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Development of Truck Equivalent Single-Axle Load (ESAL) Factors Based on Weigh-in-Motion Data for Pavement Design in Virginia

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Abstract:				
<p>The Virginia Department of Transportation's (VDOT's) current pavement design procedure is based on the 1993 AASHTO <i>Guide for Design of Pavement Structures</i>. In this procedure, a required structural capacity is calculated as a function of the anticipated service life, the serviceability of the pavement, and the number of equivalent loads applied. The concept of equivalent applied loads allows for the pavement designer to account for the damage caused by loads of varying magnitudes and axle configurations. Although pavement damage can be expressed per axle, expressing the damage in terms of the average amount of damage caused by a particular vehicle is more convenient. This is referred to as a <i>truck factor</i>, which is the average number of equivalent single-axle load (ESAL) applications per vehicle.</p> <p>VDOT's current pavement design procedure subdivides truck traffic into two categories, i.e., single-unit trucks and combination trucks, and was based on studies performed in the early 1990s. Over the last few years, VDOT has installed weigh-in-motion (WIM) devices at 15 locations around the state that measure the loads actually applied by vehicles in the travel lanes. These WIM stations allow for continuous data collection that was previously not available and therefore can provide a better representation of actual traffic loading.</p> <p>This study developed updated truck ESAL factors based on WIM data from June 2007 through May 2008 in Virginia. These factors were found to be 0.46 for single-unit trucks and 1.05 for combination trucks using flexible pavements and 0.59 for single-unit trucks and 1.59 for combination trucks using rigid pavements. The updated truck ESAL factors determined in this study should be incorporated into VDOT's pavement design procedure. Using the updated truck ESAL factors recommended in this study will allow a more optimal pavement design that more accurately reflects the traffic loading on roadways in Virginia.</p>				

FINAL REPORT

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IN VIRGINIA**

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Virginia Transportation Research Council
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ABSTRACT

The Virginia Department of Transportation's (VDOT's) current pavement design procedure is based on the 1993 AASHTO *Guide for Design of Pavement Structures*. In this procedure, a required structural capacity is calculated as a function of the anticipated service life, the serviceability of the pavement, and the number of equivalent loads applied. The concept of equivalent applied loads allows for the pavement designer to account for the damage caused by loads of varying magnitudes and axle configurations. Although pavement damage can be expressed per axle, expressing the damage in terms of the average amount of damage caused by a particular vehicle is more convenient. This is referred to as a *truck factor*, which is the average number of equivalent single-axle load (ESAL) applications per vehicle.

VDOT's current pavement design procedure subdivides truck traffic into two categories, i.e., single-unit trucks and combination trucks, and was based on studies performed in the early 1990s. Over the last few years, VDOT has installed weigh-in-motion (WIM) devices at 15 locations around the state that measure the loads actually applied by vehicles in the travel lanes. These WIM stations allow for continuous data collection that was previously not available and therefore can provide a better representation of actual traffic loading.

This study developed updated truck ESAL factors based on WIM data from June 2007 through May 2008 in Virginia. These factors were found to be 0.46 for single-unit trucks and 1.05 for combination trucks using flexible pavements and 0.59 for single-unit trucks and 1.59 for combination trucks using rigid pavements. The updated truck ESAL factors determined in this study should be incorporated into VDOT's pavement design procedure. Using the updated truck ESAL factors recommended in this study will allow a more optimal pavement design that more accurately reflects the traffic loading on roadways in Virginia.

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INTRODUCTION

The Virginia Department of Transportation's (VDOT's) current pavement design procedure (VDOT, 2008) for all new and rehabilitated pavements is based on the 1993 AASHTO *Guide for Design of Pavement Structures* (AASHTO, 1993) (hereinafter called the 1993 AASHTO design guide). This design procedure is based on the results of the AASHTO Road Test of the late 1950s in which the designed pavement thickness was found to be primarily a function of the anticipated service life, the serviceability of the pavement, and the number of equivalent loads applied.

The concept of pavement serviceability stems from the belief that the pavement is designed for the riding comfort of the user. As a pavement begins to deteriorate with age and repeated traffic loading, the comfort of the user is reduced. The quantitative measure relating physical properties affecting the ride quality and subjective ride comfort is termed the *present serviceability index*. The present serviceability index of a pavement is obtained from measurements of pavement smoothness and distresses and has a maximum value of 5.0. Two other defined parameters include the initial and terminal serviceability, p_i and p_t , respectively. *Initial serviceability* is defined as the perceived user comfort initially after a pavement is constructed. *Terminal serviceability* is the least acceptable condition before rehabilitation is required. Usually, the terminal serviceability is higher for a pavement that carries more traffic or does not allow for system redundancy (e.g., an interstate pavement) than for a lower priority route.

Equivalent loading is a means to equate the effect of traffic loading (pavement damage) caused by different axle configurations carrying different weights. Using the procedure in the 1993 AASHTO design guide, these varying configurations and loadings are equated to the damage caused by a single axle (having dual tires on each side) with a load of 18,000 lb by means of a load equivalency factor (LEF). The LEF of any axle is defined as the ratio of the damage per pass of the axle in question versus the damage per pass of a standard load (usually the 18,000-lb single axle). Because pavements having differing structural capacities respond differently to a given axle load, for a range of structural capacities there will be a corresponding range of LEFs for the same axle load. LEFs can be calculated for flexible and rigid pavements,

for different structural capacities (structural number [SN] for flexible pavements or slab thickness for rigid pavements), for different axle loads and types (single, tandem, triple, and quad), and for a range of terminal serviceability levels. A summation of the LEFs for various axle configurations is given in terms of the number of equivalent single-axle loads (ESALs).

Although LEFs provide a means of expressing equivalent levels of damage between axles, expressing that damage in terms of the average amount of damage inflicted by a particular vehicle is more convenient. The LEF from each axle on a vehicle can be summed and expressed as the total amount of damage from one pass of that one vehicle. This is referred to as a *vehicle ESAL factor*, which is the average number of ESAL applications per vehicle. A truck ESAL factor may be computed for each truck classification or as an average for all trucks in a given traffic stream. VDOT’s current pavement design procedure subdivides traffic into three categories: passenger vehicles, single-unit trucks, and combination trucks. Vehicle ESAL factors for rigid and flexible pavement currently used by VDOT are shown in Table 1.

Table 1 is useful in characterizing a traffic stream if only the percentage of the various vehicle types is known. However, it is possible to subdivide the total traffic stream into 13 vehicle classes as specified by the Federal Highway Administration (FHWA) (2001) and to assign a vehicle ESAL factor for each classification. This further subdivision offers a more accurate representation of the effects of the total traffic stream. However, this type of information is not often used in VDOT pavement designs even if the traffic distribution data are available since no vehicle ESAL factors have been developed for this larger set of vehicle classifications.

The 13 FHWA vehicle classifications are as follows:

1. motorcycles
2. passenger cars
3. other 2 axle 4 tire single units
4. buses
5. 2 axle 6 tire single units
6. 3 axle single units
7. 4 or more axle single units
8. 4 or less axle single trailers
9. 5 axle single trailers
10. 6 or more axle single trailers
11. 5 or less axle multi-trailers
12. 6 axle multi-trailers
13. 7 or more axle multi-trailers.

These classifications are shown in Figure 1.

Table 1. VDOT Current Vehicle ESAL Factors Used in Pavement Design

Pavement Type	Passenger Vehicles	Single-Unit Trucks	Combination Trucks
Rigid pavement	0.0003	0.56	1.92
Flexible pavement	0.0002	0.37	1.28

The source of the values is VDOT (2008).

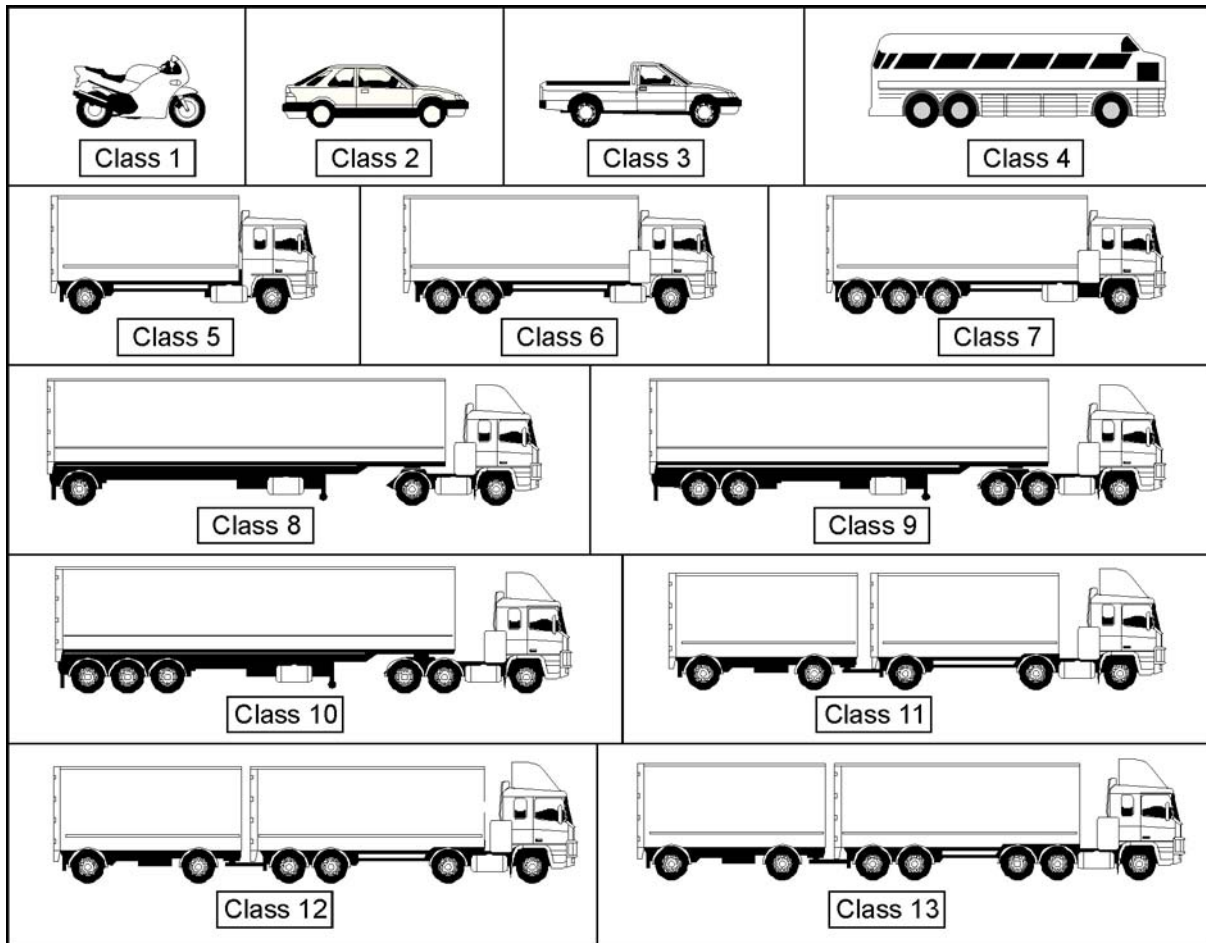


Figure 1. The 13 FHWA Vehicle Classes Used for Collecting Traffic Data (after FHWA, 2001). Class 1 = motorcycles; Class 2 = passenger cars; Class 3 = other 2 axle 4 tire single units; Class 4 = buses; Class 5 = 2 axle 6 tire single units; Class 6 = 3 axle single units; Class 7 = 4 or more axle single units; Class 8 = 4 or less axle single trailers; Class 9 = 5 axle single trailers; Class 10 = 6 or more axle single trailers; Class 11 = 5 or less axle multi-trailers; Class 12 = 6 axle multi-trailers; Class 13 = 7 or more axle multi-trailers.

Although it is anticipated that VDOT will ultimately adopt the *Guide for the Mechanistic-Empirical Design of New & Rehabilitated Pavement Structures* (MEPDG) (ARA, Inc., 2004) and its use of load spectra, there will likely still be a need to determine the cumulative ESALs for pavement designs for the near future. It is also expected that an initial step in the implementation of the MEPDG in Virginia will be to develop trial designs using the 1993 AASHTO empirical-based procedure and then analyze the pavement designs within the MEPDG software. Therefore, the ESAL concept will still remain valid in VDOT's pavement designs for the foreseeable future.

The last update of truck ESAL factors for pavement design in Virginia was more than 17 years ago (McGhee, 1991). It is expected that the typical truck operating weights have changed since this time with changes in manufacturing and trends in current trucking practices. Only within the past few years have weigh-in-motion (WIM) data been available on a more widespread basis that can be used for this purpose (Cottrell et al., 2002). VDOT's WIM program was developed to collect traffic data for input into the MEPDG design procedure, but these

traffic data are also useful for evaluating the inputs into the current 1993 AASHTO pavement design procedure. WIM provides a larger sampling of vehicles because it allows for a greater time period of data collection. Further, it is cost-effective for use at more locations than are provided by static weigh stations. Having a larger vehicle sample provides a better representation of the vehicles in the state.

PURPOSE AND SCOPE

The purpose of this study was to update VDOT's truck ESAL factors for pavement design using Virginia WIM data. These updated truck factors can be used with the 1993 AASHTO design guide procedure. Axle load data, collected from in-lane WIM sensors, were converted to truck ESAL factors for each FHWA truck classification and VDOT truck type.

This study was based on data collected from WIM sensors at all 15 sites around Virginia, which are located on interstate and primary routes. The amount of data available from each site ranged from 10 to 42 months' worth of data, but the most recent 12-month period (June 2007 through May 2008) for which most sites had available data was selected for this analysis.

METHODS

Four tasks were conducted to fulfill the purpose of the study:

1. Conduct a literature review to document the experiences of other state and provincial departments of transportation in developing truck ESAL factors from WIM data.
2. Develop a method to calculate the truck ESAL factor from data from the various WIM sites
3. Apply the method to develop new truck ESAL factors for each WIM site and compare the developed site-specific truck ESAL factors on interstate and primary highway segments.
4. Determine change in truck ESAL factors over time.

Literature Review

The literature review was conducted by searching various databases such as the Transportation Research Information Services (TRIS) bibliographic database, the Catalog of Transportation Libraries (TLCat), the Catalog of Worldwide Libraries (WorldCat), and the Transportation Research Board's Research in Progress (RiP) and Research Needs Statements (RNS) databases.

Development of Method to Calculate Truck ESAL Factors from WIM Data at Various Sites in Virginia

Data Used

The data used for this study came from all WIM stations around Virginia. The WIM data were provided by VDOT’s Traffic Engineering Division. The location of the 15 WIM sites considered in this study is shown in Table 2: eight of the sites are on interstates, and seven of the sites are on primary highways. In general, each direction on an interstate route is considered a single site whereas opposing directions on a primary route are considered to be one site.

The WIM data for each truck include a site identification number, vehicle identification number, lane of travel, date and time, FHWA vehicle classification number, vehicle speed, gross vehicle weight, number of axles, weight of each axle, and distance between the axles.

The WIM stations are calibrated yearly to ensure they comply with the requirements of ASTM E 1318-02 (2002) for a Type I WIM system (95% of axle loads within 20% of actual axle weight). Calibration is performed by running a vehicle with a known weight over the WIM sensor 20 times and measuring the percent error of the gross vehicle weight. The accuracy of the individual WIM records is also evaluated in data processing, and any records that are marked as “low quality” are removed; a low-quality record is typically attributable to the sensor not reading all of the wheel loads. If the accuracy of any datasets was questionable, the data were not used until the site’s calibration was checked. The WIM stations are maintained by VDOT’s Traffic Engineering Division and the Department of Motor Vehicles.

The data considered for this study consisted of data for a continuous 1-week period, Sunday through Saturday, to represent each month. Dates were selected to ensure that no state or national holidays were included. Using 1 week of data to represent an entire month has been shown to provide accurate data for pavement design (Hong et al., 2008). The most recent 12 months of data, i.e., from June 2007 through May 2008, were used to develop a new truck ESAL factor.

Table 2. Virginia Weigh-in-Motion Sites

Route	Direction (Lanes)	Location
I-66	West (2)	Fauquier County
I-81	North (1)	Stephens City
I-81	South (1)	Stephens City
I-81	North (1)	Troutville
I-81	South (1)	Troutville
I-95	North (1)	Dumfries
I-95	South (1)	Dumfries
I-95	North (2)	Sussex County
SR 164	East (2), West (2)	Portsmouth
SR 234	North (2), South (2)	Prince William County
SR 288	North (2), South (2)	Midlothian
US 17	North (2), South (2)	Fauquier County
US 29	South (2)	Danville
US 58	East (2), West (2)	Lee County
US 60	East (1), West (1)	Cumberland County

Calculation of Truck ESAL Factors for Flexible Pavement

The first steps in calculating truck ESAL factors were to convert the WIM data to LEFs and then to ESALs per vehicle. For flexible pavements, the LEF is based on the axle weights of the axle group and the SN and terminal serviceability of the pavement. The equations used to calculate the LEF for each axle were taken from Huang (2004) and are shown as Equations 1 through 3; these equations are based on the formulas in the 1993 AASHTO design guide.

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79 \log(18+1) - 4.79 \log(L_x + L_2) + 4.33 \log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \quad (\text{Eq. 1})$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \quad (\text{Eq. 2})$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(\text{SN} + 1)^{5.19} L_2^{3.23}} \quad (\text{Eq. 3})$$

where

W_{tx} = number of applications of given axle

W_{t18} = number of standard axle passes (single 18 kip axle)

L_x = load in kips of axle group

L_2 = axle code (1 for single axle, 2 for tandem axles, 3 for tridem axles, and 4 for quad axles)

β_{18} = value of β_x when $L_x = 18$ and $L_2 = 1$

p_t = terminal serviceability

SN = structural number.

The axle spacing used to determine the axle group type, as defined by AASHTO (2001), is given as follows:

- A *single axle* is defined as an axle located at a distance greater than 8 feet or at a distance less than 3.33 feet from an adjacent axle.
- A *tandem axle* is defined as two adjacent axles with a spacing of 3.33 to 8 ft.
- A *tridem axle* is defined as three axles with a spacing of less than 12 ft from the first to the third axle.
- A *quad axle* is defined as four axles with a spacing of less than 16 ft from the first to the fourth axle.

Equation 1 is used to solve for (W_{t18}/W_{tx}) , which is the LEF for one axle group. The sum of LEF for each of the axle groups on a specific vehicle gives an ESAL for that vehicle. Equations 2 and 3 use the terminal serviceability (p_t) and SN of the pavement for input into Equation 1 to determine the LEF. Although it is important to use accurate inputs with the equation, the terminal serviceability and SN have a relatively small effect on the calculated LEF compared to the axle group weight or type. For this study, values of p_t and SN were chosen by a panel of VDOT pavement engineers to represent the typical conditions for Virginia highways. These values are shown in Table 3.

A MATLAB program was developed to calculate the ESALs per vehicle using Equations 1 through 3 for each truck from the collected WIM data and to summarize the large number of records to determine a truck ESAL factor for design. This program is documented in the Appendix. The MATLAB program provided a computationally efficient way to analyze the large datasets and to modify the SN or p_t values.

The developed MATLAB program uses a site identification number, date range, SN, and p_t as specified by the user and imports the raw WIM data to produce a Microsoft Excel worksheet containing the vehicle count, average truck ESAL factor, truck ESAL factor variance, and average number of axles for each vehicle class with respect to lane for each month. The vehicle classifications used were FHWA Classes 4 through 13 and the two designations used by VDOT: single-unit (FHWA Classes 4-7) and combination (FHWA Classes 8-13) vehicles.

Although the ESALs per vehicle were determined based on the equations given by Huang (2004), one notable difference is the use of axle code 4. Huang lists only axle codes of 1, 2, and 3 for single, tandem, and tridem axle groups, but quad axles were included in this study. Although this is an extrapolation of the ESAL formula, less than 1% of all vehicles captured in the WIM data had a quad axle; therefore, the researchers did not consider this extrapolation to have a negative affect on the overall results.

Table 3. Terminal Serviceability (p_t) and Structural Number (SN) for Calculating Load Equivalency Factor for Flexible Pavement

Value	Interstate	Primary
p_t	3.0	2.85
SN	6	4.75

Calculation of Truck ESAL Factors for Rigid Pavement

Rigid pavements react differently to traffic loading, and therefore truck ESAL factors for these pavements are not the same as those for flexible pavements. To determine truck ESAL factors for rigid pavements, the same WIM data were used with ESAL equations specifically for rigid pavements. These equations are given in the 1993 AASHTO design guide. The versions of these equations presented by Huang (2004) used for this study are shown in Equations 4 through 6. An assumed slab thickness of 12 in was used for LEF calculations for rigid pavement; the same terminal serviceability values as those from calculations for flexible pavement of 3.0 for interstate and 2.85 for primary highways were used. The truck ESAL factors for rigid pavement were calculated using the same MATLAB program used for those for flexible pavement shown in the Appendix for the same FHWA and VDOT vehicle classifications.

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.62 \log(18 + 1) - 4.62 \log(L_x + L_2) + 3.28 \log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \quad (\text{Eq. 4})$$

$$G_t = \log\left(\frac{4.5 - p_t}{4.5 - 1.5}\right) \quad (\text{Eq. 5})$$

$$\beta_x = 1.00 + \frac{3.63(L_x + L_2)^{5.20}}{(D + 1)^{8.46} L_2^{3.52}} \quad (\text{Eq. 6})$$

where

W_{tx} = number of applications of given axle

W_{t18} = number of standard axle passes (single 18 kip axle)

L_x = load in kips of axle group

L_2 = axle code (1 for single axle, 2 for tandem axles, 3 for tridem axles, and 4 for quad axles)

β_{18} = value of β_x when $L_x = 18$ and $L_2 = 1$

p_t = terminal serviceability

D = slab thickness in inches.

Calculation and Comparison of Site-Specific Truck ESAL Factors

Site-Specific Truck ESAL Factors for Flexible Pavement

The MATLAB results were averaged to develop site-specific truck ESAL factors for each WIM site for each vehicle classification. These average truck ESAL factors from each WIM site were weighted based on their respective vehicle counts. A sensitivity analysis of the truck ESAL factors was then performed by inputting the different sets of truck ESAL factors for flexible pavement into DARWin 2.01, the pavement design and analysis software program used by VDOT, and comparing the required SN to determine if any practical differences existed between the various truck ESAL factors. The traffic volume from two test sections was used to represent actual interstate and primary locations with high truck traffic. Sections having high truck traffic were used so that the resulting SNs would show maximum variation. The first comparison was between VDOT's single-unit/combination truck classifications and the FHWA classification. Next, site-specific truck ESAL factors were compared to the statewide average values.

Site-Specific Truck ESAL Factors for Rigid Pavement

A similar procedure was followed to analyze the truck ESAL factors for rigid pavement from the MATLAB results. Site-specific factors were developed for each site and input into a spreadsheet based on AASHTO's *Supplement to the AASHTO Guide for Design of Pavement Structures: Part II, Rigid Pavement Design and Rigid Pavement Joint Design* (AASHTO 1998 supplement for rigid pavement design) for a sensitivity analysis of the recommended depth of concrete (AASHTO, 1998). The same test sections used for the flexible pavement analysis were

used for the rigid pavement analysis. Again, comparisons were made between the VDOT and FHWA classifications and site-specific truck ESAL factors.

Determination of Change in Truck ESAL Factors Over Time

Because pavement designs are typically for 20 to 30 years, a change in expected truck ESAL factors over that time would be an important consideration when using the AASHTO pavement design methodology. To evaluate any time dependence of truck ESAL factors, the two sites with the greatest number of months of data available were considered. These sites were I-81 South at Stephens City and I-95 North at Dumfries; each had approximately 3.5 years of data available. This is still a relatively short time period to use for considering the changes in average truck ESAL factors over time; ideally, a period of more than 10 years would be considered. The time dependence was evaluated by a linear regression analysis that described the variation in average truck ESAL factors versus the month for both single-unit and combination trucks.

RESULTS AND DISCUSSION

Literature Review

Many states have performed studies to develop truck ESAL factors for pavement design that provide a good representation of the actual traffic loading. The increase in the amount of WIM data collected and accuracy of the data has prompted many state agencies to investigate updating truck ESAL factors. One of the first of these studies was performed by Desai (1988). This study showed a need to reevaluate truck ESAL factors continually because vehicle characteristics such as loading and axle configurations change over time.

In a study of traffic load forecasting, Aunet (1989) found that truck ESAL factors were increasing over time, supporting the need to reevaluate design values. Although this study used WIM data to evaluate traffic loading, there were concerns about the accuracy and limited amount of WIM data available; the study supported increasing the data collection period and the number of WIM sites.

In a study of traffic load forecasting, Vlatas and Dresser (1991) found that truck ESAL factors can vary significantly between sites, even along the same highway or in opposing directions.

In a study of traffic loading using WIM to evaluate truck weights, Lee and Souny-Slitine (1998) found that truck ESAL factors did not change significantly over the 3-year period of data collection and that the two WIM sites considered had similar axle weight distributions.

A study of WIM by Alavi and Senn (1999) determined ESAL design values. The researchers developed tables that used the truck ESAL factors based on traffic weight data from the nearest WIM station. This study used the FHWA vehicle classifications with an average

truck factor for each truck classification for each site; the study also recommended a statewide truck factor for all vehicles of 1.2, a decrease from the previous value of 1.4. This study found that site-specific truck ESAL factors may have either increased or decreased over time but that the overall factors were relatively constant over the data collection period. The study also recommended increasing the duration of the WIM data collection period and number of WIM sites.

A similar study by Alavi et al. (2002) was based on Colorado WIM data. In this study, the researchers developed site-specific ESAL design values. The study used a weighted average of the ESALs per vehicle to account for a large range in traffic volume for some vehicle classifications. A potential grouping of highway segments was investigated based on functional classification, truck volume, regions of the Colorado Department of Transportation, specific roads, and geographic region; in the end, roads were grouped solely by functional classification. The study suggested that the cumulative ESAL values for designs should be based on truck ESAL factors from site-specific WIM data when available or else average truck ESAL factors for each highway functional classification.

Calculation of Truck ESAL Factors

Truck ESAL Factors for Flexible Pavement

As discussed in the “Methods” section, a MATLAB program was developed to calculate truck ESAL factors from a dataset ranging from June 2007 to May 2008 for 15 WIM sites around Virginia (see the Appendix). Table 4 shows the average truck ESAL factors and the number of vehicles observed within each vehicle class by administrative roadway classification.

Table 4. Average Truck ESAL Factors for Flexible Pavement by Vehicle Classification and Administrative Roadway Classification

Vehicle Classification	Interstate		Primary	
	No. of Vehicles	Average Truck ESAL Factor	No. of Vehicles	Average Truck ESAL Factor
<i>FHWA Classes</i>				
4	83,584	0.44	42,445	0.35
5	91,173	0.28	87,006	0.36
6	69,069	0.42	102,112	0.60
7	5,043	1.00	27,921	1.09
8	71,606	0.47	36,751	0.50
9	2,307,904	1.06	467,982	1.01
10	20,160	1.07	16,307	1.06
11	114,922	1.52	13,574	1.19
12	44,496	0.83	2,933	0.70
13	227	1.59	39	2.23
<i>VDOT Classifications</i>				
Single-unit trucks (FHWA Classes 4-7)	248,869	0.39	259,484	0.53
Combination trucks (FHWA Classes 8-13)	2,559,315	1.06	537,587	0.98

FHWA Classes: Class 4 = buses; Class 5 = 2 axle 6 tire single units; Class 6 = 3 axle single units; Class 7 = 4 or more axle single units; Class 8 = 4 or less axle single trailers; Class 9 = 5 axle single trailers; Class 10 = 6 or more axle single trailers; Class 11 = 5 or less axle multi-trailers; Class 12 = 6 axle multi-trailers; Class 13 = 7 or more axle multi-trailers.

FHWA Class 9 was the most commonly observed vehicle class by far, representing approximately 82% of the trucks at the interstate sites and approximately 59% of the trucks on the primary sites.

Table 4 also shows some variation in truck ESAL factors for different roadway classifications. When WIM data from interstate and primary sites were compared, there was a 22% difference between the truck ESAL factors for FHWA Class 5 and a 30% difference for FHWA Class 6, leading to a 26% higher single-unit truck ESAL factors for primary sites than interstate sites. FHWA Class 11 had the largest difference in truck ESAL factors between interstate and primary sites among the combination trucks, but because the combination trucks are dominated by FHWA Class 9, the ESAL factors for all combination trucks were similar, within 5%, for interstate and primary sites.

The site-specific truck ESAL factors were split into the two VDOT classification groups of single-unit trucks and combination trucks. These truck ESAL factors are shown in Figures 2 and 3 for the interstate and primary sites, respectively. The values for the interstate sites ranged from 0.35 to 0.42 for single-unit trucks and 0.88 to 1.22 for combination trucks. The truck ESAL factors for primary sites ranged from 0.36 to 0.82 for single-unit trucks and 0.61 to 1.11 for combination trucks. The interstate site with the lowest truck ESAL factor was the I-66 West site, which was the only interstate site that was not northbound or southbound; whether this comprises a statewide trend for truck ESAL factors for east and west directions or whether this comprises a site-specific observation is unclear. Further, the truck ESAL factor for combination trucks was higher for northbound road segments than for the corresponding southbound site in all six cases; the truck ESAL factor for combination trucks was higher for the eastbound direction than for the westbound direction for the three primary sites with both directions.

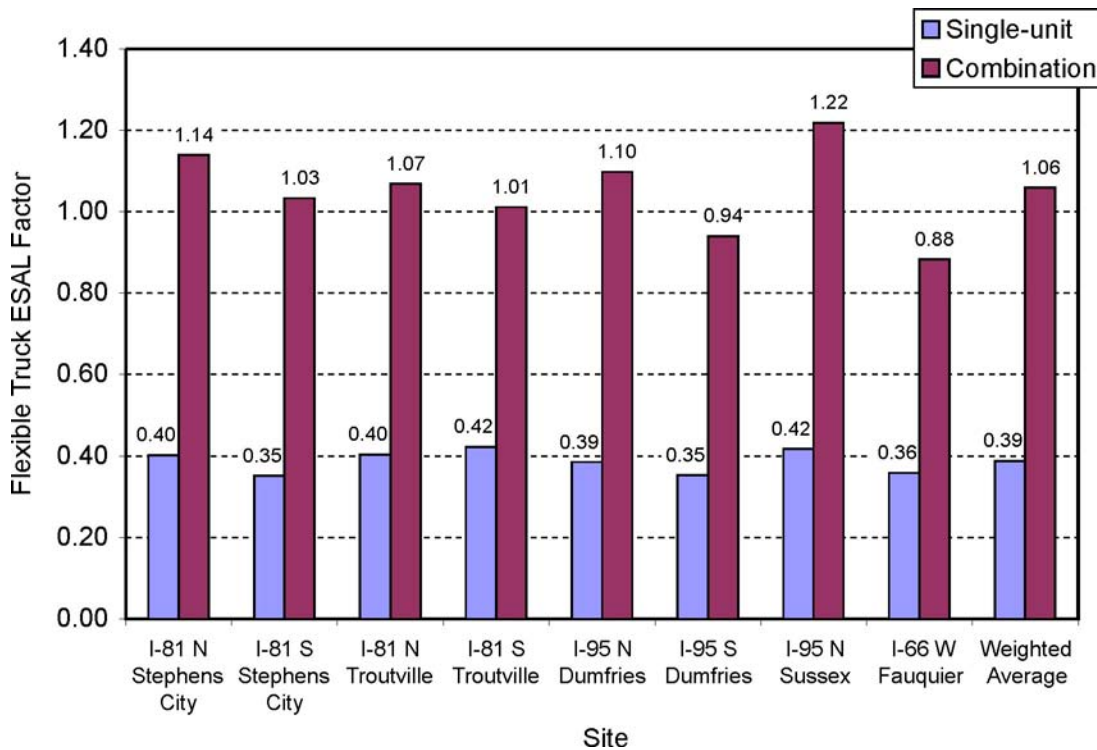


Figure 2. Truck ESAL Factors for Flexible Pavement for Interstate Sites

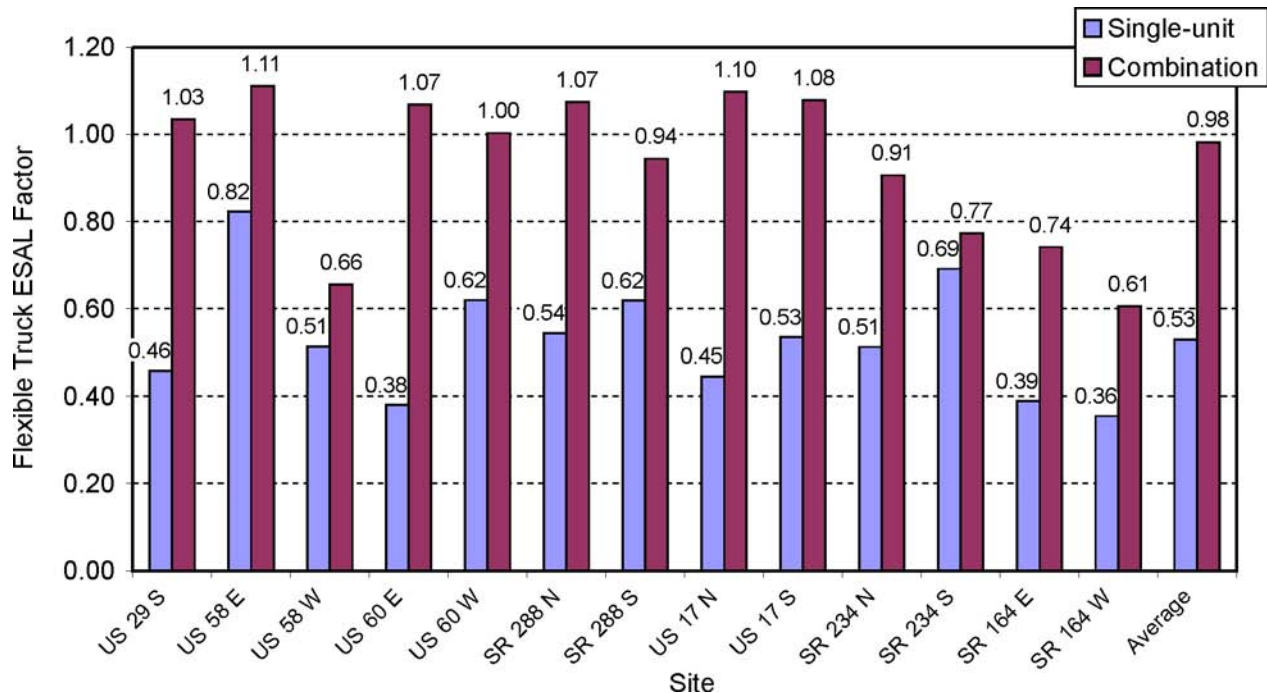


Figure 3. Truck ESAL Factors for Flexible Pavement for Primary Sites Split by Direction

Truck ESAL Factors for Rigid Pavement

Table 5 shows the average truck ESAL factors and the number of vehicles observed within each vehicle class by administrative roadway classification. Because the same vehicles were considered for the flexible pavement analysis and the rigid pavement analysis, the

Table 5. Average Truck ESAL Factors for Rigid Pavement by Vehicle Classification and Administrative Roadway Classification

Vehicle Classification	Interstate		Primary	
	No. of Vehicles	Average Truck ESAL Factor	No. of Vehicles	Average Truck ESAL Factor
<i>FHWA Classes</i>				
4	83,584	0.48	42,445	0.34
5	91,173	0.28	87,006	0.35
6	69,069	0.55	102,112	0.83
7	5,043	1.75	27,921	2.02
8	71,606	0.50	36,751	0.51
9	2,307,904	1.67	467,982	1.53
10	20,160	2.16	16,307	2.03
11	114,922	1.48	13,574	1.08
12	44,496	0.87	2,933	0.67
13	227	2.83	39	4.16
<i>VDOT Classifications</i>				
Single-unit trucks (FHWA Classes 4-7)	248,869	0.45	259,484	0.72
Combination trucks (FHWA Classes 8-13)	2,559,315	1.62	537,587	1.46

FHWA Classes: Class 4 = buses; Class 5 = 2 axle 6 tire single units; Class 6 = 3 axle single units; Class 7 = 4 or more axle single units; Class 8 = 4 or less axle single trailers; Class 9 = 5 axle single trailers; Class 10 = 6 or more axle single trailers; Class 11 = 5 or less axle multi-trailers; Class 12 = 6 axle multi-trailers; Class 13 = 7 or more axle multi-trailers.

differences among classes were similar. As expected, truck ESAL factors were higher for rigid pavement than for flexible pavement.

The site-specific truck ESAL factors for rigid pavement are shown in Figures 4 and 5 for interstate and primary highways, respectively. Because the same vehicles were considered for

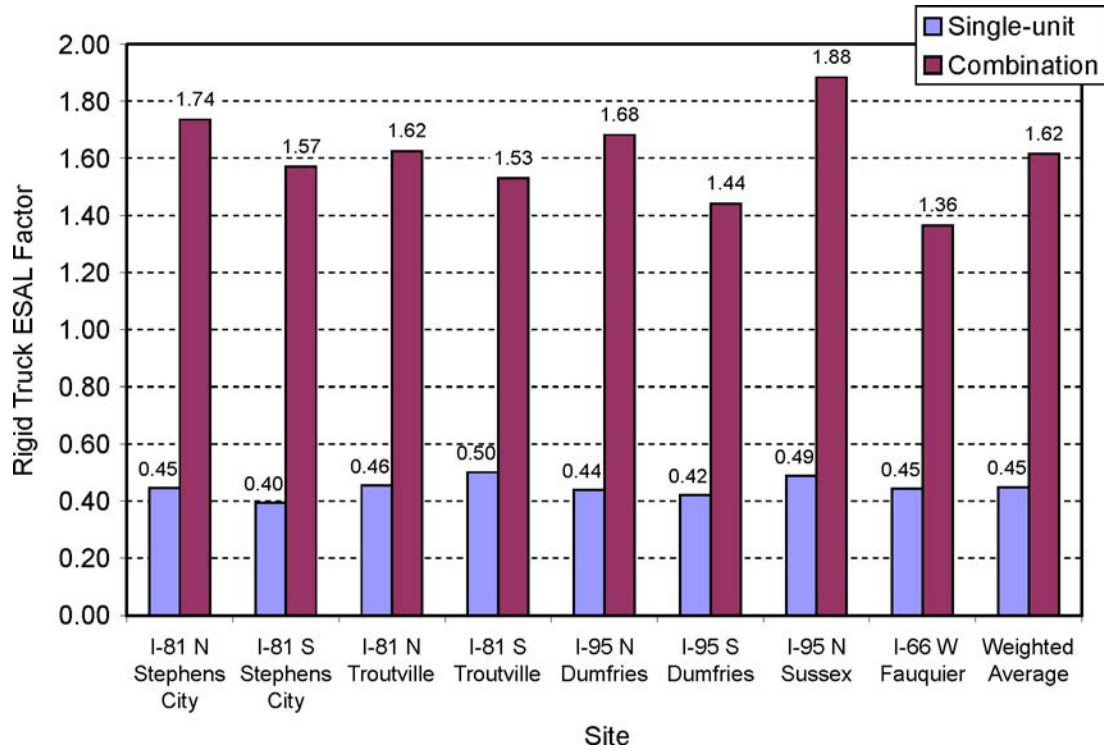


Figure 4. Rigid Pavement Truck ESAL Factors for Interstate Sites

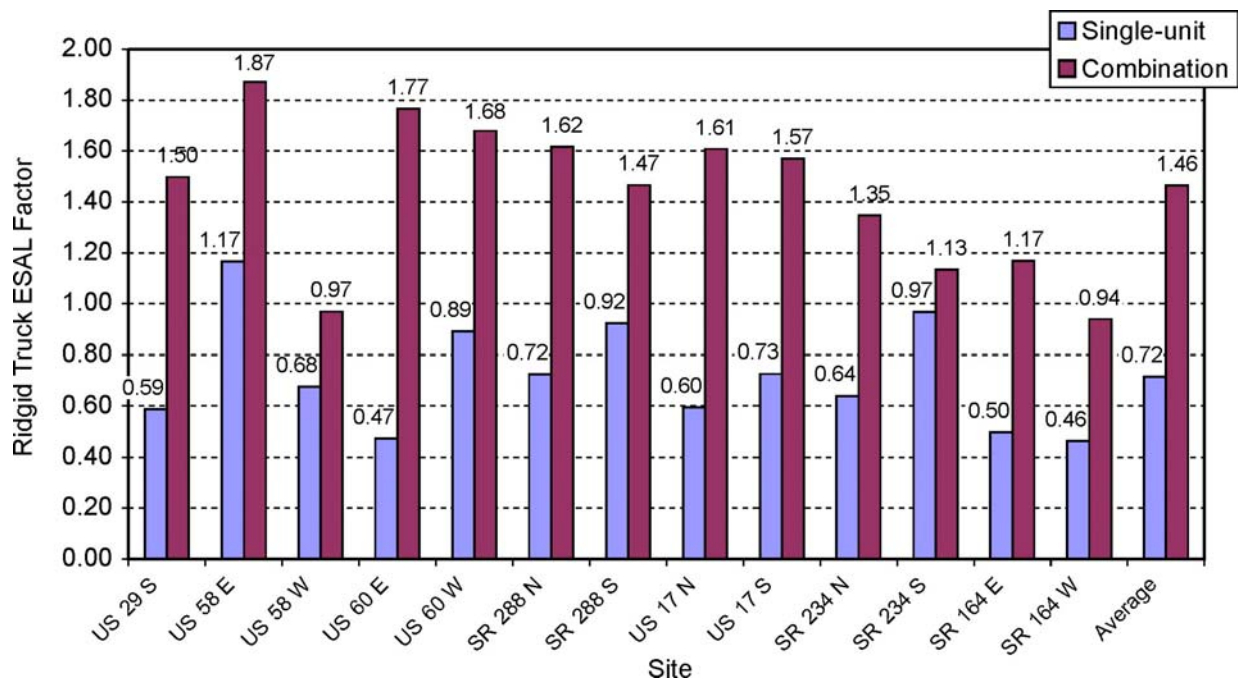


Figure 5. Rigid Pavement Truck ESAL Factors for Primary Sites Split by Direction

Site Comparison for Truck ESAL Factors

Site-Specific Truck ESAL for Flexible Pavement

To compare the effect of the different truck ESAL factor inputs on the pavement design SN for flexible pavements, two test sections were analyzed using the calculated truck ESAL factors in DARWin. The interstate route segment chosen was I-81 North in Augusta County, which had a two-way annual average daily traffic (AADT) of 59,000. The primary route segment chosen was US 17 in Stafford County, which had a two-way AADT of 43,000. These two sites were chosen as they represented an interstate and a primary location with some of the highest daily truck volumes in Virginia. The breakdown of the traffic data for both sites is shown in Table 6. These values were taken from VDOT’s traffic volume data for 2007 (VDOT, 2007). The other inputs for DARWin were based on VDOT pavement design guidelines for an interstate and undivided urban primary route (VDOT, 2008). These inputs are shown for the interstate and primary sections in Table 7.

Table 6. Two-Way AADT Volume Estimates (% Total) for Interstate and Primary Test Sections^a

Vehicle-Type Description	Interstate Site with 59,000 2-Way AADT	Primary Site with 43,000 2-Way AADT
4-Tire	67%	81%
Bus	1%	1%
2 Axle Truck	1%	1%
3+ Axle Truck	1%	1%
1 Trailer Truck	28%	15%
2 Trailer Truck	2%	1%

^aTo compare the effect of the different truck ESAL factor inputs on the pavement design SN, two test sections were analyzed using the calculated truck ESAL factors in DARWin. The interstate route segment chosen was I-81 North in Augusta County, which had a two-way AADT of 59,000. The primary route segment chosen was US 17 in Stafford County, which had a two-way AADT of 43,000. The data in this table came from VDOT (2007).

Table 7. DARWin Pavement Design Inputs for Flexible Pavement Test Sections^a

Input	Interstate	Primary
Initial serviceability	4.2	4.2
Terminal serviceability	3	2.9
Reliability level (%)	95	90
Overall standard deviation	0.49	0.49
Roadbed soil resilient modulus (psi)	6,000	6,000
Stage construction	1	1
Performance period	30	30
No. of lanes in design direction	2	2
Two-way AADT	59,000	43,000
Percent of all trucks in design lane	90	90
Percent of trucks in design direction	50	50
Traffic volume growth	3%, Compound	3%, Compound

^aTo compare the effect of the different truck ESAL factor inputs on the pavement design SN, two test sections were analyzed using the calculated truck ESAL factors in DARWin. The interstate route segment chosen was I-81 North in Augusta County; the primary route segment chosen was US 17 in Stafford County. The data in this table are based on VDOT pavement design guidelines for an interstate and undivided urban primary route (VDOT, 2008).

The comparison of SNs began by classifying the traffic distribution in two ways. The first method was to consider the traffic distribution in terms of passenger cars, single-unit trucks, and combination trucks. The single-unit truck category is composed of the sum of the bus, 2 axle truck, and 3+ axle truck percentages. The percentage of single-unit trucks was approximately 3% for both the interstate and primary sites. The combination truck category is composed of the sum of the 1 and 2 trailer truck percentages. The percentage of combination trucks was approximately 30% and 16% for the interstate and primary sites, respectively.

The second method of subdividing the traffic volume was performed in terms of the 13 FHWA vehicle classes. Because some of the truck traffic groups given by VDOT (2007) included multiple FHWA vehicle classes (e.g., the 1 trailer description includes Class 9 and Class 10 trucks), actual distributions by FHWA class from nearby WIM sites were used to obtain more accurate truck distributions. The FHWA class distribution from the four I-81 WIM sites was averaged for the interstate section, and the data from both directions of US 17 was used for the primary section. The average daily truck traffic (ADTT) for each vehicle class was determined by dividing the total count for each vehicle class by the number of months of data and dividing by 7, the number of days of data collection each month. The resulting FHWA vehicle classification group distributions that were input into DARWin are shown in Table 8.

The traffic distributions for each grouping system were combined with the truck ESAL factors shown in Table 4 and the DARWin inputs shown in Tables 6 and 7 to calculate the required SN for each test section. These results were compared to the SN calculated when using VDOT default ESAL factors, which are the current VDOT-recommended truck ESAL factors shown in Table 1. Table 9 shows the resulting SN from these comparisons. Because the layer coefficient for a surface mix is typically 0.44, a change in SN of at least 0.2 would be needed to require a change in the pavement thickness design by 0.5 in. This table shows that the updated (non-site specific) truck ESAL factors correspond to an approximately 0.5 in decrease in the calculated pavement thickness. As expected, both methods used to classify truck distributions provided similar SNs.

Table 8. FHWA Vehicle Classification Traffic Distribution for Interstate and Primary Test Sections for Flexible and Rigid Pavement Analysis

FHWA Vehicle Class	Interstate	Primary
1-3	67%	81%
4	1%	1%
5	1%	1%
6	0.96%	0.65%
7	0.04%	0.35%
8	0.72%	0.75%
9	27.11%	13.82%
10	0.17%	0.43%
11	1.43%	0.80%
12	0.56%	0.20%
13	0.00%	0.00%

Class 1 = motorcycles; Class 2 = passenger cars; Class 3 = other 2 axle 4 tire single units; Class 4 = buses; Class 5 = 2 axle 6 tire single units; Class 6 = 3 axle single units; Class 7 = 4 or more axle single units; Class 8 = 4 or less axle single trailers; Class 9 = 5 axle single trailers; Class 10 = 6 or more axle single trailers; Class 11 = 5 or less axle multi-trailers; Class 12 = 6 axle multi-trailers; Class 13 = 7 or more axle multi-trailers.

Table 9. Structural Numbers from DARWin for Comparison of Different Classification Systems

Truck Classification System	Interstate	Primary
VDOT default	9.19	7.62
VDOT single-unit/combination	9.00	7.41
FHWA classification	9.00	7.42

VDOT default = current VDOT-recommended truck ESAL factors (VDOT, 2008).

Next, site-specific truck ESAL factors were compared with the average truck ESAL factor and VDOT default ESAL factors. In each case, the same traffic loading and pavement design inputs shown in Tables 6 and 7 were used with varying truck ESAL factors based on different values calculated for each site. Tables 10 and 11 show the different vehicle ESAL factor inputs used and the resulting design SN for the interstate and primary test sections, respectively. For this comparison, seven trials were processed using DARWin. Trial 1 used the default VDOT truck ESAL factors. Trial 2 used the closest site-specific WIM data, and Trial 3 used data from the opposing direction to that site. Trial 4 used data from the site with the highest truck ESAL factors for each road type, and Trial 5 used data from the site with the lowest truck ESAL factors. Trial 6 gives the average of all the sites for that functional classification, and Trial 7 uses the weighted average of all 15 WIM sites (encompassing both interstate and primary

Table 10. DARWin Comparison of Site-Specific Truck ESAL Factors for Interstate Flexible Pavement Test Section

Trial No.	Description/Location	ESAL Factor			Design ESALs	SN
		Passenger	Single-Unit	Combination		
1	VDOT default	0.0002	0.37	1.28	182,000,000	9.19
2	I-81 N Stephens City	0.0002	0.40	1.14	163,000,000	9.07
3	I-81 S Stephens City	0.0002	0.35	1.03	147,000,000	8.96
4	I-95 N Sussex	0.0002	0.42	1.22	175,000,000	9.15
5	I-66 W Fauquier	0.0002	0.36	0.88	127,000,000	8.80
6	Interstate average	0.0002	0.39	1.06	152,000,000	9.00
7	Overall average	0.0002	0.46	1.05	152,000,000	8.99

Trial 1 used the VDOT default truck ESAL factors (i.e., the current VDOT-recommended truck ESAL factors). Trial 2 used the closest site-specific WIM data, and Trial 3 used data from the opposing direction to that site. Trial 4 used data from the site with the highest truck ESAL factors for each road type, and Trial 5 used data from the site with the lowest truck ESAL factors. Trial 6 gives the average of all the sites for that functional classification, and Trial 7 uses the weighted average of all 15 WIM sites (encompassing both interstate and primary sites).

Table 11. DARWin Comparison of Site-Specific Truck ESAL Factors for Primary Flexible Pavement Test Section

Trial No.	Description/Location	ESAL Factor			Design ESALs	SN
		Passenger	Single-Unit	Combination		
1	VDOT default	0.0002	0.37	1.28	73,000,000	7.62
2	US 17 S Fauquier	0.0002	0.53	1.08	64,000,000	7.50
3	US 17 N Fauquier	0.0002	0.45	1.10	64,000,000	7.50
4	US 58 E Lee County	0.0002	0.82	1.11	68,000,000	7.56
5	SR 164 W Portsmouth	0.0002	0.36	0.61	37,000,000	6.99
6	Primary average	0.0002	0.53	0.98	58,000,000	7.41
7	Overall average	0.0002	0.46	1.05	61,000,000	7.46

Trial 1 used the VDOT default truck ESAL factors (i.e., current VDOT-recommended truck ESAL factors). Trial 2 used the closest site-specific WIM data, and Trial 3 used data from the opposing direction to that site. Trial 4 used data from the site with the highest truck ESAL factors for each road type, and Trial 5 used data from the site with the lowest truck ESAL factors. Trial 6 gives the average of all the sites for that functional classification, and Trial 7 uses the weighted average of all 15 WIM sites (encompassing both interstate and primary sites).

sites). The passenger ESAL factor was not changed as it was not considered as a part of this study; the value is so much smaller than truck ESAL factors that it is usually insignificant in calculating design ESALs.

Tables 10 and 11 show a small change in the design SN between the site-specific data and the default VDOT truck ESAL factors. Again, a difference of SN of around 0.2 correlates to about a 0.5-in difference in pavement thickness; anything less is not practically significant because of construction tolerances. For both the interstate and primary route analysis, using site-specific truck ESAL factors resulted in SNs that were within 0.2 of the SNs calculated using statewide average truck ESAL factors. Only the sites with low truck ESAL factors (Trial 5) yielded an SN having a difference of 0.2 or greater than the SN calculated from the site-specific or average value truck ESAL factors. The small SN change obtained when calculated using average truck ESAL factors and site-specific values indicated that the average truck ESAL factors over all sites was suitable for most situations. If site-specific data are available, they could be used to improve accuracy, but the resulting pavement design will be nearly equal.

For the interstate test section, the SN from the interstate average truck ESAL factors (Trial 6) was 9.00 and for the overall average (Trial 7) was 8.99. For the primary test section, the SN from the primary average truck ESAL factors was 7.41 and the overall average was 7.46. In both cases, these values are considered similar with a difference in SN of 0.05 at most. Therefore, a separate set of truck ESAL factors for each highway classification does not appear necessary.

Truck ESAL Factor for Rigid Pavement

A spreadsheet based on the AASHTO 1998 supplement for rigid pavement design was used to compare site-specific truck ESAL factors the rigid pavement (AASHTO, 1998). This spreadsheet provides an update to the DARWin pavement design program for rigid pavements. The same traffic volume and distributions for flexible pavement comparisons were used for rigid pavements; these inputs are shown in Tables 6 and 8, respectively. The other necessary inputs for pavement design were taken from VDOT guidelines (VDOT, 2008) for a new jointed reinforced concrete pavement with tied portland cement concrete shoulders; these inputs are shown in Table 12.

The spreadsheet based on the AASHTO 1998 supplement for rigid pavement design (AASHTO, 1998) calculated the required slab thickness in inches. The design thickness determined with the truck ESAL factors for the VDOT and FHWA classification systems were compared to the default VDOT truck ESAL factors (see Table 1). These values are shown in Table 13.

For rigid pavements, a difference in design thickness of 0.5 in was considered practically significant meaning that the difference between the slab thicknesses would be within construction tolerance limits. Table 13 shows that the rigid pavement design thickness for interstate pavements using the VDOT default truck ESAL factors was within 0.5 in as compared to the rigid pavement design thickness using the updated truck ESAL factor values. There was a difference in the design thickness of 0.48 in for the primary test section. Again, the two vehicle

Table 12. Pavement Design Inputs for Interstate and Primary Rigid Pavement Test Sections

Input	Interstate	Primary
Pavement type	JRCP	JRCP
Effective joint spacing (in)	72	72
Edge support factor	0.94	0.94
Initial serviceability	4.5	4.5
Terminal serviceability	3	2.9
28-day mean modulus of rupture (psi)	650	650
Elastic modulus of slab (psi)	5,000,000	5,000,000
Poisson's ratio for concrete	0.15	0.15
Elastic modulus of base (psi)	400,000	400,000
Design thickness of base (in)	9	9
Slab-base friction factor	4	4
Reliability level	95%	90%
Overall standard deviation	0.39	0.39
Mean annual wind speed (mph)	7.6	7.6
Mean annual air temperature (°F)	57.7	57.7
Mean annual precipitation (in)	44.1	44.1
Subgrade <i>k</i> -value (psi/in)	250	250
Performance period (years)	30	30
Two-way AADT	59,000	43,000
Lanes in design direction	2	2
Percent of all trucks in design lane	90%	90%
Percent of trucks in design direction	50%	50%

JRCP = jointed reinforced concrete pavement.

Inputs were made into a spreadsheet based on the requirements of the AASHTO 1998 supplement for rigid pavement design (AASHTO, 1998).

Table 13. Comparison of Rigid Pavement Design Thickness (in) for Different Classification Systems

Classification System	Interstate	Primary
VDOT default	16.39	13.75
VDOT single-unit/combination	16.05	13.27
FHWA classification	16.05	13.26

Inputs were made into a spreadsheet based on the requirements of the AASHTO 1998 supplement for rigid pavement design (AASHTO, 1998). VDOT default = current VDOT-recommended truck ESAL factors (VDOT, 2008).

classification methods predicted a similar design thickness. Site-specific comparisons were performed next and are shown in Tables 14 and 15 for interstate and primary sites, respectively.

Similar to the flexible site comparison, Tables 14 and 15 show a small change in slab thickness between the site-specific truck ESAL factors (Trial 2) and the overall average truck ESAL factors (Trial 7). The difference between the interstate trials was 0.16 in, which was below the significant difference of 0.5 in. The sites with a low truck ESAL factor (Trial 5) had a slab thickness that was more than 0.5 in from the site-specific truck ESAL factor (Trial 2). Because there was an acceptable variation between the site-specific and overall average truck ESAL factors, the average truck ESAL factors over all sites was considered suitable for most situations. If site-specific data were available, they could be used to improve accuracy, but the resulting pavement design thickness would be nearly equal in most cases.

Table 14. Comparison of Site-Specific Truck ESAL Factors for Interstate Rigid Pavement Test Section

Trial No.	Description/ Location	ESAL Factor			Design ESAL	Depth
		Passenger	Single-Unit	Combination		
1	VDOT default	0.0003	0.56	1.92	269,000,000	16.39
2	I-81 N Stephens City	0.0003	0.45	1.74	243,000,000	16.19
3	I-81 S Stephens City	0.0003	0.40	1.57	219,000,000	15.99
4	I-95 N Sussex	0.0003	0.49	1.88	262,000,000	16.34
5	I-66 W Fauquier	0.0003	0.45	1.36	191,000,000	15.72
6	Interstate average	0.0003	0.45	1.62	226,000,000	16.05
7	Overall average	0.0003	0.59	1.59	224,000,000	16.03

Inputs were made into a spreadsheet based on the requirements of the AASHTO 1998 supplement for rigid pavement design (AASHTO, 1998). Trial 1 used the VDOT default VDT truck ESAL factors (i.e., current VDOT-recommended truck ESAL factors). Trial 2 used the closest site-specific WIM data, and Trial 3 used data from the opposing direction to that site. Trial 4 used data from the site with the highest truck ESAL factors for each road type, and Trial 5 used data from the site with the lowest truck ESAL factors. Trial 6 gives the average of all the sites for that functional classification, and Trial 7 uses the weighted average of all 15 WIM sites (encompassing both interstate and primary sites).

Table 15. Comparison of Site-Specific Truck ESAL Factors for Primary Rigid Pavement Test Section

Trial No.	Description/Location	ESAL Factor			Design ESALs	Depth
		Passenger	Single-Unit	Combination		
1	VDOT default	0.0003	0.56	1.92	107,000,000	13.75
2	US 17 S Fauquier	0.0003	0.73	1.57	90,000,000	13.41
3	US 17 N Fauquier	0.0003	0.60	1.61	91,000,000	13.43
4	US 58 E Lee County	0.0003	1.17	1.87	111,000,000	13.81
5	SR 164 W Portsmouth	0.0003	0.46	0.94	54,000,000	12.42
6	Primary average	0.0003	0.72	1.46	84,000,000	13.27
7	Overall average	0.0003	0.59	1.59	89,000,000	13.40

Inputs were made into a spreadsheet based on the requirements of the AASHTO 1998 supplement for rigid pavement design (AASHTO, 1998). Trial 1 used the VDOT default truck ESAL factors (i.e., current VDOT-recommended truck ESAL factors). Trial 2 used the closest site-specific WIM data, and Trial 3 used data from the opposing direction to that site. Trial 4 used data from the site with the highest truck ESAL factors for each road type, and Trial 5 used data from the site with the lowest truck ESAL factors. Trial 6 gives the average of all the sites for that functional classification, and Trial 7 uses the weighted average of all 15 WIM sites (encompassing both interstate and primary sites).

As seen with the flexible comparison, the design thickness from the interstate average and overall average truck ESAL factors was similar, differing by only 0.03 in. In the primary test section, there was a difference of 0.13 between the primary average and overall average truck ESAL factors; although, this value was larger than the difference from the interstate trial, it was still well below the 0.5 in considered to be practically significant. Therefore, the overall average truck ESAL factors could also be used for rigid pavement design. However, if site-specific data were available, they could be used to improve accuracy; but the resulting pavement design thickness would be nearly equal in most cases.

Time Series Analysis for Truck ESAL Factors for Flexible Pavement

A linear regression analysis was used with the two WIM stations that had more than 40 months of continuous data available to evaluate time series trends in the data. As stated

previously in the “Methods” section, the two sites considered were I-81 South at Stephens City and I-95 North at Dumfries. The average monthly truck ESAL values for single-unit and combination vehicles at each site were the dependent variables. The predictor variables were time (number of months) and the month of the year as a factor variable. Equation 7 shows the basic form of the regression model.

$$Y = b_1 + b_2 * \text{time} + b_3 * \text{Jan} + b_4 * \text{Feb} + b_5 * \text{Mar} + b_6 * \text{May} + b_7 * \text{Jun} + b_8 * \text{Jul} + b_9 * \text{Aug} + b_{10} * \text{Sep} + b_{11} * \text{Oct} + b_{12} * \text{Nov} + b_{13} * \text{Dec} \quad (\text{Eq. 7})$$

where

Y = truck ESAL factor

Time = month, numbered consecutively 1 through 42

Jan = factor variable (1 when calculating January ESAL factors, 0 all other months)

Feb = factor variable (1 when calculating February ESAL factors, 0 all other months)

Mar = factor variable (1 when calculating March ESAL factors, 0 all other months)

May = factor variable (1 when calculating May ESAL factors, 0 all other months)

Jun = factor variable (1 when calculating June ESAL factors, 0 all other months)

Jul = factor variable (1 when calculating July ESAL factors, 0 all other months)

Aug = factor variable (1 when calculating August ESAL factors, 0 all other months)

Sep = factor variable (1 when calculating September ESAL factors, 0 all other months)

Oct = factor variable (1 when calculating October ESAL factors, 0 all other months)

Nov = factor variable (1 when calculating November ESAL factors, 0 all other months)

Dec = factor variable (1 when calculating December ESAL factors, 0 all other months)

For the monthly factor variables, April was used as the base case and, therefore, does not have a coefficient (if April truck ESAL factors were to be calculated, b_4 through b_{13} would be equal to zero). Table 16 shows the coefficients from the four linear models developed. The four models are shown in Figure 6.

Three of the datasets had a statistically significant positive relationship between time and the truck ESAL factor. The positive values indicated that these three models predicted an increase in the truck ESAL factor each month. As an example, over a 1-year period, the truck ESAL factor at the Dumfries site increased by 0.0108 for a single-unit truck and 0.018 for a tractor-trailer (b_2 times 12 months); this represents an annual increase of 2.8% for single-unit trucks and 1.6% for combination trucks.

The coefficients were statistically significant for only a few of the months, indicating that the truck ESAL factor for those months was significantly different from the truck ESAL factor in the base case (April). The months of January, February, and August had at least two statistically significant negative coefficients, indicating that these months had lower truck weights than April. Because a pavement service life comprises many years, fluctuations within 1 year are less important than the average truck ESAL factor. Monthly variation could be important if the months in which heavier loading occurred were also months with a higher truck traffic volume. In addition, if vehicles were heavier during the spring thaw period when the subgrade is the weakest, the damage to the pavement would be increased.

Table 16. Time Series Model Coefficients Truck ESAL Factors

Site	Vehicle Type	Intercept	Time	Jan	Feb	March	May	June	July	Aug	Sept	Oct	Nov	Dec
I-81 S	Single-unit	0.3185	0.0009	-0.0349	-0.0208	-0.0041	-0.0084	0.0033	0.0218	0.0209	0.0167	0.0292	0.0016	-0.0159
Stephens City	Combination	1.0601	-0.0003	-0.0335	-0.0282	0.0047	-0.0122	0.0107	0.0165	0.0201	0.0205	0.0142	-0.0288	-0.0551
I-95 N	Single-unit	0.3716	0.0009	-0.0393	-0.0332	-0.0216	0.0016	0.0132	-0.0740	-0.0316	-0.0158	0.0000	-0.0142	-0.0184
Dumfries	Combination	1.0795	0.0015	-0.0710	-0.0796	-0.0535	0.0285	0.0296	-0.0090	-0.0871	-0.0885	-0.0800	-0.0615	-0.0796

Those coefficients that had a significant p -value at an alpha level of 0.05 are shown in bold.

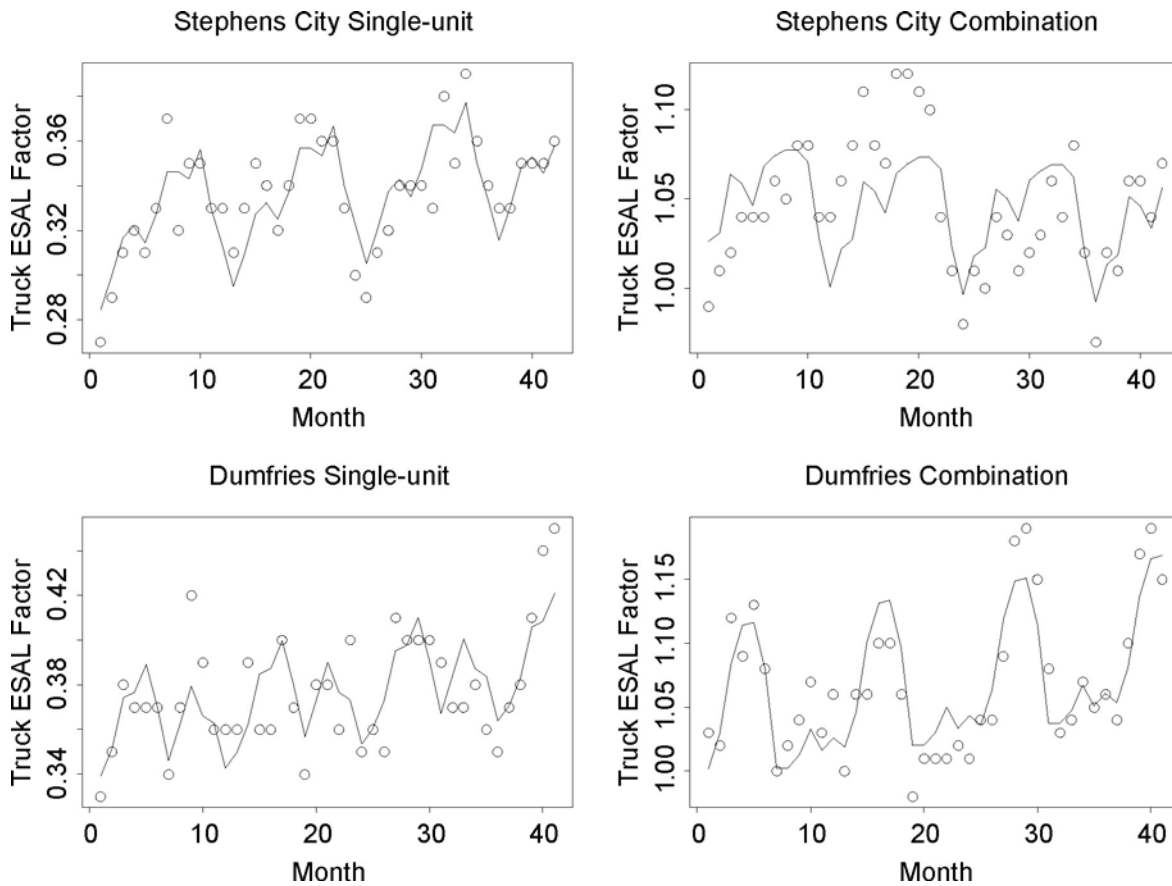


Figure 6. Time Series Models of Truck ESAL Factors

Parameters describing the fit of the four linear models shown in Figure 6 are given in Table 17. Only for the model for I-81 S Stephens City was the result of the F test not statistically significant at an alpha level of 0.05. The coefficient of determination for the I-81 S Stephens City single-unit and I-95 N Dumfries combination models showed a good fit, and that for the other two models indicated a fair fit.

Table 17. R^2 and F Test p -Value for Linear Models

Site	Vehicle Type	R^2	F Test p -value
I-81 S Stephens City	Single-unit	0.7171	0.0000
	Combination	0.4236	0.1011
I-95 N Dumfries	Single-unit	0.5506	0.0108
	Combination	0.7795	0.0000

Significant at alpha level = 0.05.

CONCLUSIONS

- *WIM data can be used to develop more accurate truck ESAL factors than previous VDOT default values because these data more accurately represent the vehicular loading applied to the pavement.* The data obtained from this study can be used by pavement designers and

pavement management engineers to design new pavements and pavement rehabilitation treatments more accurately.

- *Grouping truck vehicles into single-unit and combination vehicles provides sufficient traffic characterization for pavement design.* This method was found to be similar in estimating design ESALs for pavement design to using FHWA vehicle classifications.
- *Statewide average truck ESAL factor values can be used instead of separate truck ESAL factors for interstate and primary routes. Statewide average factors can be calculated as a weighted average of truck ESAL factors for interstate and primary highways.* There are small differences in the required structural capacity of the resulting pavement design between using statewide average truck ESAL factors or using factors specific to administrative roadway classification; however, the slight differences are within construction tolerance limits and therefore are negligible.
- *The use of site-specific truck ESAL factors typically resulted in similar pavement structural capacities as the use of average truck ESAL values.* The lowest site-specific truck ESAL factors produced structural capacity values that were well below the values of the other site-specific data and the values from average truck ESAL factors.
- *Truck ESAL factors increase slightly over time. The study of seasonal variation showed slight changes in monthly truck ESAL factor variation.*

RECOMMENDATIONS

1. *VDOT's Materials Division should incorporate the revised statewide average truck ESAL factors determined in this study into the VDOT Materials Division's Manual of Instructions, Section 604 (VDOT, 2008).* These values are presented in Table 18 by the currently used VDOT two-category truck classification system.

Table 18. Statewide Average Truck ESAL Factors

Pavement Type	Single-Unit Trucks	Combination Trucks
Flexible	0.46	1.05
Rigid	0.59	1.59

2. *VDOT's Materials Division should maintain the currently used two-category truck grouping (single-unit and combination vehicles) in the VDOT Materials Division's Manual of Instructions, Section 604 (VDOT, 2008), in lieu of incorporating the more detailed FHWA vehicle classifications.*
3. *VDOT's Materials Division should use site-specific truck ESAL factors when available for pavement design in place of the statewide average truck ESAL factors, especially for locations in which the truck ESAL factors have the greatest difference when compared to the statewide average truck ESAL factors in Table 18.* The recommended site-specific truck ESAL factors for flexible and rigid pavements on interstate and primary roadways are

provided in Tables 19 through 22. Pavement designers would need to exercise their judgment in choosing the appropriate site-specific data if the location of a design under consideration is far from a site or near more than one site listed in the tables.

Table 19. Site-Specific Average Truck ESAL Factors for Flexible Pavement: Interstate

Site	Single-Unit Trucks	Combination Trucks
I-81 N Stephens City	0.40	1.14
I-81 S Stephens City	0.35	1.03
I-81 N Troutville	0.40	1.07
I-81 S Troutville	0.42	1.01
I-95 N Dumfries	0.39	1.10
I-95 S Dumfries	0.35	0.94
I-95 N Sussex	0.42	1.22
I-66 W Fauquier	0.36	0.88

Table 20. Site-Specific Average Truck ESAL Factors for Flexible Pavement: Primary

Site	Single-Unit Trucks	Combination Trucks
US 29 S Danville	0.46	1.03
US 58 E Lee County	0.82	1.11
US 58 W Lee County	0.51	0.66
US 60 E Cumberland County	0.38	1.07
US 60 W Cumberland County	0.62	1.00
SR 288 N Midlothian	0.54	1.07
SR 288 S Midlothian	0.62	0.94
US 17 N Fauquier County	0.45	1.10
US 17 S Fauquier County	0.53	1.08
SR 234 N Prince William County	0.51	0.91
SR 234 S Prince William County	0.69	0.77
SR 164 E Portsmouth	0.39	0.74
SR 164 W Portsmouth	0.36	0.61

Table 21. Site-Specific Average Truck ESAL Factors for Rigid Pavement: Interstate

Site	Single-Unit Trucks	Combination Trucks
I-81 N Stephens City	0.45	1.74
I-81 S Stephens City	0.40	1.57
I-81 N Troutville	0.46	1.62
I-81 S Troutville	0.50	1.53
I-95 N Dumfries	0.44	1.68
I-95 S Dumfries	0.42	1.44
I-95 N Sussex	0.49	1.88
I-66 W Fauquier	0.45	1.36

Table 22. Site-Specific Average Truck ESAL Factors for Rigid Pavement: Primary

Site	Single-Unit Trucks	Combination Trucks
US 29 S Danville	0.59	1.50
US 58 E Lee County	1.17	1.87
US 58 W Lee County	0.68	0.97
US 60 E Cumberland County	0.47	1.77
US 60 W Cumberland County	0.89	1.68
SR 288 N Midlothian	0.72	1.62
SR 288 S Midlothian	0.92	1.47
US 17 N Fauquier County	0.60	1.61
US 17 S Fauquier County	0.73	1.57
SR 234 N Prince William County	0.64	1.35
SR 234 S Prince William County	0.97	1.13
SR 164 E Portsmouth	0.50	1.17
SR 164 W Portsmouth	0.46	0.94

4. *VTRC and VDOT's Materials Division should study longer periods of WIM data to evaluate further the variation in truck ESAL factors over time.* Based on the variation observed in this study, statewide truck ESAL factors need to be reassessed a minimum of every 3 years (although a longer time period may prove reasonable given more data than were available for this study).

BENEFITS AND IMPLEMENTATION PROSPECTS

Using the updated truck ESAL factors developed and recommended in this study will allow for a pavement design that more accurately reflects the current traffic loading on roadways in Virginia. These truck ESAL factors can be incorporated into VDOT's current design process by the use of either statewide average factors or site-specific factors to calculate the required pavement cross-section needed to carry traffic for the intended pavement service life. Using the updated truck ESAL factors provided in this study will provide a more optimal pavement design, which could lead to a decrease in construction material costs.

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APPENDIX
MATLAB PROGRAM

MATLAB Program: esal

```
function esal

site=input('Site?','s');
year=input('Year?(yyyy)');
month=input('Starting Month?(mm)')-1;
through=input('Number of Consecutive Months?');
type=input('Rigid(r) or Flexible(f)? ','s');
if strcmp(type,'r')
    SN=input('Depth?');
elseif strcmp(type,'f')
    SN=input('Structural Number?');
end

pt=input('pt?');
output=cell(11*through+2,18);
output(1,1:18)={' ',' ','Lane 1',' ',' ',' ','Lane 2',' ',' ',' ','Lane
3',' ',' ',' ','Lane 4',' ',' ',' '};
output(2,1:18)={'Date','VC','Count','AvgESAL','VarESAL','AvgAxles','Count','A
vgESAL','VarESAL','AvgAxles','Count','AvgESAL','VarESAL','AvgAxles','Count','
AvgESAL','VarESAL','AvgAxles'};

for k=0:1:through-1
    month=month+1;
    if month==13
        month=1;
        year=year+1;
    end
file = date(site,year,month);
disp(file)
table1=xlsread(file);

nrows= size(table1,1);
nmax=max(table1(:,10));
last = 2*(nmax-1)+8;
a = zeros(nrows,last);
CountVC411=0;ESAL411=0;ESAL4sql1=0;AxlesVC411=0;
CountVC511=0;ESAL511=0;ESAL5sql1=0;AxlesVC511=0;
CountVC611=0;ESAL611=0;ESAL6sql1=0;AxlesVC611=0;
CountVC711=0;ESAL711=0;ESAL7sql1=0;AxlesVC711=0;
CountVC811=0;ESAL811=0;ESAL8sql1=0;AxlesVC811=0;
CountVC911=0;ESAL911=0;ESAL9sql1=0;AxlesVC911=0;
CountVC1011=0;ESAL1011=0;ESAL10sql1=0;AxlesVC1011=0;
CountVC1111=0;ESAL1111=0;ESAL11sql1=0;AxlesVC1111=0;
CountVC1211=0;ESAL1211=0;ESAL12sql1=0;AxlesVC1211=0;
CountVC1311=0;ESAL1311=0;ESAL13sql1=0;AxlesVC1311=0;
CountVC412=0;ESAL412=0;ESAL4sql2=0;AxlesVC412=0;
CountVC512=0;ESAL512=0;ESAL5sql2=0;AxlesVC512=0;
CountVC612=0;ESAL612=0;ESAL6sql2=0;AxlesVC612=0;
CountVC712=0;ESAL712=0;ESAL7sql2=0;AxlesVC712=0;
CountVC812=0;ESAL812=0;ESAL8sql2=0;AxlesVC812=0;
CountVC912=0;ESAL912=0;ESAL9sql2=0;AxlesVC912=0;
CountVC1012=0;ESAL1012=0;ESAL10sql2=0;AxlesVC1012=0;
CountVC1112=0;ESAL1112=0;ESAL11sql2=0;AxlesVC1112=0;
CountVC1212=0;ESAL1212=0;ESAL12sql2=0;AxlesVC1212=0;
CountVC1312=0;ESAL1312=0;ESAL13sql2=0;AxlesVC1312=0;
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CountVC413=0;ESAL413=0;ESAL4sql3=0;AxlesVC413=0;
CountVC513=0;ESAL513=0;ESAL5sql3=0;AxlesVC513=0;
CountVC613=0;ESAL613=0;ESAL6sql3=0;AxlesVC613=0;
CountVC713=0;ESAL713=0;ESAL7sql3=0;AxlesVC713=0;
CountVC813=0;ESAL813=0;ESAL8sql3=0;AxlesVC813=0;
CountVC913=0;ESAL913=0;ESAL9sql3=0;AxlesVC913=0;
CountVC1013=0;ESAL1013=0;ESAL10sql3=0;AxlesVC1013=0;
CountVC1113=0;ESAL1113=0;ESAL11sql3=0;AxlesVC1113=0;
CountVC1213=0;ESAL1213=0;ESAL12sql3=0;AxlesVC1213=0;
CountVC1313=0;ESAL1313=0;ESAL13sql3=0;AxlesVC1313=0;
CountVC414=0;ESAL414=0;ESAL4sql4=0;AxlesVC414=0;
CountVC514=0;ESAL514=0;ESAL5sql4=0;AxlesVC514=0;
CountVC614=0;ESAL614=0;ESAL6sql4=0;AxlesVC614=0;
CountVC714=0;ESAL714=0;ESAL7sql4=0;AxlesVC714=0;
CountVC814=0;ESAL814=0;ESAL8sql4=0;AxlesVC814=0;
CountVC914=0;ESAL914=0;ESAL9sql4=0;AxlesVC914=0;
CountVC1014=0;ESAL1014=0;ESAL10sql4=0;AxlesVC1014=0;
CountVC1114=0;ESAL1114=0;ESAL11sql4=0;AxlesVC1114=0;
CountVC1214=0;ESAL1214=0;ESAL12sql4=0;AxlesVC1214=0;
CountVC1314=0;ESAL1314=0;ESAL13sql4=0;AxlesVC1314=0;

for i = 1:nrows
    a(i,1)=table1(i,1);           %link id
    a(i,2)=table1(i,6);           %vehicle class
    a(i,3)=table1(i, 3);           %lane
    a(i,4)=table1(i,8);           %Gross Vehicle Weight, kips
    a(i,5)=table1(i,10);          %Number of Axles
    a(i,6)=table1(i,9);           %Given ESAL value
    a(i,7)=table1(i,24);          %Steering Axle Wt, kips

    % Axle 2 classification
    if table1(i,12)<8 && table1(i,12)>3.33
        if (table1(i,12)+table1(i,11))<12
            a(i,8)=3;
        else
            a(i,8)=2;
        end
    elseif table1(i,12)>8 || (table1(i,12)>0 && table1(i,12)<3.33) ||
table1(i,11)>0
        a(i,8)=1;
    end

    % Axle 2 weight
    if a(i,8)==0 || a(i,10)>2
        a(i,9)=0;
    elseif a(i,8)==1
        a(i,9)=table1(i,25);
    elseif a(i,8)==2
        a(i,9)=table1(i,25)+table1(i,26);
    elseif a(i,8)==3
        a(i,9)=table1(i,25)+table1(i,26)+table1(i,24);
        a(i,7)=0;
    end

    %Axle 3 classification
    if table1(i,13)<8 && table1(i,13)>3.33
        if (table1(i,13)+table1(i,12))<12

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```

        if (table1(i,13)+table1(i,12)+table1(i,11))<16
            a(i,10)=4;
            a(i,9)=0; a(i,7)=0;
        else
            a(i,10)=3;
            a(i,9)=0;
        end
    else
        a(i,10)=2;
    end
    elseif table1(i,13)>8 || (table1(i,13)>0 && table1(i,13)<3.33) ||
table1(i,12)>0
        a(i,10)=1;
    end

    %Axle 3 weight
    if a(i,10)==0 || (a(i,8)>1 && a(i,10)==1) || a(i,12)>2
        a(i,11)=0;
    elseif a(i,10)==1
        a(i,11)=table1(i,26);
    elseif a(i,10)==2
        a(i,11)=table1(i,26)+table1(i,27);
    elseif a(i,10)==3
        a(i,11)=table1(i,26)+table1(i,27)+table1(i,25);
    elseif a(i,10)==4
        a(i,11)=table1(i,26)+table1(i,27)+table1(i,25)+table1(i,24);
    end

    for n=4:1:nmax

        %Axle n classification
        if table1(i,n+10)<8 && table1(i,n+10)>3.33
            if (table1(i,n+10)+table1(i,n+9))<12
                if (table1(i,n+10)+table1(i,n+9)+table1(i,n+8))<16
                    a(i,2*n+4)=4;
                    a(i,2*n+3)=0;
                    a(i,2*n+1)=0;
                else
                    a(i,2*n+4)=3;
                    a(i,2*n+3)=0;
                end
            else
                a(i,2*n+4)=2;
            end
        elseif table1(i,n+10)>8 || (table1(i,n+10)>0 &&
table1(i,n+10)<3.33) || table1(i,n+9)>0
            a(i,2*n+4)=1;
        end

        %Axle n weight
        if a(i,2*n+4)==0 || (a(i,2*n+2)>1 && a(i,2*n+4)==1) || a(i,2*n+6)>2
            a(i,2*n+5)=0;
        elseif a(i,2*n+4)==1
            a(i,2*n+5)=table1(i,n+23);
        elseif a(i,2*n+4)==2
            a(i,2*n+5)=table1(i,n+23)+table1(i,n+24);
        elseif a(i,2*n+4)==3

```

```

        a(i,2*n+5)=table1(i,n+23)+table1(i,n+24)+table1(i,n+22);
    elseif a(i,2*n+4)==4

a(i,2*n+5)=table1(i,n+23)+table1(i,n+24)+table1(i,n+22)+table1(i,n+21);
    end

    %Check and Break
    if isnan(table1(i,n+9)) || n==nmax
        if isnan(a(i,7))
            a(i,2)=0;
        end
        break
    end

end

%ESAL Calculation
if strcmp(type,'f')
    beta18=0.40+((0.081*(18+1)^3.23)/((SN+1)^5.19));
    Gt=log10((4.2-pt)/(4.2-1.5));
    ax=zeros(1,nmax);
    ax(1)=1/10^(4.79*log10(19)-
4.79*log10(a(i,7)+1)+4.33*log10(1)+Gt/(0.40+((0.081*(a(i,7)+1)^3.23)/((SN+1)^
5.19)))-Gt/beta18);
    for n=2:1:nmax
        ax(n)=1/10^(4.79*log10(19)-
4.79*log10(a(i,2*n+5)+a(i,2*n+4))+4.33*log10(a(i,2*n+4))+Gt/(0.40+((0.081*(a(
i,2*n+5)+a(i,2*n+4))^3.23)/(((SN+1)^5.19)*a(i,2*n+4)^3.23)))-Gt/beta18);
    end
    for n=1:1:nmax
        if isnan(ax(n))
            break
        else
            a(i,last)=sum(ax(1:n));
        end
    end
end

elseif strcmp(type,'r')
    beta18=0.40+((3.63*(18+1)^5.20)/((SN+1)^8.46));
    Gt=log10((4.5-pt)/(4.5-1.5));
    ax=zeros(1,nmax);
    ax(1)=1/10^(4.62*log10(19)-
4.62*log10(a(i,7)+1)+3.28*log10(1)+Gt/(1.00+((3.61*(a(i,7)+1)^5.21)/((SN+1)^8
.46)))-Gt/beta18);
    for n=2:1:nmax
        ax(n)=1/10^(4.62*log10(19)-
4.62*log10(a(i,2*n+5)+a(i,2*n+4))+3.28*log10(a(i,2*n+4))+Gt/(1.00+((3.61*(a(i
,2*n+5)+a(i,2*n+4))^5.21)/(((SN+1)^8.46)*a(i,2*n+4)^3.52)))-Gt/beta18);
    end
    for n=1:1:nmax
        if isnan(ax(n))
            break
        else
            a(i,last)=sum(ax(1:n));
        end
    end
end
end
end

```

```

% Summary: count of classes, ESAL summary and average axles
if a(i,3)==1
    if a(i,2) == 9
        CountVC9l1=CountVC9l1+1;
        ESAL9l1=ESAL9l1+a(i,last);
        ESAL9sql1=ESAL9sql1+a(i,last)*a(i,last);
        AxlesVC9l1=AxlesVC9l1+a(i,5);
    elseif a(i,2) == 11 % VC 11
        CountVC11l1=CountVC11l1+1;
        ESAL11l1=ESAL11l1+a(i,last);
        ESAL11sql1=ESAL11sql1+a(i,last)*a(i,last);
        AxlesVC11l1=AxlesVC11l1+a(i,5);
    elseif a(i,2) == 5 % VC 5
        CountVC5l1=CountVC5l1+1;
        ESAL5l1=ESAL5l1+a(i,last);
        ESAL5sql1=ESAL5sql1+a(i,last)*a(i,last);
        AxlesVC5l1=AxlesVC5l1+a(i,5);
    elseif a(i,2)== 8
        CountVC8l1=CountVC8l1+1;
        ESAL8l1=ESAL8l1+a(i,last);
        ESAL8sql1=ESAL8sql1+a(i,last)*a(i,last);
        AxlesVC8l1=AxlesVC8l1+a(i,5);
    elseif a(i,2)== 6
        CountVC6l1=CountVC6l1+1;
        ESAL6l1=ESAL6l1+a(i,last);
        ESAL6sql1=ESAL6sql1+a(i,last)*a(i,last);
        AxlesVC6l1=AxlesVC6l1+a(i,5);
    elseif a(i,2)== 4
        CountVC4l1=CountVC4l1+1;
        ESAL4l1=ESAL4l1+a(i,last);
        ESAL4sql1=ESAL4sql1+a(i,last)*a(i,last);
        AxlesVC4l1=AxlesVC4l1+a(i,5);
    elseif a(i,2)== 7
        CountVC7l1=CountVC7l1+1;
        ESAL7l1=ESAL7l1+a(i,last);
        ESAL7sql1=ESAL7sql1+a(i,last)*a(i,last);
        AxlesVC7l1=AxlesVC7l1+a(i,5);
    elseif a(i,2)== 10
        CountVC10l1=CountVC10l1+1;
        ESAL10l1=ESAL10l1+a(i,last);
        ESAL10sql1=ESAL10sql1+a(i,last)*a(i,last);
        AxlesVC10l1=AxlesVC10l1+a(i,5);
    elseif a(i,2)== 12
        CountVC12l1=CountVC12l1+1;
        ESAL12l1=ESAL12l1+a(i,last);
        ESAL12sql1=ESAL12sql1+a(i,last)*a(i,last);
        AxlesVC12l1=AxlesVC12l1+a(i,5);
    elseif a(i,2)==13
        CountVC13l1=CountVC13l1+1;
        ESAL13l1=ESAL13l1+a(i,last);
        ESAL13sql1=ESAL13sql1+a(i,last)*a(i,last);
        AxlesVC13l1=AxlesVC13l1+a(i,5);
    end
elseif a(i,3)==2
    if a(i,2) == 9 % VC 9

```

```

        CountVC912=CountVC912+1;
        ESAL912=ESAL912+a(i,last);
        ESAL9sql2=ESAL9sql2+a(i,last)*a(i,last);
        AxlesVC912=AxlesVC912+a(i,5);
elseif a(i,2) == 11    % VC 11
    CountVC1112=CountVC1112+1;
    ESAL1112=ESAL1112+a(i,last);
    ESAL11sql2=ESAL11sql2+a(i,last)*a(i,last);
    AxlesVC1112=AxlesVC1112+a(i,5);
elseif a(i,2) == 5    % VC 5
    CountVC512=CountVC512+1;
    ESAL512=ESAL512+a(i,last);
    ESAL5sql2=ESAL5sql2+a(i,last)*a(i,last);
    AxlesVC512=AxlesVC512+a(i,5);
elseif a(i,2)== 8
    CountVC812=CountVC812+1;
    ESAL812=ESAL812+a(i,last);
    ESAL8sql2=ESAL8sql2+a(i,last)*a(i,last);
    AxlesVC812=AxlesVC812+a(i,5);
elseif a(i,2)== 6
    CountVC612=CountVC612+1;
    ESAL612=ESAL612+a(i,last);
    ESAL6sql2=ESAL6sql2+a(i,last)*a(i,last);
    AxlesVC612=AxlesVC612+a(i,5);
elseif a(i,2)== 4
    CountVC412=CountVC412+1;
    ESAL412=ESAL412+a(i,last);
    ESAL4sql2=ESAL4sql2+a(i,last)*a(i,last);
    AxlesVC412=AxlesVC412+a(i,5);
elseif a(i,2)== 7
    CountVC712=CountVC712+1;
    ESAL712=ESAL712+a(i,last);
    ESAL7sql2=ESAL7sql2+a(i,last)*a(i,last);
    AxlesVC712=AxlesVC712+a(i,5);
elseif a(i,2)== 10
    CountVC1012=CountVC1012+1;
    ESAL1012=ESAL1012+a(i,last);
    ESAL10sql2=ESAL10sql2+a(i,last)*a(i,last);
    AxlesVC1012=AxlesVC1012+a(i,5);
elseif a(i,2)== 12
    CountVC1212=CountVC1212+1;
    ESAL1212=ESAL1212+a(i,last);
    ESAL12sql2=ESAL12sql2+a(i,last)*a(i,last);
    AxlesVC1212=AxlesVC1212+a(i,5);
elseif a(i,2)==13
    CountVC1312=CountVC1312+1;
    ESAL1312=ESAL1312+a(i,last);
    ESAL13sql2=ESAL13sql2+a(i,last)*a(i,last);
    AxlesVC1312=AxlesVC1312+a(i,5);
end
elseif a(i,3)==3
    if a(i,2) == 9        % VC 9
        CountVC913=CountVC913+1;
        ESAL913=ESAL913+a(i,last);
        ESAL9sql3=ESAL9sql3+a(i,last)*a(i,last);
        AxlesVC913=AxlesVC913+a(i,5);
    elseif a(i,2) == 11    % VC 11

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```

        CountVC1113=CountVC1113+1;
        ESAL1113=ESAL1113+a(i,last);
        ESAL11sql3=ESAL11sql3+a(i,last)*a(i,last);
        AxlesVC1113=AxlesVC1113+a(i,5);
    elseif a(i,2) == 5      % VC 5
        CountVC513=CountVC513+1;
        ESAL513=ESAL513+a(i,last);
        ESAL5sql3=ESAL5sql3+a(i,last)*a(i,last);
        AxlesVC513=AxlesVC513+a(i,5);
    elseif a(i,2)== 8
        CountVC813=CountVC813+1;
        ESAL813=ESAL813+a(i,last);
        ESAL8sql3=ESAL8sql3+a(i,last)*a(i,last);
        AxlesVC813=AxlesVC813+a(i,5);
    elseif a(i,2)== 6
        CountVC613=CountVC613+1;
        ESAL613=ESAL613+a(i,last);
        ESAL6sql3=ESAL6sql3+a(i,last)*a(i,last);
        AxlesVC613=AxlesVC613+a(i,5);
    elseif a(i,2)== 4
        CountVC413=CountVC413+1;
        ESAL413=ESAL413+a(i,last);
        ESAL4sql3=ESAL4sql3+a(i,last)*a(i,last);
        AxlesVC413=AxlesVC413+a(i,5);
    elseif a(i,2)== 7
        CountVC713=CountVC713+1;
        ESAL713=ESAL713+a(i,last);
        ESAL7sql3=ESAL7sql3+a(i,last)*a(i,last);
        AxlesVC713=AxlesVC713+a(i,5);
    elseif a(i,2)== 10
        CountVC1013=CountVC1013+1;
        ESAL1013=ESAL1013+a(i,last);
        ESAL10sql3=ESAL10sql3+a(i,last)*a(i,last);
        AxlesVC1013=AxlesVC1013+a(i,5);
    elseif a(i,2)== 12
        CountVC1213=CountVC1213+1;
        ESAL1213=ESAL1213+a(i,last);
        ESAL12sql3=ESAL12sql3+a(i,last)*a(i,last);
        AxlesVC1213=AxlesVC1213+a(i,5);
    elseif a(i,2)==13
        CountVC1313=CountVC1313+1;
        ESAL1313=ESAL1313+a(i,last);
        ESAL13sql3=ESAL13sql3+a(i,last)*a(i,last);
        AxlesVC1313=AxlesVC1313+a(i,5);
    end
elseif a(i,3)==4
    if a(i,2) == 9      % VC 9
        CountVC914=CountVC914+1;
        ESAL914=ESAL914+a(i,last);
        ESAL9sql4=ESAL9sql4+a(i,last)*a(i,last);
        AxlesVC914=AxlesVC914+a(i,5);
    elseif a(i,2) == 11 % VC 11
        CountVC1114=CountVC1114+1;
        ESAL1114=ESAL1114+a(i,last);
        ESAL11sql4=ESAL11sql4+a(i,last)*a(i,last);
        AxlesVC1114=AxlesVC1114+a(i,5);
    elseif a(i,2) == 5 % VC 5

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        CountVC5l4=CountVC5l4+1;
        ESAL5l4=ESAL5l4+a(i,last);
        ESAL5sql4=ESAL5sql4+a(i,last)*a(i,last);
        AxlesVC5l4=AxlesVC5l4+a(i,5);
elseif a(i,2)== 8
        CountVC8l4=CountVC8l4+1;
        ESAL8l4=ESAL8l4+a(i,last);
        ESAL8sql4=ESAL8sql4+a(i,last)*a(i,last);
        AxlesVC8l4=AxlesVC8l4+a(i,5);
elseif a(i,2)== 6
        CountVC6l4=CountVC6l4+1;
        ESAL6l4=ESAL6l4+a(i,last);
        ESAL6sql4=ESAL6sql4+a(i,last)*a(i,last);
        AxlesVC6l4=AxlesVC6l4+a(i,5);
elseif a(i,2)== 4
        CountVC4l4=CountVC4l4+1;
        ESAL4l4=ESAL4l4+a(i,last);
        ESAL4sql4=ESAL4sql4+a(i,last)*a(i,last);
        AxlesVC4l4=AxlesVC4l4+a(i,5);
elseif a(i,2)== 7
        CountVC7l4=CountVC7l4+1;
        ESAL7l4=ESAL7l4+a(i,last);
        ESAL7sql4=ESAL7sql4+a(i,last)*a(i,last);
        AxlesVC7l4=AxlesVC7l4+a(i,5);
elseif a(i,2)== 10
        CountVC10l4=CountVC10l4+1;
        ESAL10l4=ESAL10l4+a(i,last);
        ESAL10sql4=ESAL10sql4+a(i,last)*a(i,last);
        AxlesVC10l4=AxlesVC10l4+a(i,5);
elseif a(i,2)== 12
        CountVC12l4=CountVC12l4+1;
        ESAL12l4=ESAL12l4+a(i,last);
        ESAL12sql4=ESAL12sql4+a(i,last)*a(i,last);
        AxlesVC12l4=AxlesVC12l4+a(i,5);
elseif a(i,2)==13
        CountVC13l4=CountVC13l4+1;
        ESAL13l4=ESAL13l4+a(i,last);
        ESAL13sql4=ESAL13sql4+a(i,last)*a(i,last);
        AxlesVC13l4=AxlesVC13l4+a(i,5);
end
end
end

%calculations and output
%VC4
avgVC4l1=ESAL4l1/CountVC4l1;
varVC4l1=(ESAL4sql1*CountVC4l1-ESAL4l1*ESAL4l1)/(CountVC4l1*(CountVC4l1-1));
AvgAxlesVC4l1=AxlesVC4l1/CountVC4l1;
avgVC4l2=ESAL4l2/CountVC4l2;
varVC4l2=(ESAL4sql2*CountVC4l2-ESAL4l2*ESAL4l2)/(CountVC4l2*(CountVC4l2-1));
AvgAxlesVC4l2=AxlesVC4l2/CountVC4l2;
avgVC4l3=ESAL4l3/CountVC4l3;
varVC4l3=(ESAL4sql3*CountVC4l3-ESAL4l3*ESAL4l3)/(CountVC4l3*(CountVC4l3-1));
AvgAxlesVC4l3=AxlesVC4l3/CountVC4l3;
avgVC4l4=ESAL4l4/CountVC4l4;
varVC4l4=(ESAL4sql4*CountVC4l4-ESAL4l4*ESAL4l4)/(CountVC4l4*(CountVC4l4-1));
AvgAxlesVC4l4=AxlesVC4l4/CountVC4l4;

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%VC5
avgVC511=ESAL511/CountVC511;
varVC511=(ESAL5sql1*CountVC511-ESAL511*ESAL511)/(CountVC511*(CountVC511-1));
AvgAxlesVC511=AxlesVC511/CountVC511;
avgVC512=ESAL512/CountVC512;
varVC512=(ESAL5sql2*CountVC512-ESAL512*ESAL512)/(CountVC512*(CountVC512-1));
AvgAxlesVC512=AxlesVC512/CountVC512;
avgVC513=ESAL513/CountVC513;
varVC513=(ESAL5sql3*CountVC513-ESAL513*ESAL513)/(CountVC513*(CountVC513-1));
AvgAxlesVC513=AxlesVC513/CountVC513;
avgVC514=ESAL514/CountVC514;
varVC514=(ESAL5sql4*CountVC514-ESAL514*ESAL514)/(CountVC514*(CountVC514-1));
AvgAxlesVC514=AxlesVC514/CountVC514;
%VC6
avgVC611=ESAL611/CountVC611;
varVC611=(ESAL6sql1*CountVC611-ESAL611*ESAL611)/(CountVC611*(CountVC611-1));
AvgAxlesVC611=AxlesVC611/CountVC611;
avgVC612=ESAL612/CountVC612;
varVC612=(ESAL6sql2*CountVC612-ESAL612*ESAL612)/(CountVC612*(CountVC612-1));
AvgAxlesVC612=AxlesVC612/CountVC612;
avgVC613=ESAL613/CountVC613;
varVC613=(ESAL6sql3*CountVC613-ESAL613*ESAL613)/(CountVC613*(CountVC613-1));
AvgAxlesVC613=AxlesVC613/CountVC613;
avgVC614=ESAL614/CountVC614;
varVC614=(ESAL6sql4*CountVC614-ESAL614*ESAL614)/(CountVC614*(CountVC614-1));
AvgAxlesVC614=AxlesVC614/CountVC614;
%VC7
avgVC711=ESAL711/CountVC711;
varVC711=(ESAL7sql1*CountVC711-ESAL711*ESAL711)/(CountVC711*(CountVC711-1));
AvgAxlesVC711=AxlesVC711/CountVC711;
avgVC712=ESAL712/CountVC712;
varVC712=(ESAL7sql2*CountVC712-ESAL712*ESAL712)/(CountVC712*(CountVC712-1));
AvgAxlesVC712=AxlesVC712/CountVC712;
avgVC713=ESAL713/CountVC713;
varVC713=(ESAL7sql3*CountVC713-ESAL713*ESAL713)/(CountVC713*(CountVC713-1));
AvgAxlesVC713=AxlesVC713/CountVC713;
avgVC714=ESAL714/CountVC714;
varVC714=(ESAL7sql4*CountVC714-ESAL714*ESAL714)/(CountVC714*(CountVC714-1));
AvgAxlesVC714=AxlesVC714/CountVC714;
%VC8
avgVC811=ESAL811/CountVC811;
varVC811=(ESAL8sql1*CountVC811-ESAL811*ESAL811)/(CountVC811*(CountVC811-1));
AvgAxlesVC811=AxlesVC811/CountVC811;
avgVC812=ESAL812/CountVC812;
varVC812=(ESAL8sql2*CountVC812-ESAL812*ESAL812)/(CountVC812*(CountVC812-1));
AvgAxlesVC812=AxlesVC812/CountVC812;
avgVC813=ESAL813/CountVC813;
varVC813=(ESAL8sql3*CountVC813-ESAL813*ESAL813)/(CountVC813*(CountVC813-1));
AvgAxlesVC813=AxlesVC813/CountVC813;
avgVC814=ESAL814/CountVC814;
varVC814=(ESAL8sql4*CountVC814-ESAL814*ESAL814)/(CountVC814*(CountVC814-1));
AvgAxlesVC814=AxlesVC814/CountVC814;
%VC9
avgVC911=ESAL911/CountVC911;
varVC911=(ESAL9sql1*CountVC911-ESAL911*ESAL911)/(CountVC911*(CountVC911-1));
AvgAxlesVC911=AxlesVC911/CountVC911;
avgVC912=ESAL912/CountVC912;

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varVC912=(ESAL9sql2*CountVC912-ESAL912*ESAL912)/(CountVC912*(CountVC912-1));
AvgAxlesVC912=AxlesVC912/CountVC912;
avgVC913=ESAL913/CountVC913;
varVC913=(ESAL9sql3*CountVC913-ESAL913*ESAL913)/(CountVC913*(CountVC913-1));
AvgAxlesVC913=AxlesVC913/CountVC913;
avgVC914=ESAL914/CountVC914;
varVC914=(ESAL9sql4*CountVC914-ESAL914*ESAL914)/(CountVC914*(CountVC914-1));
AvgAxlesVC914=AxlesVC914/CountVC914;
%VC10
avgVC1011=ESAL1011/CountVC1011;
varVC1011=(ESAL10sql1*CountVC1011-
ESAL1011*ESAL1011)/(CountVC1011*(CountVC1011-1));
AvgAxlesVC1011=AxlesVC1011/CountVC1011;
avgVC1012=ESAL1012/CountVC1012;
varVC1012=(ESAL10sql2*CountVC1012-
ESAL1012*ESAL1012)/(CountVC1012*(CountVC1012-1));
AvgAxlesVC1012=AxlesVC1012/CountVC1012;
avgVC1013=ESAL1013/CountVC1013;
varVC1013=(ESAL10sql3*CountVC1013-
ESAL1013*ESAL1013)/(CountVC1013*(CountVC1013-1));
AvgAxlesVC1013=AxlesVC1013/CountVC1013;
avgVC1014=ESAL1014/CountVC1014;
varVC1014=(ESAL10sql4*CountVC1014-
ESAL1014*ESAL1014)/(CountVC1014*(CountVC1014-1));
AvgAxlesVC1014=AxlesVC1014/CountVC1014;
%VC11
avgVC1111=ESAL1111/CountVC1111;
varVC1111=(ESAL11sql1*CountVC1111-
ESAL1111*ESAL1111)/(CountVC1111*(CountVC1111-1));
AvgAxlesVC1111=AxlesVC1111/CountVC1111;
avgVC1112=ESAL1112/CountVC1112;
varVC1112=(ESAL11sql2*CountVC1112-
ESAL1112*ESAL1112)/(CountVC1112*(CountVC1112-1));
AvgAxlesVC1112=AxlesVC1112/CountVC1112;
avgVC1113=ESAL1113/CountVC1113;
varVC1113=(ESAL11sql3*CountVC1113-
ESAL1113*ESAL1113)/(CountVC1113*(CountVC1113-1));
AvgAxlesVC1113=AxlesVC1113/CountVC1113;
avgVC1114=ESAL1114/CountVC1114;
varVC1114=(ESAL11sql4*CountVC1114-
ESAL1114*ESAL1114)/(CountVC1114*(CountVC1114-1));
AvgAxlesVC1114=AxlesVC1114/CountVC1114;
%VC12
avgVC1211=ESAL1211/CountVC1211;
varVC1211=(ESAL12sql1*CountVC1211-
ESAL1211*ESAL1211)/(CountVC1211*(CountVC1211-1));
AvgAxlesVC1211=AxlesVC1211/CountVC1211;
avgVC1212=ESAL1212/CountVC1212;
varVC1212=(ESAL12sql2*CountVC1212-
ESAL1212*ESAL1212)/(CountVC1212*(CountVC1212-1));
AvgAxlesVC1212=AxlesVC1212/CountVC1212;
avgVC1213=ESAL1213/CountVC1213;
varVC1213=(ESAL12sql3*CountVC1213-
ESAL1213*ESAL1213)/(CountVC1213*(CountVC1213-1));
AvgAxlesVC1213=AxlesVC1213/CountVC1213;
avgVC1214=ESAL1214/CountVC1214;

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varVC1214=(ESAL12sql4*CountVC1214-
ESAL1214*ESAL1214)/(CountVC1214*(CountVC1214-1));
AvgAxlesVC1214=AxlesVC1214/CountVC1214;
%VC13
avgVC1311=ESAL1311/CountVC1311;
varVC1311=(ESAL13sql1*CountVC1311-
ESAL1311*ESAL1311)/(CountVC1311*(CountVC1311-1));
AvgAxlesVC1311=AxlesVC1311/CountVC1311;
avgVC1312=ESAL1312/CountVC1312;
varVC1312=(ESAL13sql2*CountVC1312-
ESAL1312*ESAL1312)/(CountVC1312*(CountVC1312-1));
AvgAxlesVC1312=AxlesVC1312/CountVC1312;
avgVC1313=ESAL1313/CountVC1313;
varVC1313=(ESAL13sql3*CountVC1313-
ESAL1313*ESAL1313)/(CountVC1313*(CountVC1313-1));
AvgAxlesVC1313=AxlesVC1313/CountVC1313;
avgVC1314=ESAL1314/CountVC1314;
varVC1314=(ESAL13sql4*CountVC1314-
ESAL1314*ESAL1314)/(CountVC1314*(CountVC1314-1));
AvgAxlesVC1314=AxlesVC1314/CountVC1314;
%Single Unit
countsul1=CountVC411+CountVC511+CountVC611+CountVC711;
avgs11=(ESAL411+ESAL511+ESAL611+ESAL711)/countsul1;
vars11=((ESAL4sql1+ESAL5sql1+ESAL6sql1+ESAL7sql1)*countsul1-(ESAL411+ESAL511
+ESAL611+ ESAL711)*(ESAL411+ESAL511 +ESAL611+
ESAL711))/(countsul1*(countsul1-1));
AvgAxless11=(AxlesVC411+AxlesVC511+AxlesVC611+AxlesVC711)/countsul1;
countsul2=CountVC412+CountVC512+CountVC612+CountVC712;
avgs12=(ESAL412+ESAL512+ESAL612+ESAL712)/countsul2;
vars12=((ESAL4sql2+ESAL5sql2+ESAL6sql2+ESAL7sql2)*countsul2-(ESAL412+ESAL512
+ESAL612+ ESAL712)*(ESAL412+ESAL512 +ESAL612+
ESAL712))/(countsul2*(countsul2-1));
AvgAxless12=(AxlesVC412+AxlesVC512+AxlesVC612+AxlesVC712)/countsul2;
countsul3=CountVC413+CountVC513+CountVC613+CountVC713;
avgs13=(ESAL413+ESAL513+ESAL613+ESAL713)/countsul3;
vars13=((ESAL4sql3+ESAL5sql3+ESAL6sql3+ESAL7sql3)*countsul3-(ESAL413+ESAL513
+ESAL613+ ESAL713)*(ESAL413+ESAL513 +ESAL613+
ESAL713))/(countsul3*(countsul3-1));
AvgAxless13=(AxlesVC413+AxlesVC513+AxlesVC613+AxlesVC713)/countsul3;
countsul4=CountVC414+CountVC514+CountVC614+CountVC714;
avgs14=(ESAL414+ESAL514+ESAL614+ESAL714)/countsul4;
vars14=((ESAL4sql4+ESAL5sql4+ESAL6sql4+ESAL7sql4)*countsul4-(ESAL414+ESAL514
+ESAL614+ ESAL714)*(ESAL414+ESAL514 +ESAL614+
ESAL714))/(countsul4*(countsul4-1));
AvgAxless14=(AxlesVC414+AxlesVC514+AxlesVC614+AxlesVC714)/countsul4;
%Trailer
countt11=CountVC811+CountVC911+CountVC1011+CountVC1111+CountVC1211+CountVC131
1;
avgt11=(ESAL811+ESAL911+ESAL1011+ESAL1111+ESAL1211+ESAL1311)/countt11;
vart11=((ESAL8sql1+ESAL9sql1+ESAL10sql1+ESAL11sql1+ESAL12sql1+ESAL13sql1)*cou
ntt11-
(ESAL811+ESAL911+ESAL1011+ESAL1111+ESAL1211+ESAL1311)*(ESAL811+ESAL911+ESAL10
11+ESAL1111+ESAL1211+ESAL1311))/(countt11*(countt11-1));
AvgAxlest11=(AxlesVC811+AxlesVC911+AxlesVC1011+AxlesVC1111+AxlesVC1211+AxlesV
C1311)/(CountVC811+CountVC911+CountVC1011+CountVC1111+CountVC1211+CountVC1311
);

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```

countt12=CountVC812+CountVC912+CountVC1012+CountVC1112+CountVC1212+CountVC1312;
avgt12=(ESAL812+ESAL912+ESAL1012+ESAL1112+ESAL1212+ESAL1312)/countt12;
vart12=((ESAL8sql2+ESAL9sql2+ESAL10sql2+ESAL11sql2+ESAL12sql2+ESAL13sql2)*countt12-(ESAL812+ESAL912+ESAL1012+ESAL1112+ESAL1212+ESAL1312)*(ESAL812+ESAL912+ESAL1012+ESAL1112+ESAL1212+ESAL1312))/(countt12*(countt12-1));
AvgAxlest12=(AxlesVC812+AxlesVC912+AxlesVC1012+AxlesVC1112+AxlesVC1212+AxlesVC1312)/(CountVC812+CountVC912+CountVC1012+CountVC1112+CountVC1212+CountVC1312);
countt13=CountVC813+CountVC913+CountVC1013+CountVC1113+CountVC1213+CountVC1313;
avgt13=(ESAL813+ESAL913+ESAL1013+ESAL1113+ESAL1213+ESAL1313)/countt13;
vart13=((ESAL8sql3+ESAL9sql3+ESAL10sql3+ESAL11sql3+ESAL12sql3+ESAL13sql3)*countt13-(ESAL813+ESAL913+ESAL1013+ESAL1113+ESAL1213+ESAL1313)*(ESAL813+ESAL913+ESAL1013+ESAL1113+ESAL1213+ESAL1313))/(countt13*(countt13-1));
AvgAxlest13=(AxlesVC813+AxlesVC913+AxlesVC1013+AxlesVC1113+AxlesVC1213+AxlesVC1313)/(CountVC813+CountVC913+CountVC1013+CountVC1113+CountVC1213+CountVC1313);
countt14=CountVC814+CountVC914+CountVC1014+CountVC1114+CountVC1214+CountVC1314;
avgt14=(ESAL814+ESAL914+ESAL1014+ESAL1114+ESAL1214+ESAL1314)/countt14;
vart14=((ESAL8sql4+ESAL9sql4+ESAL10sql4+ESAL11sql4+ESAL12sql4+ESAL13sql4)*countt14-(ESAL814+ESAL914+ESAL1014+ESAL1114+ESAL1214+ESAL1314)*(ESAL814+ESAL914+ESAL1014+ESAL1114+ESAL1214+ESAL1314))/(countt14*(countt14-1));
AvgAxlest14=(AxlesVC814+AxlesVC914+AxlesVC1014+AxlesVC1114+AxlesVC1214+AxlesVC1314)/(CountVC814+CountVC914+CountVC1014+CountVC1114+CountVC1214+CountVC1314);

output(12*k+3,1)={datestr([year month 1 1 1 1],28)};
output(12*k+3:14+12*k,2)={4 5 6 7 8 9 10 11 12 13 'Single-unit' 'Trailer'};
output(12*k+3:14+12*k,3)={CountVC411 CountVC511 CountVC611 CountVC711 CountVC811 CountVC911 CountVC1011 CountVC1111 CountVC1211 CountVC1311 countsull countt11};
output(12*k+3:14+12*k,4)={avgVC411 avgVC511 avgVC611 avgVC711 avgVC811 avgVC911 avgVC1011 avgVC1111 avgVC1211 avgVC1311 avgs11 avgt11};
output(12*k+3:14+12*k,5)={varVC411 varVC511 varVC611 varVC711 varVC811 varVC911 varVC1011 varVC1111 varVC1211 varVC1311 vars11 vart11};
output(12*k+3:14+12*k,6)={AvgAxlesVC411 AvgAxlesVC511 AvgAxlesVC611 AvgAxlesVC711 AvgAxlesVC811 AvgAxlesVC911 AvgAxlesVC1011 AvgAxlesVC1111 AvgAxlesVC1211 AvgAxlesVC1311 AvgAxless11 AvgAxlest11};

output(12*k+3:14+12*k,7)={CountVC412 CountVC512 CountVC612 CountVC712 CountVC812 CountVC912 CountVC1012 CountVC1112 CountVC1212 CountVC1312 countsul2 countt12};
output(12*k+3:14+12*k,8)={avgVC412 avgVC512 avgVC612 avgVC712 avgVC812 avgVC912 avgVC1012 avgVC1112 avgVC1212 avgVC1312 avgs12 avgt12};
output(12*k+3:14+12*k,9)={varVC412 varVC512 varVC612 varVC712 varVC812 varVC912 varVC1012 varVC1112 varVC1212 varVC1312 vars12 vart12};
output(12*k+3:14+12*k,10)={AvgAxlesVC412 AvgAxlesVC512 AvgAxlesVC612 AvgAxlesVC712 AvgAxlesVC812 AvgAxlesVC912 AvgAxlesVC1012 AvgAxlesVC1112 AvgAxlesVC1212 AvgAxlesVC1312 AvgAxless12 AvgAxlest12};

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```

output(12*k+3:14+12*k,11)={CountVC413 CountVC513 CountVC613 CountVC713
CountVC813 CountVC913 CountVC1013 CountVC1113 CountVC1213 CountVC1313
countsul3 countt13};
output(12*k+3:14+12*k,12)={avgVC413 avgVC513 avgVC613 avgVC713 avgVC813
avgVC913 avgVC1013 avgVC1113 avgVC1213 avgVC1313 avgs13 avgt13};
output(12*k+3:14+12*k,13)={varVC413 varVC513 varVC613 varVC713 varVC813
varVC913 varVC1013 varVC1113 varVC1213 varVC1313 vars13 vart13};
output(12*k+3:14+12*k,14)={AvgAxlesVC413 AvgAxlesVC513 AvgAxlesVC613
AvgAxlesVC713 AvgAxlesVC813 AvgAxlesVC913 AvgAxlesVC1013 AvgAxlesVC1113
AvgAxlesVC1213 AvgAxlesVC1313 AvgAxless13 AvgAxlest13};

output(12*k+3:14+12*k,15)={CountVC414 CountVC514 CountVC614 CountVC714
CountVC814 CountVC914 CountVC1014 CountVC1114 CountVC1214 CountVC1314
countsul4 countt14};
output(12*k+3:14+12*k,16)={avgVC414 avgVC514 avgVC614 avgVC714 avgVC814
avgVC914 avgVC1014 avgVC1114 avgVC1214 avgVC1314 avgs14 avgt14};
output(12*k+3:14+12*k,17)={varVC414 varVC514 varVC614 varVC714 varVC814
varVC914 varVC1014 varVC1114 varVC1214 varVC1314 vars14 vart14};
output(12*k+3:14+12*k,18)={AvgAxlesVC414 AvgAxlesVC514 AvgAxlesVC614
AvgAxlesVC714 AvgAxlesVC814 AvgAxlesVC914 AvgAxlesVC1014 AvgAxlesVC1114
AvgAxlesVC1214 AvgAxlesVC1314 AvgAxless14 AvgAxlest14};

end

if strcmp(type, 'r')
    xlswrite('RigidESALoutput',output, site)
elseif strcmp(type,'f')
    xlswrite('FlexibleESALoutput',output, site)
end

```

MATLAB program: date

```
function [file] = date(site,year,month)

if year==2007
    if month == 1
        file=strcat(site,'_20070121.csv');
    elseif month==2
        file=strcat(site,'_20070211.csv');
    elseif month==3
        file=strcat(site,'_20070311.csv');
    elseif month==4
        file=strcat(site,'_20070415.csv');
    elseif month==5
        file=strcat(site,'_20070513.csv');
    elseif month==6
        file=strcat(site,'_20070617.csv');
    elseif month==7
        file=strcat(site,'_20070715.csv');
    elseif month==8
        file=strcat(site,'_20070812.csv');
    elseif month==9
        file=strcat(site,'_20070909.csv');
    elseif month==10
        file=strcat(site,'_20071014.csv');
    elseif month==11
        file=strcat(site,'_20071111.csv');
    elseif month==12
        file=strcat(site,'_20071209.csv');
    else
        error('invalid month')
    end
elseif year==2008
    if month == 1
        file=strcat(site,'_20080113.csv');
    elseif month==2
        file=strcat(site,'_20080210.csv');
    elseif month==3
        file=strcat(site,'_20080309.csv');
    elseif month==4
        file=strcat(site,'_20080420.csv');
    elseif month==5
        file=strcat(site,'_20080504.csv');
    elseif month==6
        file=strcat(site,'_20080615.csv');
    else
        error('invalid month')
    end
elseif year==2006
    if month == 1
        file=strcat(site,'_20060122.csv');
    elseif month==2
        file=strcat(site,'_20060212.csv');
    elseif month==3
        file=strcat(site,'_20060312.csv');
    elseif month==4
        file=strcat(site,'_20060409.csv');
```

```

elseif month==5
    file=strcat(site,'_20060507.csv');
elseif month==6
    file=strcat(site,'_20060611.csv');
elseif month==7
    file=strcat(site,'_20060709.csv');
elseif month==8
    file=strcat(site,'_20060813.csv');
elseif month==9
    file=strcat(site,'_20060910.csv');
elseif month==10
    file=strcat(site,'_20061015.csv');
elseif month==11
    file=strcat(site,'_20061112.csv');
elseif month==12
    file=strcat(site,'_20061210.csv');
else
    error('invalid month')
end
elseif year==2005
    if month == 1
        file=strcat(site,'_20050123.csv');
    elseif month==2
        file=strcat(site,'_20050213.csv');
    elseif month==3
        file=strcat(site,'_20050313.csv');
    elseif month==4
        file=strcat(site,'_20050410.csv');
    elseif month==5
        file=strcat(site,'_20050508.csv');
    elseif month==6
        file=strcat(site,'_20050612.csv');
    elseif month==7
        file=strcat(site,'_20050710.csv');
    elseif month==8
        file=strcat(site,'_20050814.csv');
    elseif month==9
        file=strcat(site,'_20050911.csv');
    elseif month==10
        file=strcat(site,'_20051016.csv');
    elseif month==11
        file=strcat(site,'_20051113.csv');
    elseif month==12
        file=strcat(site,'_20051211.csv');
    else
        error('invalid month')
    end
else
    error('invalid year')
end

```