Lect. 7 ***Pavement Structural Design***

Flexible Pavement Design-Part2
(AASHTOO Method , Design variables)

Main Sources

- *"AASHTO Guide for Design of Pavement Structures 1993", AASHTO, American Association of State Highway and Transportation Officials, U.S.A., 1993.*
- *Yaug H. Huang, "Pavement Analysis and Design", Prentic Hall Inc., U.S.A., 2004.*
- *Nicholas J. Garber and Lester A. Hoel."Traffic and Highway Engineering", Fourth Edition.*
- *Yoder; E. J. and M. W. Witczak, "Principles of Pavement Design", A Wiley- Interscience Publication, John Wiley & Sons Inc., U.S.A., 1975.*
- *A.T. Papagiannakis and E. A. Masad "Pavement Design and Materials", 2008, Published by john Wiley & Sons, Inc.*

2. AASHTO (The American Association of State Highway and Transportation Officials) Guide design.

The design procedure recommended by the American Association of State Highway and Transportation Officials (AASHTO) is based on the results of the extensive AASHO Road Test conducted in Ottawa, Illinois, in the late 1950s and early 1960s. The AASHO Committee on Design first published an interim design guide in 1961. It was revised further.

In 1984-85, the Subcommittee on Pavement Design and a team of consultants revised and expanded the guide under NCHRP Project 20-7/24; they issued the guide in 1986. The guide was revised in 1993 with practically no change in the design method presented in this section.

Design variables:

- **Time Constraints**
- **Pavement Performance (Loss in serviceability)**
- **Environment effect**
- **Traffic**
- **Reliability**

- **Time Constraints**

To achieve the best use of available funds, the AASHTO design guide encourages the use of a longer analysis period for high-volume facilities, including at least one rehabilitation period.

Thus, the analysis period should be equal to or greater than the performance period.

Performance Period refers to the time that an initial pavement structure will last before it needs rehabilitation or the performance time between rehabilitation operations. It is equivalent to the time elapsed as a new, reconstructed, or rehabilitated structure deteriorates from its initial serviceability to its terminal serviceability.

The designer must select the performance period within the minimum and maximum allowable bounds that are established by agency experience and policy.

The selection of performance period can be affected by such factors:

- ✓ The functional classification of the pavement.
- ✓ The type and level of maintenance applied.
- ✓ The funds available for initial construction.
- ✓ Life cycle costs.

and other engineering considerations.

Analysis Period

Analysis Period is the period of time that any design strategy must cover. It may be identical to the selected performance period. However; realistic performance limitations may necessitate the consideration of staged construction or planned rehabilitation for the desired analysis period.

In the past, pavements were typically designed and analyzed for a 20-year performance period. It is now recommended that consideration be given to longer analysis periods, because they can be better suited for the evaluation of alternative long-term strategies based on life cycle costs.

Table 11.13 contains general guidelines for the length of the analysis period.

TABLE 11.13 Guidelines for Length of Analysis Period

Highway conditions	Analysis period (years)
High-volume urban	30–50
High-volume rural	20–50
Low-volume paved	15–25
Low-volume aggregate surface	10–20

Source. After AASHTO (1986).

- **Pavement Performance (Loss in serviceability)**

The ability of a specific section of pavement to serve high speed, high volume, and mixed traffic in its existing condition or PSI is defined as "Ability of a pavement to serve the traffic for which it is designed". The primary factors considered under pavement performance are the structural and functional performance of the pavement.

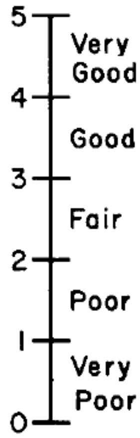
Structural performance is related to the physical condition of the pavement with respect to factors that have a negative impact on the capability of the pavement to carry the traffic load. These factors include cracking, faulting, raveling, and so forth.

Functional performance is an indication of how effectively the pavement serves the user. The main factor considered under functional performance is riding comfort.

To quantify pavement performance, a concept known as the ***serviceability performance*** was developed.

Under this concept, a procedure was developed to determine *the present serviceability index (PSI)* of the pavement, based on its roughness and distress, which were measured in terms of extent of cracking, patching, and rut depth for flexible pavements.

- The original expression developed gave the PSI as a function of the extent and type of cracking and patching and the slope variance in the two wheel paths which is a measure of the variations in the longitudinal profile in rating form (The Present Serviceability Rating (PSR)), from 0 to 5, where 0 is the lowest PSI and 5 is the highest. It reflects the users' opinion.



- Two serviceability indices are used in the design procedure: the initial serviceability (pi) and terminal serviceability index (pt),
  - The initial serviceability index (pi) which is the serviceability index immediately after the construction of the pavement. It is a function of pavement type and construction quality. A value of **4.2** was used for pi for flexible pavements.
  - The terminal serviceability index (pt), which is the minimum acceptable value before resurfacing or reconstruction is necessary. Recommended values for the terminal serviceability index are **2.5 or 3.0 for major highways and 2.0 for highways with a lower classification**. In cases where economic constraints restrict capital expenditures for construction, the pt can be taken **as 1.5,** or the performance period may be reduced.

$$PSI = 5.03 - 1.91 log1 + SV - 1.38 (RD) 2 - 0.01 (C+P) 12$$

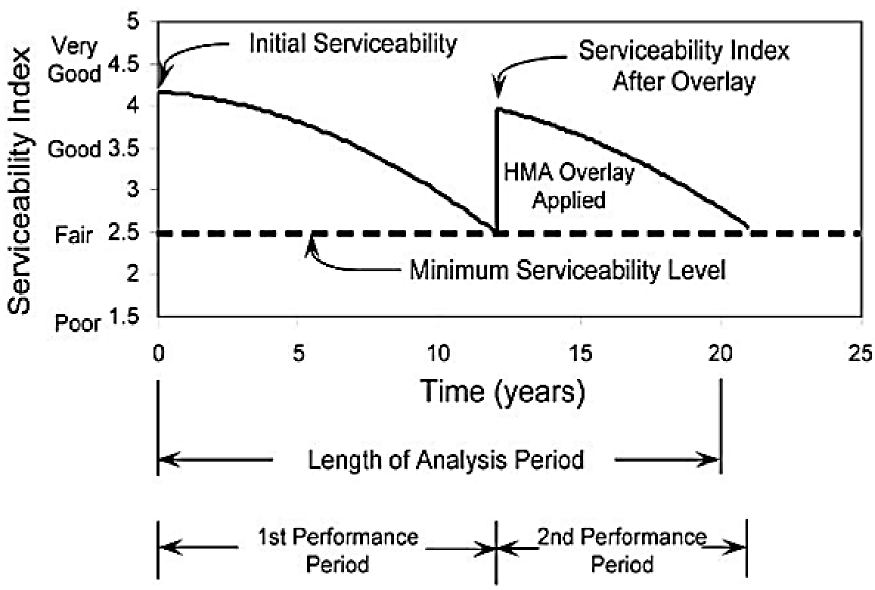
Where SV = slope variance (measure of longitudinal surface irregularities (roughness)

RD = average rut depth (inches / 4 feet straight edge)

C = area of cracking in ft2 per 1000 ft2

P = area of patching in ft2 per 1000 ft2

$$\Delta PSI = PSI_o - PSI_t$$
$$= Pi - Pt$$



➢ Environment effect

The AASHO design equations were based on the results of traffic tests over a two-year period. The long-term effects of temperature and moisture on the reduction of serviceability were not included. If problems of swell clay and frost heave are significant in a given region and have not been properly corrected, the loss of serviceability over the analysis period should be estimated and added to that due to cumulative traffic loads. Figure 11.23 shows the serviceability loss versus time curves for a specific location.

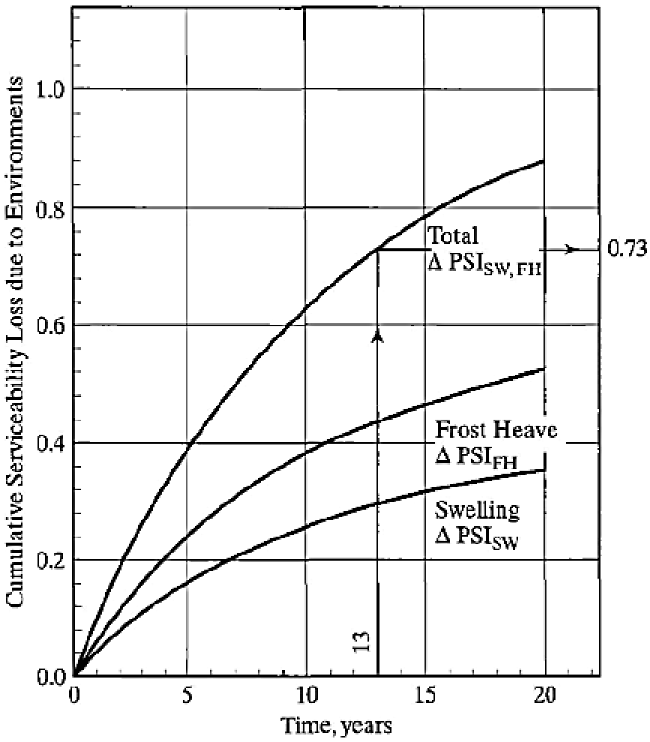


FIGURE 11.23
Environmental serviceability loss versus time for a specific location. (From the *AASHTO Guide for Design of Pavement Structures*. Copyright 1986. American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.)

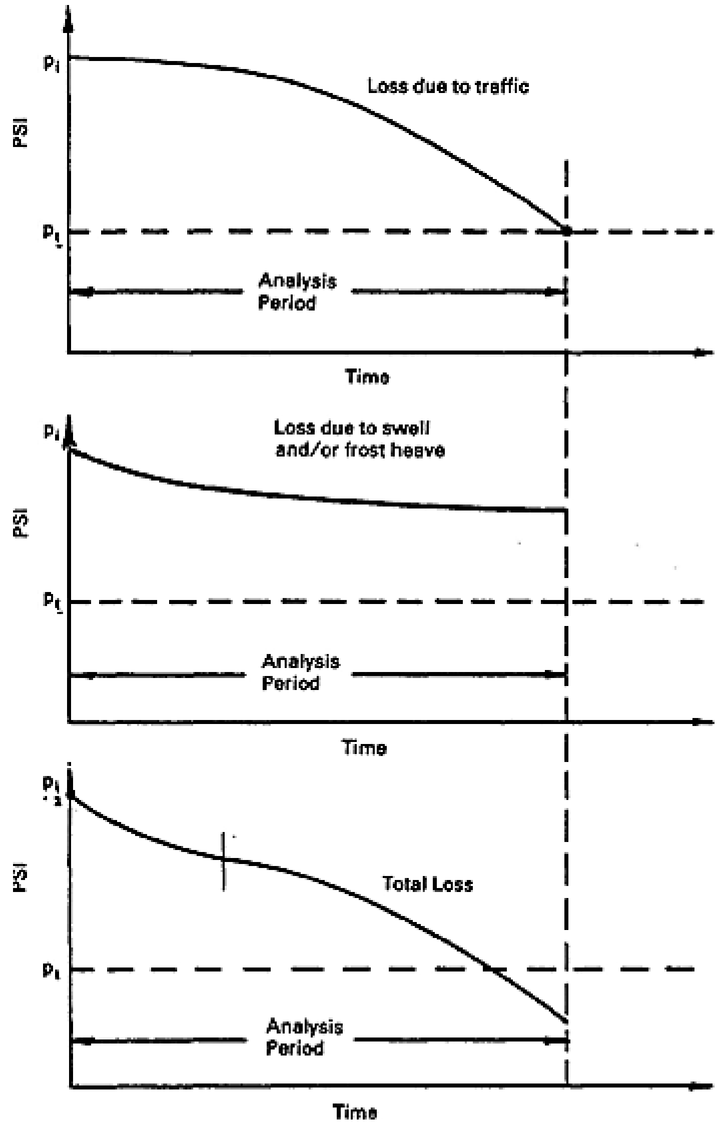
The environmental loss is a summation of losses from both swelling and frost heave. The chart may be used to estimate the serviceability loss at any intermediate period, for example, a loss of 0.73 at the end of 13 years. Of course, if only swelling or frost heave is considered, there will be only one curve on the graph. The shape of these curves indicates that the serviceability loss due to environment increases at a decreasing rate. This may favor the use of stage construction because most of the loss will occur during the first stage and can be corrected with little additional loss in later stages

$$\Delta PSI = \Delta\ PSI\ Traffic + \Delta\ PSI\ Environment$$

ΔPSI = Total loss of serviceability during a specific period of time in years.

Δ PSI Traffic = Serviceability loss due to traffic (ESAL’s)

Δ PSI Environment = Serviceability loss due to effect of swelling and /or frost heave of roadbed soil



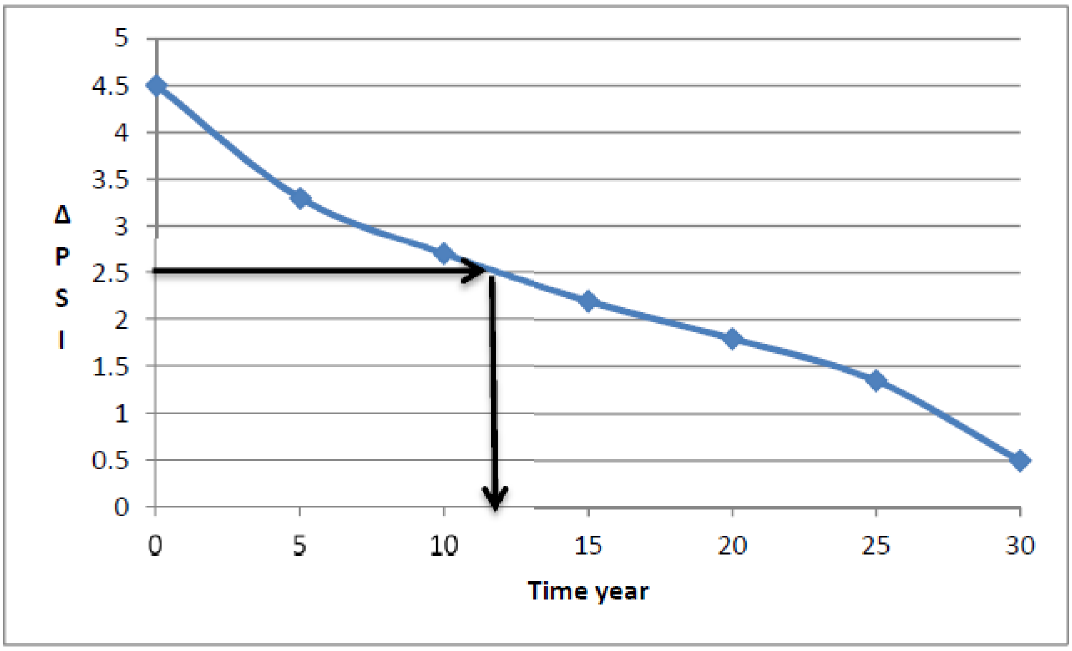
Example : For the following highway pavement information find performance period if Po = 4.5, Pt =2.5, analysis period = 30 yr

Time (year)	0	5	10	15	20	25	30
Loss in PSI due to Environmental	0	0.3	0.5	0.7	0.9	1.25	2
Loss in PSI due to traffic	0	0.9	1.3	1.6	1.8	1.9	2

Solution :

$$\Delta PSI = \Delta \ PSI \ Traffic + \Delta \ PSI \ Environment$$

Time (year)	0	5	10	15	20	25	30
Loss in PSI due to Environmental	0	0.3	0.5	0.7	0.9	1.25	2
Loss in PSI due to traffic	0	0.9	1.3	1.6	1.8	1.9	2
Total Loss	0	1.2	1.8	2.3	2.7	3.15	4
ΔPSI =(Pi –Total loss)	4.5	3.3	2.7	2.2	1.8	1.35	0.5



➢ Reliability

Basically, reliability is a means of incorporating some degree of certainty into the design process to ensure that the various design alternatives will last the analysis period.

The level of reliability to be used for design should increase as the volume of traffic, difficulty of diverting traffic, and public expectation of availability increase. Table 11.14 presents recommended levels of reliability for various functional classifications.

TABLE 11.14 Suggested Levels of Reliability for Various Functional Classifications

Functional classification	Recommended level of reliability	
	Urban	Rural
Interstate and other freeways	85–99.9	80–99.9
Principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

Note. Results based on a survey of AASHTO Pavement Design Task Force.
Source. After AASHTO (1986).

Application of the reliability concept requires the selection of a standard deviation that is representative of local conditions. It is suggested that standard deviations of **0.49 be used for flexible pavements and 0.39 for rigid pavements**.

When stage construction is considered, the reliability of each stage must be compounded to achieve the overall reliability; that is,

$$R_{stage} = (R_{overall})^{1/n}$$

in which n is the number of stages being considered . For example, if two stages are contemplated and the desired level of overall reliability is 95%, the reliability of each stage must be $(0.95)^{(1/2)}$, or 97.5% .

- **Traffic**

The design procedures are based on cumulative expected 18-kip (80-kN) equivalent single-axle load (ESAL).

- If a pavement is designed for the analysis period without any rehabilitation or resurfacing, all that is required is the total ESAL over the analysis period.

- If stage construction is considered and rehabilitation or resurfacing is anticipated, a graph or equation of cumulative ESAL versus time is needed so that the ESAL traffic during any given stages can be obtained.

  In the AASHTO design method, the traffic load is determined in terms of the number of repetitions of an 18kips (18,000-lb or 80 kilonewtons (kN)) single-axle load applied to the pavement on two sets of dual tires. This is usually referred to as the *equivalent single-axle load* (ESAL). The dual tires are represented as two circular plates, each 4.51 in. radius, spaced 13.57 in. apart. This representation corresponds to a contact pressure of 70 lb/in.

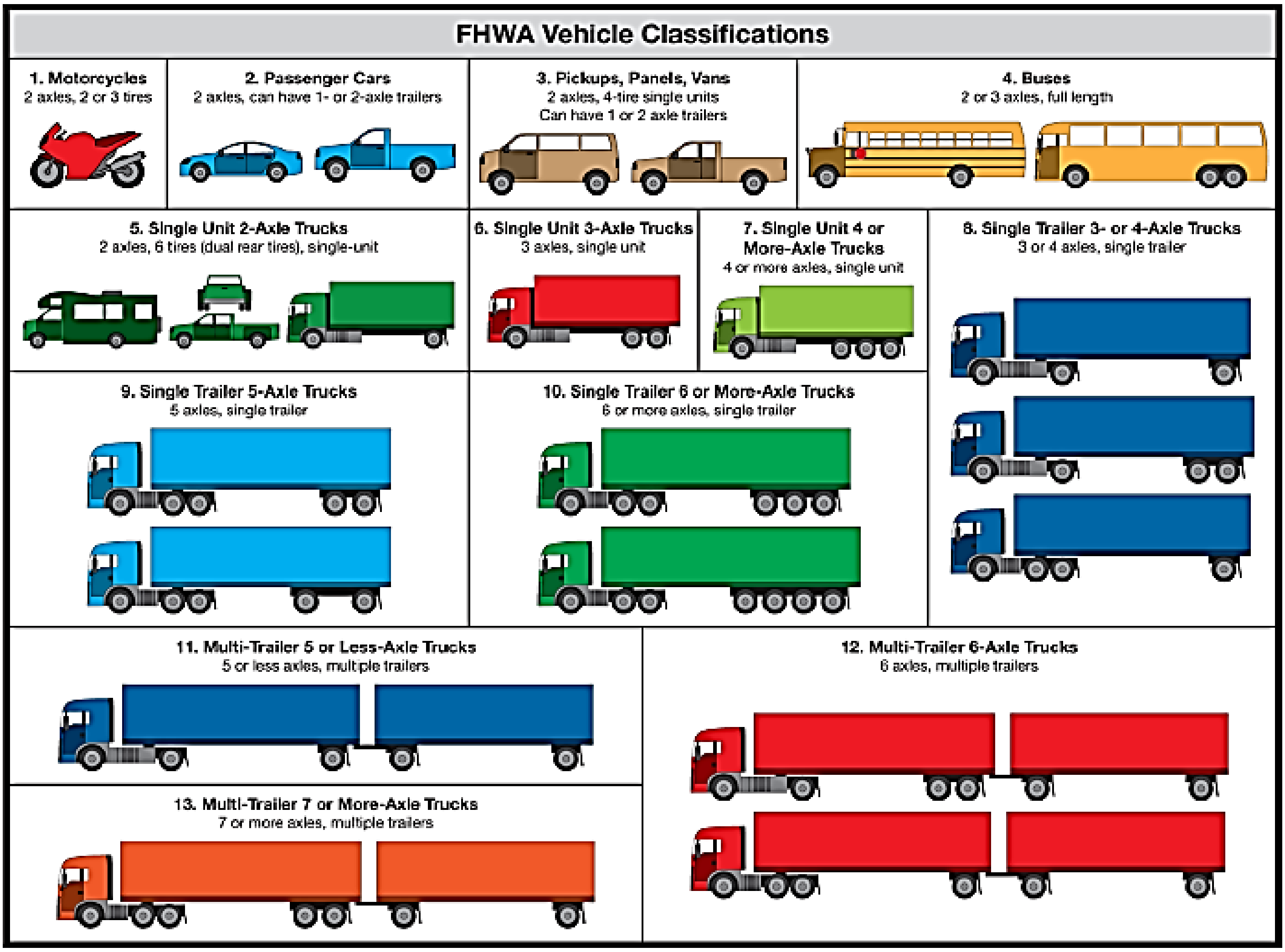
  To determine the ESAL, the following variables should be identified:

- ***Average Daily Truck Traffic***

  The minimum traffic information required for a pavement design is the average daily truck traffic (ADTT) at the start of the design period. The ADTT may be expressed as a percentage of ADT or as an actual value. This information can be obtained from the actual traffic counts on the existing roadway where the pavement is to be constructed or on nearby highways with similar travel patterns.

  Traffic volume maps showing the ADT, sometimes with the percentage of trucks, on various roadways within a given area may also be used, although they are far less accurate than the actual counts. The traffic counts must be adjusted for daily (weekday versus weekend) and seasonal (summer versus winter) variations to obtain the annual average daily traffic (AADT).

- ***The number of different types of vehicles (mix traffic)*** such as cars, buses, single-unit trucks, and multiple-unit trucks expected to use the facility during its lifetime must be known. The distribution of the different types of vehicles expected to use the proposed highway can be obtained from results of classification counts that are taken by state highway agencies at regular intervals. The initial daily traffic is in two directions over all traffic lanes.



- ***Equivalent Axle Load factors:*** An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, usually 18-kip (80-kN) single-axle load.

The design is based on the total number of passes of the standard axle load during the design period, defined as the equivalent single-axle load (ESAL)

$$\text{ESAL} = \sum_{i=1}^{m} F_i\, n_i \qquad (6.19)$$

in which m is the number of axle load groups,

F_i is the EALF for the i^{th}-axle load group,

n_i is the number of passes of the i^{th}-axle load group during the design period.

The EALF depends on the type of pavements, thickness or structural capacity, and the terminal conditions at which the pavement is considered failed.

Most of the EALFs in use today are based on experience.

One of the most widely used methods is based on the empirical equations developed from the AASHO Road Test.

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18 + 1) - 4.79\log(L_x + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \tag{6.20a}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \tag{6.20b}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(\text{SN} + 1)^{5.19}L_2^{3.23}} \tag{6.20c}$$

In these equations,

W_{tx} is the number of x-axle load applications at the end of time t;

W_{t18} is the number of 18-kip (80-kN) single-axle load applications to time t;

Lx *is* the load in kip on one single axle, one set of tandem axles, or one set of tridem axles;

L2 is the axle code (1 for single axle, *2* for tandem axles, and *3* for tridem axles);

SN is the structural number, which is a function of the thickness and modulus of each layer and the drainage conditions of base and subbase;

p_t is the terminal serviceability, which indicates the pavement conditions to be considered as failures ;

Gt is a function of Pt;

β_{18} is the value of βx when *Lx* is equal to 18 and *L2* is equal to one.

Note that

$$\text{EALF} = \frac{W_{t18}}{W_{tx}} \tag{6.21}$$

Tables of equivalent factors for SN values of 1, 2, 3, 4, 5, and 6 and *pt* values of 2, 2.5, and 3 can be found in the AASHTO design guide. (Tables D.1 to D.9)

Example

Given *pt* = 2.5 and SN = 5, determine the EALF for a 32-kip (151-kN) tandem-axle load and a 48-kip (214-kN) tridem-axle load.

Solution:

For the tandem axles, *L*x = 32 and L_2 = 2, from Eq. 6.20,

G, = log(1.7/2 .7) = -0.201,

$\beta x = 0.4 + 0.081\ (32 + 2)^{3.23}/[(5 + 1)^{5.19}\ (2)^{3.23}] = 0.470$,

$\beta_{18} = 0.4 + 0.081\ (18 + 1)^{3.23} / (5 + 1)^{5.19} = 0.5$, a

Log (W*tx/W*t18) = 4.79 log 19 - 4.79 log (32 + 2) + 4.33 log 2 - 0.201/0.47 + 0.201/0.5= 0.067,

or W*tx/W*t18= 1.167

From Eq. 6.21, EALF = 0.857, which is exactly the same as that shown in Table D.5

For the tridem (triple) axles, *Lx* = 48, *L2* = 3,

from Eq. 6.20, $\beta x = 0.4 + 0\ .081(48 + 3)^{3.23}/[(5 + 1)^{5.19}\ (3)^{3.23}] = 0.470$,

log (W*tx/W*t18) =4.79 log 19-4.79 log(48 +3)+4.33 log3- 0.201/0.47 + 0.201/0.5=-0.0139,

or *Wtx/W*r18 = 0 .968.

From Eq. 6.21, EALF =1.033, as shown in Table D.6.

- ***The design period (The analysis period),*** it is the number of years the pavement will effectively continue to carry the traffic load without requiring an overlay. Flexible highway pavements are usually designed for a 20-year period. Use table 11.13 to determine the analysis year.

TABLE 11.13 Guidelines for Length of Analysis Period

Highway conditions	Analysis period (years)
High-volume urban	30–50
High-volume rural	20–50
Low-volume paved	15–25
Low-volume aggregate surface	10–20

Source. After AASHTO (1986).

- ***The traffic growth factor***. Since traffic volume does not remain constant over the design period of the pavement, it is essential that the rate of growth be determined and applied when calculating the total ESAL.

  Annual growth rates can be obtained from regional planning agencies or from state highway departments. These usually are based on traffic volume counts over several years.

  It also is advisable to determine annual growth rates separately for trucks and passenger vehicles, since these may be significantly different in some cases.

  The overall growth rate in the United States is between 3 and 5 percent per year, although growth rates of up to 10 percent per year have been suggested for some interstate highways.

  The growth factors (*Grn*) for different growth rates and design periods can be obtained from Equation 6.33.

$$G_{rn} = [(1 + r)^n - 1]/r \qquad \ldots 6.33$$

where

$r = \frac{i}{100}$ and is not zero. If annual growth is zero, growth factor = design period

i = growth rate

n = design life, yrs

Tables 6.12 and 6.13 shows calculated growth factors (*Grn*) for different growth rates (*r*) and design periods (*n*) which can be used to determine the total ESAL over the design period.

TABLE 6.12 Traffic Growth Factors

Annual growth rate (%)	20-Year design period	40-Year design period
1.0	1.1	1.2
1.5	1.2	1.3
2.0	1.2	1.5
2.5	1.3	1.6
3.0	1.3	1.8
3.5	1.4	2.0
4.0	1.5	2.2
4.5	1.6	2.4
5.0	1.6	2.7
5.5	1.7	2.9
6.0	1.8	3.2

Source. After PCA (1984).

Table 6.13

Design Period, Years (n)	Annual Growth Rate, Percent (r)							
	No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

SOURCE: *Thickness Design–Asphalt Pavements for Highways and Streets,* Manual Series No. 1, The Asphalt Institute, Lexington, KY, February 1991. Used with permission.

The lane distribution factors. The initial daily traffic is in two directions over all traffic lanes and must be multiplied by the directional and lane distribution factors to obtain the initial traffic on the design lane.

Either lane of a two-lane highway can be considered as the design lane whereas for multilane highways, the outside lane is considered. The identification of the design lane is important because in some cases more trucks will travel in one direction than in the other or trucks may travel heavily loaded in one direction and empty in the other direction. Thus, it is necessary to determine the relevant proportion of trucks on the design lane which are shown in table 6.16.

- ***The Traffic Distribution by Direction***: The initial daily traffic is in two directions Direction distribution is usually made by assuming 50 % of the traffic and each direction unless special conditions weren't same other.

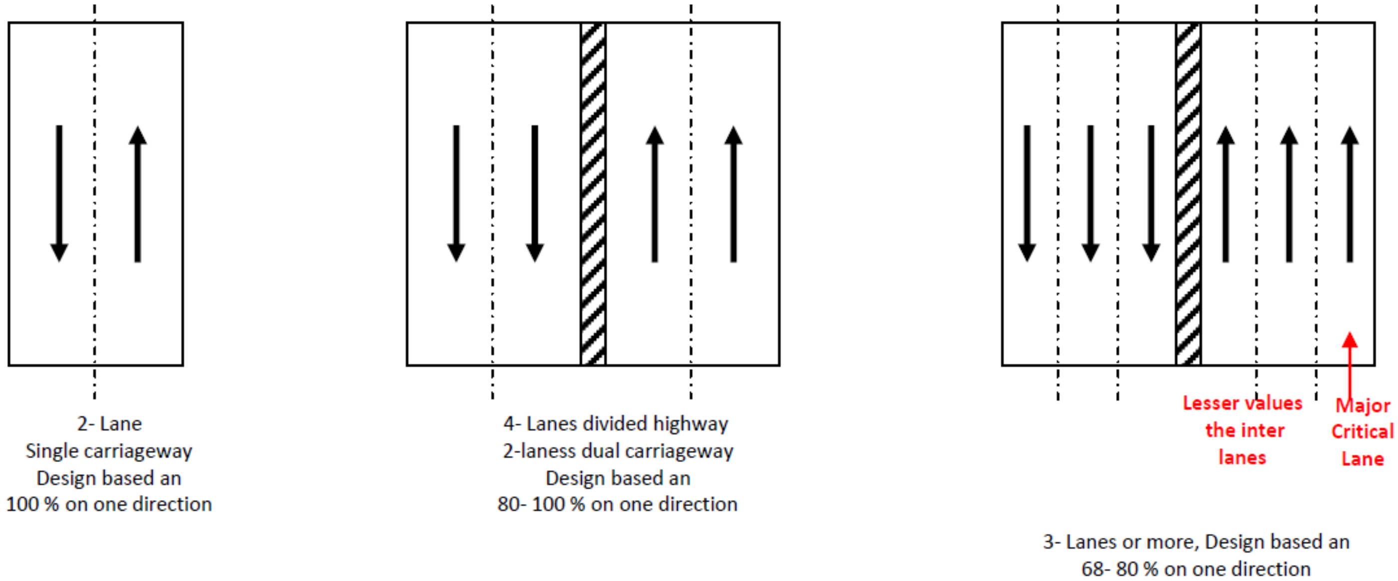


TABLE 6.16 Lane Distribution Factor

No. of lanes in each direction	Percentage of 18-kip ESAL in design lane
1	100
2	80–100
3	60–80
4	50–75

Source. After AASHTO (1986).

Determination of ESWAL

If *n,* is the total number of load repetitions to be used in design for the ith load group, then

$$n_i = (n_0)_i(G)(D)(L)(365)(Y) \quad (6.26)$$

in which (n_o) i is the initial number of repetitions per day for the ith load group,
G is the growth factor,
D is the directional distribution factor, which is usually assumed to be 0.5 unless the traffic in two directions is different,
L is the lane distribution factor
Y is the design period in years.

If the design is based on the equivalent 18-kip (80-kN) single-axle load, then the initial number of repetitions per day for the ith load group can be computed from

$$(n_0)_i = (p_iF_i)(\text{ADT})_0(T)(A) \quad (6.27)$$

in which *pi* is the percentage of total repetitions for the ith load group,
F is the equivalent axle load factor (EALF) for the ith load group,
(ADT)o is the average daily traffic at the start of the design period,
T is the percentage of trucks in the ADT
A is the average number of axles per truck. Substituting Eq. 6.27 into 6.26 and summing over all load groups, the equivalent axle load for the design lane is

$$\text{ESAL} = \left(\sum_{i=1}^{m} p_i\, F_i\right)(\text{ADT})_0(T)(A)(G)(D)(L)(365)(Y) \quad (6.28)$$

In computing ESAL, it is convenient to combine the first and fourth terms in Eq.6.28 to form a new term called the truck factor:

$$T_f = \left(\sum_{i=1}^{m} p_i\, F_i\right)(A) \quad (6.29)$$

T_f is the number of 18-kip (80-kN) single-axle load applications per truck. Thus, Eq. 6.28 becomes

$$\text{ESAL} = (\text{ADT})_0(T)(T_f)(G)(D)(L)(365)(Y) \qquad (6.30)$$

Example 19.1

An eight-lane divided highway is to be constructed on a new alignment. Traffic volume forecasts indicate that the average annual daily traffic (AADT) in both directions during the first year of operation will **be 12,000 with** the following vehicle mix and axle loads.

Passenger cars (1000 lb/axle) = 50%

2-axle single-unit trucks (6000 lb/axle) = 33%

3-axle single-unit trucks (10,000 lb/axle) = 17%

The vehicle mix is expected to remain the same throughout the design life of the pavement. If the expected annual traffic growth rate **is 4%** for all vehicles, determine **the design ESAL**, given a design period of **20 years**. The percent of traffic on the design lane **is 45%,** and the pavement has a terminal serviceability index ***(pt)* of 2.5** and **SN of 5**.

Solution:

The following data apply:

Growth factor = 29.78 (from Table 6.13)

Percent truck volume on design lane = 45

Load equivalency factors (from Table D.1-D.9)

Passenger cars (1000 lb/axle) =0.00002 (negligible)

2-axle single-unit trucks (6000 lb/axle) = 0.010

3-axle single-unit trucks (10,000 lb/axle) = 0.088

Design Period, Years (n)	Annual Growth Rate, Percent (r)							
	No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

SOURCE: *Thickness Design–Asphalt Pavements for Highways and Streets,* Manual Series No. 1, The Asphalt Institute, Lexington, KY, February 1991. Used with permission.

Table D.4. Axle Load Equivalency Factors for Flexible Pavements, Single Axles and p_t of 2.5

Axle Load (kips)	Pavement Structural Number (SN) 1	2	3	4	5	6
2	0004	0004	0003	0002	0002	0002
4	003	004	004	003	002	002
6	011	017	017	013	010	009
8	032	047	051	041	034	031
10	078	102	118	102	088	080
12	168	198	229	.213	189	176
14	328	358	399	388	360	342
16	591	613	646	645	623	606
18	1 00	1 00	1 00	1 00	1 00	1 00
20	1 61	1 57	1 49	1 47	1 51	1 55
22	2 48	2 38	2 17	2 09	2 18	2 30
24	3 69	3 49	3 09	2 89	3 03	3 27
26	5 33	4 99	4 31	3 91	4 09	4 48
28	7 49	6 98	5 90	5 21	5 39	5 98
30	10 3	9 5	7 9	6 8	7 0	7 8
32	13 9	12 8	10 5	8 8	8 9	10 0
34	18 4	16 9	13 7	11 3	11 2	12 5
36	24 0	22 0	17 7	14 4	13 9	15 5
38	30 9	28 3	22 6	18 1	17 2	19 0
40	39 3	35 9	28 5	22 5	21 1	23 0
42	49 3	45 0	35 6	27 8	25 6	27 7
44	61 3	55 9	44 0	34 0	31 0	33 1

The ESAL for each class of vehicle is computed from Eq. 19.2.

$$\text{ESAL} = (\text{ADT})_0(T)(T_f)(G)(D)(L)(365)(Y) \qquad (6.30)$$

$$\text{2-axle single-unit trucks} = 0.45 \times 29.78 \times 12{,}000 \times 0.33 \times 365 \times 2 \times 0.010 = 0.3874 \times 10^6$$

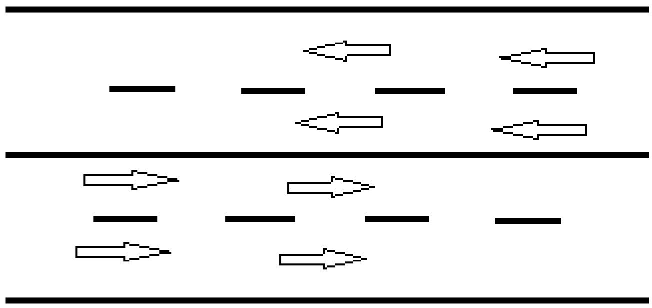
$$\text{3-axle single-unit trucks} = 0.45 \times 29.78 \times 12{,}000 \times 0.17 \times 365 \times 3 \times 0.0877 = 2.6343 \times 10^6$$

Thus,

$$\text{Total ESAL} = 3.0217 \times 10^6$$

It can be seen that the contribution of passenger cars to the ESAL is negligible. Passenger cars are therefore omitted when computing ESAL values. This example illustrates the conversion of axle loads to ESAL using axle load equivalency factors.

Example: The total AADT of a rural four lanes highway is 4600 V/day for two directions, if the annual rate of traffic growth is 2.5%. The percent and type of vehicles are shown in the table below, base year is 2000 and target year is 2020



Truck category	Load factor (ESALs per truck)	Percent of total AADT in truck category	Number of trucks per two direction
2-axles	0.5	10	460
3-axles	0.85	9	414
4-axles	1.2	6	276
5-axles	1.55	3	138
6-axles	2.24	2	92

Solution:

1- Count the number of vehicles for each type (column No.4)
2- Assume D factor, taken as 50%.
3- Find L because the highway is 4 lanes ,so there are two lanes in one direction, take L=85%

TABLE 6.16 Lane Distribution Factor

No. of lanes in each direction	Percentage of 18-kip ESAL in design lane
1	100
2	80–100
3	60–80
4	50–75

Design Period, Years (n)	Annual Growth Rate, Percent (r) No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
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30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

SOURCE: *Thickness Design–Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, KY, February 1991. Used with permission.

4- Calculate *G,* from question t=20 years, r= 0.025 , G=25.54

5. ESAL=D×L×365×25.54×460×0.5+414×0.85+276×1.2+138×1.55+92×2.44

ESAL= 0.5 ×0.85 ×365×25.54×1351.5= 5.35×10^{6} .