-69	200	8,130	2.1	13
	44	00	NB	Villeneuve	100	6	1973	2005	50-69-	455	6,970	1.4	15

[1] Electronique Contrôle Mesure
[2] Brass Linguini
[3] Northbound
[4] Southbound
[5] Eastbound
[6] Westbound

P5G epoxy. The E.C.M. sensors failed prematurely at four locations, Edson, Leduc, Fort MacLeod and Villeneuve [15]. The broken sensors were replaced in 2005 with Roadtrax Brass Linguini (BL) PVDF PE manufactured by MSI, using E.C.M. P6G epoxy. Original E.C.M. sensors in the other two locations failed in 2011 and were replaced with the Roadtrax sensors as well. The analysis in this study covers the period between 2006 and 2010 and is not affected by the recent sensor replacements.

PE WIM systems are known to be sensitive to pavement temperature and traffic characteristics of the road section [5, 14]. To isolate the effect of temperature and traffic on the measurements, the WIM sensors were auto-calibrated through an internal Automatic Gain Control (AGC) algorithm using a characteristic truck at each site. The AGC uses the minimum and average GVW as well as the average weight of the first axle of the characteristic truck at different temperatures. The Hestia will then adjust the AGC to compensate for the temperature drift based on the recorded weights for the characteristic vehicle [14, 16].

Alberta Transportation WIM Verification Test Program

To verify the accuracy of the WIM measurements, a five-axle semi-trailer (Federal Highway Administration [FHWA] Class 9) truck drove 10 times (10 “passes”) over the WIM system in each lane at each highway location at posted highway speeds on a monthly basis. The truck was loaded with the following maximum axle weights.

- Single steering axle: static axle load up to 5,500 kg
- Tandem drive axle: static axle load up to 17,000 kg
- Tandem load axle: static axle load up to 17,000 kg

The test was repeated every month between 2006 and 2008 and every other month from May 2009 through December 2010. Truck parameters including dimension and speed, as well as the four weight functions of single steering, tandem drive, tandem load axle weights, and GVW were recorded for each pass. A database for the five years of testing would include 10 (passes) × 60 (months) × 20 (lanes) to equal 12,000 data files containing the above-mentioned parameters. However, a total of 2,150 data files were missing due to changes applied to the test schedule in 2009 and 2010. Additionally, of the 9,850 available data files, 66 single steering, 69 tandem drive, 70 tandem load axles, and 69 GVW measurements were missed by the WIM sensors at various locations [17]. The WIM measurements for truck speed and dimensions consistently remained within the ASTM tolerance limits during the test period. Therefore, this paper will focus on evaluating the axle weight measurements taken by the WIM systems in Alberta.

Evaluation of WIM Weight Measurements

The WIM_{errors} for single steering, tandem drive, and load axles along with the GVW of the test truck were established for each lane at every WIM site using Eq. (1). Consequently, the WIM_{error} for every weight function in each pass was compared to the corresponding ASTM E1318 tolerance provided in Table 1. The total number of errors that did not meet the corresponding error limit suggested in the ASTM was divided by the total number of passes to establish the percent unacceptable WIM_{errors} for each weight function at each site, as presented in Fig. 2. Based on Fig. 2, the WIM_{errors} for all of the weight functions at all locations are greater than the five-percent allowable limit defined by the ASTM (95 percent compliance), except for the single-axle measurements in SB-Lane 2 in Leduc VIS and the tandem drive axle measurements in EB-Lane 1 in MacLeod.

It is noted in Fig. 2 that WIM errors for Leduc VIS and Red Deer are relatively low compared to the other sites. One explanation for this behavior may be the AADT for the two sites. According to the sensors’ manufacturer’s specifications, the E.C.M. WIM sensors perform the best at a range of 500 to 8,000 passes of the calibration

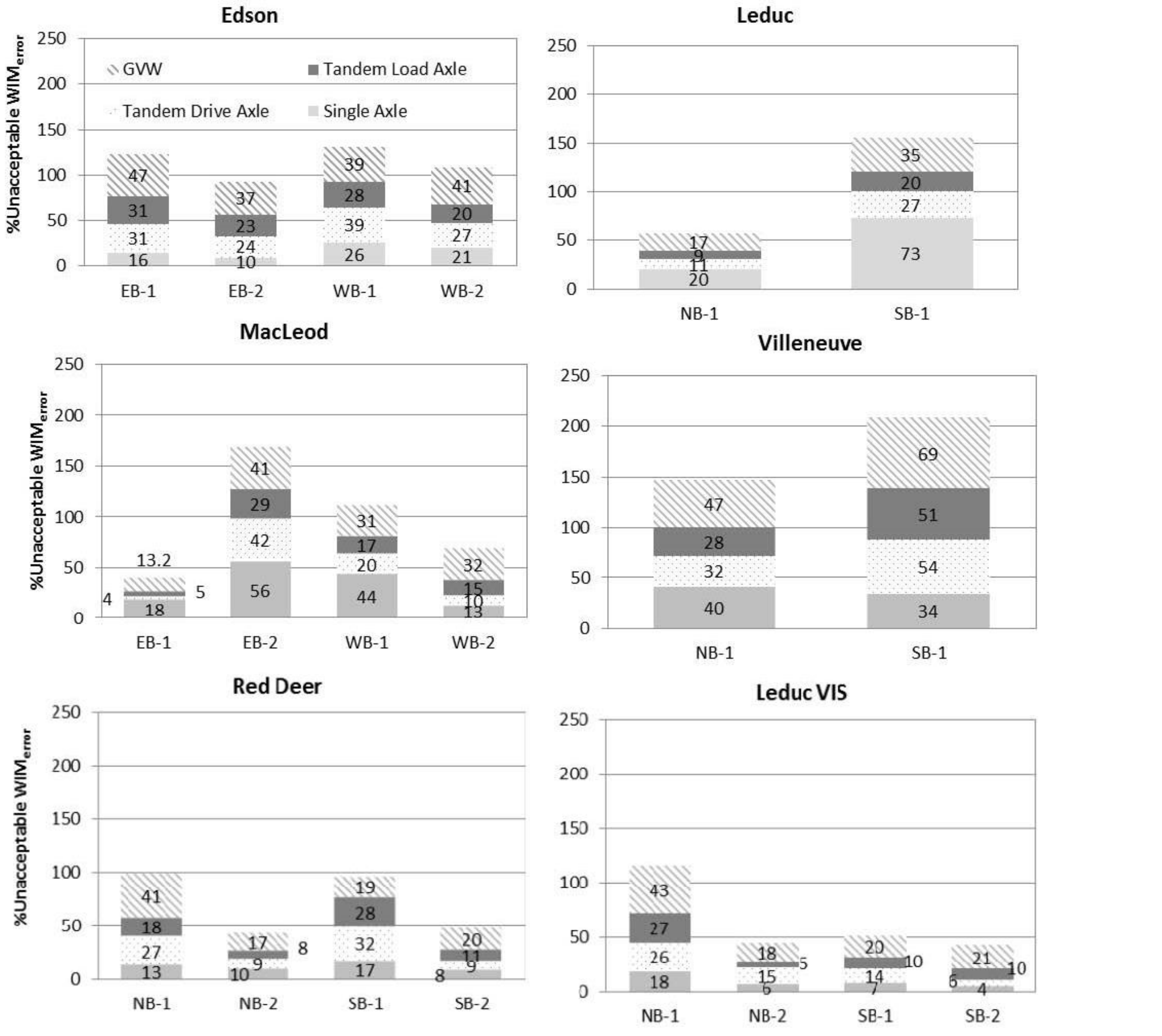


Fig. 2. Percent Unacceptable Errors According to the ASTM Criteria for Each Lane at the Six Sites Included the BL PE, While the Other Four Sites Included the Ceramic PE Sensors).

truck per hour [16]. This requirement is only satisfied for the WIMs in Red Deer and Leduc VIS on Highway 2, whose AADT ranges between 24,000 and 30,000 (Table 2). It should be noted that these two sites include the E.C.M. sensors, while the MSI BL WIM was used at the other four locations. The WIM systems in Villeneuve on Highway 44 and Edson on Highway 16 show the highest number of rejected WIM_{errors} for GVW, tandem drive, and tandem load axles. As seen in Table 2, the two sections were recently overlaid; however, they show high rutting depths of 13 and 15 mm respectively, which were confirmed by the contractor during the installation at the two locations [14]. Past studies have also shown that WIM systems best perform in smooth and level pavement sections with minimal rutting and longitudinal roughness [4, 8].

Frequency Distribution of all Errors

The frequency distribution of the WIM_{errors} is presented in Fig. 3 to investigate: 1) the frequency of occurrence of error in four different bins of 0.1-10%, 10.1-15%, 15.1-20%, 20.1-50%, and > 50%; and 2) whether the static axle loads are under- or over-estimated by the WIM systems. Fig. 3 indicates that the errors ranging from -10 to +10 percent, which are within the acceptable range for all the weight functions according to the ASTM (Table 1), are the most frequent. The frequency of occurrence of acceptable errors is 44, 57, 63, and 66 percent for single steering, tandem drive, tandem load axles, and GVW, respectively. Additionally, according to Fig. 3, almost none of the errors are larger than 50 percent (or less than -50 percent) for all of the weight functions. The rejected errors for the four weight functions are distributed within three bin values of ±10.1-15%, ±15.1-20%, and ±20.1-50%. Twenty-three percent of the errors for the single steering and tandem drive axles did not meet the ASTM criteria. This value is 20 percent for the tandem load axle and 34 percent for the GVW.

Further, in Fig. 3, the number of negative errors is slightly higher than the positive errors for GVW, single steering, and tandem drive axle weights, implying that the WIM sensors underestimated the

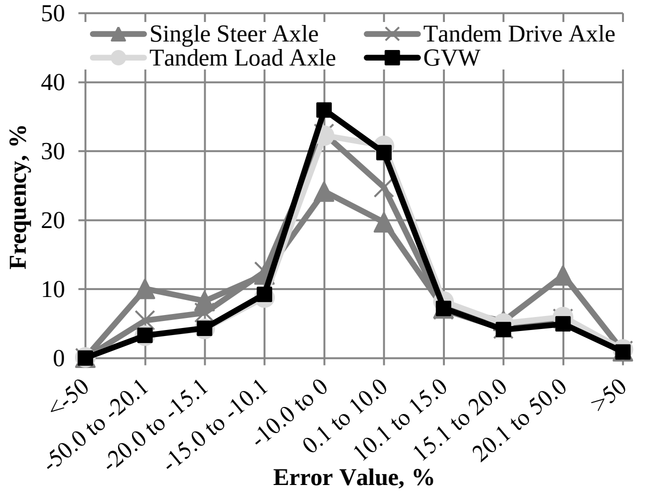


Fig. 3. Distribution of Positive and Negative Errors for all WIM Sites for the Four Weight Functions.

weights. Conversely, the majority of the errors are positive for tandem load axle weights, showing that WIM sensors overestimated tandem axle weights.

Seasonal Trends in WIM_{errors}

As mentioned previously, the AGC auto-calibration algorithm was used to eliminate the effects of changes in the AC layer temperature on WIM measurements. Fig. 4 shows the monthly average percent of rejected errors over the monitoring period for every WIM site. An increase in WIM_{errors} is evident during warmer months for Edson and Villeneuve sites. Again, it should be noted that due to the self-calibrating nature of the algorithm used for processing the data, it is difficult to identify the potential seasonal trends or explain the fluctuations in the WIM_{errors}. Fig. 4 confirms previous findings from Fig. 2, where the two sites of Leduc VIS and Red Deer had the lowest number of unacceptable WIM_{error}.

Statistical Analysis of Errors

Another way to evaluate the accuracy of the WIM axle load measurements is to establish the Probability of Conformity (PC) for each weight function. The PC value can then be compared to ASTM E1318's recommended compliance value of 95 percent. Table 3

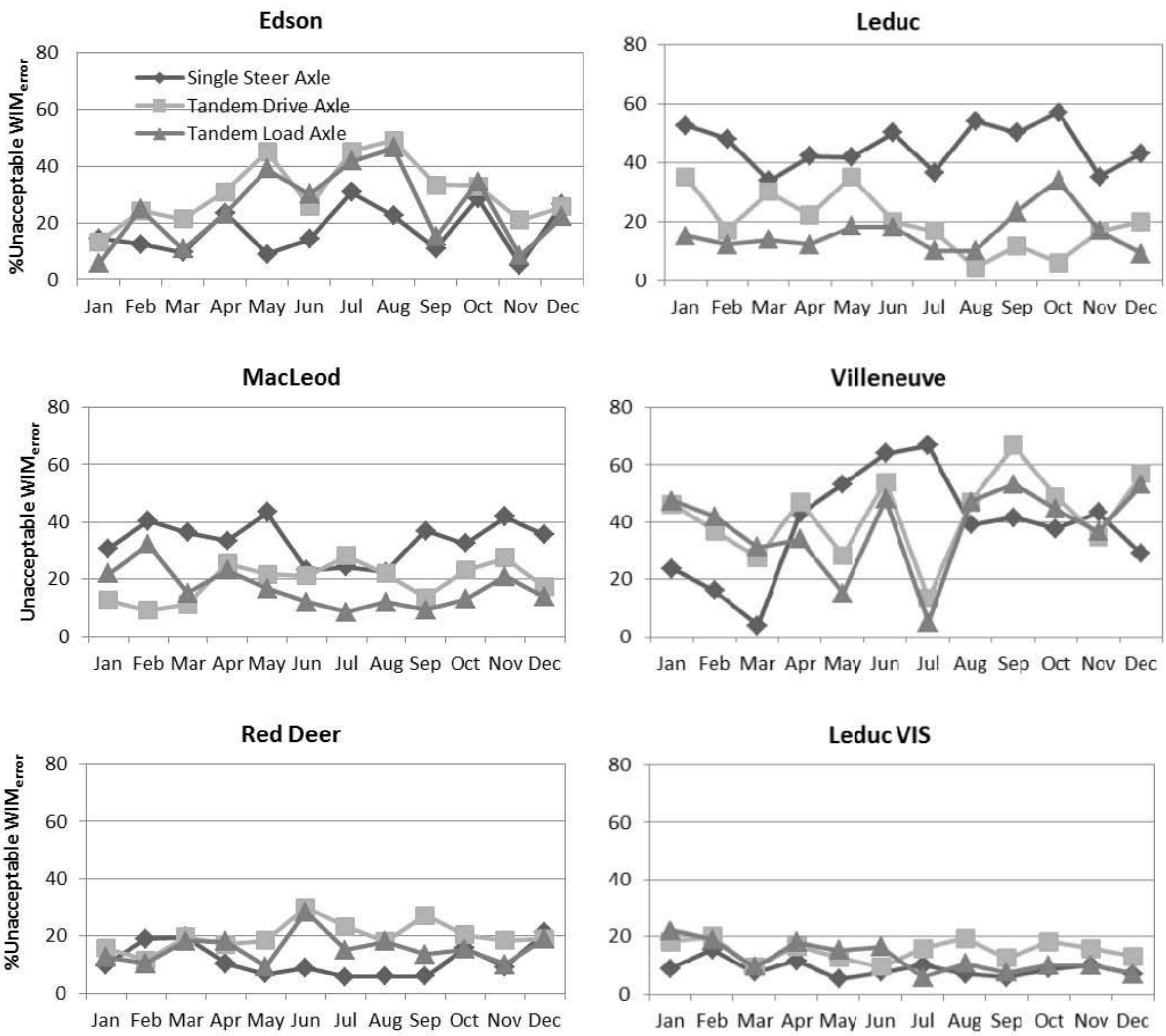


Fig. 4. Seasonal Variation in Percent Rejected WIM Weight Errors at All Sites.

Table 3. Probability of Conformity for WIM Weight Measurements in Alberta.

WIM Site/ Weight Function	Probability of Conformity (%)			
	Single Steering	Tandem Drive	Tandem Load	GVW
Edson	72	71	73	56
Leduc	53	78	84	66
Leduc VIS	90	83	84	70
MacLeod	69	79	82	68
Red Deer	88	78	78	65
Villeneuve	67	61	60	44

Table 4. Outliers of the WIM errors for Different Weight Functions.

Weight Function	Possible Errors		Probable Errors	
	Upper Limit	Lower Limit	Upper Limit	Lower Limit
Single Steering	44	-46	78	-80
Tandem Drive	31	-35	56	-60
Tandem Load	31	-30	53	-52
GVW	27	-28	48	-49

summarizes the five-year estimated PC values for the errors for each site location. The results in Table 3 agree with Fig. 2 and indicate that the sites in Red Deer and Leduc VIS have the highest PC, while Villeneuve has the lowest PC for all four weight functions.

To identify the sources and categories of the errors, the outliers for each weight function were identified first using inner and outer fences, as defined below:

Inner fence:

Lower limit: Q1 - 1.5 × IQR

Upper limit: Q3 + 1.5 × IQR

Outer fence:

Lower limit: Q1 - 3.0 × IQR

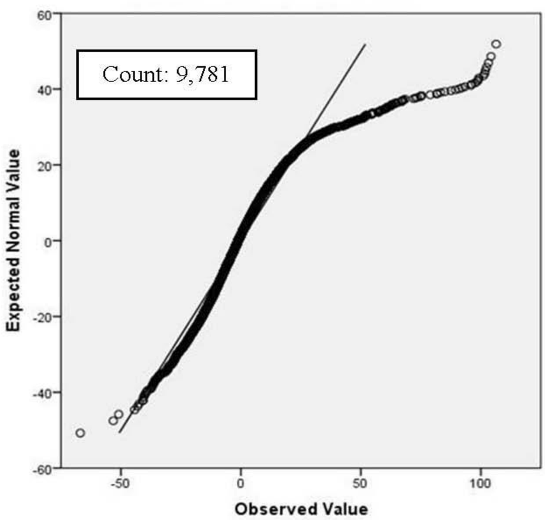
Upper limit: Q3 + 3.0 × IQR

Q1 and Q3 are the first and third quartiles, and IQR is the interquartile range, which is defined as Q3 - Q1. Observations which lie between the inner and outer fences are considered possible outliers, while the observations that occur beyond the limits of inner fences are probable outliers [18]. Three parameters of Q1, Q3, and IQR were established for all WIM_{error} to identify the inner and outer fences using the above equations. Table 4 presents the possible and probable outliers for the four weight functions' errors for all sites during the five years. According to Table 4, the possible and probable outliers for the GVW errors are in the range of approximately ±28 and ±50 percent, respectively.

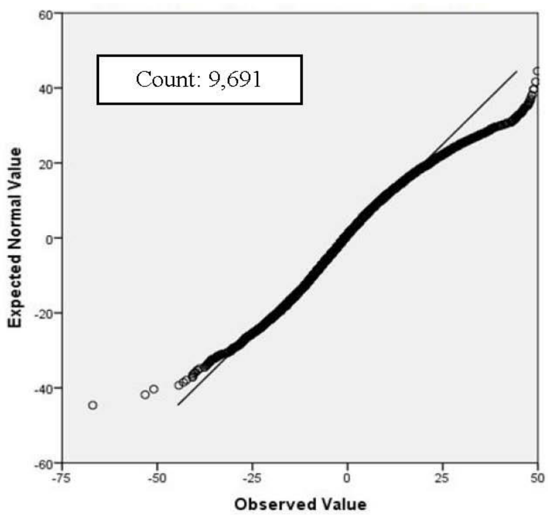
When using parametric statistical procedures, it is assumed that the data is an independent random sample extracted from a specific distribution, such as the normal distribution. In this study, the validity of the hypothesized distribution was investigated using probability plots (Q-Q). A clear deviation from the straight line in a probability plot implies that the hypothesized distribution does not fit the data well. Such analysis will also help identify random versus systematic errors as described in a previous study reviewed [11]. Fig. 5(a) shows the Q-Q plot for GVW errors at all six WIM locations (a total count of 9,781 errors) for a normal distribution. A deviation is observed from the normality line at the error value of approximately 25 percent. The outlier analysis in the previous section revealed that the errors greater than approximately 50 percent are probable outliers. The probable outliers were removed from the GVW errors database in the next step, and the normality of the new data set (a total count of 9,691 errors) was investigated again using the Q-Q plot in Fig. 5(b). As seen in Fig. 5(b), a normal distribution adequately describes the distribution of the errors. Considering Fig. 5(a) and (b) together, it was concluded that the distribution of the GVW errors is nearly normal when the errors are less than 50 percent. Random errors in real-world processes follow the normal distribution with a reasonable degree of acceptance. The observations from Fig. 5(a) and (b), as well as the probable errors from the outlier analysis, reveal that an error limit of 50 percent can be considered as the threshold for random WIM_{errors}.

Effects of WIM Errors on Pavement Design

An essential application of the WIM axle weight measurements is to



(a)



(b)

Fig. 5. Q-Q Plots of Normal Distribution for (a) all GVW Errors; (b) GVW Errors Smaller than 50 Percent.

define the axle load spectra for pavement design using the MEPDG. However, previous studies have shown that WIM errors can significantly influence the MEPDG-predicted cracking [11]. To identify the effect of Alberta's WIM errors in characterizing the test truck's axle weights on flexible pavement design, a typical AC pavement section in Edmonton, Alberta was simulated using the MEPDG Version 1.1 [1]. The required input parameters for the MEPDG design were defined based on the information available in Alberta Transportation's PMS report and the MEPDG default values at Level 3. Table 5 presents a list of the design variables and their corresponding values used for the simulations.

The pavement structure used in the study represents a typical highway section in Alberta and includes a 380-mm (15-inch) AC layer, a 250-mm (10-inch) Granular Base Course (GBC), and a clay-type subgrade layer. Default values available in the MEPDG were used to define almost all of the material properties for each layer.

As seen in Table 5, AADT was defined as 30,000 (representing the highest traffic load among the six WIM sites in Alberta) and vehicle class distribution was restricted to the test truck (five-axle semi-trailer). Axle weights for the base run were defined similar to that of the test truck, i.e. 5,500 and 17,000 kg for the single steering and tandem axles, respectively. The Edmonton International Airport weather station, available in the MEPDG, was used as the climatic file. The design criteria were kept as the MEPDG default at 90 percent reliability.

As presented previously in Fig. 3, 66 percent of GVW errors were acceptable and remained within the allowable range of -10 and 10 percent. To investigate the effect of rejected GVW negative and positive errors on the MEPDG-predicted performance and the pavement design thickness, both single and tandem axle loads were simultaneously changed by ±20, ±30, ±50, and ±100 percent in separate runs of the MEPDG. The MEPDG-predicted distresses and IRI at the end of the 20-year design life for all loading scenarios is presented in Table 6. According to Table 6, all distresses, except for AC transverse cracking, increase as the truck axle loads are increased. Transverse cracking or thermal fracture is due to cold temperatures or temperature cycling and is not expected to change with alterations in traffic loading [1].

Table 5. MEPDG Design Input Values Used in the Simulations.

Category	Design Input	Value	Source
Pavement Layers	AC Layer Thickness (mm)	380	Typical AC Thickness in the Province, Based on Alberta Transportation's PMS Report
	Binder Type	PG 58-28	Binder Type Commonly Used in Alberta
	Base Layer Type	A-1-b	GBC is the Most Typical Base Material Used in Alberta
	Base Layer Thickness (mm)	250 mm	Typical GBC Thickness in the Province, Based on Alberta Transportation's PMS Report
	Base Layer Modulus (MPa)	260	MEPDG Default Value at Level 3
	Subgrade Type	A-6	Majority of Subgrade Soil Type in Alberta is Clay, Based on Alberta Transportation's PMS Report
	Subgrade Modulus (MPa)	110	MEPDG Default Value at Level 3
Traffic	AADT	30,000	Highest AADT Among the Six Highway Sections with WIM Systems in Alberta
	Truck Traffic Classification	100% FHWA Class 9 truck while 0% other Truck Types	Truck Type Used in Alberta's WIM Test Program
	Axle Weights (kg)	Single Axle: 5,500 Tandem Axle: 17,000	Maximum Axle Weights Used in Alberta's WIM Test Program
Climate	Climate File	Edmonton International Airport Weather Station	Weather Station Available in the MEPDG for Central Alberta

Table 6. MEPDG-predicted Performance Indicators for Different Load Levels.

Run No.	%Change in Single and Tandem Axle Loads	Required AC Thickness (mm)	IRI (m/km)	AC Top-Down Long. Cracking (m/km)	AC Bottom-Up Alligator Cracking (%)	AC Trans. Cracking (m/km)	AC Rutting (mm)	Total Pavement Rutting (mm)
1	-100	51	1.54	0	0	1	0	0
2	-50	305	1.67	0	0	1	3	5
3	-30	380	1.74	0	0.1	1	4	8
4	-20	380	1.77	0	0.2	1	5	9
5	Base Run	380	1.84	0	0.6	1	6	12
6	20	380	1.91	0	1.3	1	7	14
7	30	380	1.94	0	1.8	1	8	16
8	50	380	2.02	0.1	3.2	1	9	18
9	100	>635	2.21	0.4	9.5	1	12	24

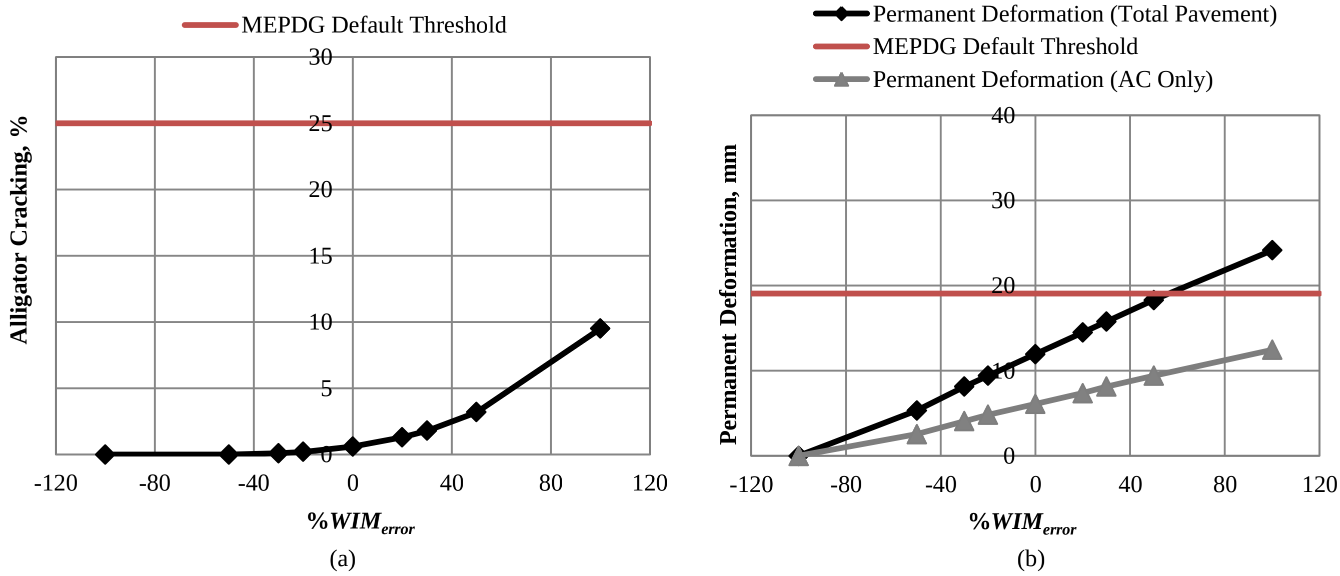


Fig. 6. Effect of WIM_{errors} on MEPDG-predicted (a) Alligator Cracking and (b) Permanent Deformation.

Fig. 6(a) and (b) present the progress in bottom-up alligator cracking and permanent deformation with respect to WIM_{error}. According to Fig. 6(a), although the loading scenario with 100 percent overestimation in the axle loads showed significantly higher cracking compared to the base run, it still met the MEPDG default deign threshold. Fig. 6(b) indicates that pavement rutting increased linearly with increase in WIM_{error} and failed to meet the design threshold for a 100-percent overestimation in axle loads.

More MEPDG simulations were conducted for each loading scenario (±20, ±30, 50, and ±100 percent change in axle loads) until the pavement design thickness was achieved. The final AC thickness design for each scenario is presented in Table 6. While ±20, and ±30 (majority of WIM errors in Alberta) did not affect the design, 50- and 100-percent decrease in axle loads resulted in 35 and 330 mm drop in the AC thickness. Also, the required AC thickness for the 50 and 100-percent increase in GVW was more than 635 mm.

Conclusions

Errors of the WIM weight measurements from a five-year test program for 20 highway lanes in Alberta were established and analyzed in this study. Error analysis showed that four of Alberta's six WIM sites were not able to satisfy the ASTM E1318 requirements during the five-year study period. In particular, the WIM sensors in Villeneuve and Edson, where the pavement showed deep ruts, demonstrated the highest number of errors. E.C.M. ceramic PE WIM sensors in Red Deer and Leduc VIS on Highway 2, with high traffic volume ranging between 20,000 and 30,000 and stiff AC layers, showed the lowest number of errors for all four weight functions.

Overall, PE WIM sensors seem to be highly sensitive to the pavement conditions and the roadway's traffic characteristics. Further efforts are required to adjust Heista's load-calculating algorithms to achieve more accurate weight measurements for low-truck traffic roadways in Alberta. The outlier analysis revealed that an error limit of 50 percent can be considered as the threshold for the WIM random errors. While WIM_{error} in the range of ±20, ±30 (corresponding to majority of WIM_{error} in Alberta) did not affect the AC design thickness established using the MEPDG, WIM_{error} magnitudes of ±50 and ±100 percent did affect the design thickness by more than 100 percent.

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