Traffic Engineering


Syllabus:

1. Traffic Stream characteristics

a) Volume

b) Speed

c) Density

2. Principles of traffic, traffic volume-speed-density relationship

3. Traffic volume Forecast

4. Traffic growth.

5. The Road user

6. The Vehicle

7. The Road

8. Traffic capacity

9. Stopping sight distance (SSD)

10. Minimum Passing sight distance (PSD)

11. Sight Distance at intersections

12. Headway distribution in highway traffic flow

References:

1. Traffic and Highway Engineering by: N.S.Garber and Hoel, 2010.

2. Highway engineering : planning, design, and operations, by : Daniel J. Findley, Thomas H. Brown, 2016.

3. Highway Capacity Manual by: Transportation Research Board, 2010.

4. Principles of highway engineering and traffic analysis, by: Mannering, Fred L., Washburn, Scott S, 2013.

5. Traffic and pavement engineering, by: Al-Khateeb 2021.

WHAT IS TRAFFIC ENGINEERING?

Traffic Engineering is that phase of engineering which deals with the planning, geometric design and traffic operations of roads, streets, and highways, their networks, terminals, abutting lands and relationships with other modes of transportation for the achievement of safe, efficient, and convenient movement of persons and goods.

Traffic Engineering applies engineering principles to help solve Transportation problems and brings into play a knowledge of psychology and habits of users of the transportation systems.

Traffic stream Parameters:

Traffic stream parameters fall into two broad categories. *Macroscopic parameters* describe the traffic stream as a whole; *Microscopic parameters* describe the behavior of individual vehicles or pairs of vehicles within the traffic stream.

Microscopic parameters include:

1- Headway,

2- Spacing.

The three principal ***macroscopic parameters*** that describe a traffic stream are:

1- Volume of traffic

2- Speed of vehicles

3- Traffic density.

1- Volume of traffic (Q):

Traffic volume is defined as the number of vehicles passing a point on a highway, or a given lane or direction of a highway, during a specified time interval. The unit of measurement is (veh/hr) or (veh/min).

Types of daily volumes:

- Annual Average Daily Traffic: AADT (veh/day)

The average 24-hour volume at a given location over a full 365-day year; the number of vehicles passing a site in a year divided by 365 days (366 days in a leap year).

- Average annual weekday traffic: AAWT (veh/day).

The average 24-hour volume occurring on weekdays over a full 365-day year; the number of vehicles passing a site on weekdays in a year divided by the number of weekdays (usually 260).

- Average Daily Traffic : ADT (veh/day)

The average 24-hour volume at a given location over a defined time period less than one year; a common application is to measure an ADT for each month of the year.

- Average Weekday Traffic: (AWT).

The average 24-hour weekday volume at a given location over a defined time period less than one year; a common application is to measure an AWT for each month of the year.

The table below illustrates the compilation of these daily volumes based upon one year of count data at a sample location.

1. Month	2. No. of Weekdays In Month (days)	3. Total Days in Month (days)	4. Total Monthly Volume (vehs)	5. Total Weekday Volume (vehs)	6. AWT 5/2 (veh/day)	7. ADT 4/3 (veh/day)
Jan	22	31	425,000	208,000	9,455	13,710
Feb	20	28	410,000	220,000	11,000	14,643
Mar	22	31	385,000	185,000	8,409	12,419
Apr	22	30	400,000	200,000	9,091	13,333
May	21	31	450,000	215,000	10,238	14,516
Jun	22	30	500,000	230,000	10,455	16,667
Jul	23	31	580,000	260,000	11,304	18,710
Aug	21	31	570,000	260,000	12,381	18,387
Sep	22	30	490,000	205,000	9,318	16,333
Oct	22	31	420,000	190,000	8,636	13,548
Nov	21	30	415,000	200,000	9,524	13,833
Dec	22	31	400,000	210,000	9,545	12,903
Total	**260**	**365**	**5,445,000**	**2,583,000**	—	—

AADT = 5,445,0001365 = 14,918 veh/day

AAWT = 2,583,0001260 = 9,935 veh/day

Average weekday traffic (AWT) for each month is found by dividing the total monthly weekday volume by the number of weekdays in the month (Column 5 ÷ Column 2). The average daily traffic is the total monthly volume divided by the number of days in the month (Column 4 ÷ Column 3). Average annual daily traffic is the total observed volume for the year divided by 365 days/year.

Average annual weekday traffic is the total observed volume on weekdays divided by 260 weekdays/year.

Hourly Volume (HV)-(veh/hr):

Daily volumes, while useful for planning purposes, cannot be used alone for design or operational analysis purposes. Volume varies considerably over the 24 hours of the day, with periods of maximum flow occurring during the morning and evening commuter.

The single hour of the day that has the highest hourly volume is referred to as the **peak hour**.

The traffic volume within this hour is of greatest interest to traffic engineers for design and operational analysis usage.

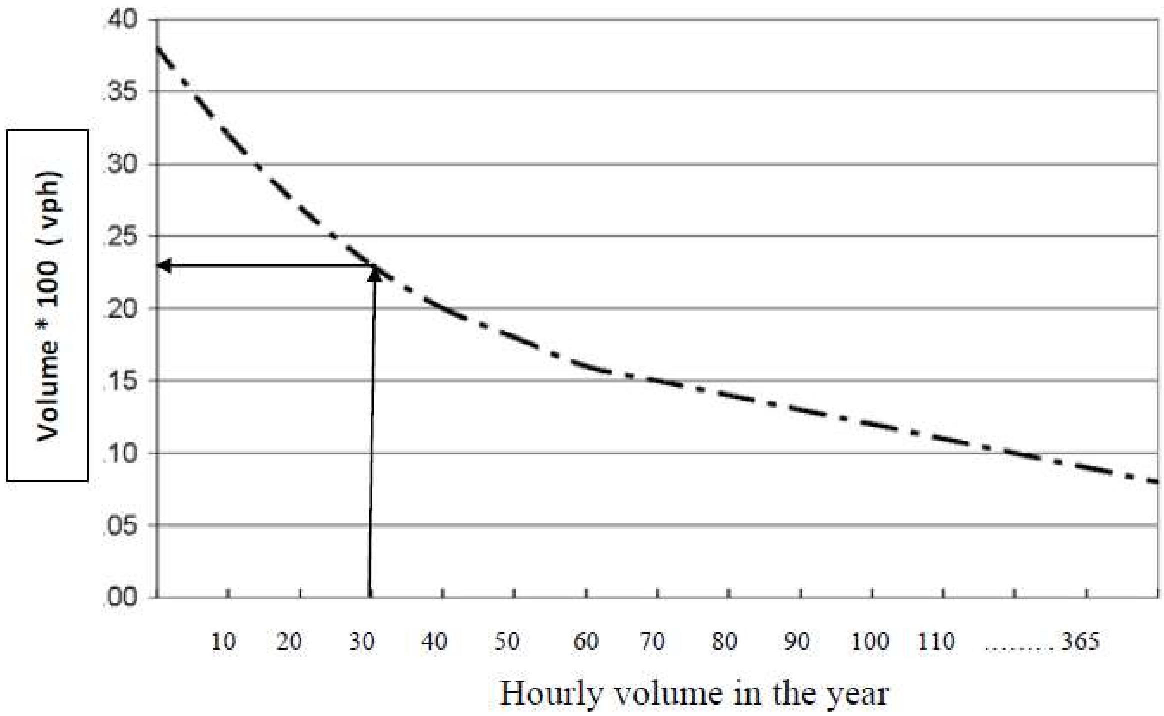
In design, because daily volumes, such as the AADT, are more stable than hourly volumes, projections can be more confidently made using them. AADTs are converted to a peak-hour volume in the peak direction of flow. This is referred to as the "directional design hour volume" (DDHV), and is found using the following relationship:

$$DDHV = AADT*K*D$$

Where: K = proportion of daily traffic occurring during the peak hour

D = Directional distribution factor: proportion of peak hour traffic traveling in the peak direction of flow.

For design, the K factor often represents the proportion of AADT occurring during the 30^{th} peak hour of the year. If the 365 peak hour volumes of the year at a given location are listed in descending order, the 30^{th} peak hour is 30th on the list and represents a volume that is exceeded in only 29 hours of the year. and it is used in geometric design (30^{TH} HV) or (DHV) as shown in figure below.



The table below shows general ranges for K and D factors.

Facility Type	Normal Range of Values	
	K-Factor	*D*-Factor
Rural	0.15–0.25	0.65–0.80
Suburban	0.12–0.15	0.55–0.65
Urban:		
Radial Route	0.07–0.12	0.55–0.60
Circumferential Route	0.07–0.12	0.50–0.55

Ex: Consider the case of a rural highway that has a 20- year forecast of AADT of 30,000 veh/day. Based upon the data of the table above, what range of directional design hour volumes might be expected for this situation?

Ans\ Using the values of the table for a rural highway, the K factor ranges from 0.15 to 0.25 (take 0.15) , and the D factor range from 0.65 to 0.80 (take 0.65) .

The range of directional design hour volumes is, therefore:

DDHV = 30,000 * 0.15 * 0.65 = 2,925 veh/h

Ex: At an area where traffic annual pattern is given below, the results of 16hr count conducted in Friday and other days in June were 1000 and 4000 vph respectively, if 16hr represents 95% of 24hr, Calculate AADT:

Month	1	2	3	4	5	6	7	8	9	10	11	12
Flow as percent of the annual average daily traffic	84 %	82 %	98 %	97 %	107 %	107 %	96 %	97 %	102 %	102 %	91 %	90 %

Ans\

1- 7-Day/16hr = 4000 * (7-1) + 1000 = 25000 vph

2- 7-Day/24 hr = 100/95 * 7-Day/16hr (because 7-Day/16hr = 95/100 * 7-Day/24hr)

= 100/95 * 25000 = 26316 vph (for 7 days)

3- ADT = 26316/ 7 = 3759 veh/day

4- AADT = $\frac{ADT}{Percent\ flow} = \frac{3759}{\frac{107}{100}}$ = 3513 veh/day

NOTE: To determine the ADT for a selected month, apply the following equation:

$$\textbf{AADT} = \frac{ADT}{Percent\ flow}$$

Ex: The following is a tabulation of ADT counts made with automatic counter, on a rural state highway , calculate the AADT and expansion factor for each month:

Month	1	2	3	4	5	6	7	8	9	10	11	12
ADT	1200	1160	1300	1110	1500	2500	4000	4500	3500	2000	2100	1600

Ans

1- To determine the average daily counts for the year, sum the 12 average monthly counts (Σ ADT) = 26760.

The annual average daily traffic AADT = $\frac{\sum ADT}{12} = \frac{26760}{12}$ = 2230 veh/day

2- To obtain the % of average daily counts in comparison to the annual AADT

For January is = $\frac{ADT}{AADT} = \frac{1200}{2230}$ = 0.54

3- To obtain the monthly expansion factor in comparison to the annual average

For January is:

Expansion factor = $\frac{1}{\%\ of\ ADT\ for\ the\ year} = \frac{1}{0.54}$ = 1.85

Month	1	2	3	4	5	6	7	8	9	10	11	12
ADT	1200	1160	1300	1110	1500	2500	4000	4500	3500	2000	2100	1600
% of ADT for the year	0.54	0.54	0.58	0.63	0.67	1.12	1.79	2.02	1.57	0.9	0.94	0.72
Expansion factor	1.85	1.12	1.72	1.24	1.49	0.94	0.56	0.49	0.64	1.11	1.6	1.39

<u>*AADT or ADT volumes are used for:*</u>

1. Highway planning.
2. highway improvements program
3. measuring the present demand for service
4. evaluating the present traffic flow

<u>*Peak hourly volumes are used for:*</u>

1. geometric design
2. developing traffic operation program
3. highway classification
4. determining the deficiencies in capacity

Rates of Flow

Volumes observed for periods of less than one hour are generally expressed as ***equivalent hourly rates of flow***.

*peak hourly factor (P.H.F) = $\frac{Hourly\ volume}{Max.\ rate\ of\ flow}$ =

Where: Hourly volume = Σ counts

$Max.\ rate\ of\ flow$ = n * max. reading at the specified period

n: Number of readings.

Ex: The following count where observed on a way compute the following rate:

a- Hourly volume

b- Peak rate of flow for 5 minutes rate

c- Peak rate of flow for 15 minutes period d- PHF based upon 15 min. period

Time	Counts عدد المركبات
2.00-2.05	201
2.05-2.10	208
2.15-2.20	217
2.20-2.25	232
2.25-2.30	219
2.25-2.30	220
2.30-2.35	205
2.35-2.40	201
2.40-2.45	195
2.45-2.50	210
2.50-2.55	190
2.55-3.00	195
total	∑2493

Ans

a. Hourly volume = Σ counts = 2494

b. Peak rate = n * max = 12 *232 = 2784 (for 5 min)

Time	Counts
2.00-2.15	201+208+217=626
2.15-2.30	671
2.30-2.45	601
2.45-3.00	595
total	∑2493

c. Peak rate = 4 * 671 = 2684 (for 15 min)

d. Peak hourly factor (P.H.F) = $\frac{Hourly\ volume}{Max.\ rate\ of\ flow}$ = 2493 / (4*671)

= 0.92 (for 15 min.)

2- Speed (V) and Travel Time:

Speed is defined as a rate of motion in distance per unit time. Travel time is the time taken to traverse a defined section of roadway. Speed and travel time are inversely related.

Speed usually expressed in distance per unit time (km/hr) or (mile/hr).

<u>Types of speed</u>:

Speeds are generally classified into three main categories:

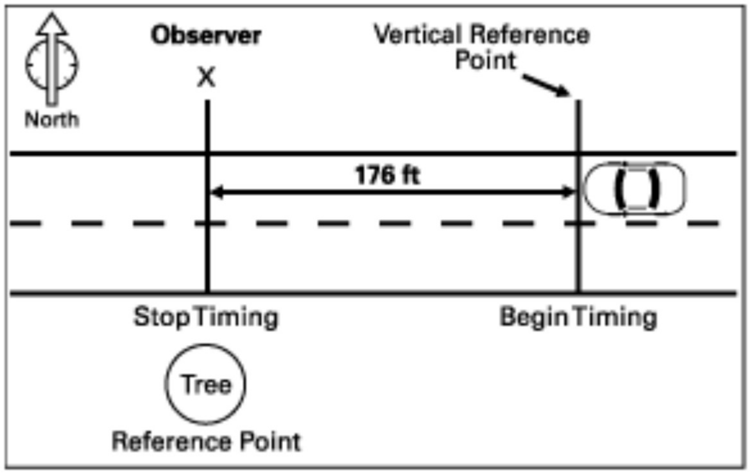
A- *Spot speed*. Is the instantaneous speed of vehicles at any specified point.

B- *Running speed*. Is the average speed maintained over a particular section of the road while the vehicle is moving, and it is found by divided the length of the section by the time where the vehicle is in motion.

C- *Journey speed*. Is the overall speed of the vehicle on a journey between two points, to compute the journey speed the distance between two points is divided by the total time taken for the vehicle, where the time includes any stopped time due to traffic delay.

Running speed = Distance/ running time

Journey speed = Distance/ total time



Note: High running speeds with low journey speeds are undesirable and represent stop-go conditions with enforced decelerations and accelerations.

Spot Speed Studies

When we measure the traffic parameter over a short distance, we generally measure the spot speed. A spot speed is made by measuring the individual speeds of a sample of the vehicle passing a given spot on a street or highway. Spot speed studies are used to determine the speed distribution of a traffic stream at a specific location. The data gathered in spot speed studies are used to determine vehicle speed percentiles, which are useful in making many speed-related decisions. Spot speed data have a number of safety applications, including the following:

1. Speed Trends: Can be determined by periodic sampling at selected locations.
2. Traffic Control Planning: The variability in speed values affects the capacity and safety. If all vehicles travelled at the same speed, the capacity would be at max and accidents would be minimized due to rear end collisions and overtaking, it is used in speed limit determination, posting safe speed at curves, signs locations, no parking zones.

3. Accident analysis of problem: The locations of accidents usually includes data of spot speed.
4. Geometric Design: Are used in determining the radius and super elevation (e) of curves , length of acceleration and deceleration lanes, etc.
5. Research Studies:

   a. Study the capacity in relation to speed

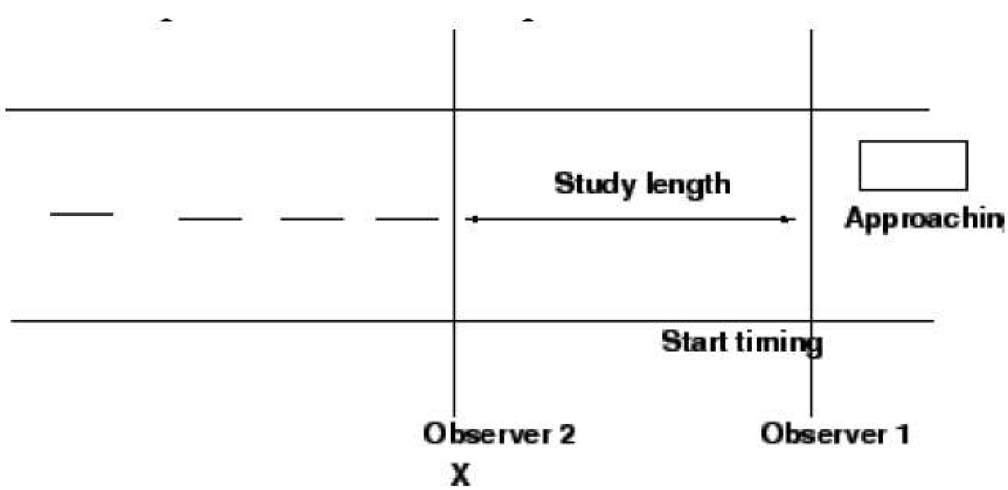
   b. Analysis of speed flow relation.

Methods of measuring Spot Speed:

There are a number of methods to measure spot speed of vehicles in a traffic stream depending upon the available equipment, in which first two are manual methods and other are automatic:

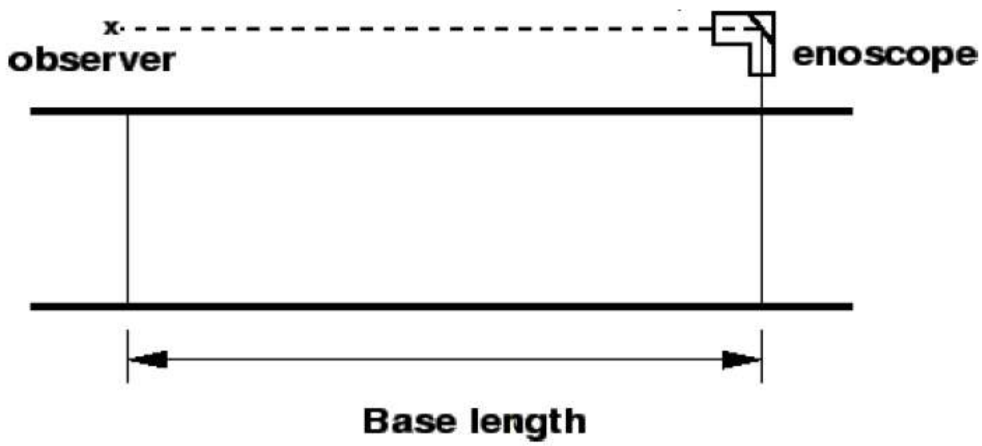
a- Pavement marking

Transverse pavement markings are placed at each end of a measured section. Observer starts and stops watch as vehicle passes lines.



b- Enoscopes or Mirror Boxes

Enoscope consists of a simple open housing containing a mirror mounted on a tripod at the side of the road in such a way that an observer's line of sight turned through 90°. The observer stands at one end of section and on the other end enoscope is placed and measure the time taken by the vehicle to cross the section.



c- Electronic Timing Apparatus

A commercially available device utilities road tubes and air switches at each end of the trap. In this method the passage of the vehicle over the 1st tube transmits a pressure pulse to a diaphragm switch which starts the timing operation and switch terminates the timing when the wheels pass over the 2nd tube. The apparatus is fully portable, and battery operated.

Average Speed of Traffic (Kph)	Recommended Trap length (m)
Below 40	30
40 - 65	60
Over 65	90

d- Radar Speed meter

The apparatus transmits high frequency electromagnetic waves in a narrow beam towards a selected vehicle and the reflected waves altered in length depending on the vehicles speed, are returned to a receiving unit, through calibration gives directly spot speed of the vehicle.

e- Photographic technique

This method a camera records the distance moved by a vehicle in a selected short period of time. Exposures are made at a constant time interval. The interval and the distance travelled between exposures is measured by projecting the film, the distance is divided by the time interval between exposures gives a speed measurements.

Variables influencing Speed

1. Physical conditions

Including: Curvature, grade, sight distance, pavement roughness, spacing of intersections, etc.

2. Environments

Including: Type of driver, time of day, weather, visibility, etc.

3. Traffic flow

Including: Volumes, classification, pedestrian, turning movements, etc.

Data Presentation

The collected data have to present into some representation table form. This makes its calculation and analysis simpler and easier. The following methods are to present the spot speed data.

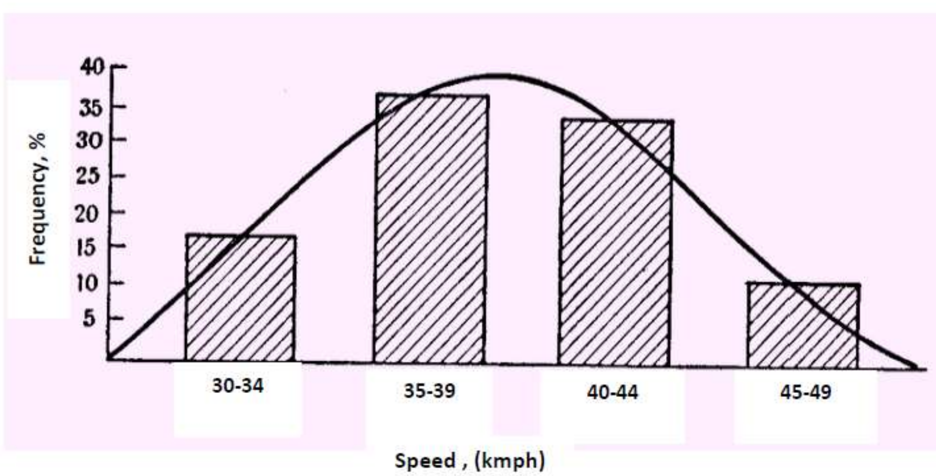
1- Frequency Distribution Table

After the collection of data in given conditions, arrange the spot speed values with respect to their magnitudes. Then select an interval speed (e.g. 5 kmph) and make grouping of data which come under this range. Now, prepare the frequency distribution table as below.

Class interval, (kph)	Frequency (f), التكـرار
30-34	16
35-39	35
40-44	31
45-49	11
Total	∑ 93

2- Frequency Distribution Curve

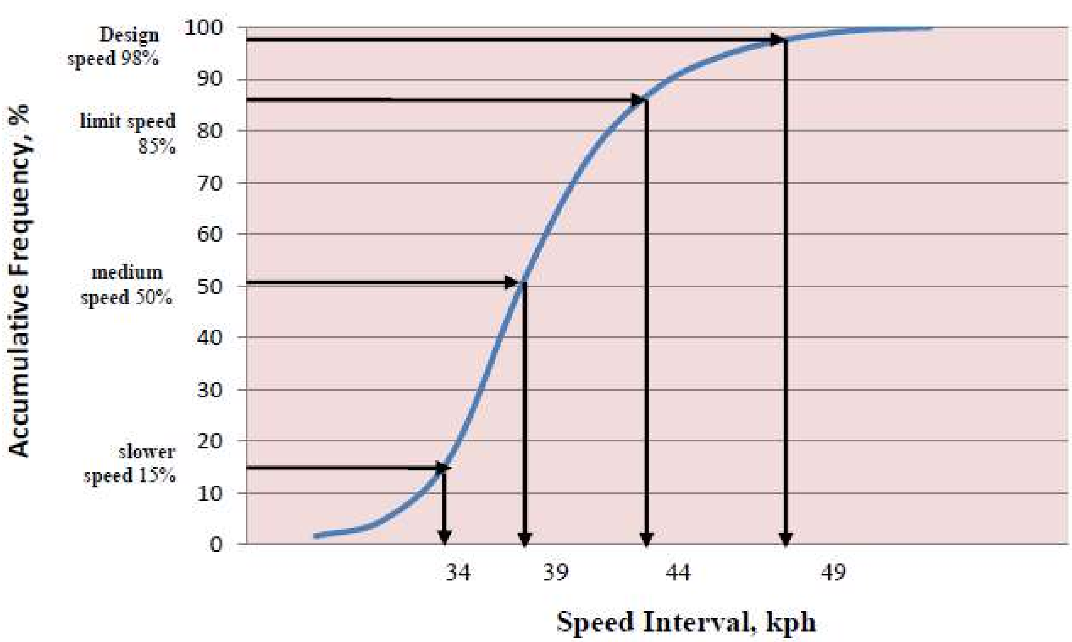
For each speed group, the % frequency of observations within the group is plotted versus the middle (mid-mark) speed of the group(s). From this curve, the modal speed and pace of traffic flow can be determined. Generally, the shape of the curve follows the normal distribution curve, this is because most of the vehicles move on road near the mean speed and very few deviate from it.



3- Cumulative Frequency Distribution Curve

For each speed group, the % cumulative frequency of observations is plotted versus the higher limit of the speed group. The cumulative frequency distribution curve, however, results in a very useful plot of speed versus the percent of vehicles traveling at or below the designated speed. For this reason, the upper limit of the speed group is used as the plotting point.

Class interval (kph)	Mid class (kph)	Frequency (f) التكرار	Frequency (%)	Accumulative Freq. % التكرار التراكمي
30-34	32	16	$\frac{16*100}{93}$=17.2	17.2
35-39	37	35	37.6	54.8
40-44	42	31	33.4	88.2
45-49	47	11	11.8	100.0
Total	--	∑ 93	∑100.0	--



98%   the design speed,   85% the limit speed

50%   the running speed,   15% the slower speed.

Speed Concepts

Highways should be designed to operate at a speed that satisfies nearly all the drivers, because only a small percentage of drivers travel at extremely high speed, it is not economically practical to design for them.

- Design Speed

Maximum safety speed that can be maintained over a section of highway, it is used to determine the various geometric design features of the roadway. The 98th percentile of the distribution of observed speeds is used to measure the design speed.

- Operating Speed: (limit speed)

It is the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is used to measure the operating speed.

- Median Speed

The median speed is defined as the speed that divides the distribution into equal parts (i.e., there are as many observations of speeds higher than the median as there are lower than the median). The 50th percentile of the distribution of observed speeds is used to measure the median speed.

98% is used for determining the design speed

85% is used for determining the limit speed

50% is used for determining the median speed

15% shows the slower vehicles where speed may be causing interference with the traffic stream

Speed Data Analysis

Common descriptive statistics may be computed from the data in the frequency distribution table or determined graphically from the frequency and cumulative frequency distribution curves.

1. Arithmetic mean speed (or average spot speed)

It is the most frequently used speed statistics. It is the measure of central tendency of the data.

$$\bar{X} = \frac{\sum Xi}{n} = \frac{\sum fiXi}{\sum fi}$$

Xi= individual speed of the i_{th} vehicle

n= number of vehicle observed

fi= frequency of speed

Mean calculated gives two kinds of mean speeds:

- ***Time mean Speed (Vt)***: Arithmetic mean of speeds of vehicles passing a point. If data collected at a point over a period of time, e.g. by radar meter or stopwatch produce speed distribution over time, so the mean of speed is time mean speed.

$$\bar{v}_t = \frac{1}{N}\sum_{n=1}^{N} v_n$$

- ***Space mean Speed (Vs)***: Harmonic mean of speeds passing a point during a period of time. It also equals the average speeds over a length of roadway.

$$\bar{v}_s = \frac{N}{\sum_{n=1}^{N} \frac{1}{v_n}} = \frac{NL}{\sum_{n=1}^{N} t_n}$$

Where

V_s: is the space mean speed of n^{th} vehicle

N: is the number of vehicles

V_n: speed of n^{th} vehicle

L: length of section of highway

t_n: time is takes n^{th} vehicle to traverse a section of highway.

If data obtained over a stretch (section) of road almost instantaneously, aerial photography or enoscope, result in speed distribution in space. The mean is space mean speed. The distribution over space and time are not the same. Time mean speed is higher than the space mean speed. The spot speed sample at one end taken over a finite period of time will tend to include some fast vehicles which had not yet entered the section at the start of the survey but will exclude some of the slower vehicles. The relationship between the two mean speeds is expressed by:

$$v_t = v_s + \frac{\sigma_s^2}{v_s}$$

where, V_t and V_s are the time mean speed and space mean speed respectively.

σ_s is the standard deviation of distribution space.

2. Standard Deviation

The most common statistical measure of dispersion in a distribution is the standard deviation. It is a measure of how far data spreads around the mean value.

$$\sigma_s = \sqrt{\frac{\Sigma f_i (v_i - v_v)^2}{n-1}}$$

3. Standard error of the mean

$$Se = \frac{\sigma s}{\sqrt{n}}$$

4. Coefficient of variation

$$V = \frac{\sigma s}{\bar{X}} * 100$$

Standard deviation can also be calculated by determining the 85% and 15% percentile speeds on the cumulative distribution curve as in the equation below:

$$\sigma_{est} = \frac{v_{85} - v_{15}}{2}$$

5. Sample Size

Generally, sample sizes of 50 to 200 vehicles are taken. In that case, standard error of mean is usually under the acceptable limit. If precision is a priority, then minimum number of sample should be taken. This can be measured by using the following equation:

$$n_r = \frac{Z^2 \sigma_s^2}{S_e^2}$$

Where η_r is the number of samples required, σ_s is the Standard deviation, **Z** is value calculated from Standard Normal distribution Table for a particular confidence level (i.e. for 95% confidence Z=1.96 and for 99.7% confidence Z=3.0) and S_e is the permissible (acceptable) error in the mean calculation.

Ex: Using the spot speed data given in the following table, collected from a freeway site operating under free-flow conditions:

(i) Plot the frequency and cumulative frequency curves for these data;

(ii) Obtain Operating Speed, Median Speed, 15% lower speed;

(iii) Compute the mean and standard deviation of the speed distribution;

(iv) Based on these results, compute the sample size needed to achieve a tolerance of ±1.5 kmph with 95% confidence.

Speed Range	Frequency f_i
21-25	2
26-30	6
31-35	18
36-40	25
41-45	19
46-50	16
51-55	17
56-60	12
61-65	7
66-70	4
71-75	3
76-80	1

Ans/ For the spot speed study, first draw a frequency distribution table show below. we can draw frequency distribution and cumulative frequency distribution curve.

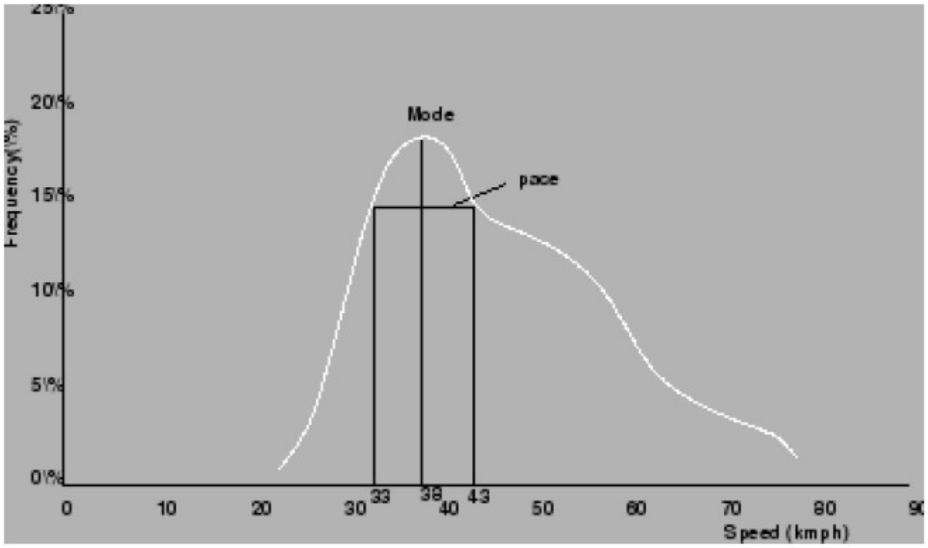
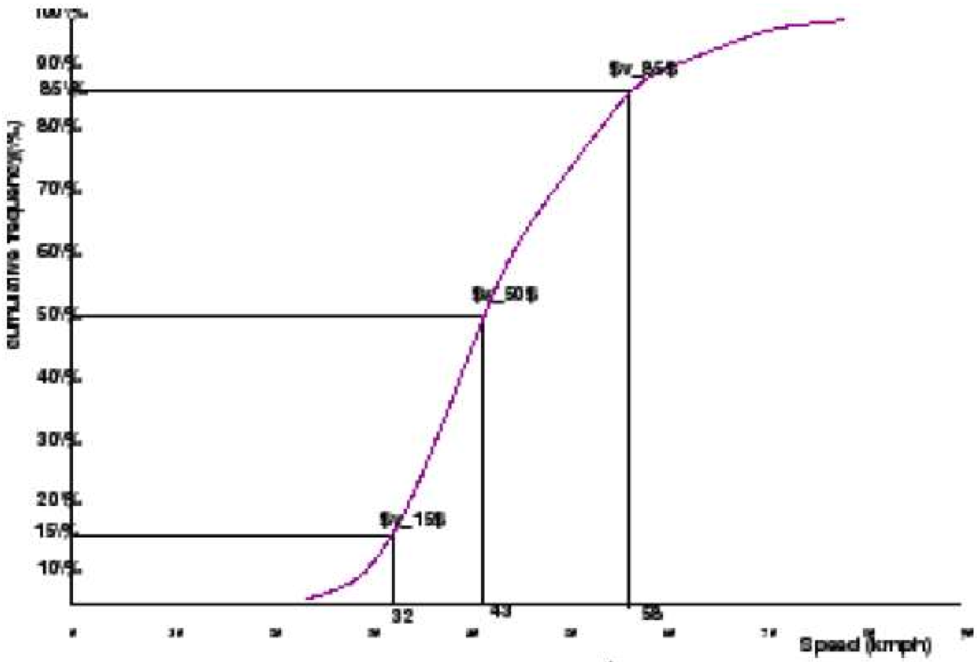


Table 1: Solution of the example problem

• Speed Range	Mid speed V_i	Frequency f_i	% f_i	$\% \sum f_i$	$f_i \times V_i$	$f_i \times (V_i - V_m)^2$
21-25	23	2	1.5%	1.5%	2*23=46	$2*(23-45.77)^2$ = 1036.876
26-30	28	6	4.5%	6%	168	1894.473
31-35	33	18	14%	20%	594	2934.959
36-40	38	25	19%	39%	950	1509.024
41-45	43	19	15%	54%	817	145.7041
46-50	48	16	12%	66%	768	79.6213
51-55	53	17	13%	79%	901	888.8284
56-60	58	12	9%	88%	696	1795.101
61-65	63	7	6%	94%	441	2078.296
66-70	68	4	3%	97%	272	1976.828
71-75	73	3	2%	99%	219	2224.544
76-80	78	1	1%	100%	78	1038.822
Total		130	100%		5950	17603.08



- From the curves, Median speed, V_{50} = 43 kmph; 15th Percentile speed = 32 kmph; and the 85th Percentile speed = 58 kmph. , 98th percentile Speed =72 kmph

Mean speed is calculated by using:

$$v_m = \frac{\Sigma f_i v_i}{n}$$

$$= \frac{5950}{130} = 45.77\ kmph$$

Standard Deviation of the Speed

$$\sigma_s = \sqrt{\frac{\Sigma f_i (v_i - v_t)^2}{n-1}}$$

$$= \sqrt{\frac{17603.08}{130-1}} = 11.7\ kmph$$

Sample size required for 95% confidence with acceptable error of 1.5 kmph

$$n_r = \frac{Z^2 \sigma_s^2}{S_e^2}$$

$$= \frac{1.96^2 \times 11.7^2}{1.5^2} = 234.$$

H.w (1) : Spot speed data on a two-way two lane highway are measured, it is required to calculate the following :

1. The mean, standard deviation , coefficient of variation
2. The frequency distribution , the cumulative curve
3. The design speed (98%), limit speed (85%), and slow speed (15%) that may causing may cause interference within the traffic stream
4. The number of drivers that have the (73-84) kph speed

Class interval (kph)	Frequency (f)التكرار
30-39.9	3
40-49.9	6
50-59.9	24
60-69.9	60
70-79.9	47
80-89.9	25
90-99.9	12
100-109.9	6
110-119.9	3
120-129.9	1
Total	187

H.w (2) : Spot speed data on a three lane rural truck highway are measured, it is required to calculate the following :

1. The arithmetic mean, standard deviation , coefficient of variation
2. The design speed (98%), limit speed (85%), and slow speed (15%) that may causing interference within the traffic stream

Class interval (kph)	Frequency (f)التكرار
21-25	2
26-30	5
31-35	18
36-40	20
41-45	26
46-50	29
51-55	20
56-60	80
61-65	6
66-70	4
Total	$\sum$

3- Density (D)

Density, the third primary measure of traffic stream characteristics, is defined as the number of vehicles occupying a given length of highway or a lane, generally expressed as (veh./mile: vpm) or (veh/km: vpkm).

Traffic lane:

Is a strip of roadway intended to accommodate a single stream of moving vehicles. It is the basic unit of width in measuring traffic stream characteristics.

Standard lane width = 12 feet.

Minimum lane width = 10 feet.

Density is perhaps the most important of the three primary traffic stream parameters, because it is the measure most directly related to traffic demand. Density is also an important measure of the quality of traffic flow, as it is a measure of the proximity of other vehicles, a factor which influences freedom to maneuver and the psychological comfort of drivers.

Traffic stream characteristics are affected by:

1- Condition of the road surface.
2- Width, number and separation of lanes.
3- Gradients.
4- Sight distance.
5- Frequency and form of intersections.
6- Drainage structures.
7- Signs, signals, markings, etc.

The relationship among Volume, Speed and Density:

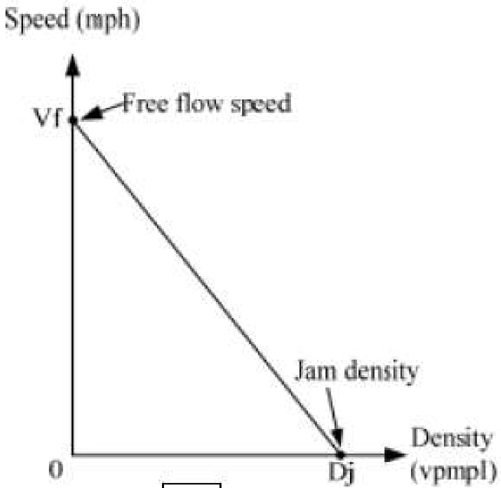
$$Q = V * D \quad , \quad D = \frac{Q}{V} \quad , \quad V = \frac{Q}{D}$$

where:

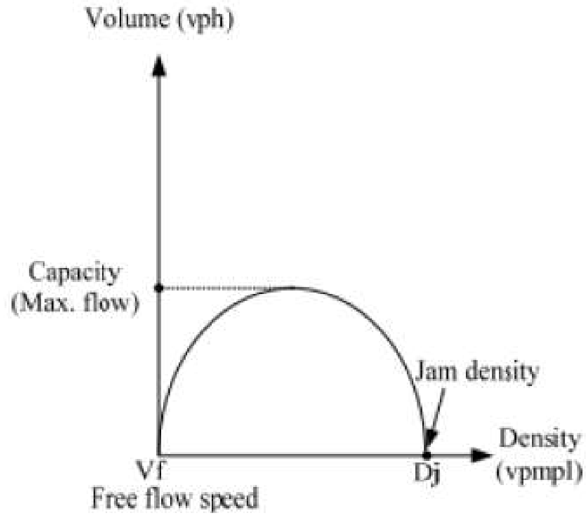
Q:Traffic volume

V: Space mean speed

D: Density



1

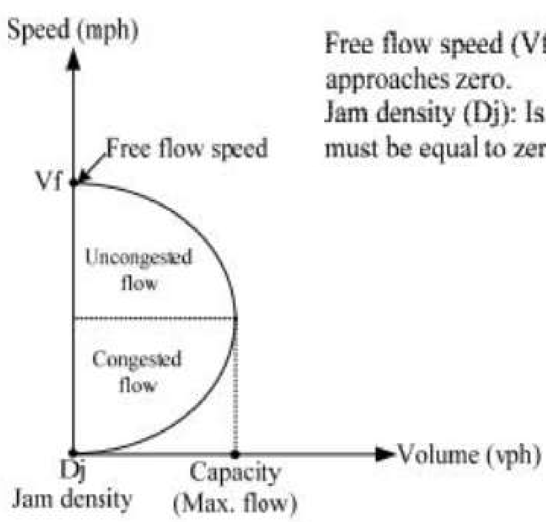


2

- Where speed is space mean speed (at density = 0, speed is freeflow = v_f). The upper half of the flow curve is uncongested, the lower half is congested.

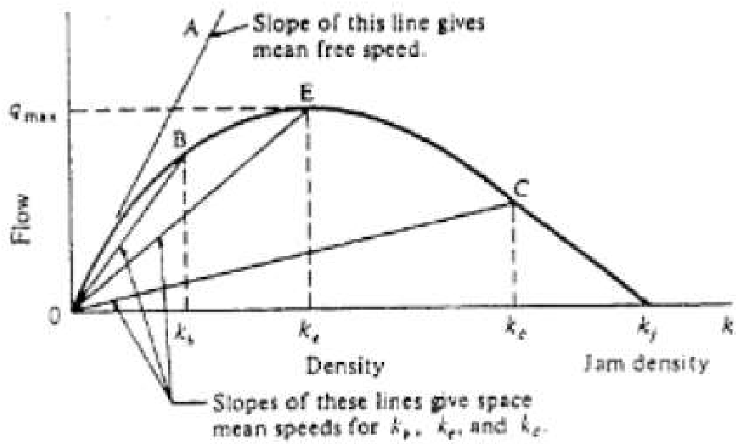
- Flow will also increase to a maximum value (q_m), increases in density beyond that point result in reductions of flow.

- When density on the highway is zero, the flow is also zero because there are no vehicles on the highway
- As density increases, flow increases
- When the density reaches a maximum jam density (k_j), flow must be zero because vehicles will line up end to end



3

Free flow speed (Vf): Is the theoretical speed of traffic as density approaches zero.
Jam density (Dj): Is the maximum value of density when the flow must be equal to zero.



(a) Flow versus density

- The slope of the flow density curve gives speed.
- Rise/Run = Flow/Density = Vehicles per hour/ Vehicles per km = km / hour.

$$Q = \frac{No.of\ vehicles}{T}$$

$$Density = \frac{No.of\ vehicle}{L}$$

$$D = \frac{Q}{Vs}$$

And by Greenshield's equation:

$$Vs = Vf - \frac{Vf}{Dj} * D \quad ....(1)$$

Multiplied by (D)

$$Q = Vf * D - \frac{Vf}{Dj} * D^2 ....(2)$$

Multiplying Eq. no. (1) by (Vs): $Vs^2 = Vf * Vs - \frac{Vf}{Dj} * D * Vs$

$$Vs^2 = Vf * Vs - \frac{Vf}{Dj} * Q$$

$$\therefore Q = Vs * Dj - \frac{Dj}{Vf} * Vs^2 \text{ ....(3)}$$

Derivation Equa. No. (2): $\frac{dQ}{dD} = Vf - 2\frac{Vf}{Dj} * D$

$$\frac{dQ}{dD} = 0 \qquad \therefore D = Dmax = \frac{Dj}{2} \text{ .... (4)}$$

Derivation Equa. No. (3): $\frac{dQ}{dVs} = Dj - 2\frac{Dj}{Vf} * Vs$

$$\frac{dQ}{dVs} = 0 \qquad \therefore Vs = Vmax = \frac{Vf}{2} \text{ ....(5)}$$

$$\therefore Qmax = \frac{Dj}{2} * \frac{Vf}{2} = \frac{Dj * Vf}{4} \text{ ....(6)}$$

Ex: Using the linear relationship between speed and density on a length of highway where the free speed= 80kph and the jam density= 70kph , what is the max. flow that could be expected on this highway? And at what speed would it occur?

Ans:

$$Qmax = \frac{Dj * Vf}{4}$$

$$= \frac{70 * 80}{4} = 1400\ vph$$

$$Vs = Vmax = \frac{Vf}{2} = \frac{80}{2} = 40\ kph$$

Ex: If the relationship between volume and density at a given highway section is: Q=$\mathbf{60\ D - 0.8 * D^2}$, what is the jam density (Dj)?

Ans./

$$Q = 60\ D - 0.8 * D^2$$

By Derivation to D:

$$\frac{dQ}{dD} = 60 - 1.6 * D$$

$$\frac{dQ}{dD} = 0 \qquad \therefore Dmax = \frac{60}{1.6} = \mathbf{37.5}\ \text{vpk}$$

$$Dmax = \frac{Dj}{2} \qquad \therefore Dj = 75\ vpk$$

OR: D =Dj when Q= 0, $Q = 60\ D - 0.8 * D^2$

$$0 = D\ (60 - 0.8 * Dj)$$

$$Dj = 60/0.8 = 75\ vpk$$

Ex: Given that mean speed and density has a nonlinear relationship of the form: $\boldsymbol{Vs = C * \ln(Dj/D)}$, where Dj= 130vpk, density is 30vpk, space mean speed Vs =30kph, find Q_{max}?

$$Vs = C * \ln(\frac{Dj}{D}) \qquad \text{Multiplied by} \quad D$$

$$Q = CD * \ln(\frac{Dj}{D})$$

$$Q = CD * [\ln Dj - \ln D]$$

$$\frac{dQ}{dD} = C[\mathrm{D}\ \frac{-\mathrm{Dj}/\mathrm{D}^2}{\frac{\mathrm{Dj}}{\mathrm{D}}} + (ln\ Dj - \ln D) * 1\ ]$$

$$\frac{dQ}{dD} = [-1 + \ln\frac{Dj}{D}]$$

$Q_{max.}$ When : $\frac{dQ}{dD} = 0$, $\therefore \frac{\ln Dj}{D} = 1$ .....(1)

$\therefore$ $Vs_{max.} = C$

$C = \frac{Vs}{\ln(\frac{Dj}{D})} = \frac{30}{\ln(\frac{130}{30})} = 20.46$

Equation (1): $\ln Dj - \ln D = 1$

$-\ln D_{max.} = 1 - \ln Dj$] * (-1)

$D_{max} = e^{(-1+\ln Dj)} = 47.824$ vpk

$Q_{max} = D_{max} * Vs_{max.}$

$= 47.824 * 20.46 = 985.18$ vph

Traffic volume characteristics

The variables which effect volume characteristics include:

1- Type or classification of highway:

- Rural
- Urban

2- Type of use:

- Inter-city
- Commercial
- Intra-city
- General purpose
- Commuter

3- Composition of traffic :

- Passenger car

- Busses
- Trucks

4- Time variation :

- By hour
- By day
- By week
- By month

Passenger Car Unit (pcu)

The effect of traffic composition on the capacity of a road is represented by the Passenger Car Unit PCU which represent the effect of varying vehicles types relative to passenger car, there equivalent factors varying according to:

- Environmental conditions
- Terrain conditions

The equivalent factors on (level) ground are as following:

- 1 Bus (≤ 24 passenger) = 1.25 PCU
- 1 Bus (> 24 passenger) = 2 PCU
- 1 Truck = 2- 3 PCU
- 1 Motorcycle = 0.33 PCU
- 1 Bicycle = 0.25 PCU
- 1 light good vehicles =1.25 PCU

Ex: If there are 1000 vehicles including: 250 buses, 100 truck, 50 motorcycles, to convert to an equivalent pcu:

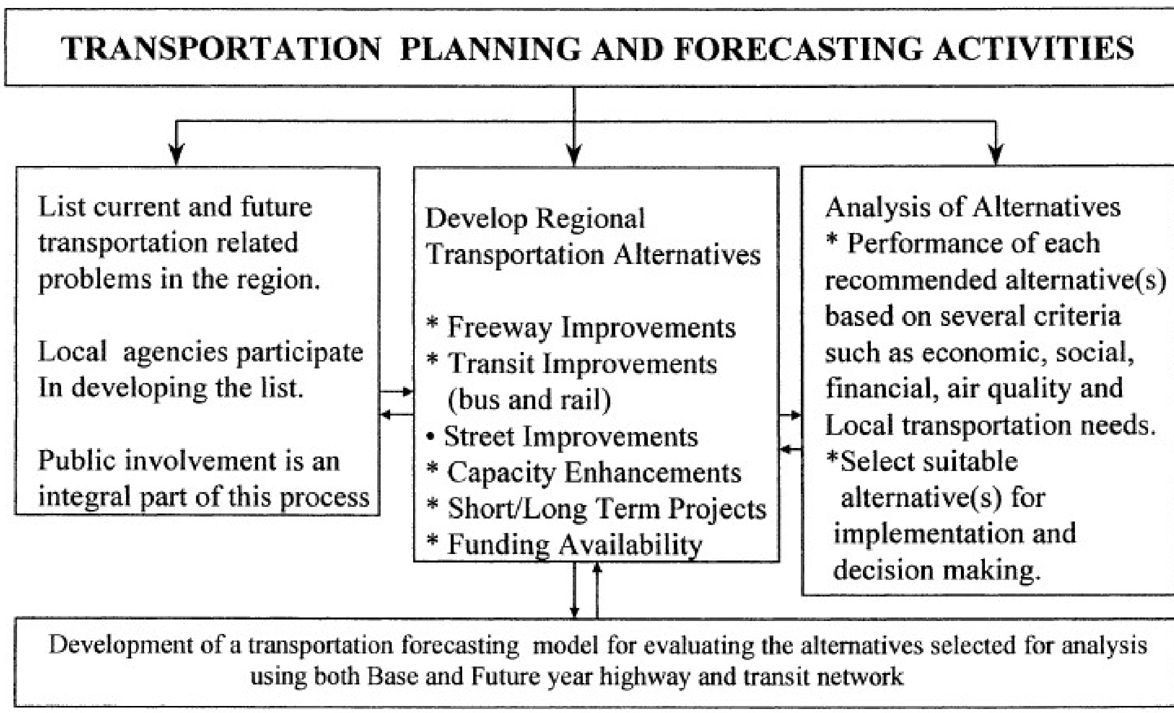
pcu = 250 *2 +100 * 3 + 50* 0.33 + (1000-(250+100+50)) * 1 = 1416.5 pcu

Ex: 15% Truck, 10% Bus, 5% motor, convert to equivalent pcu:

Remaining =100% - (15%+ 10% + 5%)
= 70 %
pcu= (0.15*3+ 0.1*3 + 0.05*0.33+ 0.7*1)
= 1.466 = 14.66 %

Traffic Volume Forecast

The design of new highways or improvement to an existing highway should not be based on current traffic volumes but on the future traffic expected to use the facilities. The forecast year design traffic should not be so far ahead of that current year. A period of 15 to 20 years is widely used.



Components of Future Traffic

1. Current traffic: (a) Existing+ (b) Attracted

(a) traffic volume that is already using the facility

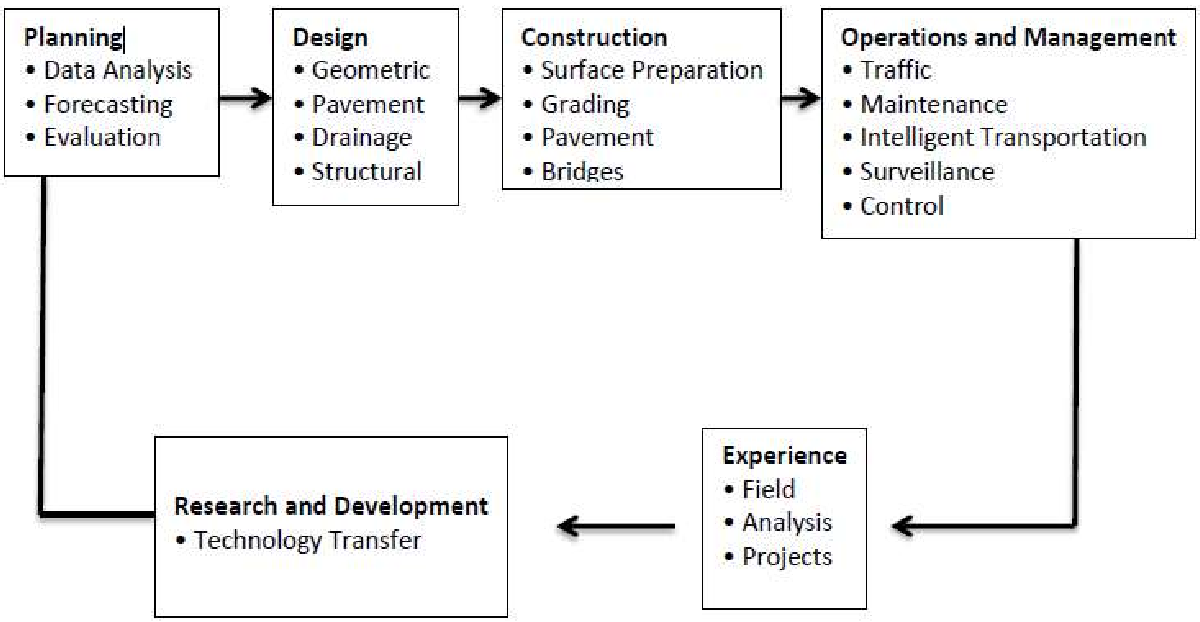
(b) traffic volume that is transferring from less attractive routes

2. Normal traffic growth: As a result, to the general increase in the number and usage of vehicles.

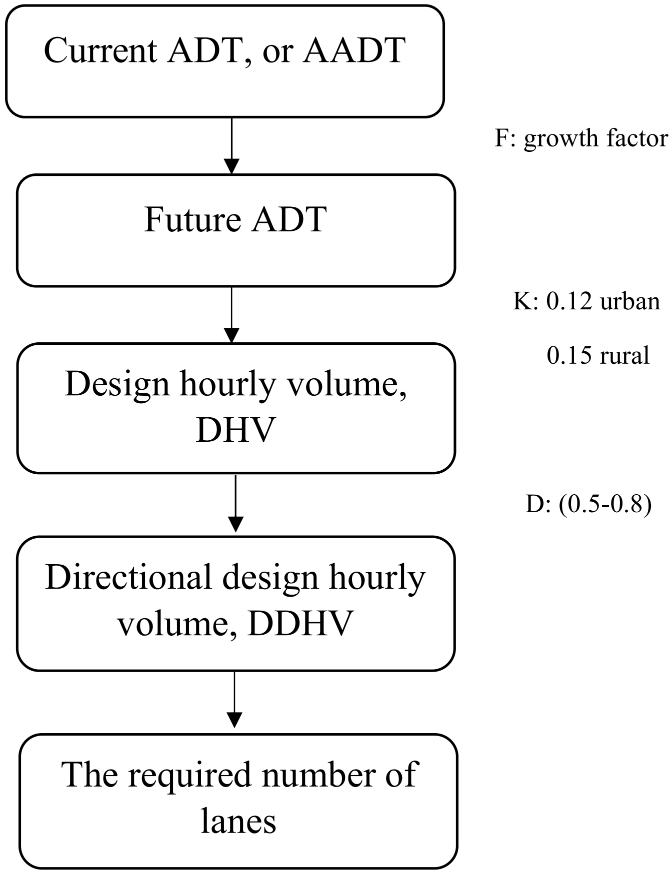
3. Generated traffic: It consists of vehicle trips as following:

- New trips not previously made by any mode of travel
- Trips made previously by public mode
- Trips that are made to different destinations

*Generated traffic is likely to be 5 -25% of the current traffic.



The flow chart to design traffic volumes:



Types of traffic stream:

1- Single-lane one-way highway (no overtaking).

2- Two-lane highway (one-way or two-way).

3- Multi-lane highways (Three-lane, Four-lane, …).

Ex: Design data is required for improvement of a two–way urban highway, the current traffic volume in 2017 expressed by AADT is 3000 veh/day in both direction. The improved road with a design life of 20 years, annual growth rate of traffic is 8%, and the construction period 5 years, percent of trucks =18%, determine the DDHV.

Ans:

* $F=(1+r)^{n+x}$, r: annual growth rate
n:design life
x: construction life

Future AADT = Current AADT * F

$= 3000 * (1+0.08)^{20+5} = 20550$ veh/d

DHV = ADT * K = 20550 * **0.12** = 2466 veh./hr

D: Directional distribution = 55% of total volume

DDHV= 2466* **0.55** = 1356 veh./hr

$$DDHV = 1356\ [\frac{100-18}{100} * 1 + \frac{18}{100} * 3] = 1844\ PCU/hr$$

Ex: design data collection on a rural highway for 16hr daily give for a two day in a week are 1800 and 1200 vehicle respectively and 2000 vehicle for other days, with 15% truck and 10% busses, if you know that the percent of 16hr volume to 24hr volume = 93%, determine:

1) The DHV after 25 years for this highway,

2) The number of lanes if the design capacity is 1200 pcu/hr?

Ans:

1) No. of vehicles during week = 2000*(7-2)+1800+1200= 13300 vehcile

(volume of 16 hr) = 93% volume of 24 hr.

So, volume of 24 hr = $\frac{100}{93}$ * volume of 16 hr

$= \frac{100}{93} * 13300 = 14301$ vehicles

$$\text{ADT (current)} = \frac{14301}{7} = 2043 \quad \text{veh./day}$$

$$\text{ADT (future)} = F * \text{ADT (current)}$$

$$= (1+0.06)^{25} * 2043 = 8764 \text{ veh./day}$$

$$\text{DHV} = \text{ADT} * K = 8764 * \mathbf{0.15}$$

$$= 1315 \text{ veh./hr}$$

$$\text{DHV} = 1315 * [\frac{100-15-10}{100} * 1 + \frac{15}{100} * 3 + \frac{10}{100} * 2] = 1841 \text{ PCU/hr}$$

2) $$\text{No. of Lanes} = \frac{\text{DHV (PCU)}}{Capacity\ (\frac{PCU}{lane})}$$

$$= \frac{1841}{1200} = 1.5$$, so, **let it (2 lane)**

Spacing and Headway: Microscopic Parameters

While flow, speed, and density represent macroscopic descriptors for the entire traffic stream, they can be related to microscopic parameters that describe individual vehicles within the traffic stream, or specific pairs of vehicles within the traffic stream.

Spacing: Spacing is defined as the distance between successive vehicles in a traffic lane, measured from some common reference point on the vehicles, such as the front bumper or front wheels. The average spacing in a traffic lane can be directly related to the density of the lane:

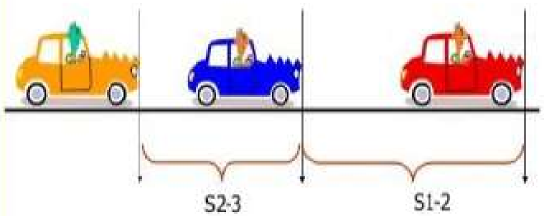
$$\text{Spacing (ft/veh)} = \frac{5280 \ (\text{ft/mi})}{\text{Density} \ (\text{veh/mi})}$$

Wher

e: D = density, veh/mi/ln

(I Mile =5280 ft)

- Front bumper to front bumper distance between successive vehicles



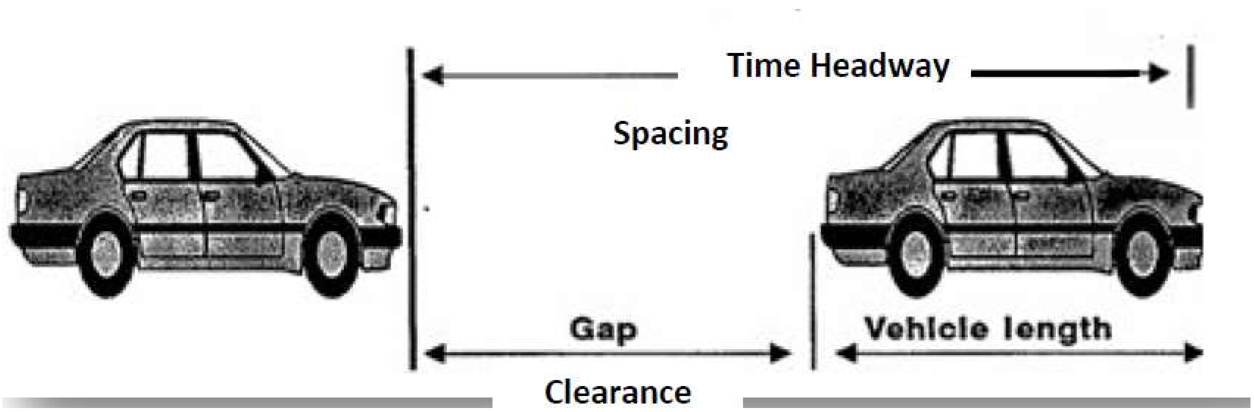
The maximum density (D_{max}) that can be achieved on a highway facility can be estimated considering the minimum spacing, s_{min}. The minimum spacing s_{min} consists of the average vehicle length plus the minimum gap between vehicles, i.e., the gap when vehicles are stopped. Assuming an average vehicle length of 20 ft and an average gap between vehicles of 5 ft, the maximum density is:

$$D_{max} = \frac{5,280}{s_{min}} = \frac{5,280}{20+5} \approx 211 \text{ vpmpl}$$

Headway distribution in Highways

Headway: It's the time interval between successive vehicles as they pass a point along the lane of roadway, expressed in seconds.

It is used in traffic calculations that are used in measuring the highway capacity.



Note: The relationship between (time headway) and traffic volume is represented as follows:

$$h_a = \frac{3600}{\upsilon}$$

Where: h_a is the average headway in a lane, sec;

υ is the rate of flow, veh/h/ln.

Note: At traffic jam, time headway= 0, and it will be at maximum value in freeways.

There are two ways to measure the time headway of traffic:

1- Electronic equipment that gives a signal when vehicles pass over a specified line on the road then record the timing between successive signals to measure the average time headway.
2- Aerial photography that can take a picture at any time.

Gap (g): Gap is very similar to headway, except that Gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, where headway focuses on front-to-front times. Gap is usually reported in units of seconds.

Clearance (c): Clearance is similar to spacing, except that the clearance is the distance between the rear bumper of the leading vehicle and the front bumper of the following vehicle. The clearance is equivalent to the spacing minus the length of the leading vehicle. Clearance, like spacing, is usually reported in units of feet or meters.

Note: Headway can be classified into:

- Counting distribution: Depends on the number of vehicles passing at a specified time period.
- Space distribution: Depends on the time space between successive vehicles.

Note: To calculate the probability that there are ***n*** vehicles passing any point of the road at a specified time ***t***, use the following formula:

$$probability\ (n\ vehicles) = \frac{(qt)^n . e^{-qt}}{n!}$$

t is the given time and ***q*** is the average number of arrival that point at the given time.

Note: Poison distribution refers to the counting distribution, which represents the number of vehicles arrive at a given time interval.

$$probability\ (h > t) = e^{-qt}$$

Components of the Traffic System and their Characteristics

Overview of Traffic Stream Components

To begin to understand the functional and operational aspects of traffic on streets and highways, it is important to understand how the various elements of a traffic system interact. Further, the characteristics of traffic streams are heavily influenced by the characteristics and limitations of each of these elements. There are five critical components that interact in a traffic system:

- Road users: drivers, pedestrians, bicyclists
- Vehicles: private and commercial
- Streets and highways
- Traffic control devices
- The general environment

Traffic engineering would be a great deal simpler if the various components of the traffic system had uniform characteristics. Traffic controls could be easily designed if all drivers reacted to them in exactly the same way. Safety could be more easily achieved if all vehicles had uniform dimensions, weights, and operating characteristics.

Drivers and other road users, however, have widely varying characteristics. The traffic engineer must deal with elderly drivers as well as 18-year-olds, aggressive drivers and timid drivers, and drivers subject to myriad distractions both inside and outside their vehicles. Simple subjects like reaction time, vision characteristics, and walking speed become complex because no two road users are the same.

The Road User

Human beings are complex and have a wide range of characteristics that can and do influence the driving task. In a system where the driver is in complete control of vehicle operations, good traffic engineering requires a keen understanding of driver characteristics. Much of the task of traffic engineers is to find ways to provide drivers with information in a clear, effective manner that induces safe and proper responses.

Human beings as vehicle operator and pedestrians are prime elements in highway traffic. They must be well understood to be properly guided and controlled.

The human performance process may be analyzed as:

1- Reception of information through the senses.

2- Perception during which the brain intercepts the information and decision making.

3- Intellection, including reasoning, problem solving and decision making.

4- Movement control, when the brain sends instructions to parts of the body.

5- Response by parts of the body to the movement instructions.

***response time for the 5 stages ranging 113-528 millisecond**.*

Human Characteristics

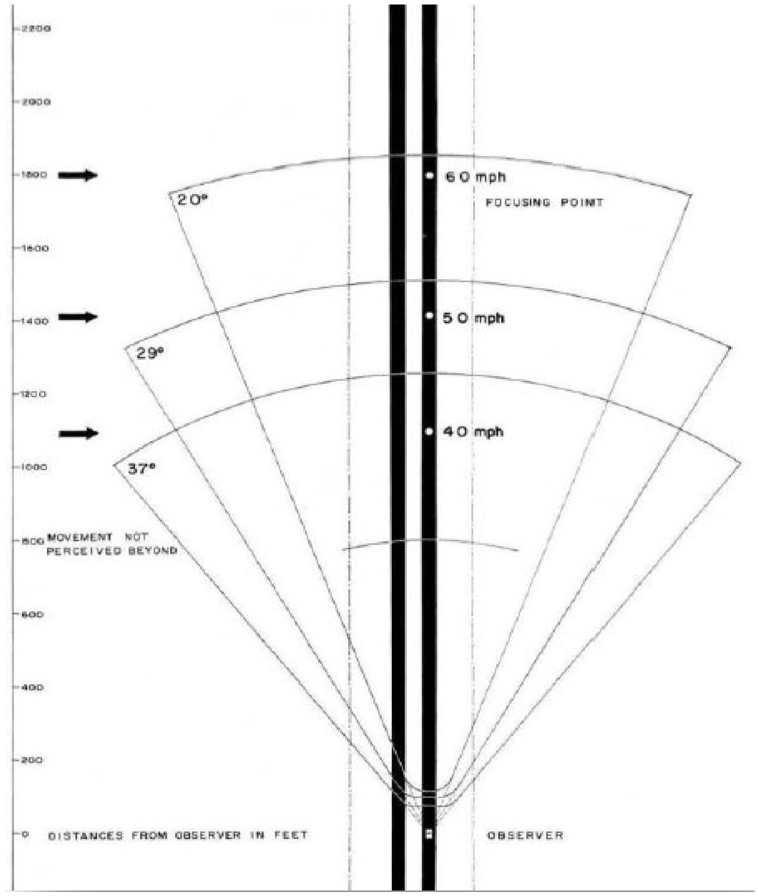
There are several factors must be considered when studying Human Characteristics:

A- Physical Factors

1- Vision: the most important sense for driver and pedestrians.

- Acuity: varies with each individual and with level of illumination

- Eye movements: the eyes must fixate, roll together, and follow the moving object.
- Peripheral vision: Is the ability to perceive objects outside the cone of clear vision.



$$Speed \propto focal\ point\ distance$$

$$Speed \propto \frac{1}{peripheral\ View}$$

Field of vision:

a- Acute or clear cone (tunnel, night)

b- Fairly clear vision cone

c- Peripheral vision.

- Visual sensitivity to colors: About 8% of men and 4% of women suffer some degree of colour blinds, i.e distinguishing between red and green is hard therefore the blue is used in signals instead of green.
- Pedestrian vision: There is no minimum eyes light requirements for pedestrian.

2- Hearing: Lack of hearing acuity presents no major problem to drivers but may to pedestrians who rely on sound to respond to vehicle dangers if existing.

3- Other senses: Like stability sensations caused by rough roads, sharp curves, sharp cross slop.

B- Psychological factors:

1- Motivation:

a-time-distance economy

b-comfort and convenience

c- security from accidents and crime

2- Intelligent level

3- Learning process

4- Maturity and environmental conditions

C- Modifying Factors: There are many factors affect the alert degree:

1- Fatigue: lack of sleep

2- Drugs

3- Alcohol

4- Weather

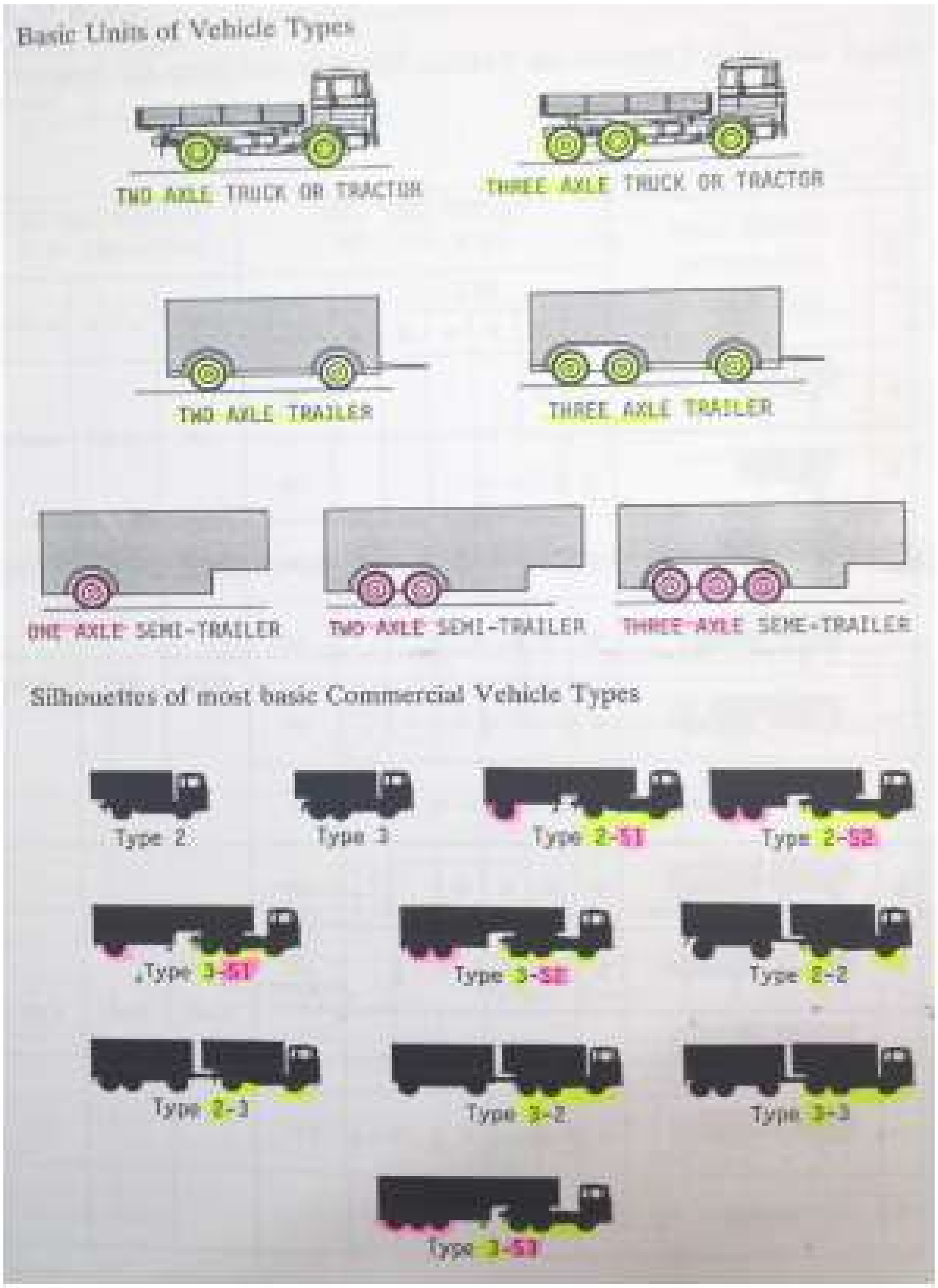
5- Illness

The Vehicle

The characteristics and performance capability of motor – vehicle plays a major role in defining the tasks of traffic engineering:

A- Dimensions: To determine the geometric and structural design of highway and parking facility.

- Length, width, and height.
- Turning radii.
- Weight of vehicles.



Commercial vehicle types

Legal Limits of Commercial Vehicle Weights and Sizes for Iraq

CLASS	VEHICLE SHAPE (SILHOUETTE) AXLE NUMBER	MAXIMUM AXLE LOAD IN METRIC TONS							MAXIMUM VEHICLE DIMENSIONS IN M		
		AXLE						GROSS WEIGHT	LENGTH	WIDTH	HEIGHT
		1	2	3	4	5	6				
A	2 1	6	12					18	12.00	2.60	4.10
B	3 2 1	6	← 18 →					24			
C	3 2 1	6	12	12				30	16.50	2.60	4.10
D	4 3 2 1	6	12	← 18 →				36			
E	4 3 2 1	6	← 18 →		12			36			
F	5 4 3 2 1	6	← 18 →		← 18 →			42			
G	4 3 2 1	6	12	12	12			42	20.00	2.60	4.10
H	5 4 3 2 1	6	12	12	← 18 →			48			
I	5 4 3 2 1	6	← 18 →		12	12		48			
J	6 5 4 3 2 1	6	← 18 →		12	← 18 →		54			
K	OTHERS										

B- Performance:

- Power: ability of vehicle to accelerate , maintain speed and climb grade .
- Acceleration rates for different vehicles normally within a range:

3-8 km/h/s for passenger cars

12-16 km/h/s for fast vehicle

0.75-2 km/h/s for trucks

- Deceleration rates in normal operation are higher than acceleration rates.
- Braking and skidding: Vehicles must have the ability to respond to the driver's reaction if he wants to stop suddenly in emergency cases.

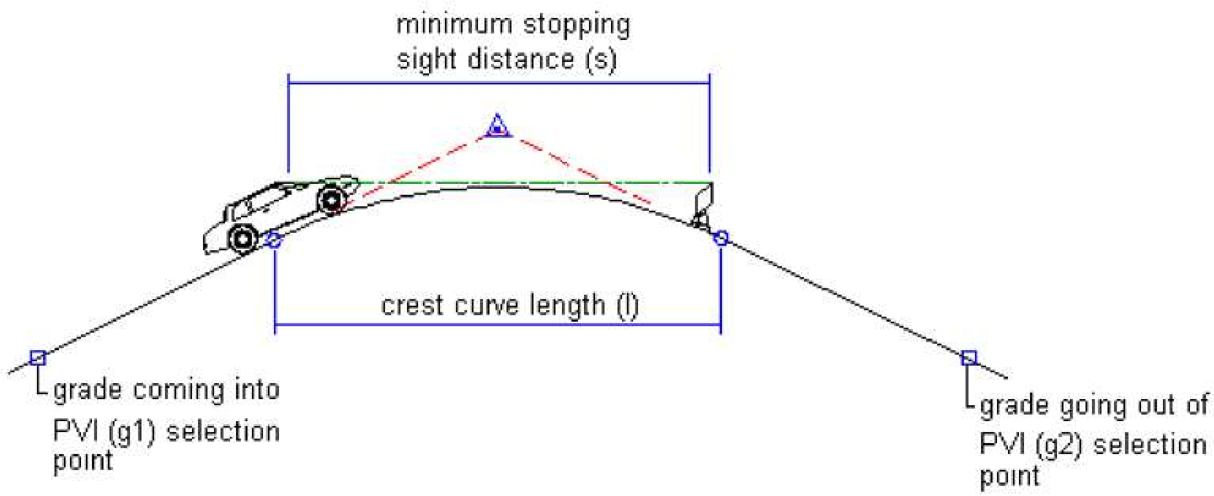
Note: The ability to climb for small vehicles is higher than that for the larger vehicles, because the heavy vehicles can not climb easily on roads with slopes and their speed will be reduced to the minimum. These vehicles would affect other vehicles and will be queuing behind. Therefore, the climbing lanes are made.

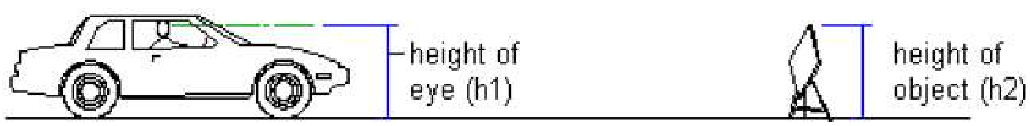
Climbing lane: is a roadway lane designed typically on interstate highways to allow slower travel for large vehicles, such as large trucks or Semi –trailer trucks, ascending a steep grade.

The Road

For safe vehicle operation, a clear line of sight of suitable length must be provided along the road, the minimum safe sight distance can be compared from principles of dynamics and coefficients related to driver, vehicle and road effects.

1- **Stopping sight distance (SSD)**: It is the distance traveled during the two phases of stopping a vehicle:





A- *perception-reaction time (d_1)*: is the time it takes for a road user to realize that a reaction is needed due to a road condition and start the maneuver (taking the foot off the accelerator and depressing the brake pedal).

$d1 = 0.278\, vt$, d_1:distance in meter
V: speed in kph
t: reaction time in sec.

Reaction and perception time, (sec)	*Urban*	*Rural*
	1.5	**2.5**

B- *maneuver time (d_2)*: is the time it takes to complete the maneuver (decelerating and coming to a stop). The distance driven during perception-reaction time and maneuver time is the sight distance needed.

$$d2 = \frac{Vi^2 - Vf^2}{254\,(f \pm g)}$$

d_2: braking distance , m
vi: initial speed, kph
v_f: final speed, kph
g: slope
f: coefficient of friction (0.27-0.36)

$$SSD = d1 + d2 = 0.278\,vt + \frac{Vi^2 - Vf^2}{254\,(f \pm g)}$$

Ex: If the design speed of a multilane highway is 90kph, what is the minimum stopping sight distance that should be provided on a road if:

1- road is horizontal

2- has a max grade of 5%, assume t= 2.5 sec.

Ans:

$$SSD = d1 + d2 = 0.278\,vt + \frac{Vi^2 - Vf^2}{254\,(f \pm g)}$$

1- horizontal : g=0

$$SSD = 0.278 * 90 * 2.5 + \frac{90^2 - 0^2}{254\,(0.3 \pm 0)} = 170\ m$$

2- $SSD = 0.278 * 90 * 2.5 + \frac{90^2 - 0^2}{254\,(0.3 \pm 0.05)} = 190\ m$

Ex: A car travelling at 70kph required 40m to stop after the brakes have been applied, what average coefficient of friction was developed between tyres and pavement surface? The grade g= 10%.

Ans:

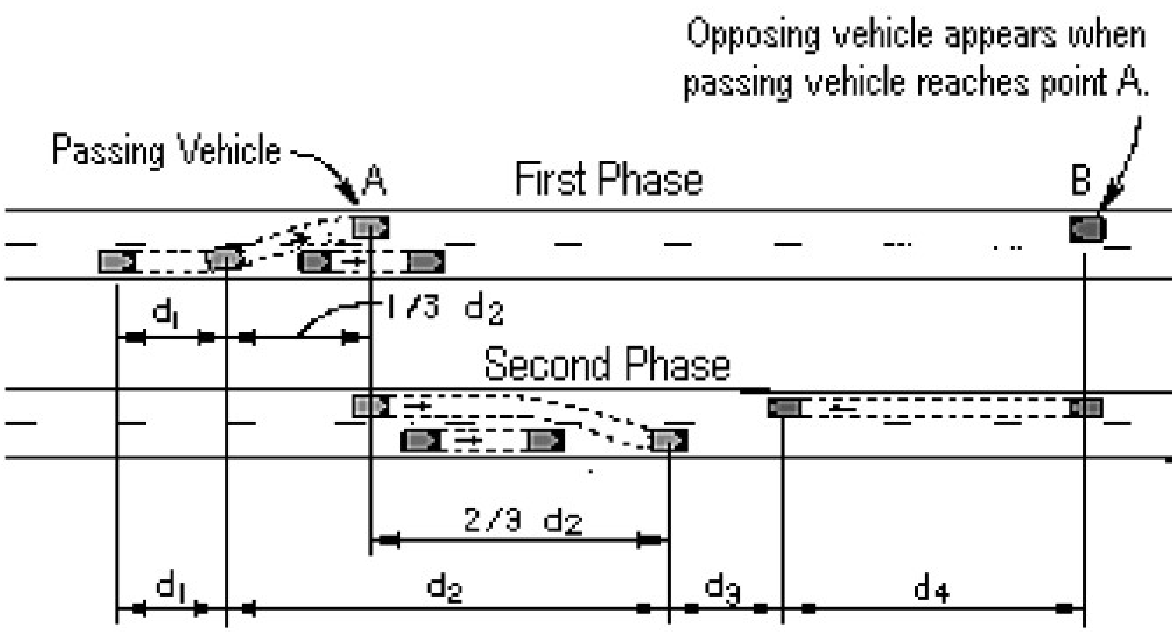
$$d2 = \frac{Vi^2 - Vf^2}{254\,(f \pm g)}$$

$$40 = \frac{70^2 - 0}{254\,(f \pm 0.1)}$$

$$f = 0.3823$$

2- **Minimum Passing Sight Distance (PSD)**:

Is the minimum distance required on a two-lane, two-way highways to give the opportunity to pass slow moving vehicles and it must be provided at intervals otherwise capacity decreases and accident may occur.



The assumed operating conditions are as follows:

1- The overtaken vehicle travels at uniform speed.

2- The passing vehicle has reduced speed and trails the overtaken vehicle as it enters the passing sections.

3- When the passing section is reached, the driver requires a short period of time to passing the overtaken vehicle.

4- Passing is accomplished under accelerated speed, it is about **16km/hr** higher than that of the overtaken vehicle.

5- When the passing vehicle returns to its lane, there must be a suitable clearance length between it and an oncoming vehicle in the opposing direction.

$$\mathbf{PSD = d1 + d2 + d3 + d4}$$

$$d1 = 0.278\, t_1\, (v_1 + a\, t_1 /2)$$

d_1: initial maneuver distance (m)

v_1: average speed of the overtaken vehicle (km/hr)

t_1: preliminary delay time in sec. (3.5-4.5 sec) for speed range (40-90 km/hr)

a: acceleration rates usually taken (2-3) m/sec^2.

$$d2 = 0.278\, v_2 t_2$$

d_2: distance in the opposite lane.

v_2: average speed of overtaking vehicle (km/hr).

t_2: the time the vehicle occupies in opposing lane (9.5-11.5sec) for speed range (45-90km/hr).

$\boldsymbol{d3 = 50 - 100\ m}$, use higher distance with higher speed.

d_3:safty distance.

$$\boldsymbol{d4 = \frac{2}{3}\, d_2}$$

d_4: distance travelled by the opposite vehicle in the opposite lane.

Notes:

1- For the three-lane roads, passing sight distance PSD= $d_1+d_2+d_3$

2- Safe passing distance is considered greater than safe stopping sight distance and sometimes, it is uneconomical to provide such distances. Thus, restriction in providing them means reduction in capacity and speed.

Ex: Calculate the safe passing sight distance for car travelling on a highway with 96 km/hr, a=2.5 m/sec^2, t=4 sec, time vehicle occupies in opposing lane 11.5 sec for:

a- two- lane highway.

b- three- lane highway.

Ans:

$$d1 = 0.278\, t_1 \left(v_1 + a\frac{t_1}{2} \right)$$

$$= 0.278 * 4 \left((96 - 16) + 2.5 * \frac{4}{2} \right) \quad = 94.52\, m$$

$$d2 = 0.278\, v_2 t_2$$

$$d2 = 0.278 * 96 * 11.5 = 307 \text{ m}$$

d3= let 90

d4= 2/3 d2 = 2/3 *307 = 204

a) PSD = d1 + d2 + d3 + d4 = 94.52 +307 +90 +204 = 697 m

b) PSD = d1 + d2 + d3= 492 m

Ex: What will be the passing distance that is required for a two-lane rural road with speed limit 60 kph, the average speed of passing 65 kph and average acceleration 2.3 km/hr/sec? t= 4 sec.

Ans:

$$d1 = 0.278\, t_1 \left(v_1 + a \frac{t_1}{2} \right)$$

$$= 0.278 * 4 \left((65 - 16) + 2.3 * \frac{4}{2} \right)$$

$$= 60\ m$$

$$d2 = 0.278\, v_2 t_2$$

$$d2 = 0.278 * 65 * 11.5$$

$$= 207\ \text{m}$$

d3= let 90

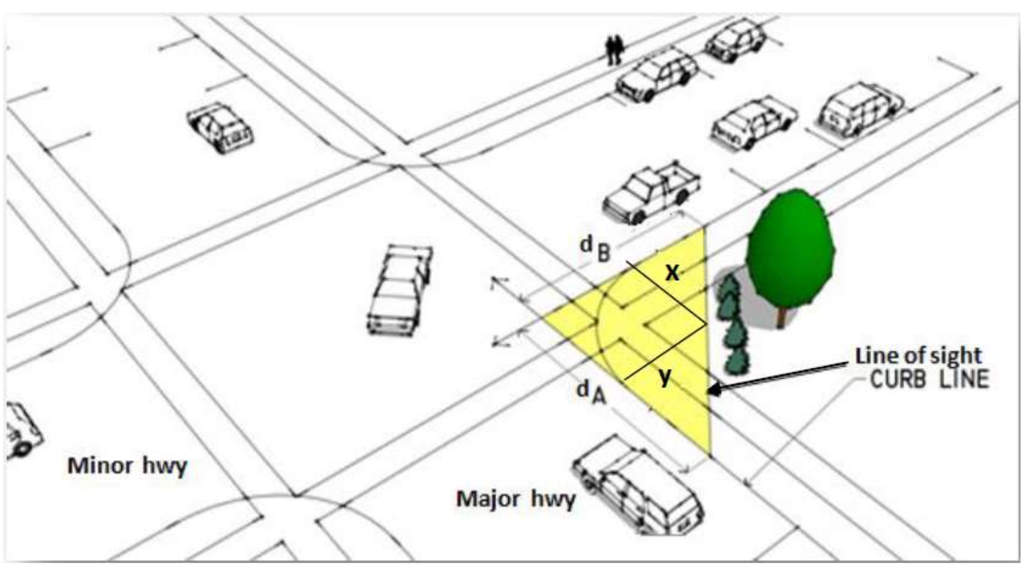
d4= 2/3 d2 = 2/3 * = 138 m

PSD = d1 + d2 + d3 + d4

= 60 +207 +90 +138 = 495 m

3- **Sight Distance at intersections**:

The operation of intersection is affected by the sight distances allowed for approaching drivers and the vehicle speed.



$$dA = 0.278\, v_A t \quad + \left(\frac{V_A^2}{254(f \mp g)}\right)$$

$$dB = 0.278\, v_B t \quad + \left(\frac{V_B^2}{254(f \mp g)}\right)$$

dA: major road

dB: minor road

f: friction factor 0.2-0.6

g: grade,

t: 1.5 - 2.5 sec.

From similarity of triangles:

$$\frac{dB}{dA} = \frac{y}{dA - X}$$

$$\therefore dB = \frac{dA.y}{dA - X}$$

Ex: In a priority intersection, the speed of minor vehicle V_B was 30km/hr, the edge of a building to the edge of the pavement is 5m and 7m, respectively. Determine the speed of the major vehicle, knowing that major width 8m, minor width 4m?

Ans:

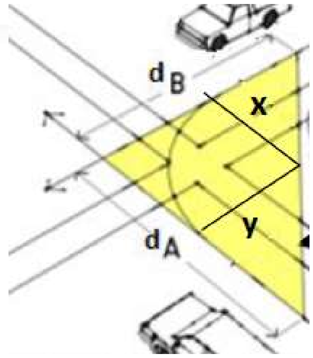
V_B=30 km/hr
X=5m
Y=7m

X' = 5+2 = 7 m
Y'=7+4 = 11m

$$dB = 0.278\, v_B t \quad + \left(\frac{V_B^2}{254(f \mp g)}\right)$$

$$= 0.278 * 30 * 1.5 + \left(\frac{30^2}{254(0.3 \mp 0)}\right)$$

$$= 25 \text{ m}$$



$$\frac{dB}{dA} = \frac{y}{dA - X}$$

$$\frac{25}{dA} = \frac{11}{dA - 7}$$

dA= 12 m

$$dA = 0.278\ v_A t \quad + \left(\frac{V_A^2}{254(f \mp g)}\right)$$

$12 = 0.278 * Va * 1.5 + \left(\frac{V_A^2}{254(0.3 \mp 0)}\right)$

$12 = 0.417\ V_A + 0.013\ V_A^{\ 2}$

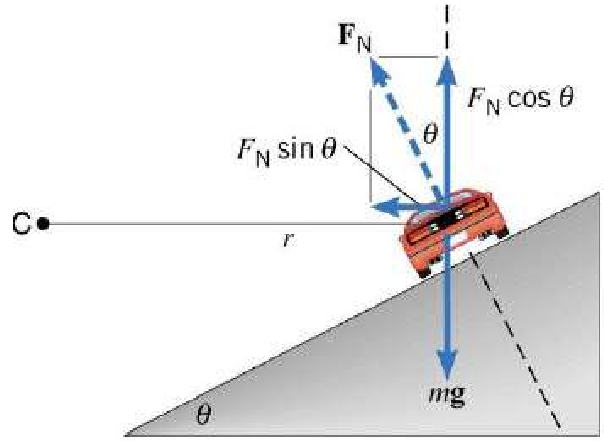
V_A= km/hr

Turning Radii

The minimum radius of a circular curve (R) for a vehicle travelling at (V) km/hr can be determined considering the equilibrium of the vehicle with respect to its movement up or down the inclination.

The centrifugal force $F = \frac{wg}{g}$,

where : a: acceleration for curve motion $=V^2/R$, w: weight of the vehicle, g: acceleration of gravity, when the vehicle is in equilibrium .



$$\frac{WV^2}{gR}\cos\theta = w\sin\theta + w\,f\cos\theta$$

$$R = \frac{V^2}{g(\tan\theta \mp f)}$$

tanθ =e =superelevation (i.e. the inclination of the roadway toward the center of the curve.

V: vehicle speed, km/hr
R: radius of the curve, m
f: side friction

$$R = \frac{V^2}{127(e \mp f)}$$

Side speed (kph)	48	64	80	96	102
Side friction coefficient (f)	0.16	0.15	0.14	0.12	0.10

Ex: Determine the minimum radius required at a curve section of a highway if the design speed is 110 km/hr and the super elevation is 0.08?

Ans:

$$R = \frac{V^2}{127(e+f)}$$

$$= \frac{110^2}{127(0.08+0.14)}$$

$= 433$ m

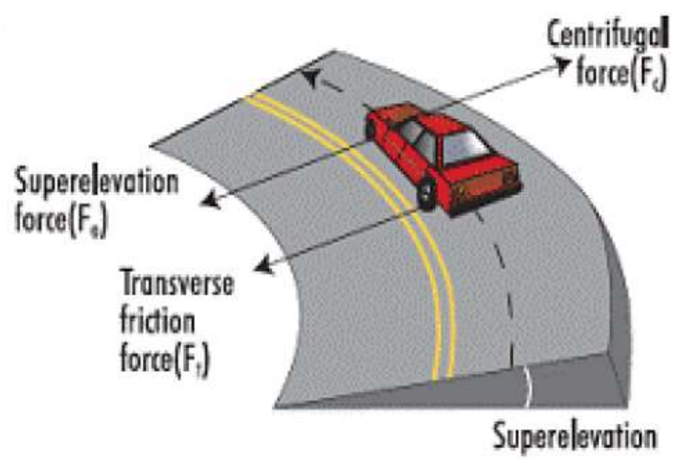
Ex: A horizontal curve is to be designed for a section of highway having a design speed 95kph, if the physical conditions restrict the radius to 310m, Design the value for the superelevation to fit the available conditions. f=0.14.

Ans:

$$R = \frac{V^2}{127(e+f)}$$

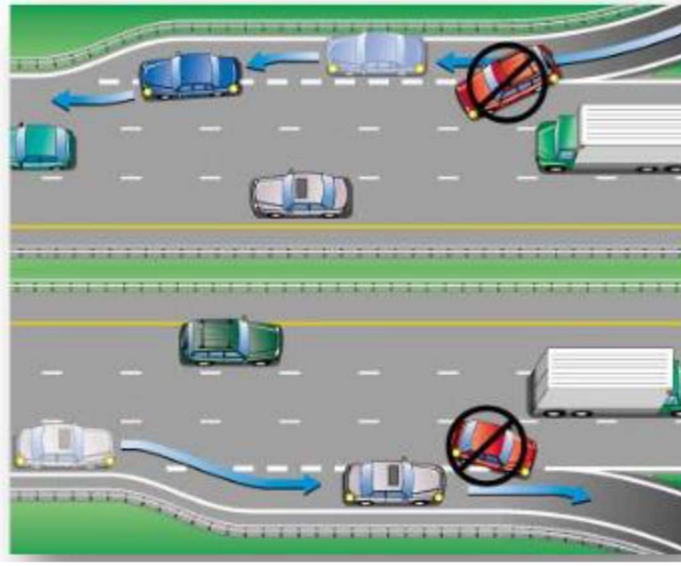
$$310 = \frac{95^2}{127(e+0.14)}$$

e= 0.09 =9%



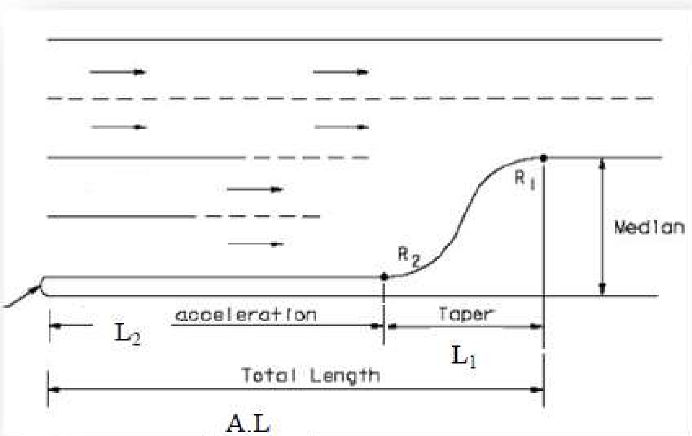
Speed Change Lanes

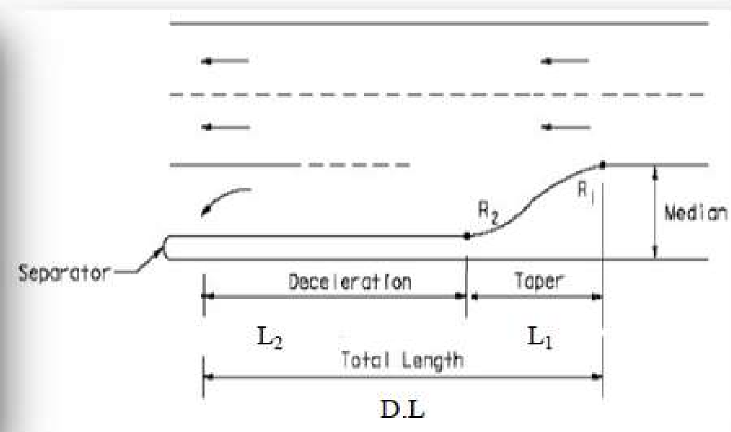
Acceleration/deceleration lanes (also known as speed -change lanes or auxiliary lanes) provide drivers with an opportunity to speed up or slow down in a space not used by high-speed through traffic.



A.L$= L_1 + L_2$ (acceleration length)

D.L $= L_1 + L_2$ (deceleration length)





Where : $L_1 = 0.278\ V_1\ t$

$$L_2 = \frac{V_1^2 - V_2^2}{7.2\ d\ (a)}$$

t: transformation time 4.5 sec.

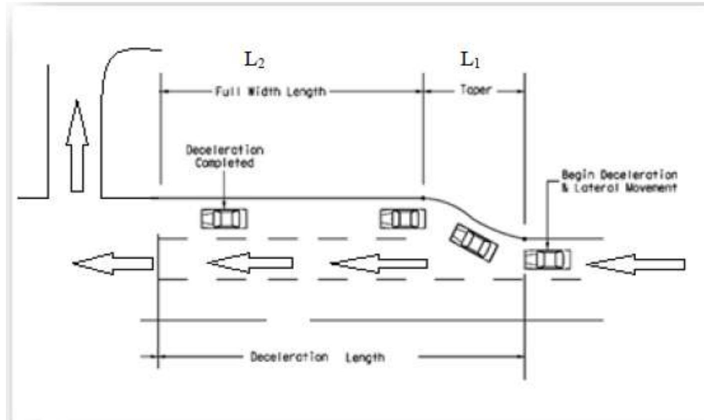
a: acceleration factor = 5 m/sec^2

d: deceleration factor =8 m/sec^2 or 28.5 m/sec^2 in emergency.

Ex: Determine the length of acceleration and deceleration lane for major and minor road with:

Design speed = 100 kph (for major road)

Design speed = 60 kph (for minor road)



Ans:

$L_1 = 0.278\ V_1\ t \quad = 0.287 * 100 * 4.5 \ = 127\ m$

$$L_2 = \frac{V_1^2 - V_2^2}{7.2\ (a)} \quad = \frac{100^2 - 60^2}{7.2*5} \ = 178\ m$$

A.L= $L_1 + L_2$ (acceleration length)

= 127+187 = 305 m

D.L = $L_1 + L_2$ (deceleration length)

$$L_2 = \frac{V_1^2 - V_2^2}{7.2\ (d)} \quad = \frac{100^2 - 60^2}{7.2*8} \ = 111\ m$$

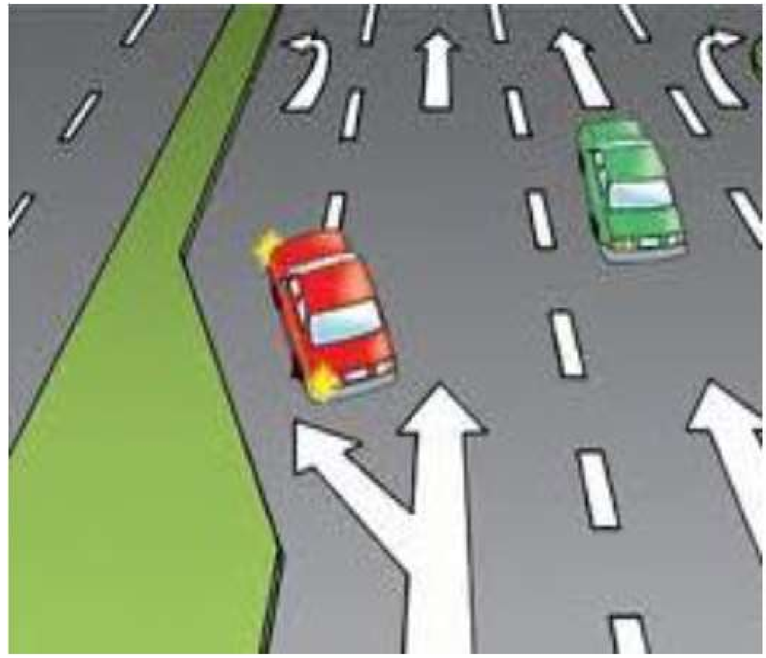
So , D.L = 127 + 111 = 238 m

Ex: A driver travelling at 80kph needed to make a left turn at T-junction with turning radius of 40m. Determine the required deceleration lane length for safe maneuver, no superelevation, side friction 0.12.

$$R = \frac{V^2}{127(e+f)}$$

$V^2 = 127\ (0.12)\ (40)$

$V = 24.7$ km/hr



$D.L = L_1 + L_2$

$L_1 = 0.278\ V_1\ t$

$= 0.278 * 80 * 4.5$

$= 100$ m

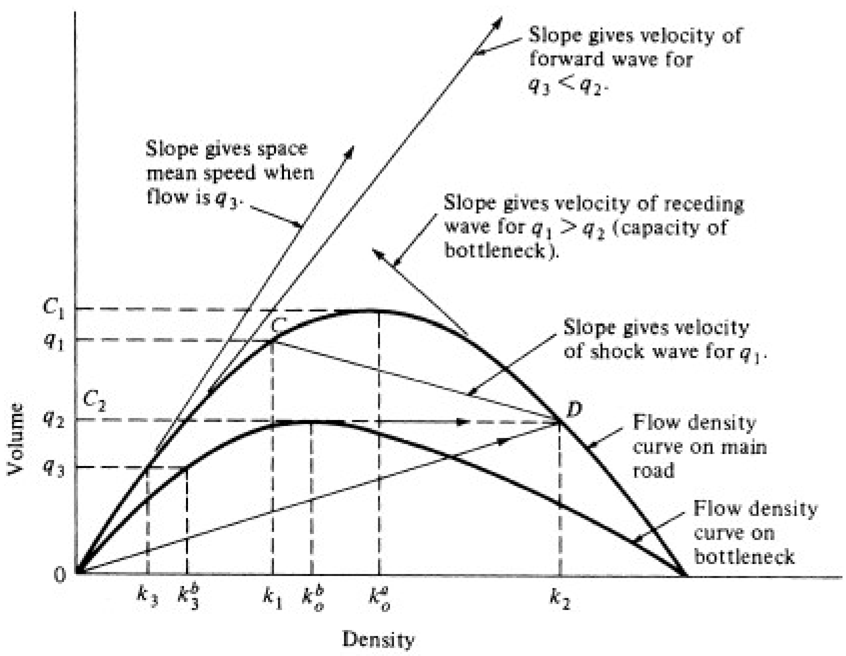
$$L_2 = \frac{V_1^2 - V_2^2}{7.2\ (d)} = \frac{80^2 - 24.7^2}{7.2 * 8} = 100\ m$$

$D.L = 100 + 100 = 200$ m

Shock waves in traffic streams

Shock wave is the phenomenon of backups and queuing on a highway due to a sudden reduction of the capacity of the highway (known as a bottleneck condition). The sudden reduction in capacity could be due to a crash, reduction in the number of lanes, restricted bridge sizes, work zones, a signal turning red, and so forth.

The figure below shows the Kinematic and Shock Wave Measurements Related to Flow-Density Curve.



Types of Shock Waves

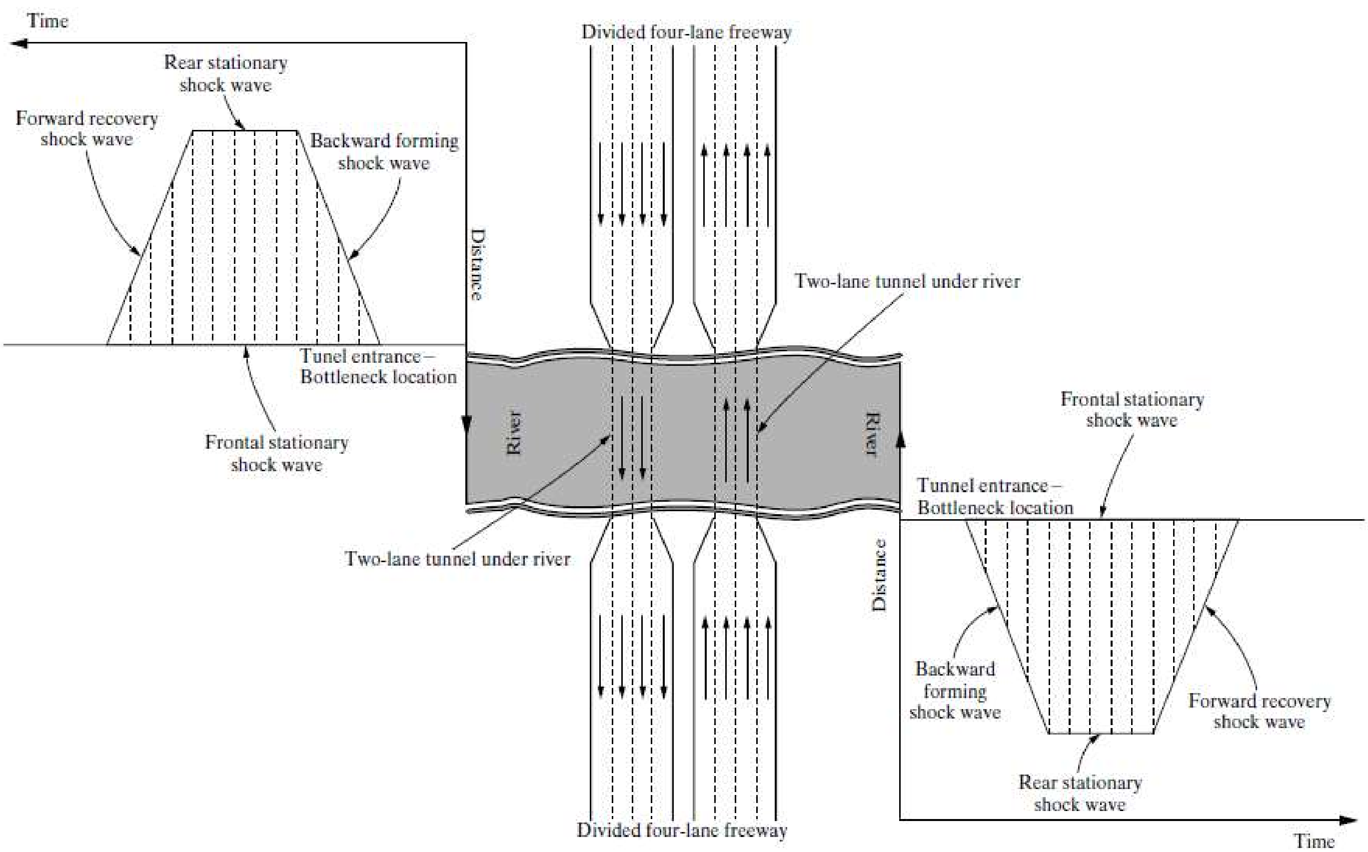
1- ***Frontal stationary shock waves*** are formed when the capacity suddenly reduces to zero at an approach or set of lanes having the red indication at a signalized intersection or when a highway is completely closed because of a serious incident.

2- ***Backward forming shock waves*** are formed when the capacity is reduced below the demand flow rate resulting in the formation of a queue upstream of the bottleneck.

3- ***Backward recovery shock waves*** are formed when the demand flow rate becomes less than the capacity of the bottleneck or the restriction causing the capacity reduction at the bottleneck is removed.

4- ***Rear stationary and forward recovery shock waves*** are formed when demand flow rate upstream of a bottleneck is first higher than the capacity of the bottleneck and then the demand flow rate reduces to the capacity of the bottleneck.

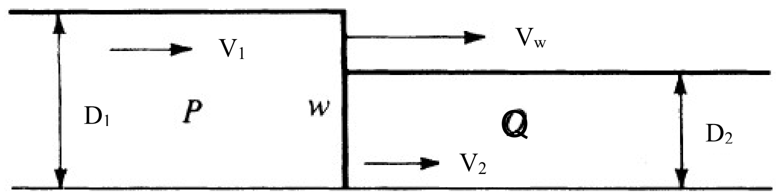
The figure below shows a shock wave at a bottleneck.



Velocity of Shock Waves

Consider D_1 and D_2 are two different densities of traffic along a straight highway, where $D_1 > D_2$.

Assume that the line *w* represents the shock wave moving at a speed V_w. If the line *w* moves in the direction of the arrow (that is, in the direction of the traffic flow), then, V_w is positive.



With V_1 equal to the space mean speed of vehicles in the area with density D_1 (section P), the speed of the vehicles in this area relative to line *w* is:

$$V_{r1} = V_1 - V_w$$

Where V_{r1} the speed of the vehicle before the line of the shock wave.

The number of vehicles crossing line *w* from area P during a time period *t* is:

$$N_1 = V_{r1} D_1 t$$

Similarly, the speed of vehicles in the area with density D_2 (section Q) relative to line *w* is:

$$V_{r2} = V_2 - V_w$$

and the number of vehicles crossing line *w* during a time period *t* is:

$$N_2 = V_{r2} D_2 t$$

Since the net change is zero - that is $N_1 = N_2$ and $(V_1 - V_w)D_1 = (V_2 - V_w)D_2$

$$V_2 D_2 - V_1 D_1 = V_w (D_2 - D_1)$$

If the flow rates in sections P and Q are Q_1 and Q_2, respectively, then:

$Q_1 = V_1 D_1$ and $Q_2 = V_2 D_2$

Substituting Q_1 and Q_2 for $V_1 D_1$ and $V_2 D_2$

$Q_2 - Q_1 = V_w (D_2 - D_1)$ ➡ $\boldsymbol{V_w = \frac{Q_2 - Q_1}{D_2 - D_1}}$

Ex: The volume at a section of a two-lane highway is 1500 veh/h in each direction and the density is about 25 veh/mi. A large dump truck loaded with soil from an adjacent construction site joins the traffic stream and travels at a speed of 10 mi/h for a length of 2.5 mi along the upgrade before turning off onto a dump site. Due to the relatively high flow in the opposite direction, it is impossible for any car to pass the truck. Vehicles just behind the truck therefore have to travel at the speed of the truck which results in the formation of a platoon having a density of 100 veh/mi and a flow of 1000 veh/h. Determine how many vehicles will be in the platoon by the time the truck leaves the highway.

Ans:

$V_w = \frac{Q_2 - Q_1}{D_2 - D_1} = \frac{1000 - 1500}{100 - 25}$ = - 6.7 mi/h (shock wave is *moving backward*)

growth rate of the platoon = 10 – 1(- 6.72) = 16.7 mi/h

Calculate the time spent by the truck on the highway = 2.5/10 = 0.25h

Length of the platoon by the time the truck leaves the highway = 0.25*16.7 = 4.2 mi

The number of vehicles in the platoon = 100*4.2 = 420 vehicles.

Highway Safety

As the number of motor vehicles and vehicle-miles of travel increases throughout the world, the exposure of the population to traffic crashes also increases.

Traffic and highway engineers are continually engaged in working to ensure that the street and highway system is designed and operated such that highway crash rates can be reduced. They also work with law-enforcement officials and educators in a team effort to ensure that traffic laws, such as those regarding speed limits and drinking, are enforced, and that motorists are educated about their responsibility to drive defensively and to understand and obey traffic regulations.

There are five major safety programs that are addressed by states in developing a safety management program. They are:

1. Coordinating and integrating broad-based safety programs, such as motor community-based safety activities, into a comprehensive management approach for highway safety.

2. Identifying and investigating hazardous highway safety problems and roadway locations and features, including railroad–highway grade crossings, and establishing countermeasures and priorities to correct identified or potential hazards.

3. Ensuring early consideration of safety in all highway construction programs and projects.

4. Identifying safety needs of special user groups (such as older drivers, pedestrians, bicyclists, motorcyclists, commercial motor carriers, and hazardous materials carriers) in the planning, design, construction, and operation of the highway system.

5. Routinely maintaining and upgrading safety hardware (including highway–rail crossing warning devices), highway elements, and operational features.

Crashes or Accidents

"Accident" is the commonly accepted word for an occurrence involving one or more transportation vehicles in a collision that results in property damages, injury, or death. The term "accident" implies a random event that occurs for no apparent reason.

The National Highway Traffic Safety Administration has suggested replacing the word "*accident*" with the word "*crash*" ***because "crash" implies that the collision could have been prevented or its effect minimized by modifying driver behavior, vehicle design (called "crashworthiness"), roadway geometry, or the traveling environment.***

The word "crash" is not universally-accepted terminology for all transportation modes and is most common in the context of highway and traffic incidents.

Factors Involved in Transportation Crashes

- Driver or Operator Action

The major contributing cause of many crash situations is the performance of the driver of one or both (in multiple vehicle crashes) of the vehicles involved. Driver error can occur in many ways, such as inattention to the roadway and surrounding traffic, failure to yield the right of way, and/or traffic laws. These "failures" can occur as a result of unfamiliarity with roadway conditions, traveling at high speeds, drowsiness, drinking, and using a cell phone or other distractions within the vehicle.

- The Vehicle Condition

The mechanical condition of a vehicle can be the cause of transportation crashes. Faulty brakes in heavy trucks have caused crashes. Other reasons are failure of the electrical system, worn tires, and the location of the vehicle's center of gravity.

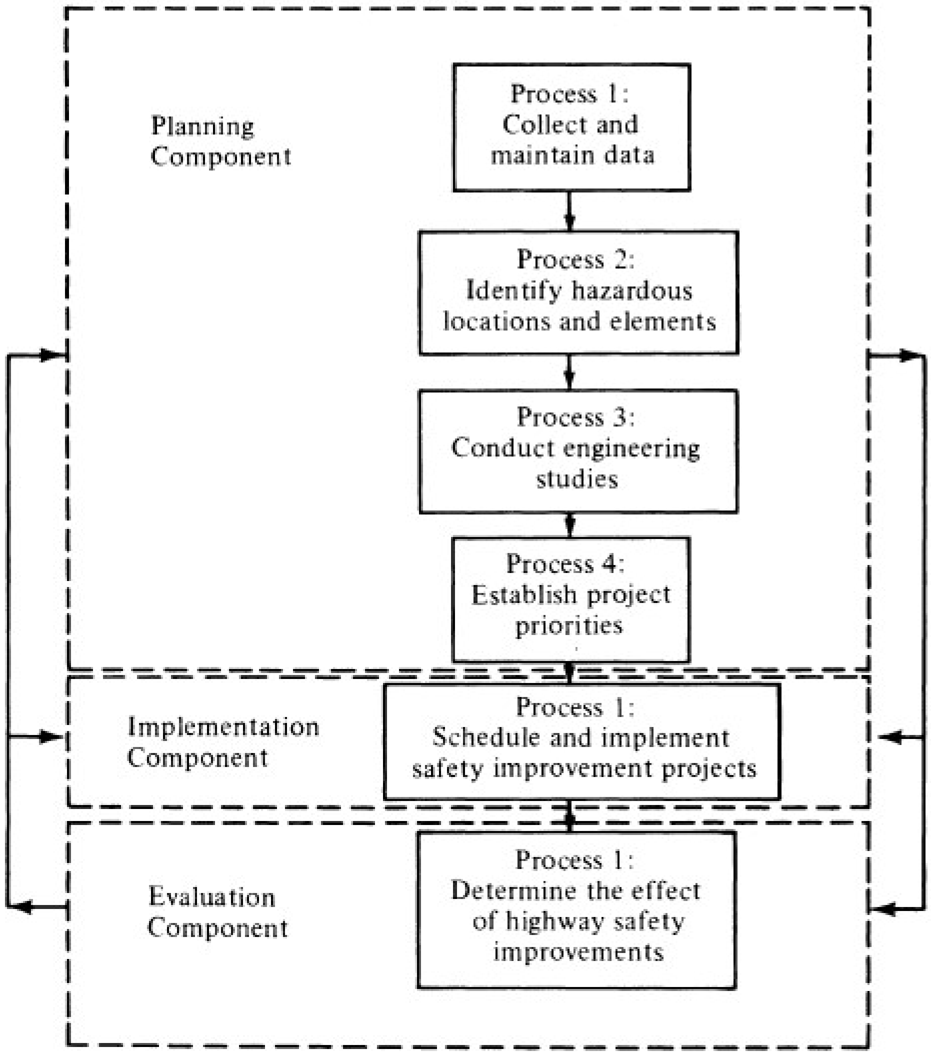
- The Roadway Condition

The condition and quality of the roadway, which includes the pavement, shoulders, intersections, and the traffic control system, can be a factor in a crash. Highways must be designed to provide adequate sight distance at the design speed. Highway curves must be carefully designed to accommodate vehicles traveling at or below the design speed of the road.

- The Environment

Weather on roads can contribute to highway crashes; for example, wet pavement reduces stopping friction and can cause vehicles to hydroplane. Many severe crashes have been caused by fog because vehicles traveling at high speeds are unable to see other vehicles ahead that may have stopped or slowed down, creating a multivehicle pile-up.

Figure below presents an example of highway safety improvement program at the process level of strategic highway safety plan.


Planning Component
Process 1: Collect and maintain data
Process 2: Identify hazardous locations and elements
Process 3: Conduct engineering studies
Process 4: Establish project priorities
Implementation Component
Process 1: Schedule and implement safety improvement projects
Evaluation Component
Process 1: Determine the effect of highway safety improvements