3. Traffic Loading and Volume

Traffic is the most important factor in pavement design and stress analysis. Traffic constitutes the load imparted on the pavement causing the stresses, strains and deflections in the pavement layers and the subgrade. Hence the pavement design must account for the amount of traffic load expected over its design life.

The traffic loads on pavement can be characterized by:

- Magnitude of load (wheel load or axle load)
- Configuration of load (axle and wheel configuration – single/dual wheel, single/tandem/tridem axle, wheel and axle spacing): these relate to the number of contact points per vehicle (no. of wheels) and their spacing. As spacing between wheels gets smaller, then their influence areas will overlap and one has to consider the combined effect of all interacting wheel loads instead of dealing with a single wheel load.
- Load repetitions: Loads, along with the environment, damage pavement over time. Each individual load (from commercial vehicles) inflicts a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.
- Other considerations include tire pressure, contact area, vehicle speed, traffic distribution across the pavement etc.

There are three different procedures for considering traffic effects in pavement design. These are:

- Fixed traffic
- Fixed vehicle
- Variable traffic and vehicle

3.1 Fixed Traffic Procedure

In fixed traffic procedure, the pavement design is made for a single wheel load only and the number of load repetition is not considered. If the pavement is subjected to multiple wheels, they must be converted to an equivalent single wheel load (ESWL), so that the design method based on single wheel can be applied.

This method has been used most frequently for airport pavements or for highway pavements to be used by heavy wheel loads but light traffic volume. Usually the heaviest wheel load anticipated is used for design purposes. This method is not so commonly used today. However, the concept of converting multiple-wheel loads to a single wheel load is important and discussed here.
3.1.1 Equivalent Single Wheel Load (ESWL)

The ESWL can be defined as the load on a single wheel that will induce an equivalent amount of response (stress, strain or deflection) on a given pavement system to that resulting from multiple-wheel load. The ESWL obtained from any theory depends on the criteria selected to compare the single-wheel load with multiple-wheel loads. The use of different criteria for the comparison of equivalent response (i.e. based on stress, strain or deflection) has an effect on the computed value of ESWL.

For flexible pavements, the ESWL can be determined from theoretically calculated or experimentally measured stress, strain, and deflections. It can also be determined from pavement distress and performance tests. It should be noted that any theoretical method can be used as a guide and should be verified by performance.

The comparisons of equal response (stress, strain, deflection) can be made by assuming equal contact pressure under both the equivalent single wheel and the multiple wheels or by assuming equal contact area under all wheels. Some of the methods used for converting multiple-wheel loads to an equivalent single wheel load include:

- Equal vertical stress criterion
- Equal vertical deflection criterion
- Equal tensile strain criterion
- Equal contact pressure criterion

For rigid pavements ESWL can be determined by comparing the critical flexural stress in the concrete.

A - Equal Vertical Stress Criterion

Boyd and Foster (1950) presented a semi rational method for determining ESWL based on the consideration of the vertical stress in an elastic half-space. The method assumes that the ESWL varies with the pavement thickness, as shown in figure 3.1 below.

The figure shows a total load $2P_d$ applied on a dual wheel assembly, with center to center spacing between tires of $S_d$ and clear distance between tire edges of $d$ ($d=S_d-2a$). For thicknesses (depth) smaller than half the clearance between dual tires, i.e. $d/2$, no stress overlap occurs and the stress at these depths is due to only one wheel of the dual, hence ESWL is equal to one half the total load ($\text{ESWL} = P_d$). For thickness greater than twice the center-to-center spacing of tires, i.e. $2S_d$, the subgrade stresses due to the two wheels overlap completely, hence ESWL is equal to the total load ($\text{ESWL} = 2P_d$). By assuming a straight-line relationship between thickness and wheel load on logarithmic scales, the ESWL for any intermediate thickness can be easily determined. After the ESWL for dual wheels is applied, the procedure can be applied to tandem wheels.
Fig. 3.1: Instead of plotting the pavement thickness and wheel load, it is more convenient to compute the ESWL by:

$$\log(ESWL) = \log P_d + \frac{0.301 \log(2z/d)}{\log(4S_d/d)}$$ \hspace{1cm} (3.1)

The vertical stress factor $\sigma_z/q$ discussed in chapter two (figure 2.2) can also be used to determine the theoretical ESWL based on Boussinesq’s theory. For the same vertical stress $\sigma_z$, at a depth $z$ both for the single and dual wheel load having the same contact radius $a$, the maximum subgrade stress under a single wheel occurs at the center of the applied load with the stress factor of $\sigma_z/q_s$, where $q_s$ is the contact pressure under a single wheel. The location of the maximum stress under dual wheels is not known and can be determined by comparing the stresses at different points: point 1 under the center of one tyre, point 3 at the center between tires and point 2 midway between points 1 & 3 (as illustrated in the example problem solved in class). The stress factor at each point is obtained by superposition of the two wheels and the maximum stress factor $\sigma_z/q_d$ is found, where $q_d$ is the contact pressure under dual wheels. Thus to obtain the same stress:

$$q_s \left( \frac{\sigma_z}{q_s} \right) = q_d \left( \frac{\sigma_z}{q_d} \right)$$ \hspace{1cm} (3.2)

No stresses overlap if pavement thickness is less than $2S_d$.

Complete stress overlap if pavement thickness is greater than $2S_d$. 

No stresses overlap if pavement thickness is less than $2S_d$. 

Complete stress overlap if pavement thickness is greater than $2S_d$. 

For the same contact radius, contact pressure is proportional to wheel loads, or

\[
\frac{P_s}{P_d} = \frac{\sigma_z / q_d}{\sigma_z / q_s}
\]

(3.3)

Where \(P_s\) is the single wheel load, which is the ESWL to be determined, and \(P_d\) is the load on each of the duals and \(q_s\) and \(q_d\) are the contact pressures under a single wheel and dual wheels respectively.

**B - Equal Vertical deflection Criterion**

In this method, developed by Foster and Ahlvin (1958), the pavement system is considered as a homogeneous half-space and the vertical deflections at a depth equal to the thickness of the pavement can be obtained from Boussinesq’s solutions. A single-wheel load that has the same contact radius as one of the dual wheels and results in a maximum deflection equal to that caused by the dual wheels is the ESWL.

The vertical deflection factor \(F\) presented in Chapter 2, figure 2.6 can be used to determine ESWL. The vertical deflection under the single wheel and the dual wheels is given by:

**Single wheel**

\[
W_s = \frac{q_s a}{E} F_s
\]

(3.4a)

**Dual wheels**

\[
W_d = \frac{q_d a}{E} F_d
\]

(3.4b)

Where \(F_d\) is the deflection factor for the duals (the maximum value obtained after superposing the deflection factors \(F_s\) for each wheel of the dual wheel assembly at the three critical points discussed previously) and \(F_s\) is deflection factor for single wheel.

To obtain equal deflection, \(W_s = W_d\), or;

\[
q_s F_s = q_d F_d
\]

(3.5)

For the same contact radius, contact pressure is proportional to wheel load:

\[
ESWL = P_s = \frac{F_d}{F_s} P_d
\]

(3.6)

The method discussed above is an improvement over the Boyd and Foster method. However, it assumes a homogeneous half space instead of a layered system which is not logical from the theoretical viewpoint. Determination of ESWL based on comparison of deflections determined from layered theory would give a better (ESWL of higher magnitude) result.
C - Equal Tensile Strain Criterion

The conversion factors discussed in chapter two (figure 2.12, page 9 and figure 2.23) for the critical tensile strain at the bottom of first layer can be used to determine the ESWL.

The tensile strain due to single wheel load is:

\[ e = \frac{q_s F_e}{E_1} \tag{3.7} \]

and the tensile strain under dual or dual-tandem wheels is

\[ e = \frac{C q_d F_e}{E_1} \tag{3.8} \]

in which \( C \) is the conversion factor (obtained from figure 2.23) and \( q_d \) is the contact pressure of dual or dual-tandem wheels. For the same tensile strain:

\[ q_s = C q_d \tag{3.9} \]

For equal contact radius, contact pressure is proportional to wheel load:

\[ ESWL = P_s = CP_d \tag{3.10} \]

D - Criterion based on Equal Contact Pressure

The above analyses of ESWL are based on the assumption that the single wheel has the same contact radius as each of the dual wheels. Another assumption, which has been frequently made, is that the single wheel has a different contact radius but the same contact pressure as the dual wheels.

The interface deflections for single and dual wheels with the same pressure can be written as

\[ W_s = \frac{q a_s}{E_2} F_s \tag{3.11} \]

\[ W_d = \frac{q a_d}{E_2} F_d \tag{3.12} \]

For equal deflection, \( W_s = W_d \)

\[ \frac{q a_s}{E_2} F_s = \frac{q a_d}{E_2} F_d \tag{3.13} \]
where,

\[ a_s = \sqrt{\frac{P_s}{\pi q}} \quad \text{and} \quad a_d = \sqrt{\frac{P_d}{\pi q}} \]  \hspace{1cm} (3.14)

Substituting equations 3.14 into equation 3.13 and simplifying:

\[ ESWL = P_s = \left( \frac{F_d}{F_s} \right)^2 P_d \]  \hspace{1cm} (3.15)

### 3.2 Variable Traffic and Vehicle

In this procedure, both traffic and vehicle are considered variable, so there is no need to assign an equivalent factor for each axle load. The various axle loads can be divided into a number of groups and the stresses, strains and deflections under each load group can be determined separately and used for design purposes. This procedure is most suited to mechanistic methods of design, wherein the responses of pavement under different loads can be evaluated by using a computer.

### 3.3 Fixed vehicle Procedure

In this procedure, the thickness of a pavement is governed by the number of repetitions of a standard vehicle or axle load (usually 80kN single axle load). Axle loads which are not equal to 80kN or consist of tandem or tridem axles must be converted to an 80kN single-axle load by an equivalent axle load factor (EALF).

EALF is defined as the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, (80KN). The number of repetitions under each single or multiple axle load must be multiplied by its EALF to obtain the equivalent effect based on an 80kN single axle load. A summation of the equivalent effects of all axle loads during the design period results in an equivalent single axle load (ESAL). ESAL is the design parameter to be used in pavement thickness design. Due to the great varieties of axle loads and traffic volumes and their intractable effects on pavement performance, most of the design methods in use today are based on the fixed vehicle procedure.

#### 3.3.1 Determination of EALF

The EALF depends on:

- Type of pavement,
- Thickness or structural capacity
- Terminal condition at which the pavement is considered failed,
- Failure criterion
- The condition of the deterioration of pavement at the time of evaluation, etc.
The most widely used method for determining EALF is based on empirical equations developed from the AASHO road test (AASHTO 1972). EALF can also be determined theoretically based on the critical stresses and strains in the pavement and the failure criteria.

### 3.3.2 EALF for Flexible Pavement

**AASHTO Equivalency Factors**

The following regression equation is one of the most widely used methods for determining EALF obtained from the AASHTO Road Test:

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

\[
G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)
\]

\[
\beta_x = 0.4 + \frac{0.081(L_x + L_2)^{3.23}}{(SN + 1)^{5.19} L_2^{3.23}}
\]

Where, \(W_{tx}\) = the number of x-axle load application at the end of time \(t\),

\(W_{t18}\) = the number of 18kip (80KN) single axle load application to time \(t\),

\(L_x\) = the load in kip on one single axle, one set of tandem axles, or one set of tridem axles,

\(L_2\) is the axle code: = 1 for single axles, 2 for tandem axles, and 3 for tridem axles,

\(SN\) = structural number - a function of thickness, modulus of each layer, and drainage condition of base and subbase.

\(p_t\) = terminal serviceability – which indicates the pavement conditions to be considered as failures,

\(\beta_{18}\) = the value of \(\beta_x\) when \(L_x = 18\) and \(L_2 = 1\)

And

\[
EALF = \frac{W_{t18}}{W_{tx}}
\]

Practically, EALF is not very sensitive to pavement thickness and SN equal to 5 may be used for most cases and a \(p_t\) value of 2 or 2.5 can be used.
Theoretical Analysis

In mechanistic analysis, fatigue cracking and permanent deformation of pavements are employed as failure criteria. To limit the failure due to fatigue cracking, the allowable number of load repetition is expressed as:

\[ N_f = f_1 (\varepsilon_t)^{-f_2} (E_1)^{-f_3} \]  \hspace{1cm} (3.18)

Where, \( N_f \) = the allowable number of load repetitions to prevent fatigue cracking, 
\( \varepsilon_t \) = the tensile strain at the bottom of the asphalt layer, 
\( E_1 \) = modulus of the asphalt layer, and 
\( f_1, f_2, \) and \( f_3 \) are constants to be determined from laboratory fatigue tests (\( f_1 \) modified to correlate with field observations).

If \( N_{fx} \) and \( N_{f80} \) are the allowable number of x-kN and 80 kN axle load repetitions, then

\[ EALF = \frac{W_{80}}{W_{x}} = \frac{N_{f80}}{N_{fx}} = \left( \frac{\varepsilon_x}{\varepsilon_{80}} \right)^{f_2} \]  \hspace{1cm} (3.19)

Where, \( \varepsilon_x \) and \( \varepsilon_{80} \) are the tensile strains at the bottom of asphalt layer due to x kN and 80 kN axle load repetitions respectively.

The constant \( f_2 \) was determined by Asphalt institute and Shell and the values are 3.291 and 5.671 respectively. A theoretical analysis of EALF was also conducted by Deacon based on an assumed \( f_2 \) value of 4, which is in the range determined by Asphalt institute and Shell. For single axles, it is reasonable to assume that tensile strains due to the axles in question and the standard single-axle are directly proportional to axle loads. Using 4 as the value of \( f_2 \), the EALF can be approximated by what is known as the fourth power rule as:

\[ EALF = \left( \frac{L_x}{L_{80}} \right)^4 \]  \hspace{1cm} (3.20)

For tandem and tridem axles, a more general equation is

\[ EALF = \left( \frac{L_x}{L_y} \right)^4 \]  \hspace{1cm} (3.21)

Where, \( L_x \) is the load on standard axles which have the same number of axles as \( L_x \). If the EALF for one set of tandem or tridem axles is known, that for other axles can be determined by the above equation.
The other failure criterion is to control permanent deformation by limiting the vertical compressive strain on top of the subgrade, which can be expressed as:

\[ N_d = f_4 \left( \varepsilon_c \right)^{f_5} \]  

(3.22)

Suggested values of \( f_5 \) are 4.477 by the Asphalt Institute, 4.0 by Shell, and 3.71 by the University of Nottingham. The use of 4 for \( f_5 \) is also reasonable. Therefore, when \( L_s \) and \( L_x \) are of the same axle configuration, the EALF based on fatigue cracking may not be much different from that based on permanent deformation and similar equation with the power of 4 can be applied.

ERA pavement design manual, which is based on TRL Road Note 31, relates the damaging effect of axle loads to the standard 80kN axle using a power of 4.5 instead of 4. For multiple axle vehicles, i.e. tandem or tridem axles, each axle in the multiple-group is considered separately.

3.3.3 EALFs for Rigid Pavements

AASHTO Equivalency Factors

The AASHTO equations for determining the EALF of rigid pavements are:

\[
\log \left( \frac{W_{tx}}{W_{t18}} \right) = 4.62 \log(18 + 1) - 4.62 \log(L_x + L_2) + 3.28 \log L_2 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}
\]  

(3.23)

\[ G_t = \log \left( \frac{4.5 - \rho_t}{4.5 - 1.5} \right) \]

\[ \beta_x = 1.00 + \frac{3.63(L_x + L_2)^{5.20}}{(D + 1)^{0.46} L_2^{3.52}} \]

Where \( W_{tx}, W_{t18}, L_x, L_2, \rho_t, \) and \( \beta_{18} \) are as defined for flexible pavements and \( D \) is the slab thickness in inches. Value of \( \rho_t = 2.5 \) and \( D = 9 \) inches can be used for unknown cases.

Theoretical Analysis

Based on fatigue cracking the allowable number of repetitions can be expressed as:

\[ \log N_f = f_1 - f_2 \left( \frac{\sigma}{S_c} \right) \]  

(3.24)

in which, \( N_f \) is the allowable number of load repetitions for fatigue cracking, \( \sigma \) is the flexural stress in slab, \( S_c \) is modulus of rupture of concrete, and \( f_1 \) and \( f_2 \) are constants. In the design of zero maintenance jointed plain concrete pavements, \( f_1 = 16.61 \) and \( f_2 = 17.61 \) are recommended (Darter and Barenberg (1977)).
The Portland Cement Association (USA) recommends the following fatigue equations

For $\sigma/S_c \geq 0.55$:

$$\log N_f = 11.737 - 12.077 \left( \frac{\sigma}{S_c} \right)$$  \hspace{1cm} (3.25)

For $0.45 < \sigma/S_c < 0.55$:

$$N_f = \left( \frac{4.2577}{\sigma/S_c - 0.4325} \right)^{3.268}$$  \hspace{1cm} (3.26)

For $\sigma/S_c \leq 0.45$:

$$N_f = \text{unlimited}$$  \hspace{1cm} (3.27)

3.4 Traffic Analysis

The deterioration of paved roads is caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. Hence, to design a paved highway, it is necessary to consider not only the traffic volume or the total number of vehicles that will use the road but also to predict the number of repetitions of each axle load group (or wheel load group) during the design period. To convert the traffic volumes into cumulative equivalent standard axle loads (ESAL or CESAL which is one design parameter in pavement design) equivalency factors are used.

On the other hand, the mechanism of deterioration of gravel roads differs from that of paved roads. Design of thickness of gravel roads is directly related to the number of vehicles using the road rather than the number of equivalent standard axles as that for paved roads. The traffic volume is therefore used in the design of unpaved roads (gravel roads), as opposed to the paved roads which require the conversion of traffic volumes into the appropriate cumulative number of equivalent standard axles.

In this section, method of determining the traffic volume and CESAL with reference to Ethiopian Roads Authority (ERA) Pavement Design Manual will be discussed.

3.4 Traffic Analysis

- The deterioration of paved roads by traffic results both from
  - Magnitude of Load
  - Repetition of Load
- Hence, to design a paved highway, it is necessary to consider
  - the traffic volume or the total number of vehicles that will use the road &
  - to predict the number of repetitions of each axle load group (or wheel load group) during the design period.
  - The traffic volume is converted into cumulative equivalent standard axle loads (ESAL or CESAL) using equivalency factors (EALF).
  - CESAL is one design parameter in pavement design
- Gravel Roads - mechanism of deterioration of gravel roads different from that of paved roads.
Design of thickness of gravel roads is more related to the number of vehicles using the road rather than the CESAL.

The Traffic Volume in terms of initial AADT is used in the design of unpaved roads (gravel roads).

The following Parameters and Considerations/Steps are involved in Traffic Analysis for pavement design.

### 3.4.1 Design Period

The length or duration of time during which the pavement structure is expected to function satisfactorily without the need for major intervention (rehabilitation such as overlays or reconstruction) or the duration in time until the pavement structure reaches its terminal condition (failure condition). Selecting appropriate design period depends on

- Functional importance of the road
- Traffic volume
- Location and terrain of the project
- Financial constraints
- Difficulty in forecasting traffic

Longer Design Period – for important roads, high traffic volume, roads in difficult location and terrain where regular maintenance is costly and difficult due to access problems or lack of construction material

Short Design Period – if there is problem in traffic forecasting, financial constraints, etc.

**ERA recommended: Design Period**

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>Design Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk Road</td>
<td>20</td>
</tr>
<tr>
<td>Link Road</td>
<td>20</td>
</tr>
<tr>
<td>Main Access Road</td>
<td>15</td>
</tr>
<tr>
<td>Other Roads</td>
<td>10</td>
</tr>
</tbody>
</table>

### 3.4.2 Determine Traffic Volume (ADT, AADT)

#### i) Vehicle classification

- Small axle loads from private cars and other light vehicles do not cause significant pavement damage.
- Damage caused by heavier vehicles (commercial vehicles)
- Hence, important to distinguish
the proportion of vehicles which cause pavement damage (commercial vehicles) from total traffic

• To do this, we need to have a vehicle classification system –
  o To distinguish between commercial vehicles and small cars
  o Distinguish between the different types of commercial vehicles and group them according to their type, size (loading), configuration, etc.

• ERA vehicle classification system

Table 3-1: ERA Vehicle Classification

<table>
<thead>
<tr>
<th>Vehicle Code</th>
<th>Type of Vehicle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small car</td>
<td>Passenger cars, minibuses (up to 24-passenger seats), taxis, pick-ups, and Land Cruisers, Land Rovers, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Bus</td>
<td>Medium and large size buses above 24 passenger seats</td>
</tr>
<tr>
<td>3</td>
<td>Medium Truck</td>
<td>Small and medium sized trucks including tankers up to 7 tons load</td>
</tr>
<tr>
<td>4</td>
<td>Heavy Truck</td>
<td>Trucks above 7 tons load</td>
</tr>
<tr>
<td>5</td>
<td>Articulated Truck</td>
<td>Trucks with trailer or semi-trailer and Tanker Trailers</td>
</tr>
</tbody>
</table>

ii) Traffic Count

Traffic Count necessary

• To assess the traffic-carrying capacity of different types of roads
• Examine the distribution of traffic between the available traffic lanes
• In the preparation of maintenance schedules for in-service roads
• In the forecasting of expected traffic on a proposed new road from traffic studies on the surrounding road system

Traffic volume data determined from

  o Historical traffic data available in relevant authorities (ERA conducts regular 3 times a year (Feb., Jul., Nov.) traffic counts on its major road network) and/or

  o By conducting classified traffic counts:
    • On the road to be designed – if the road is an existing road and the project is Upgrading, Rehabilitation, Maintenance, reconstruction, etc.
    • On other parallel routes and/or adjacent roads – for new roads

• Traffic volume data may vary daily, weekly, seasonally.
• Hence to avoid error in traffic analysis and capture the average yearly trend, minimum 7 days count recommended
• ERA recommended procedure
  o Conduct 7 days classified traffic count
    ▪ 5 days for 16 hrs
    ▪ Minimum 2 days for 24 hrs (one week day and one weekend)
• For long projects, there may be large difference in traffic volume along the road and hence it is necessary to make the traffic counts at several locations.

iii) ADT (Average Daily Traffic)

• ADT is determined from the traffic count data as follows
  o Adjust the 16hrs traffic count data into 24hr data by multiplying with the average night adjustment factor
    ▪ Night adjustment factor = (24hr traffic)/(16hr traffic) :- obtained from the two days 24hr count data.
  o \((ADT)_o\) = the current Average Daily Traffic= Average of the 7 days 24 hr traffic volume data

iv) \((AADT)_o\) (Annual Average Daily Traffic = total annual traffic in both directions divided by 365)

• In order to capture the average annual traffic flow trend, adjustment must be made for seasonal traffic variation,
  
• Hence traffic count as above must be made at different representative seasons (ERA conducts traffic counts on February, July and November)
• Make adjustment to \((ADT)_o\) – based on the season at which the current traffic count belongs to and based on seasonal adjustment factors for the road (or similar roads) derived from historic traffic data (ERA or other regional/national sources)
• \((AADT)_o = (ADT)_o\) adjusted for seasonal variation

3.4.3 Traffic Forecast – determining traffic growth rate over the design period

• Very uncertain process
• Requires making analysis and forecast of past and future traffic growth trends, social and economic development trends, etc
• In forecasting, Traffic categorized into the following:
• **Normal Traffic:** Traffic that would pass along the existing road or track even if no new or improved pavement were provided.
  - Forecasted by extrapolating data on traffic levels and assume that growth will remain either
    - Constant in absolute terms i.e. a fixed number of vehicles per year, or
    - Constant in relative terms i.e. a fixed percentage increase.
  - Growth rate can also be related linearly to anticipated Gross Domestic Product (GDP).

• **Diverted Traffic:** Traffic that *changes* from another route (or mode of transport) to the project road because of the improved pavement, but still travels between the same origin and destination.
  - Origin and destination surveys (O/D survey) should preferably be carried out to provide data on the traffic diversions likely to arise.

• **Generated Traffic:**
  - Additional traffic which occurs in response to the provision or improvement of the road.
  - It may arise either because a journey becomes more attractive by virtue of a cost or time reduction or because of the increased development that is brought about by the road investment.
  - Generated traffic is also difficult to forecast accurately and can be easily overestimated.

From thorough analysis of economic, social and development trends, determine overall growth rate $r$ for all vehicle categories or separate growth rate $r_i$ for each vehicle category.

3.4.4 **Axle Load Survey**

- Carried out together with the traffic count
- Portable vehicle(wheel) weighing devices or weigh in motion (WIM) devices can be used for survey
- Each axle of the vehicle is weighed and EALF computed for each axle

\[
EALF = \left( \frac{L_x}{80} \right)^{4.5}
\]

- Each axle of a tandem axle or tridem axle assembly is considered as one repetition and EALF calculated for each axle i.e. a tandem axle constitutes 2 load repetitions and a tridem axle constitutes 3 load repetitions. (according to ERA Pavement design manual)
- AASHTO pavement design procedure considers each passage of a tandem or tridem axle assembly as one repetition and EALF calculated correspondingly.
• **Truck factor**
  - Truck factor can be computed for each vehicle by summing up the number of ESAL per vehicle.
  - Average truck factor can be computed for each vehicle category (for example for Buses, Light Trucks, Medium Trucks, etc.), by summing up the ESAL of all the vehicles in each category and dividing by the number of vehicles (of that category) weighed:

\[
TF_i = \frac{\sum_{j=1}^{n} ESAL_j}{n}
\]

Where \(TF_i\) = Truck factor for the \(i^{th}\) vehicle category
  - \(n\) = number of vehicles weighed (of the \(i^{th}\) vehicle category) during the axle load survey
  - \(ESAL_j\) = number of equivalent standard axle loads for the \(j^{th}\) vehicle

### 3.4.5 Design Traffic Loading

The data and parameters obtained from the studies discussed in the preceding sections can now be used to estimate the design cumulative design traffic volume and loading.

i) Adjustment for Lane and Directional Distribution of Traffic – the AADT should be adjusted as follows

**Lane Distribution Factor (P):** accounts for the proportion of commercial vehicles in the design lane. For two lane highways, the lane in each direction is the design lane, so the lane distribution factor is 100%. For multilane highways, the design lane is the heavily loaded lane (outside lane).

<table>
<thead>
<tr>
<th>Number of Lanes in each direction</th>
<th>Percent Traffic (ESAL) in design Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>80 – 100</td>
</tr>
<tr>
<td>3</td>
<td>60 – 80</td>
</tr>
<tr>
<td>4</td>
<td>50 – 75</td>
</tr>
</tbody>
</table>

**Directional Distribution Factor (D):** factor that accounts for any directional variation in total traffic volume or loading pattern. It is usually 0.5 (50%). However, could be adjusted based on actual condition (if there is directional tendency to commercial vehicle distribution (volume or loading); for example if the heavy vehicles in one direction are loaded and come back empty in the other direction).
ii) Calculating (AADT)$_1$

- AADT$_1$ = Annual Average Daily Traffic (both directions) at year of Road Opening (year at which construction works are completed and the whole road is made open for traffic).

- If time between traffic count year (design time) and estimated year of road opening = $x$, then

$$ AADT_1 = AADT_0 (1+r)^x $$  \hspace{1cm} (3.30)

- Note that AADT1 is used as the Design Traffic Parameter for Gravel Roads (ERA Pavement Design Manual)

iii) Cumulative Traffic Volume ($T$) – can be computed for all traffic ($T$) or for each vehicle class ($T_i$)

$$ T_i = 365 (P) (D) AADT_{1i} [(1+r_i)^N - 1] / (r_i) $$  \hspace{1cm} (3.31)

$T_i$ = cumulative volume of traffic for the $i^{th}$ commercial vehicle class in the design lane over the design period (adjusted for lane distribution and direction).

$r_i$ = annual growth rate for the $i^{th}$ commercial vehicle class

$P$ = Lane distribution factor;  $D$ = Directional distribution factor

$N$ = Design Period in years

iv) Design Traffic (Cumulative Equivalent Standard Axle Load - CESAL) – is computed by multiplying the total traffic volume for each vehicle category ($T_i$) by its corresponding truck factor ($TF_i$)

$$ \text{Design Traffic Load} = \text{CESAL} = \sum (T_i \times TF_i) $$  \hspace{1cm} (3.32)

v) The CESAL is used to determine the traffic class to be employed for pavement design.

<table>
<thead>
<tr>
<th>Traffic classes</th>
<th>Range (10$^6$ ESAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>T2</td>
<td>0.3 – 0.7</td>
</tr>
<tr>
<td>T3</td>
<td>0.7 – 1.5</td>
</tr>
<tr>
<td>T4</td>
<td>1.5 – 3</td>
</tr>
<tr>
<td>T5</td>
<td>3 – 6</td>
</tr>
<tr>
<td>T6</td>
<td>6 – 10</td>
</tr>
<tr>
<td>T7</td>
<td>10 – 17</td>
</tr>
<tr>
<td>T8</td>
<td>17 – 30</td>
</tr>
</tbody>
</table>
Design Example

Initial traffic volumes in terms of AADTs have been established for 2001 for a section of a trunk road under study, as follows:

<table>
<thead>
<tr>
<th>Vehicle classification</th>
<th>2001 AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>250</td>
</tr>
<tr>
<td>Bus</td>
<td>40</td>
</tr>
<tr>
<td>Truck</td>
<td>130</td>
</tr>
<tr>
<td>Truck-trailer</td>
<td>180</td>
</tr>
</tbody>
</table>

The anticipated traffic growth is a constant 5%, and the opening of the road is scheduled for 2005. In addition, an axle load survey has been conducted, giving representative axle loads for the various classes of heavy vehicles, such as given below for truck-trailers (it is assumed that the loads are equally representative for each direction of traffic):

<table>
<thead>
<tr>
<th>Vehicle No</th>
<th>Axle 1</th>
<th>Axle 2</th>
<th>Axle 3</th>
<th>Axle 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6780</td>
<td>14150</td>
<td>8290</td>
<td>8370</td>
</tr>
<tr>
<td>2</td>
<td>6260</td>
<td>12920</td>
<td>8090</td>
<td>9940</td>
</tr>
<tr>
<td>3</td>
<td>6350</td>
<td>13000</td>
<td>8490</td>
<td>9340</td>
</tr>
<tr>
<td>4</td>
<td>5480</td>
<td>12480</td>
<td>7940</td>
<td>9470</td>
</tr>
<tr>
<td>5</td>
<td>6450</td>
<td>8880</td>
<td>6290</td>
<td>10160</td>
</tr>
<tr>
<td>6</td>
<td>5550</td>
<td>12240</td>
<td>8550</td>
<td>10150</td>
</tr>
<tr>
<td>7</td>
<td>5500</td>
<td>11820</td>
<td>7640</td>
<td>9420</td>
</tr>
<tr>
<td>8</td>
<td>4570</td>
<td>13930</td>
<td>2720</td>
<td>2410</td>
</tr>
<tr>
<td>9</td>
<td>4190</td>
<td>15300</td>
<td>3110</td>
<td>2450</td>
</tr>
<tr>
<td>10</td>
<td>4940</td>
<td>15060</td>
<td>2880</td>
<td>2800</td>
</tr>
</tbody>
</table>

The projected AADTs in 2005 can be calculated as (AADTs in 2001) x (1.05)^3, and the corresponding one-directional volumes for each class of vehicle in 2005 are:

<table>
<thead>
<tr>
<th>Vehicle classification</th>
<th>One-directional traffic volume in 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>145</td>
</tr>
<tr>
<td>Bus</td>
<td>23</td>
</tr>
<tr>
<td>Truck</td>
<td>75</td>
</tr>
<tr>
<td>Truck-trailer</td>
<td>104</td>
</tr>
</tbody>
</table>

Selecting, for this trunk road, a design period of 20 years, the cumulative number of vehicles in one direction over the design period is calculated as:
## Vehicle classification

<table>
<thead>
<tr>
<th>Cumulative no. of vehicles in one direction over 20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car 365x145((1.05)^20-1)/0.05=1750016</td>
</tr>
<tr>
<td>Bus 365x23((1.05)^20-1)/0.05=277589</td>
</tr>
<tr>
<td>Truck 365x75((1.05)^20-1)/0.05=905180</td>
</tr>
<tr>
<td>Truck-trailer 365x104((1.05)^20-1)/0.05=1255184</td>
</tr>
</tbody>
</table>

Equivalency factors for the sample of truck-trailers, and a mean equivalency factor for that class of heavy vehicles, can be calculated as outlined below:

<table>
<thead>
<tr>
<th>Vehicle No</th>
<th>Axle 1</th>
<th>Axle 2</th>
<th>Axle 3</th>
<th>Axle 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Load</td>
<td>Factor</td>
<td>Load</td>
<td>Factor</td>
<td>Load</td>
</tr>
<tr>
<td>1</td>
<td>6780</td>
<td>0.43</td>
<td>14150</td>
<td>11.91</td>
<td>8290</td>
</tr>
<tr>
<td>2</td>
<td>6260</td>
<td>0.30</td>
<td>12920</td>
<td>7.91</td>
<td>8090</td>
</tr>
<tr>
<td>3</td>
<td>6350</td>
<td>0.32</td>
<td>13000</td>
<td>8.13</td>
<td>8490</td>
</tr>
<tr>
<td>4</td>
<td>5480</td>
<td>0.17</td>
<td>12480</td>
<td>6.77</td>
<td>7940</td>
</tr>
<tr>
<td>5</td>
<td>6450</td>
<td>0.35</td>
<td>8880</td>
<td>1.46</td>
<td>6290</td>
</tr>
<tr>
<td>6</td>
<td>5550</td>
<td>0.18</td>
<td>12240</td>
<td>6.20</td>
<td>8550</td>
</tr>
<tr>
<td>7</td>
<td>5500</td>
<td>0.17</td>
<td>11820</td>
<td>5.30</td>
<td>7640</td>
</tr>
<tr>
<td>8</td>
<td>4570</td>
<td>0.07</td>
<td>13930</td>
<td>11.10</td>
<td>2720</td>
</tr>
<tr>
<td>9</td>
<td>4190</td>
<td>0.05</td>
<td>15300</td>
<td>16.92</td>
<td>3110</td>
</tr>
<tr>
<td>10</td>
<td>4940</td>
<td>0.10</td>
<td>15060</td>
<td>15.76</td>
<td>2880</td>
</tr>
</tbody>
</table>

Mean equivalency factor for truck-trailers = 11.47

For the sake of this example, it will be assumed that similar calculations have been performed, giving mean equivalency factors for buses and trucks of 0.14 and 6.67 respectively.

Finally, the cumulative numbers of ESAs over the design period are calculated as follows, using the cumulative numbers of vehicles previously calculated and the equivalency factors:

<table>
<thead>
<tr>
<th>Vehicle classification</th>
<th>Cum. no. of vehicles</th>
<th>Equivalency factor</th>
<th>10^6 ESAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>1750016</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>Bus</td>
<td>277589</td>
<td>0.14</td>
<td>0.0</td>
</tr>
<tr>
<td>Truck</td>
<td>905180</td>
<td>6.67</td>
<td>6.0</td>
</tr>
<tr>
<td>Truck-trailer</td>
<td>1255184</td>
<td>11.47</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Total ESAs = 20.4

Based on the above analysis, the trunk road under study would belong to the traffic class T8 for flexible pavement design.
Table 2-5: Traffic Classes for Flexible Pavement Design

<table>
<thead>
<tr>
<th>Traffic classes</th>
<th>Range (10^6 ESAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>&lt; 0.3</td>
</tr>
<tr>
<td>T2</td>
<td>0.3 - 0.7</td>
</tr>
<tr>
<td>T3</td>
<td>0.7 - 1.5</td>
</tr>
<tr>
<td>T4</td>
<td>1.5 - 3.0</td>
</tr>
<tr>
<td>T5</td>
<td>3.0 - 6.0</td>
</tr>
<tr>
<td>T6</td>
<td>6.0 - 10</td>
</tr>
<tr>
<td>T7</td>
<td>10 - 17</td>
</tr>
<tr>
<td>T8</td>
<td>17 – 30</td>
</tr>
</tbody>
</table>