6 Design Input—Equivalent Single Axle Loads

6.1 Introduction

This chapter applies to designing normal pavement structures for highway projects. Highway pavement structures are designed to withstand the design number of standardized loadings derived from a known mix of truck-types in the traffic stream. Standardized vehicle loadings used in highway design are termed “equivalent single axle loads” (ESALs), i.e., the pavement structure will be subjected to a specific number of ESALs during its design life. This chapter describes how to calculate standardized ESAL loadings for the project. To facilitate the ESAL computation, planning personnel will provide information concerning vehicle loadings as well as traffic growth rate and traffic lane distribution data. Similar concepts involving standardized vehicle loadings are used to calculate design aircraft loadings for aviation projects, although that methodology is not presented here.

With every application of an ESAL, the surface of a pavement structure, that structure experiences a quantifiable amount of structural damage. In other words, every ESAL application subtracts a finite amount of life from the pavement structure’s available life. If the project involves construction of a new pavement structure or replacing an old one, one ESAL value will be needed for design, i.e., future ESALs (ESALs estimated for the design life of the new pavement structure). If the project involves placing an overlay on an existing pavement layer, two ESAL values will be required: (1) historical ESALs (ESALs accumulated on the existing pavement structure during its past service life), and (2) future ESALs.

Categories of truck-type vehicles are defined in terms of standard ESAL loadings for each category. Only medium and large trucks are assigned ESAL equivalency. Automobiles, pickup trucks, and other small vehicles do negligible damage to the pavement structure. Consequently, they are not considered in the structural design. An old rule-of-thumb is that pavement structural damage done by the passage of a single large truck is equivalent to that done by about 9,000 automobiles.

ESAL Defined: One ESAL represents the loading that produces an amount of damage to the pavement structure equivalent to one pass of a single 18,000-pound, dual-tire axle with all four tires inflated to 110 psi.

ESAL Truck Category and Load Factor Defined: DOT&PF defines five truck categories (2-axle, 3-axle, 4-axle, 5- axle, and ≥6-axle). Trucks assigned to the 2-axle category have one front axle and one rear axle. Trucks assigned to the 3-axle category have one front axle and a tandem rear axle set. Trucks assigned to the 4-axle category are “semi” tractor/trailer combinations having one front axle on the tractor, a tandem set of driver axles on the tractor, and one axle at the rear of the trailer. Trucks assigned to categories higher than the 4-axle type are simply tractor/ trailer or tractor/multi-trailer combinations having a total of two or more trailer axles.

The truck categories represent a simplification of the FHWA truck classifications. Table 6-1 provides a summary of the DOT&PF truck categories and the FHWA truck classifications.

Each of the five truck categories, is assigned an ESAL equivalency based on scalehouse data. The assigned ESAL equivalency is termed the **load factor**—and every truck in that category is assigned that load factor.

Table 6-1 Summary of DOT&PF Truck Categories and FHWA Truck Classification

DOT&PF Truck Categories	FHWA Truck Classification	Load Factors
2-axle truck	Class 5	0.50
3-axle truck	Class 6 and 8	0.85
4-axle truck	Class 7 and 8	1.20
5-axle truck	Class 9 and 11	1.55
6 or more axle truck	Class 10, 12, and 13	2.24

6.2 Calculate the Load Factor for Each Vehicle Category

This section provides a somewhat generalized description of how a load factor for each DOT&PF truck category is determined. Even though load factor data will be supplied to the designer, basic load factor computations are briefly discussed here to promote more thoroughly understanding of the concept of standardized loadings.

Load factor is defined as the average number of ESALs associated with each truck of a truck size category. Load factors for all categories of truck size are usually calculated by regional planning sections and will be supplied to when the designer requests traffic data for your project. Load factors are necessary input data for the design ESAL calculations described in Section 6.3. One ESAL equivalent loading is defined for various axles or axle group configurations loaded as shown in Table 6.-2.

An axle is considered part of an axle group when it is less than 8 feet from another axle or group. For example, if two single axles are less than 8 feet apart, they are considered a tandem axle. If a single axle is less than 8 feet from a tandem axle, the three are considered a tridem axle.

Load factors are determined from scalehouse weight data obtained from many trucks. At the scalehouse, axle and axle group weights are sampled from numerous trucks representing each truck category. Each truck to be weighed is first assigned to a category. Then each axle and axle group (single, dual, tandem, etc.) for that truck is weighed individually. An ESAL value is calculated for each axle and axle group (using the following ESAL equation).

Table 6-2 ESAL Load Equivalent for Axle Groupings

Type of Axle or Axle Group	Load Equivalent to One ESAL (kips)
single tire single axle	12
dual tire axle	18
tandem axle group	32
tridem axle group	48
4 or more axle group	48

The ESAL equation from truck axle weight and axle spacing for all axles or groups is:

$$ESAL = \left(\frac{W_1}{W_2}\right)^{4.3}$$

where:

W_1 = weight in kips of the loaded axle or axle group.

W_2 = weight in kips of the standard axle or axle group (see Table 6-2)

The total ESAL value, i.e., load factor, for that truck is the sum of ESAL values for all axles and axle groups of that truck.

The load factor for each truck category is determined by averaging the total ESAL values for all trucks in that category. See Table 6.1

6.3 Calculate Design ESALs

Estimate total ESALS for the design period by projecting forward the construction year ESALS for each truck category.

6.3.1 Outline of Computation Steps

1. Obtain basic information from traffic/planning personnel. These data are based on studies of scalehouse data, weigh- in-motion data, traffic counts, administrative studies/projections, and miscellaneous observations.
    - AADTs for base year (both directions). Base year data is a best estimate of design data for the design location and for a specific year—usually for the year that the project is being designed. Using compound growth calculations, a past year or future year, AADT may be calculated from the base year AADT. The base year must be identified by whoever supplies the AADT data.
    - Traffic growth rate (% per year) from base year
        - Forward

- Backcast (if applicable for historical ESAL calculations)

- Number of driving lanes
- Lane split(s)
  - Determine design lane as lane having highest portion of lane split
- Load factor information for each truck category
- Percent of AADT in each truck category

To facilitate collecting previously indicated data, submit a request to your regional planning section. Traffic reports and maps are also available online at: http://dot.alaska.gov/stwdplng/transdata/traffic_maps_home.shtml.[21] Large projects may require more than one pavement structural design which, in turn, requires multiple sets of traffic data. Exercise engineering judgment to determine if more than one pavement design is required for your project. In general, road segments within a project that are expected to have significantly different traffic volumes and/or vehicular mix may warrant separate pavement designs.

2. For the year of construction, determine number of ESALs in each truck category based on AADT of the design lane.

   a. Calculate total AADT for year of construction using $i_{\text{B to D}}$ and "single payment" compound amount factor $P = (1 + i_{B\ to\ D})^n$

      where:

      n = year of construction – base year

      $i_{\text{B to D}}$ = growth rate from base year to last year of design period

      Construction year AADT = (base year AADT) × (P); (values for *i* and *n* are obtained from the traffic section).

   b. Calculate construction year AADT in the design lane.

      Construction year design lane AADT = (construction year total AADT) × (% AADT in design lane/100)

   c. For each truck category, calculate the construction year ESALs in the design lane. Use the following equation for each truck category.

      Construction year ESALs for truck category = (construction year AADT in design lane) × (%total AADT in truck category/100) × (load factor for truck category) × 365

   d. Calculate the total of construction year ESALs for all truck categories.

      Total construction year ESALs = Σ construction year ESALs for every truck category

3. Calculate total number of ESALs for each truck category accumulated from the year of construction through the end of the design period.

   Calculate total ESALs for design. Project total construction year ESALs for all truck categories (calculated in step 2d) forward to end of design period using $i_{\text{B to D}}$ and "uniform series," compound amount factor $[(1 + i)^n – 1] / i$

   where:

   n = last year of design period – construction year

Total design ESALs = (total construction year ESALs) × (compound amount factor)

6.3.2 An Example (Calculate Design ESALs Forward in Time)

Input Data:

The project will be constructed in 2021 and has a 15-year design life (end year of design period = 2036). Design work was done in 2019, the base year chosen for estimating the AADT growth rate.

For this example, Table 6.3 shows an example of basic traffic data obtained,

Table 6-3 Example Traffic Data

Base Year: 2019	Construction Year: 2021	Lane Distribution (% AADT)	
Base Year AADT: 1,600		Lane 1	60 (50 Historic)
AADT Growth Rate:		Lane 2	40 (50 Historic)
Forward (%/year): 2.5	End Year: 2036		
Past (%/year): 1.6	Begin Year: 2006		

Truck Category	Load Factor (ESALS/Truck)	% of total AADT
2-axle	0.50	2
3-axle	0.85	4
4-axle	1.20	4
5-axle	1.55	3
≥6-axle	2.24	1

Calculations:

Design ESAL computations for this example follow the Section 6.3.1 outline.

Step 1

Already completed with the collection of the indicated input data (use Table 6-3).

Step 2

a. Construction year total AADT = (base year total AADT) × $(1+i_{\text{B to D}})^n$ = (1600) × $(1+0.025)^2$ = 1,681

b. Construction year AADT in design lane = (construction year total AADT) × (% AADT in design lane/ 100) = (1681) × (0.6) = 1,009

c. Construction year ESALs for specific truck category = (construction year AADT in design lane) × (% of total AADT in truck category/100) × (load factor for truck category) × 365

See rows of computations in Table 6-4.

d. Total construction year ESALs = Σ of construction year ESALs for all truck categories = 3,683 + 12,522 + 17,678 + 17,125 + 8,250 = 59,258

See summation in Table 6-4.

Table 6-4 Computation of Construction Year ESALs

	(1)	(2)	(3)	(4)
Truck Category	Load Factor (ESALS/Truck)	% of total AADT	Lane AADT	ESALs in Construction Year
2-axle	0.5	2	1,009	3,683
3-axle	0.85	4	1,009	12,522
4-axle	1.2	4	1,009	17,678
5-axle	1.55	3	1,009	17,125
≥6-axle	2.24	1	1,009	8,250
	Total ESALS in Construction Year:			59,258

Truck Category ESALs in Construction year(4) = (1) X (2) X (3) X 3.65

$$Total\ design\ ESALs = (total\ construction\ year\ ESALs \times [(1 + i_{B\ to\ D})^n - 1]/i_{B\ to\ D}$$
$$= (59258) \times \frac{[(1 + .025)^{15} - 1]}{.025} = 1{,}062{,}610$$

6.4 Historical ESALs

For rehabilitation projects, the historical ESALs are required for the analysis of the remaining pavement life. If historical AADTs exist for each year since the last pavement construction project, calculate ESALs for each year to the present—using methods in Section 6.3. The total historical ESAL is the sum of the past yearly ESALs. If load factors for past years are not available, use base year (present) load factors, and perhaps adjust based on careful consideration and judgment. Past growth rate information must be obtained from planning personnel. Request that historical traffic data if historical ESALs need to be calculated. After obtaining the historical growth rate from planning and collecting or estimating the other input data, calculate historical ESALs using the same steps outlined in Section 6.3.1.

6.4.1 An Example (ESAL Calculation Extended Backwards and Based on Previous Example)

Input Data:

Input data for calculating historical ESALs are like those used for calculating future ESALs (see section 6.3.2 example) except that data come from the construction year and years prior to that time.

The project will be constructed in 2021 and the backward (backcast) projection of ESALs will extend to the previous surfacing application in 2006, i.e., the historical construction year.

Use data pertaining to historical ESAL calculations in Table 6-3. Since construction work will be done in 2021, this now becomes the "base" year for estimating the AADT in 2006.

AADT for (2021) = 1,681 (from previous example)

The traffic growth rate from the last historical construction event (2006) to the original base year (2019) of design period was 1.6% (this historical growth rate is identified as $i_{\text{H to C}}$)

Load factors and percent of AADT in each truck category are the same data used in the previous example for projecting ESALs into the future (a simplification for this example). For historical ESAL projections, use actual historical truck category data if they are available.

Calculations:

Historical ESAL computations generally follow the method outlined in Section 6.3.1.

Step 1

Already completed with the collection of the indicated input data (use Table 6.3).

Step 2

a. $Historical\ construction\ year\ total\ AADT = (construction\ year\ AADT) \times \frac{1}{(1+i_{H\ to\ C})^n}$

$$= \frac{(1681)}{(1 + 0.016)^{15}} = 1325$$

Where:

$i_{\text{H to C}} = 0.016$

n = construction year – historical construction year = 2021 – 2006 = 15

b. Historical construction year AADT in design lane = (historical construction year total AADT) × (historical % of total AADT in truck lane/100) = (1325) × (0.5) = 663

c. Historical construction year ESALs for specific truck category = (historical construction year AADT in design lane) × (historical % of total AADT in truck category/100) × (historic load factor for truck category) × 365

See Table 6-5

d. Total construction year ESALs = Σ of construction year ESALs for all truck categories

= 2,420 + 8,228 + 11,616 + 11,253 + 5,421 = 38,938

See summation in Table 6-5.

Table 6-5 Historical Construction Year ESAL Calculations

	(1)	(2)	(3)	(4)
Truck Category	**Load Factor (ESALS/Truck)**	**% of total AADT**	**Historical Lane AADT**	**ESALs in Historical Construction Year**
2-axle	0.5	2	663	2,420
3-axle	0.85	4	663	8,228
4-axle	1.2	4	663	11,616
5-axle	1.55	3	663	11,253
≥6-axle	2.24	1	663	5,421
Total ESALS in Historical Construction Year:				38,938

Truck Category ESALs in Construction year(4) = (1) X (2) X (3) X 3.65

Step 3

$$Total\ historical\ ESALs = (total\ historical\ construction\ year\ ESALs) \times [(1 + i_{H\ to\ C})^{n} - 1]/i_{H\ to\ C}$$

$$= (39{,}938) \times [(1 + 0.016)^{15} - 1]/0.016 = 654{,}247$$