Weigh-in-Motion (WIM) Data for Site-Specific LRFR Bridge Load Rating

By
Nasim Uddin, Hua Zhao, Christopher Waldron, Li Dong, and Amber Greer
Department of Civil, Construction, and Environmental Engineering
University of Alabama at Birmingham
Birmingham, AL

Prepared by

UTCA

University Transportation Center for Alabama
The University of Alabama, The University of Alabama at Birmingham,
And The University of Alabama in Huntsville

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16. Abstract

The live load factors in the Load and Resistant Factor Rating (LRFR) Manual are based on load data from Ontario thought to be representative of traffic volumes nationwide. However, in accordance with the methodology for developing site-specific live load factors in the provisions of the LRFR Manual, live load factors for six locations in Alabama were developed using statistical weigh-in-motion (WIM) data. WIM data were collected from six sites in Alabama, including sites located on state and interstate routes. Data were collected throughout the year and in both travel directions to account for possible seasonal and directional variations. Different WIM data collection windows were also analyzed to determine the minimum required collection window to achieve statistically valid results. WIM records representing truck traffic at each WIM site were categorized based on weight in accordance with the Code of Alabama and Alabama Department of Transportation (ALDOT) practices. This analysis of WIM data in Alabama resulted in lower live load factors for each of the six sites than those presented in the LRFR Manual. It is recommended that ALDOT consider using these lower live load factors to more accurately represent the load rating of bridges across the state.

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Executive Summary

The live load factors in the Load and Resistant Factor Rating (LRFR) Manual are based on load data from Ontario thought to be representative of traffic volumes nationwide. However, in accordance with the methodology for developing site-specific live load factors in the provisions of the LRFR Manual, live load factors for six locations in Alabama were developed using statistical weigh-in-motion (WIM) data. WIM data were collected from six sites in Alabama, including sites located on state and interstate routes. Data were collected throughout the year and in both travel directions to account for possible seasonal and directional variations. Different WIM data collection windows were also analyzed to determine the minimum required collection window to achieve statistically valid results. WIM records representing truck traffic at each WIM site were categorized based on weight in accordance with the Code of Alabama and Alabama Department of Transportation (ALDOT) practices. This analysis of WIM data in Alabama resulted in lower live load factors for each of the six sites than those presented in the LRFR Manual. It is recommended that ALDOT consider using these lower live load factors to more accurately represent the load rating of bridges across the state.

Section 1
Introduction, Problem Statement, Overall Project Approach

Much of the bridge stock in North America and Europe was constructed in the 1950s and 1960s and has since deteriorated significantly. The nation's bridge infrastructure is plagued with two major problems: deterioration and structural deficiency, both of which have, for some time, been underscored as strategic research issues by the National Science Foundation (NSF 1993). In the United States a large portion of highway bridges are classified as "deficient." As of 2009 over 24% of bridges are structurally deficient or functionally obsolete and 30% are over 50 years old (USDOT 2009). Deteriorating bridges can lead to a reduced load rating and a bridge posting for a live load significantly below the legal limit, resulting in transportation network inefficiencies. Low load ratings and subsequent postings can lead to increased maintenance requirements, major rehabilitation, or complete replacement. It is therefore important that bridge load ratings be carefully determined to maintain public safety while limiting unnecessary bridge postings.

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 1994). This manual is consistent with the AASHTO Load and Resistance Factor Design (LRFD) Specifications (AASHTO 2010) and includes live load factors determined when the LRFD Specifications were calibrated. However, realizing that these load factors may be overly conservative for load rating and posting bridges, the LRFR Manual 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.

This project investigates six WIM sites in Alabama to determine live load factors that are more representative of truck traffic in the state. Directional and seasonal variations are investigated at each WIM site, as are various collection window lengths to determine the most appropriate time, direction, and duration of WIM data collection for accurate, yet conservative, live load factor determination. Also, to evaluate the impact of truck-weight regulations on site-specific live load factors, the WIM data are sorted in accordance with the truck-weight regulations in force in Alabama and the truck-weight regulations in force in Oregon. Oregon truck-weight regulations were chosen for this study because they are significantly different from Alabama's regulations and will therefore highlight the effect of regulatory differences and because Oregon has completed a similar study of site-specific live load factors using WIM data (Pelphery 2008).

Section 2
Background

The LRFD Bridge Design Specifications were developed to bring a more uniform probability of failure to bridge design. Several years later, the LRFR Manual was developed to bring the same level of uniform reliability to bridge load rating. 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. The first live load factor developed for the LRFD Specifications was 1.70, as reported in NCHRP Report 368 (Nowak 1999). 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. It was assumed that the surveyed truck data from Ontario were representative of two weeks of heavy traffic on a two-lane bridge with Average Daily Truck Traffic (ADTT) of 1,000 in one direction. Several years later NCHRP Project 20-7/186 (Kulicki, *et al.* 2007) increased the live load factor from 1.70 to 1.75 to account for the increase in the design ADTT from 1,000 to 5,000.

Live loads represent much of the uncertainty in bridge loads. To yield the most accurate bridge ratings, site-to-site variability of live loads should be incorporated into the reliability analyses (Ghosn and Moses 1986). More refined live load factors appropriate for a specific bridge site may be estimated if more detailed traffic and load data are available for the site. ADTT and truck weight collected through weigh-in-motion measurements recorded over a period of time allow the estimation of site-specific live load factors that are characteristic of a particular bridge site. Since the 1980s, reliable truck-weight data have been collected through the WIM system nationwide. As these data become available, states are adjusting for the live load factors used for load rating to be representative of their specific truck traffic. The Michigan DOT has proposed an adjustment factor to increase the live load to account for heavy truck traffic in metropolitan areas (Van de Lindt, *et al.* 2006). Additionally, the Missouri, Oregon, Florida, and New York DOTs have calibrated live load factors using WIM data collected in each state in accordance with the procedures defined in the commentary of the LRFR Manual (Kwon, *et al.* 2010).

The LRFR Manual commentary provides a simplified procedure for calculating site-specific load factors using truck-weight data for a site. This procedure follows the methodology developed in NCHRP Project No. 12-46 (Moses 2001) and is the same methodology used in the determination of the live load factors presented in the LRFD Specifications and the LRFR Manual.

The LRFR approach is to determine the distribution of truck weights within the 3S2 truck population to characterize the uncertainty of the alongside truck. The 3S2 truck population represents the most common heavy vehicle consisting of a three-axle tractor and a two-axle semi-trailer. 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*. 2006). Therefore, the basic case for load rating in accordance with the LRFR Manual occurs with two lanes of live load, and the live load factor for the rating vehicle is influenced by both the weight of the rating vehicle and the weight of the random vehicle alongside it.

Section 3
Methodology

Selection of WIM Sites in Alabama and Data Collection

There are five highways of interest for which ALDOT collects WIM data. These are US-280, US- 43, US-78, US-231, and US-84. Specific WIM sites on these highways were selected based on the truck volume, and WIM data were gathered from ALDOT's website for 2007 and 2008 at the sites 911, 915, 934, 942, 960, and 964. The traffic volume for each site is shown in Table 3-1, and the location of each WIM site is shown in Figure 3-1.

Table 3-1. Total traffic volume and truck traffic volume at each WIM site

Site	Location	2008			2007		
		AADT	TADT (%)	ADTT	AADT	TADT (%)	ADTT
911	Coosa County / US 280	10130	17%	1722	10510	17%	1787
915	Washington County / US-43	7740	18%	1393	8020	18%	1444
934	Walker County / US-78	18030	17%	3065	30120	17%	5120
942	Montgomery County / US-231	14430	22%	3175	15370	22%	3381
960	Clarke County / US-84	3760	22%	827	4050	22%	891
964	Dale County / US-231(53)	16630	16%	2661	17840	16%	2854

The WIM sites selected are spread across the state and as such represent a sampling of various truck traffic conditions within Alabama on both the State Highway System and the US Highway System. They cover a range of ADTTs and roadway classifications. However for this study very high ADTTs (as are found on major Interstate Highway System truck routes) were not considered due to the limited scope of the study, and future research will be conducted to investigate more stations including these routes in Alabama.

NCHRP Report 454 rcommended a two-week collection interval for calculating live load factors based on WIM data. To validate this assertion and determine the optimum time within a month for data collection, each month was divided into three periods, including (1) the entire month; (2) the first two weeks, from the 1st to the 14th; and (3) the last two weeks, from the 15th to the 28th.

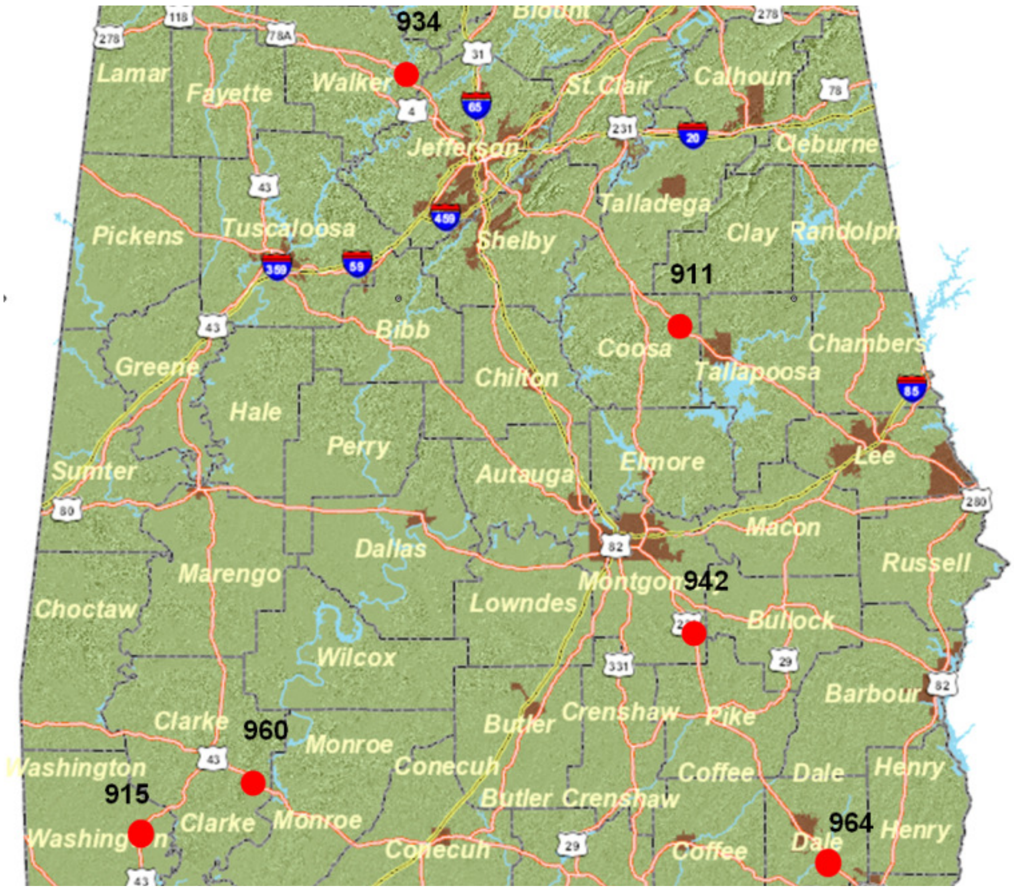

Figure 3-1. WIM station locations and site numbers

Finally, to see the effect of seasonal variations on traffic at each site, the data were divided into four seasons: winter, spring, summer, and fall. Each season covered three months, with winter including December through February, spring including March through May, summer including June through August, and fall including September through November.

Sorting WIM Data by Vehicle Weight

After selection of appropriate WIM sites, the next step in determining site-specific live load factors is to sort the truck-weight data from WIM records in accordance with the truck-weight regulations of the jurisdiction. Each state has their own regulations for determining legal weights and different classifications of permit weights. For this study, data were collected from six representative WIM sites in Alabama for two years. 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 ODOT permit weight tables, and the other approach is based on the classification of legal vehicles, annual permit vehicles, and single trip permit vehicles used by ALDOT.

ODOT classifies legal and permit vehicles according to five detailed weight tables. This vehicle classification system is used in this study for comparison purposes only, so the full details of each permit weight table is not presented here. The permit weight tables are available from ODOT's website (ODOT 2011).

ALDOT classifies trucks into three broad categories based on weight:

1. Legal trucks – The definition of legal trucks closely follows the bridge weight formula defined by the Federal Highway Administration website (USDOT 2006). The primary difference is the expansion of the definition of a legal truck in Alabama to include certain six-axle trucks with gross vehicle weights (GVW) up to 84,000 lb.
2. Annual permits or continuous trip permits (CTP) – This category covers trucks exceeding the statutory limits but allowed to operate using an annual permit. This category is further broken down into trucks not requiring advanced routing and trucks requiring advanced routing as follows:
    a. Annual Permit (no routing) – This sub-category includes trucks exceeding the statutory limits but not exceeding 100,000 lb GVW or 75 ft in length.
    b. Annual Permit (routing) – This sub-category includes trucks exceeding the 100,000 lb GVW limit to travel without advanced routing, but not exceeding 150,000 lb GVW or 75 ft in length.
3. Single Trip Permits (STP) – This category includes trucks that exceed 150,000 lb GVW or 75 ft in length. However, since this study is concerned with bridge load rating and the effect of heavy trucks, trucks exceeding 75 ft in length but not exceeding 150,000 lb were excluded from the data sort.

The raw WIM records from each collection site were provided in text format for data processing. NCHRP Report 454 (Moses 2001) indicates that the live load factors should be calculated based on one direction of data. Therefore, in this study, WIM data sorting was performed for each travel direction independently at each site to evaluate directional variations. 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 were filtered using the following criteria and removed from the data set if it met the following criteria (Pelphrey 2008):

1. GVW equals 0
2. Axle weight is over 50 kip
3. Sum of axle spacing is over 200 ft or less than 7 ft
4. Axle spacing of first axle is less than 5 ft
5. Any axle spacing is less than 3.4 ft
6. GVW is over 280 kip or less than 2 kip
7. GVW error is > 7%
8. No. of axles is greater than 13
9. Speed is greater than or equal to 99 mph or less than or equal to 7 mph

After filtering the WIM data, the truck records were sorted into proper permit weight tables. Permitted trucks were excluded from the WIM data that represents the alongside truck volume as the alongside truck is to be representative of regular traffic, or legal trucks. Two sorting algorithms were used, which are noted as conventional sort and modified sort in this report. 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). The conventional sort was used to classify trucks into permit weight tables 1-5 in accordance with the ODOT regulations and 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 CTPs that do not require routing; weight table 3, representing CTPs that do require annual routing; and weight table 4, STPs. 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 and not included in the statistical analysis.

Calculation of Live Load Factors

As noted previously, two classification methods were used to sort trucks into permit weight tables; the first is based on the ODOT permit weight tables and the second on the ALDOT classifications. 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, CTPs, and STPs were developed based on the two classifications.

NCHRP Report 454 gives the following equation for the LRFR live load factor based on two-lanes of live load (Moses 2001):

$$\gamma_L = 1.8 \times \frac{W_T}{240} \times \frac{72}{W} \qquad \text{(eq. 1)}$$

W equals the gross weight of vehicle (legal truck or permit truck with units of kip), and W_T—the expected maximum total weight of rating and alongside vehicles is computed as

$$W_T = R_T + A_T \qquad \text{(eq. 2)}$$

R_T is the rating truck; for legal loads it is

$$R_T = W^* + t_{ADTT} \times \sigma^*_{3S2} \qquad \text{(eq. 3)}$$

and for permit loads it is

$$R_T = P + t_{ADTT} \times \sigma^*_{along} \qquad \text{(eq. 4)}$$

A_T is the alongside truck:

$$A_T = W^*_{along} + t_{ADTT}\sigma^*_{along} \qquad \text{(eq. 5)}$$

W* is the mean value of the top 20% of legal trucks taken from the 3S2 population, where the 3S2 population includes all five-axle trucks within the category of legal trucks (weight table 1). Here are descriptions for other notations:

- σ^*_{3S2} is the standard deviation of the top 20% of legal trucks.
- P is the weight of permit truck.
- σ^*_{along} is the standard deviation of the top 20% of alongside trucks.
- W^*_{along} is the mean of the top 20% of alongside trucks.
- t_{ADTT} is the fractile value corresponding to the number of side-by-side events, N. N is computed as

$$N(legals) = (ADTT) \times (365\ days/year) \times (evaluation\ \ period) \times (P_{s/s}) \times (\%\ of\ record) \qquad \text{(eq. 6)}$$

$$N(permits) = (N_P) \times (365\ days/year) \times (evaluation\ \ period) \times (P_{s/s}) \qquad \text{(eq. 7)}$$

where N_P = number of observed STPs and $P_{S/S}$ = probability of side-by-side concurrence.

The two-lane case governs for most cases of legal loads and routine permits; however, for special permits (STP), NCHRP 454 recommends calculating live load factors using a single lane of load. In this case,

$$\gamma_{L\ (one\ lane)} = 1.8 \times \frac{W_1}{120} \times \frac{72}{P}, \qquad \text{(eq. 8)}$$

where $W_1 = A_T + P$ (eq. 9)

However, for STP, if the number of crossings during the total during evaluation period is less than one, A_T is small and

$$W_1 = W_R + P \approx P \qquad \text{(eq.10)}$$

Thus, the live load factor for the rating vehicles is

$$\gamma_{L\ (one\ \ lane)} = 1.8 \times \frac{W_1}{120} \times \frac{72}{P} \approx 1.8 \times \frac{P}{120} \times \frac{72}{P} = 1.08 \qquad \text{(eq. 11)}$$

For STP vehicles, the live load calculations in the ODOT study were based on the two-lane case (Pelphrey 2008). To make a comparison of the results based both on ALDOT regulations and ODOT regulations, the average equivalent two-lane live load factor is estimated by dividing the one-lane factor by 1.7 (Moses 2001). Therefore, for STP vehicles sorted in accordance with the ALDOT regulations, where the average number of crossings during the evaluation period is less than one, the equivalent two-lane live load factor is taken as 0.64.

We use five years as the evaluation period when calculating live load factors, as five years is a reasonable time frame for which bridge ratings may remain valid without reanalysis. In NCHRP Report 454, $P_{S/S}$ is taken as 1/30 for an ADTT > 5,000 based on a study of I-75 in Ohio; $P_{S/S}$ is taken as 0.01 for an ADTT = 1,000; and $P_{S/S}$ is taken as 0.001 for an ADTT = 100.

The statistical parameters for the alongside truck are dependent on the regulations of each state and should be representative of truck traffic in the regular traffic stream. So that a meaningful comparison could be made to the live load factors developed by ODOT, we took the alongside truck statistics using the ODOT regulations included WIM records from permit weight tables 1 and 2 and the CTP records from permit weight table 3 (Pelphrey 2008) as representative of regular truck traffic in Oregon. In contrast, when determining the site-specific live load factors based on Alabama regulations, permit vehicles were excluded from the alongside truck population in accordance with NCHRP Report 454.

With the statistical parameters determined, the final information needed to determine site-specific live load factors is a set of rating vehicles. ODOT has a set of 13 rating vehicles, shown in Figure 3-2, for which live load factors were calculated when sorting the WIM data in accordance with the ODOT regulations.

ALDOT does not have specific rating vehicles corresponding to permit loads in the state, so the ODOT vehicles were used to determine live load factors when sorting the WIM data in accordance with ALDOT regulations. Due to the differences in permit weight classifications, several of the ODOT vehicles were reclassified. OR-CTP-2A and OR-CTP-2B have a length exceeding the limit for CTPs in Alabama; therefore, they cannot be treated as CTP vehicles according to ALDOT classifications and are treated as STP vehicles. OR-STP-3 has a length 70 ft and GVW 120.5 kip, and OR-STP-4A has length 39 ft and GVW 99 kip. According to ALDOT classifications, both should be treated as CTP vehicles; thus, OR-STP-3 is classified as an annual permit with routing and OR-STP-4A as an annual permit without routing.

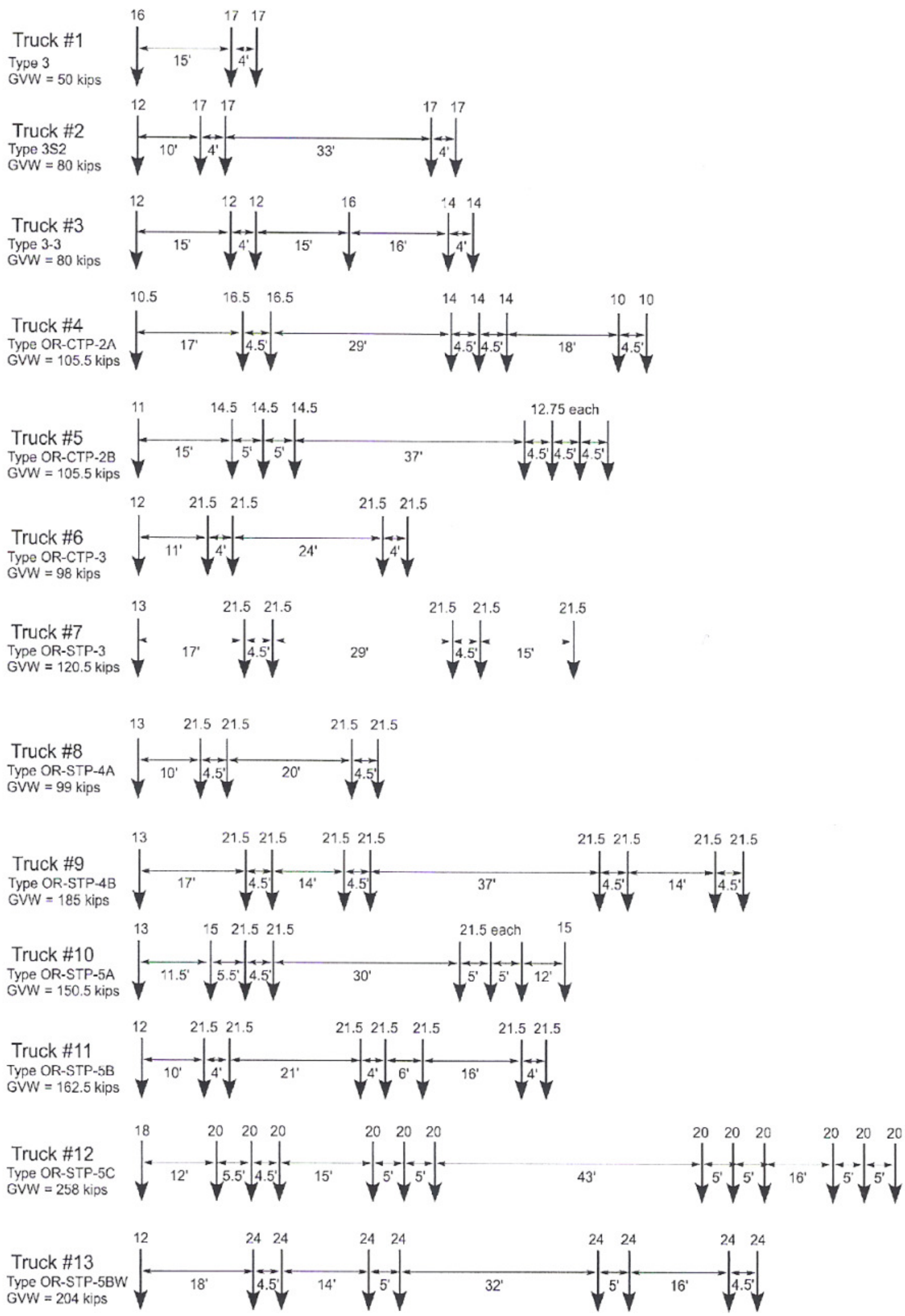

Figure 3-2. ODOT rating vehicles (Pelphrey 2008)

To make a comparison of the live load factors based on the two regulations and provide some guidance for the evaluation of permit vehicles in Alabama, this report calculates the live load factors for the following cases (the number in parentheses corresponding the permit vehicles in ODOT):

- CTP vehicles
    - P=90 kip
    - P=98 kip (CTP-3 (98 k))
    - P=99 k (STP-4A (99 k))
    - P=110 kip
    - P=120.5 kip (STP-3(120.5 k))
    - P=130 kip
    - P=140 kip
    - P=150 kip
- STP vehicles
    - P=105.5 kip (CTP-2A/B(105.5 k))
    - P=150.5 kip (STP-5A(150.5 k))
    - P=162.5 kip (STP-5B(162.5 k))
    - P=170 kip
    - P=185 kip (STP-4B(185 k))
    - P=190 k
    - P=204 k (STP-5BW(204 k))
    - P=220 k
    - P=240 k
    - P=258 k (STP-5C(258 k))
    - P=280 k
    - P=300 k

Section 4
Results

Site-specific live load factors were calculated for six WIM sites in Alabama using both the ODOT regulations for truck weight and the ALDOT regulations for truck weight. Detailed results for site 911, on US-280 in Coosa County, in 2007 are presented in this section. The detailed results for the other sites are similar and are not presented here for the sake of brevity. A comparison of the results for site 911 is presented, where the live load factors for this site are compared with live load factors from the LRFR Manual and live load factors from two sites in Oregon.

Live Load Factors Based on ODOT Regulations

The effect of season and direction on the calculated live load factors for each rating vehicle is illustrated in Figure 4-1. Using the ODOT regulations at this site, the directional variation and seasonal variation in the calculated live load factors is not large, yielding a maximum variation in live load factor of approximately 0.2. Since the live load factors based on truck traffic heading west are consistently slightly higher than those based on truck traffic heading east, the west direction of traffic will be used in the summary comparisons.

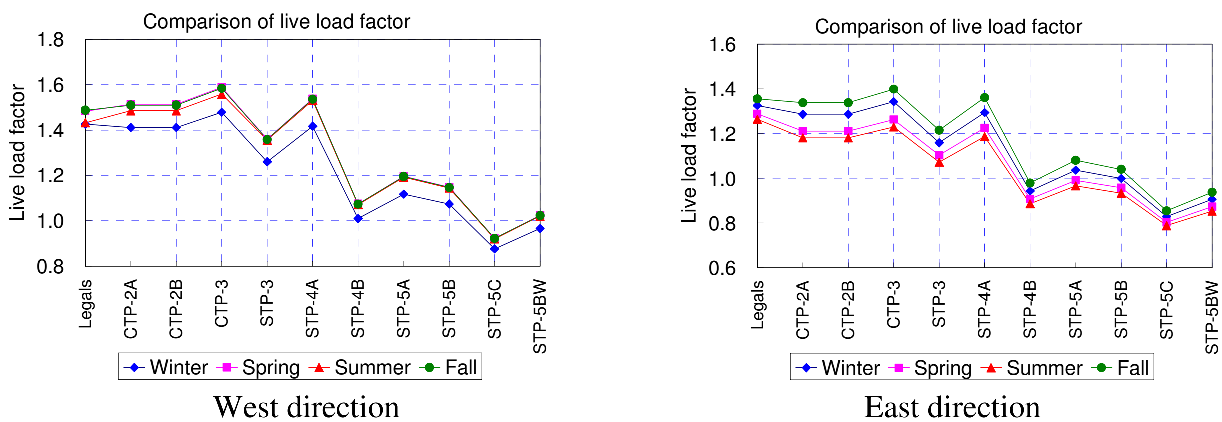

Figure 4-1. Seasonal and directional variation at site 911 – ODOT sort

The effect of collection window interval is illustrated in illustrated in Figure 4-2. In each case, the three collection windows show similar trends and comparable live load factors, indicating that a two-week collection window is sufficient to gather representative traffic data.

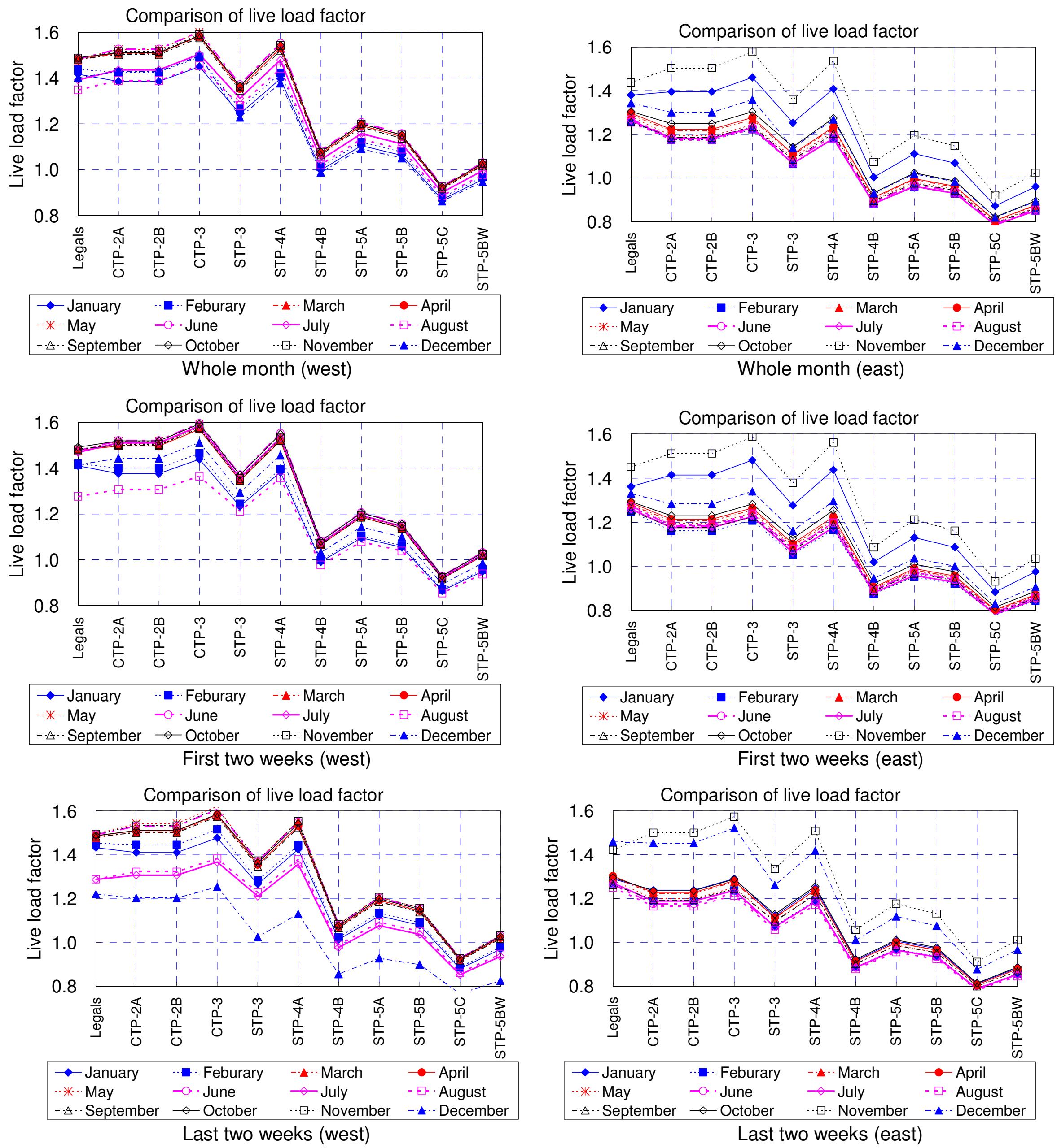

Figure 4-2. Data collection interval variation at site 911 – ODOT sort

Live Load Factors Based on ALDOT Regulations

The effect of season and direction on the calculated live load factors for each rating vehicle is illustrated in Figure 4-3. Using the ALDOT regulations at this site, the directional variation and seasonal variation in the calculated live load factors is quite small, yielding a maximum variation in live load factor of approximately 0.2. Since the live load factors based on truck traffic are generally similar, the west direction of traffic will again be used in the summary comparisons.

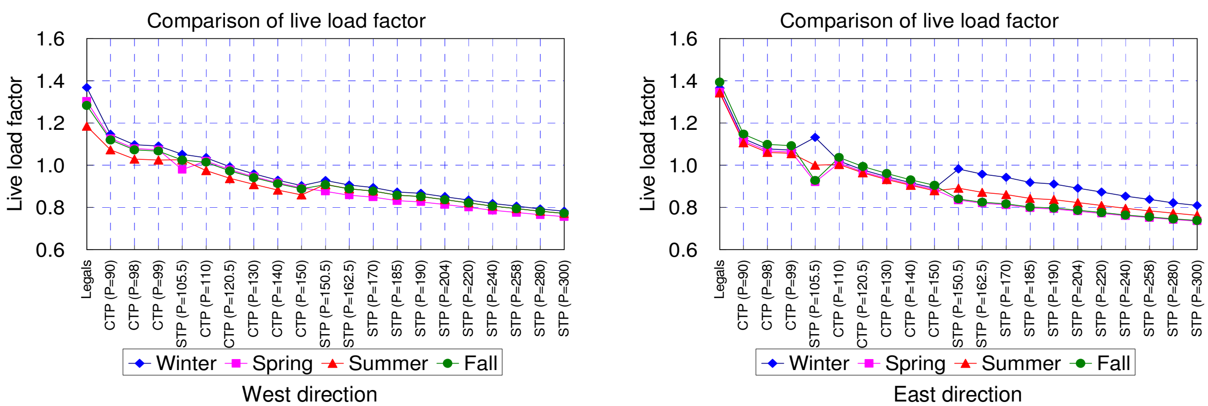

Figure 4-3. Seasonal and directional variation at site 911 – ALDOT sort

The effect of collection window interval is illustrated in Figure 4-4. The live load factors are similar for the three time windows (each month and the first and last two weeks) unless the average number of crossings of STP trucks per day is less than one during the time period. In this case, the live load factor is equal to a constant 1.08 for one-lane calculation, with an equivalent two-lane live load factor of 0.635 as discussed in the Methodology section.

By comparing the plots for the three collection windows, it can be determined that a continuous two weeks of WIM data are 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 to ensure that the average number of STP trucks crossing the site per day during the interval exceeds one. If care is taken in selecting the two-week interval in this manner, then Figure 4-4 indicates that two weeks of data are sufficient.

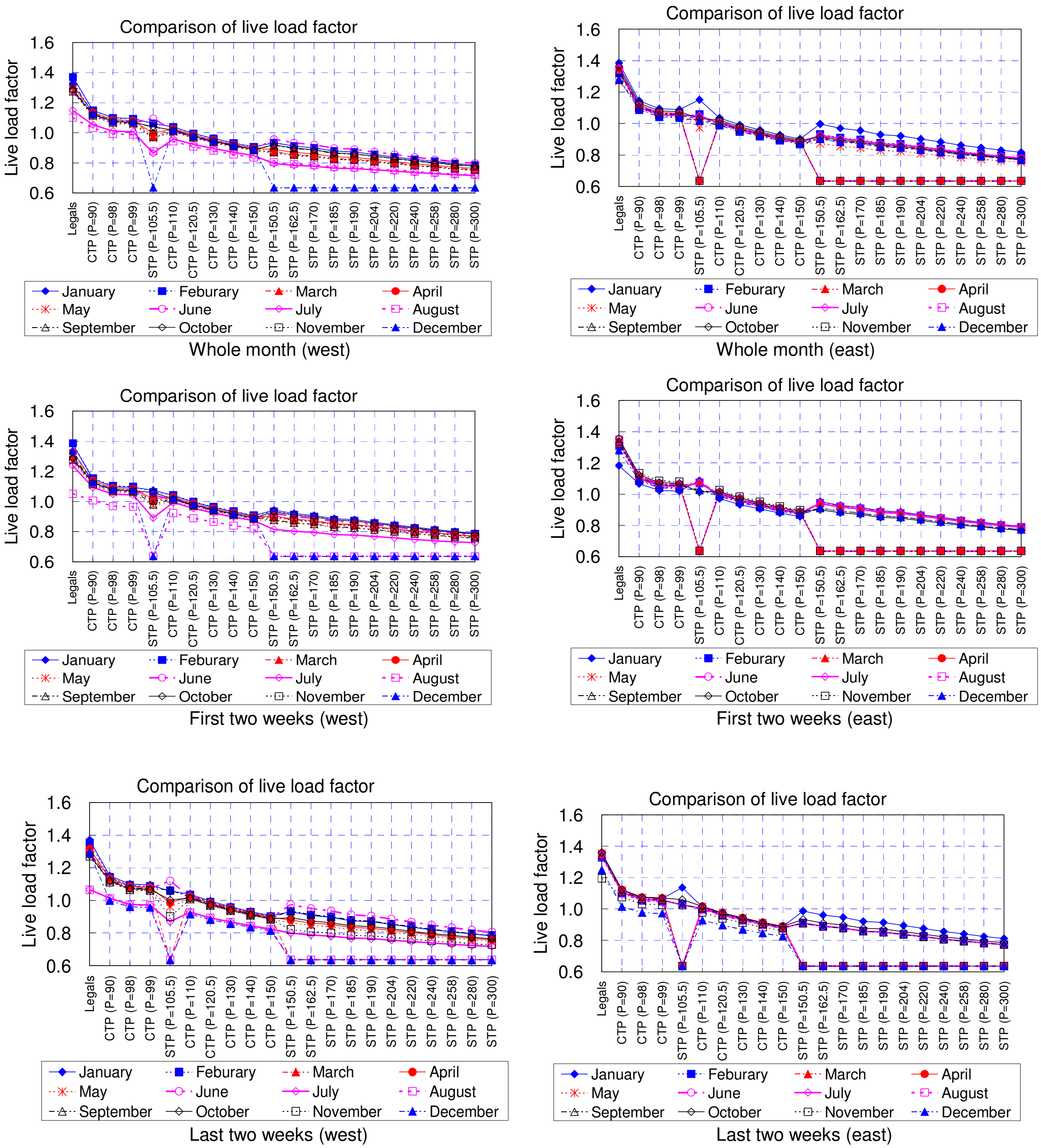

Figure 4-4. Data collection interval variation at site 911 – ALDOT sort

Comparison of Live Load Factors with LRFR Manual and Oregon Sites

The live load factors from site 911 in Alabama are compared with the live load factors in the LRFR Manual and the site-specific live load factors for two sites in Oregon. In the following figures, Alabama 1 represents the live load factors for the site 911 with the WIM data sorted in accordance with the ODOT regulations, and Alabama 2 represents the live load factors with the WIM data sorted in accordance with the ALDOT regulations. Oregon 1 represents live load factors for I-84 in Oregon (ADTT = 1,800), and Oregon 2 represents live load factors for OR-58 (AADT 600). Finally, LRFR represents the live load factors contained in the LRFR Manual for an ADTT of 1,500.

Figure 4-5 compares the live load factors for site 911 based on truck traffic heading west and WIM data collected in 2007. The WIM data collected at this site in 2008 and WIM data collected at other sites shows similar trends.

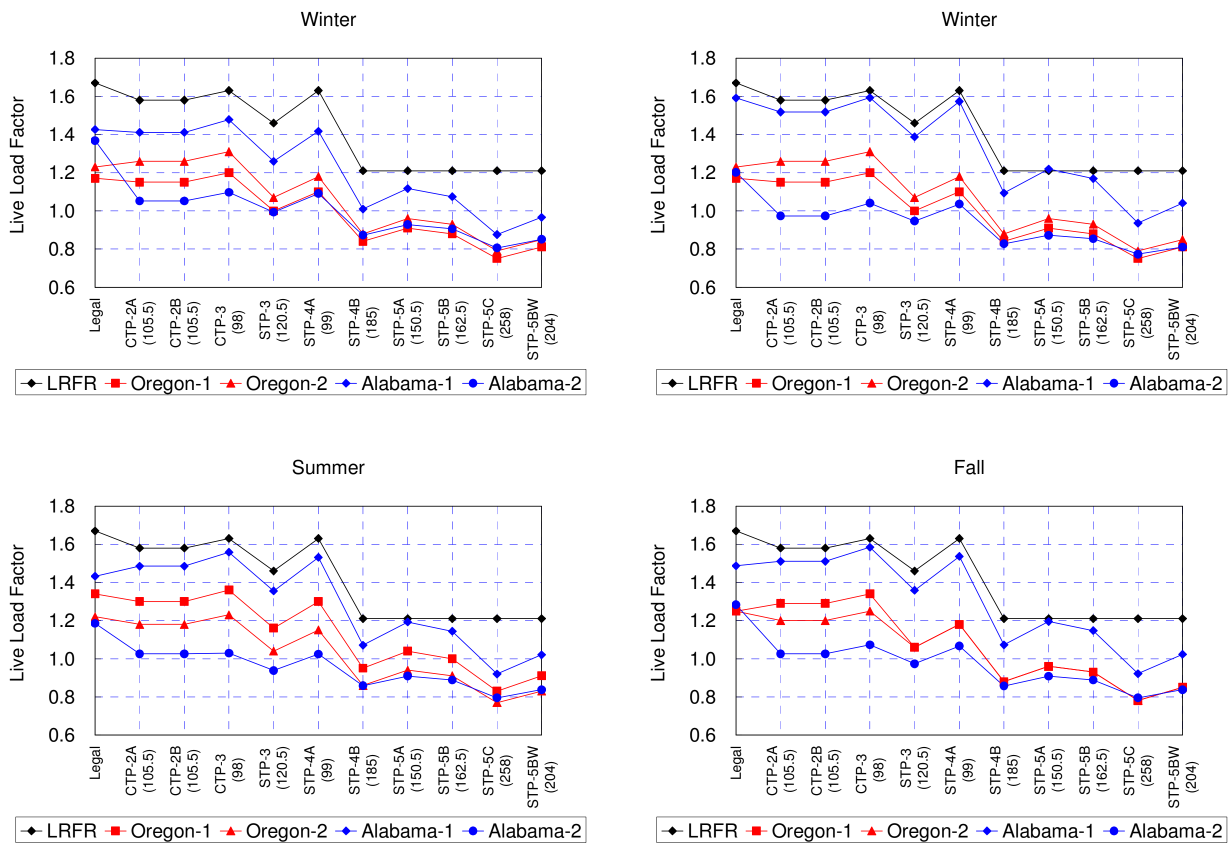

Figure 4-5. Comparison of live load factors

Section 5
Project Conclusions and Recommendations

A statewide calibration of live load factors was investigated for LRFR bridge load rating by ALDOT. Lower factors compared to those presented in the LRFR Manual were developed utilizing large sets of WIM data from six highways within Alabama. 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 in the LRFR Manual. 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 (less than 20% of the total vehicles) between the two directions. Seasonal variations in the calculated live load factors are also not large.

The ODOT classification is based on five specific ODOT permit weight tables and 13 ODOT rating vehicles. The ALDOT classification is based on ALDOT regulations, which splits permit vehicles into three broad categories. To compare these two approaches, rating vehicles similar to the ODOT rating vehicles were used with the ALDOT weight classifications since ALDOT does not currently have specific permit rating vehicles. The two methods are derived from NCHRP Report 454. For cases of similar ADTT and similar permit load, lower live load factors are obtained by using ALDOT classifications. When compared to the live load factors of the LRFR Manual, the site-specific live load factors are approximately 20% lower for legal vehicles and up to 35% lower for certain permit vehicles.

As is stated in the NCHRP Report 454, the live load factor is sensitive to the number of crossings of permit vehicles. If the vehicles are sorted based using ODOT permit weight tables, more STP vehicles are obtained than when the vehicles are sorted based on ALDOT regulations. For the approach based on ALDOT classifications, the number of STPs is limited, especially when considering only two weeks of data. As a result, the live load factors for STPs are not as reliable as in the ODOT classification. It this case, it is recommended to use a longer data collection window until sufficient STP crossings are encountered. The required window will likely vary by site. Two weeks of data collection is acceptable for the live load factor calibration for legal vehicles and CTP vehicles.

The live load factors in the LRFR Manual are too conservative to efficiently and economically evaluate bridges. It is recommended that ALDOT use 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.

It is also recommended that ALDOT develop three to five rating vehicles similar to the CTP and STP vehicles that travel the state highways, so that bridges can be efficiently load rated for permit vehicles without the need to rate specifically for each vehicle requesting a permit.

Section 6
References

AASHTO (American Association of State Highway and Transportation Officials). *Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges*. Washington, D.C. 2003.

AASHTO (American Association of State Highway and Transportation Officials). *Manual for Condition Evaluation of Bridges*. Washington, D.C. 1994.

Ghosn, M. and F. Moses. “Reliability calibration of a bridge design code.” *Journal of Structural Engineering*. Vol. 112, no. 4, pp. 745–763. 1986.

Kulicki, J.M., A. Prucz, C.M. Clancy, D.R. Mertz, and A.S. Nowak. *Updating the Calibration Report for AASHTO LRFD Code*. Transportation Research Board of the National Academies, NCHRP 20-7/186, Washington, D.C., 2007.

Kwon, O.S., E. Kim, and S. Orton. “Calibration of the live load factor in LRFD bridge design specifications based on state-specific traffic environments.” *Journal of Bridge Engineering*. Vol. 16, pp. 812-819. 2011.

Moses, F. *Calibration of Load Factors for LRFR Bridge Evaluation*. Transportation Research Board National Research Council, NCHRP report number 454, Washington, D.C. 2011.

Novak, A. *Calibration of LRFD Bridge Design Code*. Transportation Research Board National Research Council report number 368, Washington, D.C., 1999.

NSF (National Science Foundation). *Civil Infrastructure Systems Research: Strategic Issues*. Civil Infrastructure Systems Task Group. 1993.

Pelphrey, J. and C. Higgins. *Calibration of LRFR Live Load Factors for Oregon State-Owned Bridges Using Weigh-in-Motion Data*. Kiewit Center for Infrastructure and Transportation, Oregon State University, Corvallis, OR, 2006.

Pelphrey, J., C. Higgins, B. Sivakumar, R.L. Groff, B.H. Hartman, J.P. Charbonneau, J.W. Rooper, and B.V. Johnson. “State-specific LRFR live load factors using weigh-in-motion data.” *Journal of Bridge Engineering*. Vol. 13, no. 4, pp. 339-350. 2008.

USDOT (US Department of Transportation). *Transportation Statistics Annual Report*. Bureau of Transportation Statistics. 2008.

Van de Lindt, J.W., G. Fu, Y. Zhou, and R. Pablo Jr. “Locality of truck loads and adequacy of bridge design load.” *Journal of Bridge Engineering*. Vol. 10, no. 5, pp. 622-629. 2006.