USE OF WEIGH-IN-MOTION (WIM) DATA FOR SITE-SPECIFIC LRFR BRIDGE RATING

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Abstract

In this paper, truck weigh-in-motion (WIM) data are used to develop live load factors for use on Alabama state-owned bridges. The factors are calibrated using the same statistical methods that were used in the original development of AASHTO's Load and Resistance Factor Rating (LRFR) Manual. This paper describes the jurisdictional and enforcement characteristics in the state, the WIM data filtering, sorting, and quality control, as well as the calibration process. Large WIM data sets from five sites were used in the calibration and included different truck volumes, seasonal and directional variations, and WIM data collection windows. Certain MATLAB programs were developed in the live load factor calibration process. The resulting state-specific live load factors are smaller than those of LRFR manual and are recommended to the Alabama Department of Transportation (ALDOT) in rating their bridges more efficiently.

Keywords: Live load factors, Bridge rating; Weight-In-Motion, LRFR

1. Introduction

As of 2009 over 24% of bridges in the United States are structurally deficient or functionally obsolete and 30% are over 50 years old (U.S. DOT, 2009). Deteriorating bridges can lead to a reduced load rating and the requirement to post a bridge for a live load significantly below the legal limit, resulting in transportation network inefficiencies. One method for load rating bridges is to use the American Association of State Highway and Transportation Official's (AASHTO) Load and Resistance Factor Rating (LRFR) Manual (AASHTO, 2003). For bridge rating and evaluation, LRFR Specifications are the transition from the AASHTO Manual for Condition Evaluation of Bridges (AASHTO, 1994), and the specifications extend the limit states design philosophy from AASHTO load and resistance factor design (LRFD) (AASHTO, 2004) to evaluation of existing bridges. The live load factors presented in the LRFR Manual are, therefore, the result of the live load calibration for the LRFD Specifications and are meant to encompass legal trucks and certain exclusion vehicles across the United States. However, realizing that these load factors may be overly conservative for load rating and posting bridges, the LRFR Manual

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allows for the determination of site-specific live load factors using a statistical analysis of weigh-in-motion (WIM) data at or near the bridge site. Due to the lack of reliable truck data in the United States at that time, the truck data from the Ontario Ministry of Transportation were used in the calibration of this live load factor. To yield the most accurate bridge ratings, site-to-site variability of live loads should be incorporated in the reliability analyses (Ghosn and Moses, 1986). Following the methodology developed in NCHRP Project No. 12-46 (Moses, 2001) and incorporated in the LRFR specifications, live load factors for strength evaluation were developed for state-owned bridges in Alabama using WIM data from sites across the state. This paper investigates five WIM sites in Alabama to determine live load factors more representative of truck traffic in the state based on the characteristic vehicle population. Significant differences in permitting requirements exist in different States in the United States. Thus, to evaluate the impact of truck weight regulations on site-specific live load factors, the WIM data is sorted in accordance with the truck weight regulations in force in Alabama and Oregon, respectively. The purpose of the comparison analysis concerning the regulations for both Alabama and Oregon is to provide more accurate site-specific live load factors for the evaluation of existing bridges in Alabama and to provide guidelines for the determination of live load factors for other states with different enforcement regulations.

2. Live Load Factor Methodology

It is assumed when determining the live load factors that only the top 20 percent of the truck weight population influences the maximum loading events (Moses, 2001). The maximum loading event for calibration places a legal truck or a permit truck (whichever is the rating vehicle of interest at the time) in one lane and a random truck (referred to as the alongside vehicle) in the adjoining lane (Pelphrey et al, 2008). Therefore, the basic case for load rating in accordance with the LRFR Manual occurs with two-lanes of live load, and live load factor for the rating vehicle is influenced by both the weight of the rating vehicle and that of the random alongside one.

2.1 Selection of WIM Sites in Alabama and Data Collection

Five specific WIM sites on five highways were selected based on the truck volume, and WIM data were collected from ALDOT's website for 2008 at the sites 911, 915, 934, 942, and 960, along each route, respectively. The traffic volume for each site is shown in Table 1. In order to determine the optimum time for data collection, each month was divided into three periods, including: (1) the entire month; (2) the first 2 weeks from 1st to 14th; and (3) the last 2 weeks from 15th to 28th. In addition, each calendar year of data was divided into four seasons: winter, spring, summer, and fall. Each season covered three months, with winter including Dec – Feb, spring including Mar – May, summer including June – Aug, and fall including Sep - Nov.

Table 1 - Total traffic volume and truck traffic volume at each WIM site

Site	Location	ADTT	TADT	Winter	Spring	Summer	Fall
911	Coosa County / US-280	1722	17%	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
915	Washington County / US-43	1393	18%	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
934	Walker County / US-78	3065	17%	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
942	Montgomery County / US-231	3175	22%	Dec, Feb	Mar, Apr, May	Jun, Jul, Aug	Oct, Nov
960	Clarke County / US-84	827	22%	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul	Sep, Oct, Nov

Note: (1) ADTT means Average Daily Truck Traffic and TADT means percentage of Trucks in the Average Daily Traffic.

2.2 Sorting WIM Data by Vehicle Weight

Each state has their own regulations for determining legal weights and different classifications of permit weights. Two approaches were used to classify the site-specific data. One sorting is based on the classifications of vehicle weight used by the Oregon Department of Transportation (ODOT) and presented in five ODOT permit Weight Tables. The other approach is based on the classification used by ALDOT. ALDOT classifies trucks into three broad categories based on weight as: (1) Legal trucks; (2) Annual permits or continuous trip permits (CTP) which can be divided into two subcategories (a) Annual Permit (no routing); (b) Annual Permit (routing); and (3) Single Trip Permits (STP).

The raw WIM records from each collection site were provided in text format for data processing. Several programs were written in MatLab to organize and filter the data to remove records with formatting mistakes, spurious data, and other errors. The data was filtered using the criteria presented by Pelphrey et al. in 2008 (Pelphrey et al., 2008). In addition, NCHRP Report 454 (Moses, 2001) indicates that the live load factors should be calculated based on one direction of data. For the brevity, this paper just lists the filtered vehicles numbers of site 911 as in table 2.

Table 2 - Vehicle number of different directions for each month of site 911

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	36063	49400	54435	57739	53040	61510	43344	53617	56699	56912	51813	50402
West	31221	26747	29552	30664	20905	32303	17111	26652	25854	26366	24525	24174
East	4842	22653	24883	27075	32135	29207	26233	26965	30845	30546	27288	26228
% of West	86.6%	54.1%	54.3%	53.1%	39.4%	52.5%	39.5%	49.7%	45.6%	46.3%	47.3%	48.0%
% of East	13.4%	45.9%	45.7%	46.9%	60.6%	47.5%	60.5%	50.3%	54.4%	53.7%	52.7%	52.0%

After filtering the WIM data, the truck records were sorted into proper permit Weight Tables. Two sorting algorithms were used, which are noted as conventional sort and modified sort in this paper. The conventional sort method sorts vehicles based on their GVW, axle group weights, and length (GVW + axle group sort) in accordance with the detailed Weight Tables. The modified sort method sorts vehicles based only on their GVW and rear-to-steer axle length, and it does not account for axle groupings (GVW + truck length sort) (Pelphrey et al., 2008).

2.3 Sorting Results Based on ODOT Regulation

As ODOT has detailed permit Weight Tables, the conventional sort method was used to classify trucks into permit Weight Tables 1, 2, 3, 4, and 5, or Weight Table X in accordance with the ODOT regulations. The column Weight Table X represents the trucks that did not meet the criteria for Weight Tables 1-5 (Pelphrey et al., 2008). For the brevity, herein we just list the sorting results for the whole month to the West direction as table 3; the sorting results for the first two weeks (1st-14th) and the last two weeks (15th-28th) are not listed. Statistical values that were calculated based on the GVW of the top 20% of the 3S2 legal truck and the alongside one, respectively, were listed in table 4.

2.4 Sorting Results Based on ALDOT Regulation

The conventional sort method was used to classify trucks into Weight Table 1 representing legal trucks in accordance with the ALDOT regulations. The modified sort was used to classify permit trucks according to the ALDOT regulations into Weight Table 2, representing CTP's that do not

require routing, Weight Table 3, representing CTP's that do require annual routing, and Weight Table 4, STP's. For each sorting routine, a small portion of the WIM data could not be classified according to the weight regulations and these records were placed into Weight Table X. The sorting results of each month of site 911 to the West direction are listed in table 5. Statistical values based on the GVW of the top 20% of the rating and alongside truck are listed in table 6.

Table 3 Number of vehicles of site 911 to the West direction – ODOT sort

Season	Month	Weight Table 1	Weight Table 2	Weight Table 3	Weight Table 4	Weight Table 5	Weight Table X	Total Records	CTP from WT3 to WT2	3S2 truck	Along-side truck	Permit truck	STP per day	Days
Winter	Dec	22293	1	1441	12	3	424	24174	1312	8917	23606	568	18	31
	Jan	29196	23	1838	14	1	149	31221	1283	8885	30502	719	23	31
	Feb	25239	12	1370	14	0	112	26747	723	5951	25974	773	27	29
Spring	Mar	27835	51	1490	33	0	143	29552	1162	9808	29048	504	16	31
	Apr	28876	45	1479	67	5	192	30664	1023	9353	29944	720	24	30
	May	19624	25	1101	25	1	129	20905	841	6816	20490	415	13	31
Summer	Jun	30456	14	1647	32	0	154	32303	1259	1050	31729	574	19	30
	Jul	16206	8	762	22	2	111	17111	624	6197	16838	273	9	31
	Aug	25181	7	1276	9	2	177	26652	1189	1084	26377	275	9	31
Fall	Sep	24246	10	1400	16	1	181	25854	1286	1070	25542	312	10	30
	Oct	24473	5	1479	41	4	364	26366	1345	1025	25823	543	18	31
	Nov	22879	8	1279	8	6	345	24525	1150	9035	24037	488	16	30

Note: The column Days means the effective days in the data recording.

Table 4 Statistics of trucks to the West direction of site 911 - ODOT sort

Statistic Items	Winter				Spring				Summer				Fall			
	Dec	Jan	Feb	Season	Mar	Apr	May	Season	Jun	Jul	Aug	Season	Sep	Oct	Nov	Season
W^*_{3S2}	71.34	72.86	72.91	72.37	72.73	72.15	72.71	72.52	73.36	72.54	72.27	72.77	72.02	71.61	71.52	71.74
σ^*_{3S2}	2.94	2.63	2.37	2.68	2.66	2.51	2.46	2.56	2.33	2.40	2.58	2.44	2.51	2.87	2.89	2.74
W^*_{along}	70.38	67.28	62.32	66.94	69.35	67.67	69.31	68.73	69.20	68.73	70.37	69.55	71.24	70.29	69.63	70.47
σ^*_{along}	8.53	10.58	12.60	10.58	8.56	9.23	8.32	8.75	8.50	8.28	7.22	7.96	6.84	8.08	8.63	7.78

Table 5 Number of vehicles of site 911 to the West direction – ALDOT sort

Season	Month	Weight Table 1	Weight Table 2	Weight Table 3	Weight Table 4	Weight Table X	Total Records	3S2 truck	Number of CTPs	CTP per day	Days	Number of STPs
Winter	Dec	22621	1529	23	0	1	24174	9218	1552	50	31	1
	Jan	29807	1399	11	0	4	31221	9308	1410	45	31	4
	Feb	25709	1028	8	0	2	26747	6202	1036	36	29	2
Spring	Mar	28338	1194	11	0	9	29552	10209	1205	39	31	9
	Apr	29341	1286	32	0	5	30664	9661	1318	44	30	5
	May	20006	877	22	0	0	20905	7108	899	29	31	0
Summer	Jun	31006	1285	9	1	2	32303	10984	1294	43	30	3
	Jul	16460	642	7	0	2	17111	6418	649	21	31	2
	Aug	25528	1117	6	0	1	26652	11173	1123	36	31	1
Fall	Sep	24569	1273	12	0	0	25854	10997	1285	43	30	0
	Oct	24830	1506	28	1	1	26366	10587	1534	49	31	2
	Nov	23145	1359	21	0	0	24525	9284	1380	46	30	0

Note: The number of alongside truck is the vehicle numbers belong to Weight Table 1.

Table 6 Statistics of trucks to the West direction of site 911 - ALDOT sort

Statistic Items	Winter				Spring				Summer				Fall			
	Dec	Jan	Feb	Season	Mar	Apr	May	Season	Jun	Jul	Aug	Season	Sep	Oct	Nov	Season
W^*_{3S2}	72.50	74.27	74.03	73.63	73.96	73.20	73.86	73.67	74.52	73.53	73.16	73.82	72.85	72.70	72.53	72.71
σ^*_{3S2}	2.95	2.58	2.42	2.69	2.68	2.72	2.49	2.66	2.32	2.43	2.52	2.43	2.53	2.86	2.97	2.77
W^*_{along}	64.33	62.52	59.09	62.05	65.46	63.82	65.43	64.85	65.64	65.38	66.33	65.85	66.78	65.03	64.18	65.42
σ^*_{along}	8.56	10.56	11.86	10.48	8.49	8.98	8.40	8.66	8.85	8.43	7.52	8.26	6.80	8.24	8.70	7.87

3. Calculation of Live Load Factors

In order to make a comparison and provide more detailed information in evaluating existing bridges for ALDOT and other states as well, the live load factors for legal vehicles, CTP's and STP's were developed based on the two sorting methods, say, the ODOT sort and ALDOT sort.

3.1 Live Load Factors Based on Oregon Regulation

NCHRP Report 454 gives the equations for the LRFR live load factors based on two-lanes of live load (Moses, 2001). Pelphrey et al. (2008) modifies the equations and calibrate the site-specific live load factors for Oregon based on the WIM data base of the state. In addition, Oregon DOT has a set of 13 rating vehicles (including legal, CTP, and STP) with detailed figures (ODOT, 2011). The first calibration method of live load factor for Alabama is based on Oregon regulation and strictly follows the process applied in Oregon. Similarly, five years is used for the evaluation period and the possibility of side-by-side occurrence is same as that applied in Oregon.

3.2 Live Load Factors Based on ALDOT Regulation

The second calibration method is based on Alabama regulation and strictly follows the process applied in NCHRP Report 454 (Moses, 2001). The report gives the specific equation to calibrate the live load factor for legal truck based on the statistics parameter of legal trucks for two-lane case and one-lane case, respectively. As the calibration process in Oregon are based on two-lane case, herein, in order to make a comparison with the live load factors calculated based on ODOT regulations, the two-lane case was chosen to calibrate the live load factor for legal trucks.

NCHRP Report 454 also mentions that in the case of routine permits, there is random traffic alongside the permit vehicle, while special permits, on the other hand, are assumed to cross the span without another truck alongside. This means for CTPs, the two-lane case will govern the live load calibration; while for STPs, the one-lane case will dominate.

The calibrated live load factors for STP vehicles in terms of ODOT regulation are based on two-lane case. In order to make a comparison of the results based both on ALDOT regulations and ODOT ones, we should estimate the average equivalent two-lane live-load factor by dividing one-lane factor by 1.7 (Moses, 2001). However, for the STPs, if the number of crossings during the total during evaluation period is less than one, the live load factor for the rating vehicles will be a constant equaling to 1.08 (the equivalent two-lane live load factor is taken as 0.64).
ALDOT does not have specific rating vehicles in the state, so the ODOT vehicles were used to determine live load factors for comparison when sorting the WIM data in accordance with ALDOT regulations. Due to the differences in permit weight classifications, several permit rating vehicles of ODOT were reclassified as following: OR-CTP-2A and OR-CTP-2B are treated as

STP vehicles according to ALDOT classifications; OR-STP-3 is classified as an annual permit with routing and OR-STP-4A as an annual permit without routing. The proposed rating vehicles (including 13 rating vehicles of ODOT) are referred to table 7.

4. Results of Site-specific Live Load Factor

Site-specific live load factors were calculated for five WIM sites in Alabama using both the ODOT and ALDOT regulations. Herein we just illustrate the results for site 911. The effect of different time windows and directions on the calculated live load factors for each rating vehicle based on ODOT regulation and ALDOT one are illustrated in figures 1 and 2, respectively.

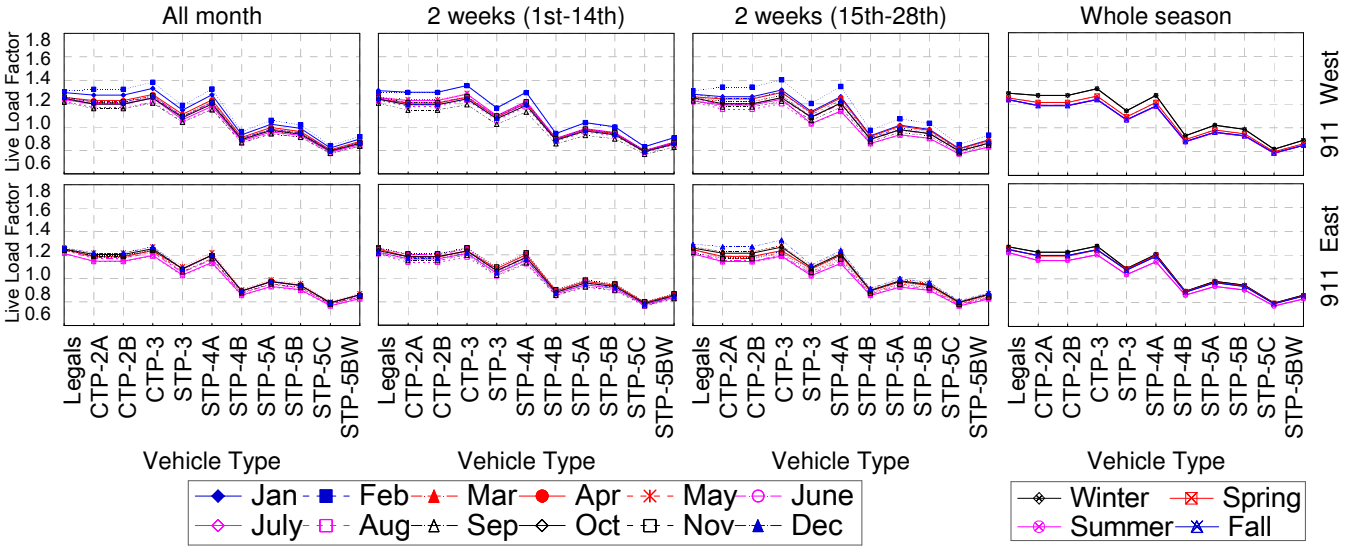


Figure 1 - Live load factors for WIM site 911 at different time windows– ODOT sort

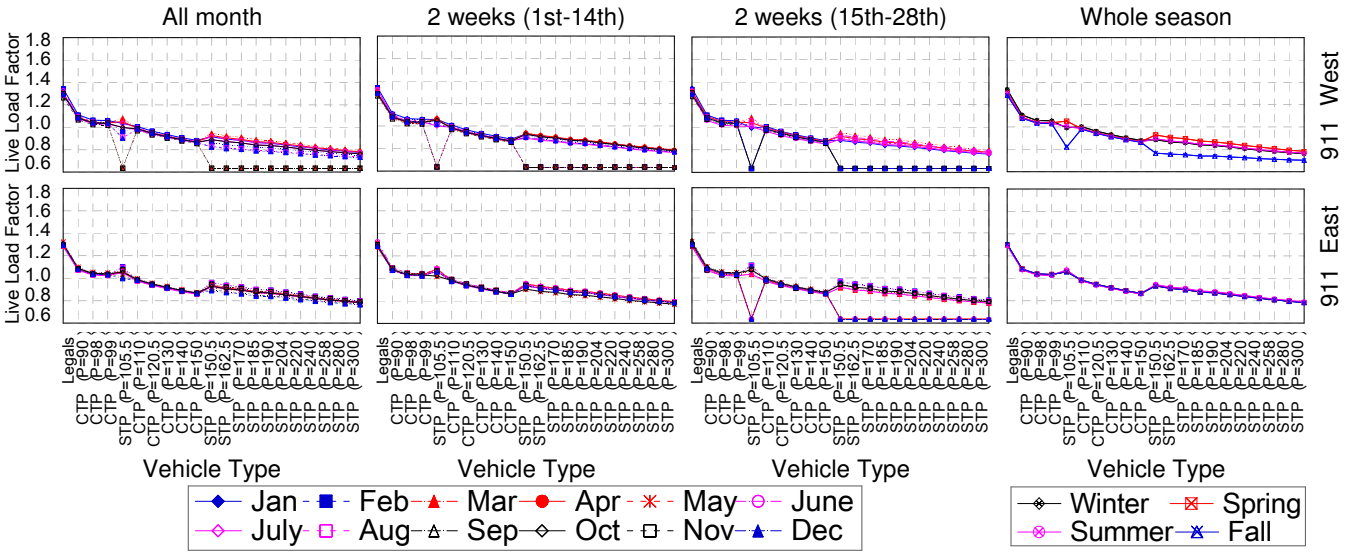
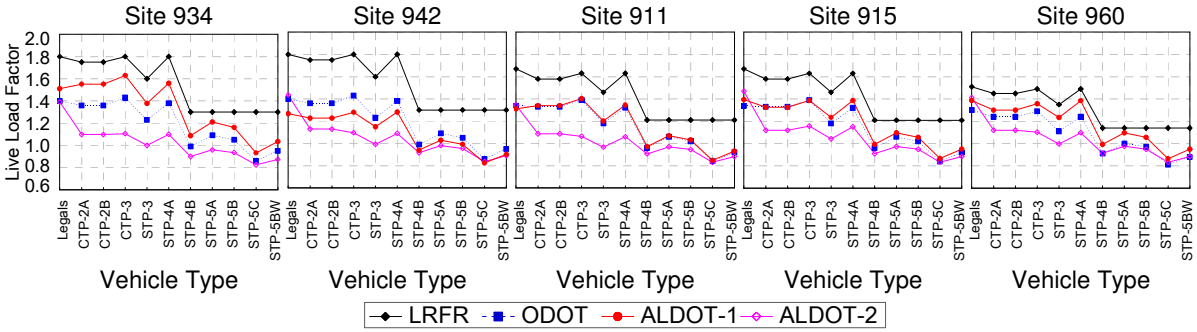


Figure 2 - Live load factors for WIM site 911 at different time windows– ALDOT sort

By comparing the plots for the three collection windows, it can be determined that a continuous two weeks of WIM data is generally sufficient to accurately determine the live load factors for legal trucks and CTP trucks, but may not be sufficient to determine the live load factor for STP trucks. To determine the live load factor for STP trucks using a two week interval of data, that interval should be selected carefully to ensure that the average number of STP trucks crossing the site per day during the interval exceeds one. Figure 3 shows the comparison of live load factor of different sites among the LRFR Manual, the Oregon site-specific live load factor with similar ADTT, and the Alabama site-specific live load factor based on different sorting method. The live load factors from different sources are listed in table 7.



Note: (1) "ODOT" means the live load factor based on the Oregon data base with ODOT sort; (2) "ALDOT-1, ALDOT-2" means the live load factor based on the Alabama data base with the application of the ODOT sort and ALDOT sore, respectively.

Figure 3 - Comparison of live load factor of different sites

Table 7 Comparison of live load factors at different sites

ODOT	ALDOT	Live load Factor by ADTT											
		ADTT≈5000				ADTT≈1500				ADTT≈500			
		①	②	③	④	①	②	③	④	①	②	③	④
Legals	Legals	1.80	1.40	1.27	1.44	1.67	1.34	1.39	1.47	1.51	1.30	1.39	1.41
	CTP (P=90)				1.16				1.21				1.15
CTP-3 (98)	CTP (P=98)	1.80	1.43	1.28	1.11	1.63	1.39	1.40	1.16	1.49	1.29	1.36	1.10
STP-4A (99)	CTP (P=99)	1.80	1.38	1.28	1.10	1.63	1.32	1.39	1.15	1.49	1.24	1.39	1.10
CTP-2A/2B	STP (P=105.5)	1.75	1.36	1.23	1.13	1.58	1.33	1.34	1.12	1.45	1.24	1.30	1.12
	CTP (P=110)				1.04				1.09				1.04
STP-3 (120.5)	CTP (P=120.5)	1.60	1.23	1.15	1.00	1.46	1.18	1.24	1.04	1.35	1.11	1.23	1.00
	CTP (P=130)				0.97				1.01				0.96
	CTP (P=140)				0.94				0.97				0.93
	CTP (P=150)				0.91				0.94				0.91
STP-5A (150.5)	STP (P=150.5)	1.30	1.09	1.03	0.98	1.21	1.06	1.10	0.97	1.14	1.00	1.10	0.97
STP-5B (162.5)	STP (P=162.5)	1.30	1.05	0.99	0.96	1.21	1.02	1.06	0.95	1.14	0.97	1.06	0.95
	STP (P=170)				0.94				0.94				0.94
STP-4B (185)	STP (P=185)	1.30	0.99	0.94	0.92	1.21	0.96	0.99	0.91	1.14	0.91	0.99	0.91
	STP (P=190)				0.91				0.90				0.90
STP-5BW (204)	STP (P=204)	1.30	0.95	0.90	0.89	1.21	0.92	0.95	0.89	1.14	0.88	0.95	0.89
	STP (P=220)				0.87				0.87				0.87
	STP (P=240)				0.85				0.85				0.85
STP-5C (258)	STP (P=258)	1.30	0.86	0.83	0.84	1.21	0.84	0.87	0.83	1.14	0.81	0.86	0.83
	STP (P=280)				0.82				0.82				0.82
	STP (P=300)				0.81				0.81				0.81

Note: (1) Column ① means the live load factors from LRFR; Column ② means the live load factors are computed based on Oregon WIM data and Oregon regulations; Columns ③ and ④ mean the live load factors are computed based on Alabama WIM data with Oregon regulation and Alabama regulation, respectively; (2) The live load factor for columns ③ and ④ are the

selected maximum value considering: two different directions, four different time windows, and sites with similar ADTT, after leaving out the data of those months which have missing data record over four days and significantly large standard deviation.

5. Conclusions and Recommendations

(1) A statewide calibration of live load factors is investigated for LRFR bridge load rating by ALDOT. Lower factors compared to those presented in the LRFR Manual are developed utilizing large sets of WIM data from five highways within Alabama.
(2) In accordance with the original LRFR calibration process, the WIM data were filtered and organized so that high quality data were used to yield reliable statistical values. The live load factors were calculated based on ODOT and ALDOT permit weight classifications, and both classification systems resulted in live load factors less than those of the LRFR Manual.
(3) The live load factors calculated from traffic traveling in different directions does not demonstrate obvious differences if the volume of traffic does not differ significantly between the two directions. Seasonal variations in the calculated live load factors are also not large.
(4) The live load factors for STPs for the ODOT regulation are not as reliable as for the ODOT classification. It this case, it is recommended to use a longer data collection window until sufficient STP crossings are encountered. Two weeks of data collection is acceptable for the live load factor calibration for legal vehicles and CTP vehicles.
(5) The live load factors in LRFR Manual are overly conservative for efficiently and economically evaluating bridges. It is recommended that ALDOT consider using site specific live load factors when load rating bridges to improve network efficiency, especially when the prescribed live load factors result in a bridge needing to be posted.

6. Acknowledgements

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