G PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

Department of Civil Engineering

Transportation Engineering – I

Lecture notes on

Traffic Engineering

Fundamental parameters of traffic flow:

Traffic stream parameters:

The traffic stream includes a combination of driver and vehicle behavior. The driver or human behavior being non-uniform, traffic stream is also non-uniform in nature. It is influenced not only by the individual characteristics of both vehicle and human but also by the way a group of such units interacts with each other. Thus a flow of traffic through a street of defined characteristics will vary both by location and time corresponding to the changes in the human behavior.

The traffic engineer, but for the purpose of planning and design, assumes that these changes are within certain ranges which can be predicted. For example, if the maximum permissible speed of a highway is 60 kmph, the whole traffic stream can be assumed to move on an average speed of 40 kmph rather than 100 or 20 kmph.

Thus the traffic stream itself is having some parameters on which the characteristics can be predicted. The parameters can be mainly classified as: measurements of quantity, which includes density and flow of traffic and measurements of quality which includes speed. The traffic stream parameters can be macroscopic which characterizes the traffic as a whole or microscopic which studies the behavior of individual vehicle in the stream with respect to each other.

As far as the macroscopic characteristics are concerned, they can be grouped as measurement of quantity or quality as described above, i.e. flow, density, and speed. While the microscopic characteristics include the measures of separation, i.e. the headway or separation between vehicles which can be either time or space headway. The fundamental stream characteristics are speed, flow, and density and are discussed below.

Speed:

Speed is considered as a quality measurement of travel as the drivers and passengers will be concerned more about the speed of the journey than the design aspects of the traffic. It is defined as the rate of motion in distance per unit of time. Mathematically speed or velocity v is given by,

$$v = \frac{d}{t}$$

Where, v is the speed of the vehicle in m/s, d is distance traveled in m in time t seconds. Speed of different vehicles will vary with respect to time and space. To represent these variations, several types of speed can be defined. Important among them are spot speed, running speed, journey speed, time mean speed and space mean speed. These are discussed below.

Spot Speed:

Spot speed is the instantaneous speed of a vehicle at a specified location. Spot speed can be used to design the geometry of road like horizontal and vertical curves, super elevation etc. Location and size of signs, design of signals, safe speed, and speed zone determination, require the spot speed data. Accident analysis, road maintenance, and congestion are the modern fields of traffic engineer, which uses spot speed data as the basic input. Spot speed can be measured using an endoscope, pressure contact tubes or direct timing procedure or radar speedometer or by time-lapse photographic methods. It can be determined by speeds extracted from video images by recording the distance traveling by all vehicles between a particular pair of frames.

Running speed:

Running speed is the average speed maintained over a particular course while the vehicle is moving and is found by dividing the length of the course by the time duration the vehicle was in motion. i.e. this speed doesn't consider the time during which the vehicle is brought to a stop, or has to wait till it has a clear road ahead. The running speed will always be more than or equal to the journey speed, as delays are not considered in calculating the running speed

Journey speed:
Journey speed is the effective speed of the vehicle on a journey between two points and is the distance between the two points divided by the total time taken for the vehicle to complete the journey including any stopped time. If the journey speed is less than running speed, it indicates that the journey follows a stop-go condition with enforced acceleration and deceleration. The spot speed here may vary from zero to some maximum in excess of the running speed. Uniformity between journey and running speeds denotes comfortable travel conditions.
Time mean speed and space mean speed
Time mean speed is defined as the average speed of all the vehicles passing a point on a highway over some specified time period. Space mean speed is defined as the average speed of all the vehicles occupying a given section of a highway over some specified time period. Both mean speeds will always be different from each other except in the unlikely event that all vehicles are traveling at the same speed. Time mean speed is a point measurement while space mean speed is a measure relating to length of highway or lane, i.e. the mean speed of vehicles over a period of time at a point in space is time mean speed and the mean speed over a space at a given instant is the space mean speed.
Flow
There are practically two ways of counting the number of vehicles on a road. One is flow or volume, which is defined as the number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specific time interval. The measurement is carried out by counting the number of vehicles, nt, passing a particular point in one lane in a definite period t. Then the flow q expressed in vehicles/hour is given by

$$q = \frac{n_t}{t}$$

Flow is expressed in planning and design field taking a day as the measurement of time.
Variations of Volume
The variation of volume with time, i.e. month to month, day to day, and hour to hour and within a hour is also as important as volume calculation. Volume variations can also be observed from season to season. Volume will be above average in a pleasant motoring month of summer, but will be more pronounced in rural than in urban area. But this is the most consistent of all the variations and affects the traffic stream characteristics the least. Weekdays, Saturdays and Sundays will also face difference in pattern. But comparing day with day, patterns for routes of a similar nature often show a marked similarity, which is useful in enabling predictions to be made. The most significant variation is from hour to hour. The peak hour observed during mornings and evenings of weekdays, which is usually 8 to 10 per cent of total daily flow or 2 to 3 times the average hourly volume. These trips are mainly the work trips, which are relatively stable with time and more or less constant from day to day.
Types of volume measurements
Since there is considerable variation in the volume of traffic, several types of measurements of volume are commonly adopted which will average these variations into a single volume count to be used in many design purposes.
1. **Average Annual Daily Traffic (AADT)**: The average 24-hour traffic volume at a given location over a full 365-day year, i.e. the total number of vehicles passing the site in a year divided by 365.
2. **Average Annual Weekday Traffic (AAWT)**: The average 24-hour traffic volume occurring on weekdays over a full year. It is computed by dividing the total weekday traffic volume for the year by 260.
3. **Average Daily Traffic (ADT)**: An average 24-hour traffic volume at a given location for some period of time less than a year. It may be measured for six months, a season, a month, a week, or as little as two days. An ADT is a valid number only for the period over which it was measured.

4. **Average Weekday Traffic (AWT)**: An average 24-hour traffic volume occurring on weekdays for some period of time less than one year, such as for a month or a season.

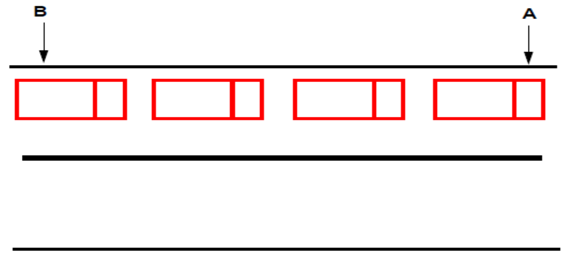


Figure 30:1: Illustration of density

The relationship between AAWT and AWT is analogous to that between AADT and ADT. Volume in generalist measured using different ways like manual counting, detector/sensor counting, moving-car observer method, etc. Mainly the volume study establishes the importance of a particular route with respect to the other routes, the distribution of traffic on road, and the fluctuations in flow. All which eventually determines the design of a highway and the related facilities. Thus, volume is treated as the most important of the entire parameters of traffic stream.

Density

Density is defined as the number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per km. One can photograph a length of road x, count the number of vehicles, nx, in one lane of the road at that point of time and derive the density k as,

$$k = \frac{n_x}{x}$$

This is illustrated in figure. From the figure, the density is the number of vehicles between the point A and B divided by the distance between A and B. Density is also equally important as flow but from a different angle as it is the measure most directly related to traffic demand. Again it measures the proximity of vehicles in the stream which in turn affects the freedom to maneuver and comfortable driving.

Derived characteristics

From the fundamental traffic flow characteristics like flow, density, and speed, a few other parameters of traffic flow can be derived. Significant among them are the time headway, distance headway and travel time. They are discussed one by one below.

Time headway:

The microscopic character related to volume is the time headway or simply headway. Time headway is defined as the time difference between any two successive vehicles when they cross a given point. Practically, it involves the measurement of time between the passage of one rear bumper and the next past a given point. If all headways h in time period, t, over which flow has been measured are added then,

$$\sum_{1}^{n_t} h_i = t$$

But the flow is defined as the number of vehicles n_t measured in time interval t, that is,

$$q = \frac{n_t}{t} = \frac{n_t}{\sum_1^{n_t} h_i} = \frac{1}{h_{av}}$$

where,

h_{av} is the average headway. Thus average headway is the inverse of flow. Time headway is often referred to as simply the headway.

Distance headway

Another related parameter is the distance headway. It is defined as the distance between corresponding points of two successive vehicles at any given time. It involves the measurement from a photograph, the distance from rear bumper of lead vehicle to rear bumper of following vehicle at a point of time. If all the space headways in distance x over which the density has been measured are added,

$$\sum_{1}^{n_x} s_i = x$$

But the density (k) is the number of vehicles n_x at a distance of x, that is

$$k = \frac{n_x}{x} = \frac{n_x}{\sum_1^{n_x} s_i} = \frac{1}{s_{av}}$$

Where, s_{av} is average distance headway. The average distance headway is the inverse of density and is sometimes called as spacing.

Travel time

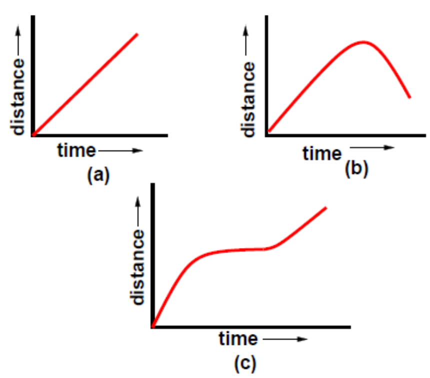
Travel time is defined as the time taken to complete a journey. As the speed increases, travel time required to reach the destination also decreases and vice versa. Thus travel time is inversely proportional to the speed. However, in practice, the speed of a vehicle fluctuates over time and the travel time represents an average measure.

Time-space diagram

Time space diagram is a convenient tool in understanding the movement of vehicles. It shows the trajectory of vehicles in the form of a two dimensional plot. Time space diagram can be plotted for a single vehicle as well as multiple vehicles. They are discussed below.

Single vehicle

Taking one vehicle at a time, analysis can be carried out on the position of the vehicle with respect to time. This analysis will generate a graph which gives the relation of its position on a road stretch relative to time.



Time space diagram for a single vehicle

This plot thus will be between distance x and time t and x will be a functions the position of the vehicle for every t along the road stretch. This graphical representation of x(t) in a (t; x) plane is a curve which is called as a trajectory. The trajectory provides an intuitive, clear, and complete summary of vehicular motion in one dimension.

In figure, the distance x goes on increasing with respect to the origin as time progresses. The vehicle is moving at a smooth condition along the road way. In figure, the vehicle at first moves with a smooth pace after reaching a position reverses its direction of movement. In figure, the vehicle in between becomes stationary and maintains the same position.

From the figure, steeply increasing section of x(t) denote a rapidly advancing vehicle and horizontal portions of x(t) denote a stopped vehicle while shallow sections show a slow-moving vehicle. A straight line denotes constant speed motion and curving sections denote accelerated motion; and if the curve is concave downwards it denotes acceleration. But a curve which is convex upwards denotes deceleration.

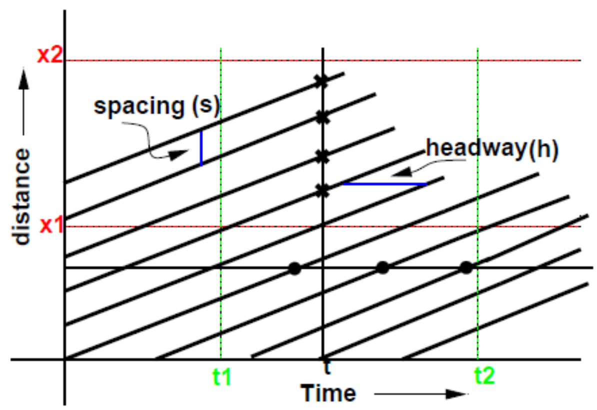
Multiple Vehicles

Time-space diagram can also be used to determine the fundamental parameters of traffic flow like speed, density and volume. It can also be used to find the derived characteristics like space headway and time headway. Figure 30:3 shows the time-space diagram for a set of vehicles traveling at constant speed. Density, by definition is the number of vehicles per unit length. From the figure, an observer looking into the stream can count 4 vehicles passing the stretch of road between x1 and x2 at time t. Hence, the density is given as

$$k = \frac{4\ vehicles}{x_1 - x_2}$$

We can also find volume from this time-space diagram. As per the definition, volume is the number of vehicles counted for a particular interval of time. From the figure we can see that 6 vehicles are present between the time t1 and t2. Therefore, the volume q is given as

$$k = \frac{3\ vehicles}{t_2 - t_1}$$



Time space diagram for many vehicles

Again the averages taken at a specific location (i.e., time ranging over an interval) are called time means and those taken at an instant over a space interval are termed as space means.

Another related definition which can be given based on the time-space diagram is the headway. Space headway is defined as the distance between corresponding points of two successive vehicles at any given time. Thus, the vertical gap between any two consecutive lines represents space headway. The reciprocal of density otherwise gives the space headway between vehicles at that time. Similarly, time headway is defined as the time difference between any two successive vehicles when they cross a given point. Thus, the horizontal gap between the vehicles represented by the lines gives the time headway. The reciprocal of flow gives the average time headway between vehicles at that point.

Time mean speed (v_t)

As noted earlier, time mean speed is the average of all vehicles passing a point over duration of time. It is the simple average of spot speed. Time mean speed vt is given by,

$$v_t = \frac{1}{n}\sum_{i=1}^{n} v_i,$$

where v is the spot speed of i_{th} vehicle, and n is the number of observations. In many speed studies, speeds are represented in the form of frequency table. Then the time mean speed is given by,

$$v_t = \frac{\sum_{i=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i},$$

Where q_i is the number of vehicles having speed vi, and n is the number of such speed categories.

Space mean speed (v_s):

The space mean speed also averages the spot speed, but spatial weight age is given instead of temporal. This is derived as below. Consider unit length of a road, and let vi is the spot speed of i_{th} vehicle. Let t_i is the time the vehicle takes to complete unit distance and is given by $1/v_i$. If there are n such vehicles, then the average travel time t_s is given by,

$$t_s = \frac{\Sigma t_i}{n} = \frac{1}{n}\Sigma\frac{1}{v_i}$$

If t_{av} is the average travel time, then average speed $v_s = 1/t_s$. Therefore from the above equation,

$$v_s = \frac{n}{\sum_{i=1}^{n}\frac{1}{v_i}}$$

No.	speed range	average speed (v_i)	volume of flow (q_i)	$v_i q_i$	$\frac{q_i}{v_i}$
1	2-5	3.5	1	3.5	2.29
2	6-9	7.5	4	30.0	0.54
3	10-13	11.5	0	0	0
4	14-17	15.5	7	108.5	0.45
	total		12	142	3.28

This is simply the harmonic mean of the spot speed. If the spot speeds are expressed as a frequency table, then,

$$v_s = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n}\frac{q_i}{v_i}}$$

where q_i vehicle will have vi speed and n_i is the number of such observations.

Example 1

If the spot speeds are 50, 40, 60,54 and 45, then find the time mean speed and space mean speed.

Solution Time mean speed v_t is the average of spot speed. Therefore, $v_t = \frac{\Sigma v_t}{n} = \frac{50+40+60+54+45}{5} = \frac{249}{5} = 49.8$
Space mean speed is the harmonic mean of spot speed.Therefore, $v_s = \frac{n}{\Sigma\frac{1}{v_t}} = \frac{5}{\frac{1}{50}+\frac{1}{40}+\frac{1}{60}+\frac{1}{54}+\frac{1}{45}} = \frac{5}{0.12} = 48.82$

Example 2

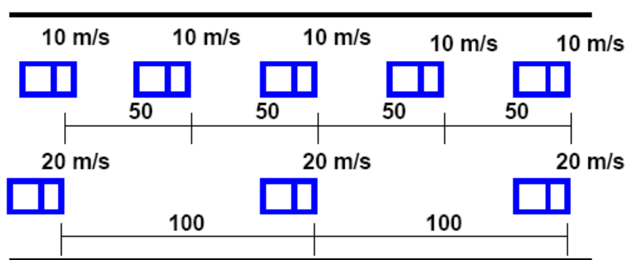
The results of a speed study is given in the form of a frequency distribution table. Find the time mean speed and space mean speed.

speed range	frequency
2-5	1
6-9	4
10-13	0
14-17	7

Solution The time mean speed and space mean speed can be found out from the frequency table given below. First, the average speed is computed, which is the mean of the speed range. For example, for the first speed range, average speed, $v_i = \frac{2+5}{2} = 3.5$ seconds. The volume of flow q_i for that speed range is same as the frequency. The terms $v_i.q_i$ and $\frac{q_i}{v_i}$ are also tabulated, and their summations in the last row. Time mean speed can be computed as, $v_t = \frac{\Sigma q_i v_i}{\Sigma q_i} = \frac{142}{12} = 11.83$ Similarly, space mean speed can be computed as, $v_s = \frac{\Sigma q_i}{\Sigma \frac{q_i}{v_i}} = \frac{12}{3.28} = 3.65$

Illustration of mean speeds

In order to understand the concept of time mean speed and space mean speed, following illustration will help. Let there be a road stretch having two sets of vehicle as in fig. The first vehicle is traveling at 10m/s with 50 m spacing, and the second set at 20m/s with 100 m spacing. Therefore, the headway of the slow vehicle



$h_s = 50/20 = 5sec$ $n_s = 60/5 = 12$ $k_s = 1000/50 = 20$

$h_f = 100/20 = 5sec$ $n_f = 60/5 = 12$ $k_f = 1000/100 = 10$

Illustration of relation between time mean speed and space mean speed

h_s will be 50 m divided by 10 m/s which is 5 sec. Therefore, the number of slow moving vehicles observed at A in one hour n_s will be $60/5 = 12$ vehicles. The density K is the number of vehicles in 1 km, and is the inverse of spacing. Therefore, $K_s = 1000/50 = 20$ vehicles/km. Therefore, by definition, time mean speed v_t is given by $v_t = \frac{12\times10+12\times20}{24} = 15$ m/s. Similarly, by definition, space mean speed is the mean of vehicle speeds over time. Therefore, $v_s = \frac{20\times10+10\times20}{30} = 13.3$ m/s This is same as the harmonic mean of spot speeds obtained at location A; ie $v_s = \frac{24}{12\times\frac{1}{10}+12\times\frac{1}{20}} = 13.3$ m/s. It may be noted that since harmonic mean is always lower than the arithmetic mean, and also as observed , space mean speed is always lower than the time mean speed. In other words, space mean speed weights slower vehicles more heavily as they occupy the road stretch for longer duration of time. For this reason, in many fundamental traffic equations, space mean speed is preferred over time mean speed.

Relation between time mean speed and space mean speed:

The relation between time mean speed and space mean speed can be derived as below. Consider a stream of vehicles with a set of sub stream flow $q_1, q_2, \ldots q_i, \ldots q_n$ having speed $v_1, v_2, \ldots v_i, \ldots v_n$. The fundamental relation between flow (q), density (k) and mean speed v_s is,

$$Q = k \times v_s$$

Therefore for any sub stream q_i, the following relationship will be valid.

$$q_i = k_i \_ vi$$

The summation of all sub stream flows will give the total flow q.

$$\Sigma qi = q$$

Similarly the summation of all sub stream density will give the total density k.

$$\Sigma ki = k$$

Let f_i denote the proportion of sub stream density ki to the total density k,

$$f_i = k_i / k$$

Space mean speed averages the speed over space. Therefore, if k_i vehicles has v_i speed, then space mean speed is given by,

$$v_s = \frac{\Sigma k_i v_i}{k}$$

Time mean speed averages the speed over time.Therefore,

$$v_t = \frac{\Sigma q_i v_i}{q}$$

Substituting in 31.7 v_t can be written as,

$$v_t = \frac{\Sigma k_i {v_i}^2}{q}$$

Rewriting the above equation and substituting 31.11, and then substituting 31.6, we get,

$$\begin{aligned} v_t &= k\Sigma \frac{k_i}{k} v_i^2 \\ &= \frac{k\Sigma f_i {v_i}^2}{q} \\ &= \frac{\Sigma f_i {v_i}^2}{v_s} \end{aligned}$$

By adding and subtracting v_s and doing algebraic manipulations, v_t can be written as,

$$v_t = \frac{\Sigma f_i (v_s + (v_i - v_s))^2}{v_s}$$

$$= \frac{\Sigma f_i (v_s)^2 + (v_i - v_s)^2 + 2.v_s.(v_i - v_s)}{v_s}$$

$$= \frac{\Sigma f_i {v_s}^2}{v_s} + \frac{\Sigma f_i (v_i - v_s)^2}{v_s} + \frac{2.v_s.\Sigma f_i (v_i - v_s)}{v_s}$$

The third term of the equation will be zero because $\Sigma f_i (v_i - v_s)$ will be zero, since v_s is the mean speed of v_i. The numerator of the second term gives the standard deviation of v_i. Σfi by definition is 1.Therefore,

$$v_s \Sigma f_i + \frac{\sigma^2}{v_s} + 0$$

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

Hence, time mean speed is space mean speed plus standard deviation of the spot speed divided by the space mean speed. Time mean speed will be always greater than space mean speed since standard deviation cannot be negative. If all the speed of the vehicles are the same, then spot speed, time mean speed and space mean speed will also be same.

Fundamental relations of traffic flow:

The relationship between the fundamental variables of traffic flow, namely speed, volume, and density is called the fundamental relations of traffic flow. This can be derived by a simple concept. Let there be a road with length v km, and assume all the vehicles are moving with v km/hr. Let the number of vehicles

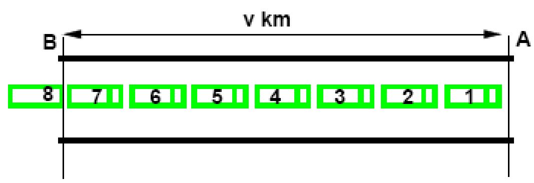


Illustration of relation between fundamental parameters of traffic flow

Counted by an observer at A for one hour be n1. By definition, the number of vehicles counted in one hour is flow (q). Therefore,

$$n_1 = q$$

Similarly, by definition, density is the number of vehicles in unit distance. Therefore number of vehicles n2 in a road stretch of distance v1 will be density X distance. Therefore,

$$n_2 = k \; X \; v$$

Since all the vehicles have speed v, the number of vehicles counted in 1 hour and the number of vehicles in the stretch of distance v will also be same. (i.e n1 = n2). Therefore,

$$q = k \; X \; v$$

This is the fundamental equation of traffic flow. Please note that, v in the above equation refers to the space mean speed.

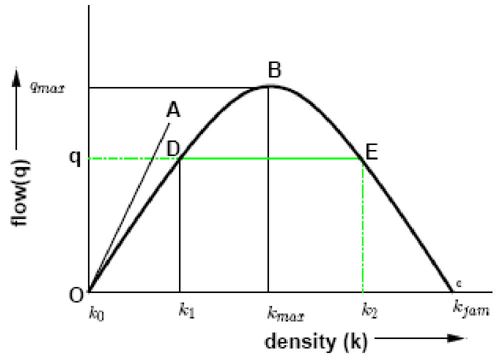
Fundamental diagrams of traffic flow:

The relation between flow and density, density and speed, speed and flow, can be represented with the help of some curves. They are referred to as the fundamental diagrams of traffic flow. They will be explained in detail one by one below.

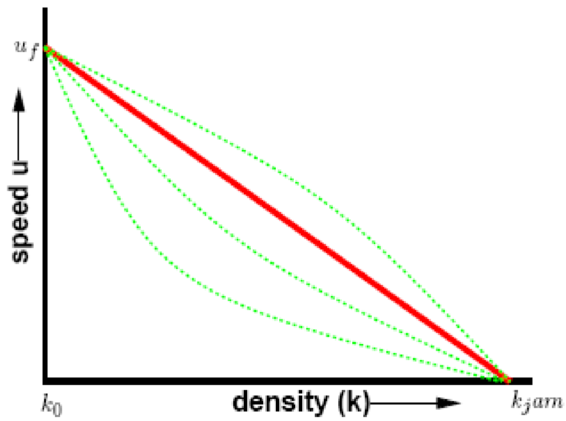
Flow-density curve

The flow and density varies with time and location. The relation between the density and the corresponding flow on a given stretch of road is referred to as one of the fundamental diagram of traffic flow. Some characteristics of an ideal flow-density relationship are listed below:

1. When the density is zero, flow will also be zero, since there is no vehicle on the road.
2. When the number of vehicles gradually increases the density as well as flow increases.
3. When more and more vehicles are added, it reaches a situation where vehicles can't move. This is referred to as the jam density or the maximum density. At jam density, flow will be zero because the vehicles are not moving.
4. There will be some density between zero density and jam density, when the flow is maximum. The relationship is normally represented by a parabolic curve as shown in figure



Flow Density Curve

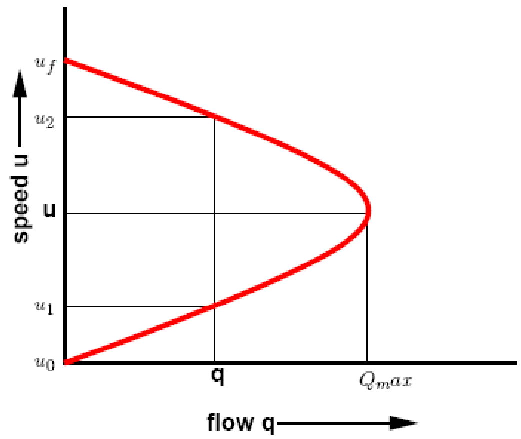


Speed Density Diagram

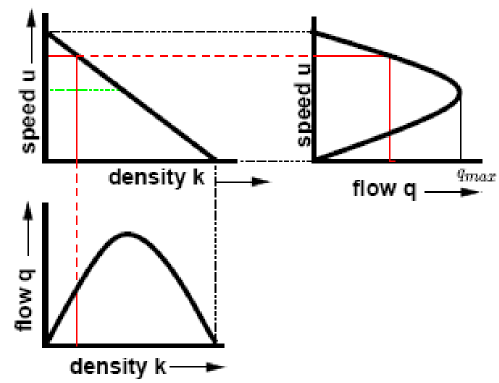
The point O refers to the case with zero density and zero flow. The point B refers to the maximum flow and the corresponding density is k_{max}. The point C refers to the maximum density k_{jam} and the corresponding flow is zero. OA is the tangent drawn to the parabola at O, and the slope of the line OA gives the mean free flow speed, i.e. the speed with which a vehicle can travel when there is no flow. It can also be noted that points D and E correspond to same flow but has two different densities. Further, the slope of the line OD gives the mean speed at density k_1 and slope of the line OE will give mean speed at density k_2. Clearly the speed at density k1 will be higher since there is less number of vehicles on the road.

Speed-density diagram:

Similar to the flow-density relationship, speed will be maximum, referred to as the free flow speed, and when the density is maximum, the speed will be zero. The simplest assumption is that this variation of speed with density is linear as shown by the solid line in figure. Corresponding to the zero density, vehicles will be flowing with their desire speed, or free flow speed. When the density is jam density, the speed of the vehicles becomes zero. It is also possible to have non-linear relationships as shown by the dotted lines. These will be discussed later.



Speed Flow Diagram



Fundamental Diagram of traffic flow

Speed flow relation

The relationship between the speed and flow can be postulated as follows. The flow is zero either because there are no vehicles or there are too many vehicles so that they cannot move. At maximum flow, the speed will be in between zero and free flow speed. This relationship is shown in figure. The maximum flow q_{max} occurs at speed u. It is possible to have two different speeds for a given flow.

Combined diagrams

The diagrams shown in the relationship between speed-flow, speed-density, and flow-density are called the fundamental diagrams of traffic flow. These are as shown in figure.

Traffic data collection

Data requirements

The most important traffic characteristics to be collected from the field include sped, travel time, flow and density. Some cases, spacing and headway are directly measured. In addition, the occupancy, ie percentage of time a point on the road is occupied by vehicles is also of interest. The measurement procedures can be classified based on the geographical extent of the survey into five categories:

(a) Measurement at point on the road,

(b) Measurement over a short section of the road (less than 500 metres)

(c) Measurement over a length of the road (more than about 500 metres)

(d) Wide area samples obtained from number of locations, and

(e) The use of an observer moving in the traffic stream. In each category, numerous data collection is there. However, important and basic methods will be discussed.

Measurements at a point

The most important point measurement is the vehicle volume count. Data can be collected manually or automatically. In manual method, the observer will stand at the point of interest and count the vehicles with the help of hand tallies. Normally, data will be collected for short interval of 5 minutes or 15 minutes etc. and for each type of vehicles like cars, two wheelers, three wheelers, LCV, HCV, multi axle trucks, non-motorized traffic like bullock cart, hand cart etc. From the flow data, flow and headway can be derived. Modern methods include the use of inductive loop detector, video camera, and many other technologies. These methods help to collect accurate information for long duration. In video cameras, data is collected from the field and is then analyzed in the lab for obtaining results. Radars and microwave detectors are used to obtain the speed of a vehicle at a point. Since no length is involved, density cannot be obtained by measuring at a point.

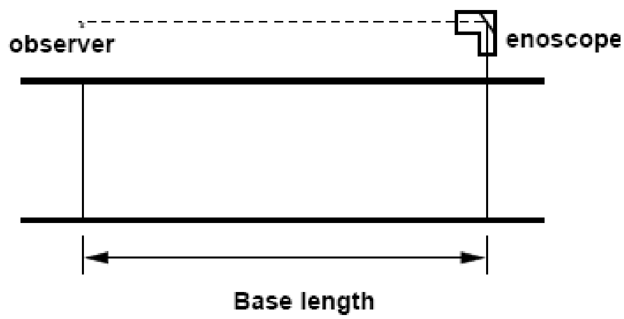


Illustration of measurement over short section using enoscope

Measurements over short section

The main objective of this study is to find the spot speed of vehicles. Manual methods include the use of enoscope. In this method a base length of about 30-90 metres is marked on the road. Enoscope is placed at one end and observer will stand at the other end. He could see the vehicle passing the farther end through enoscope and starts the stop watch. Then he stops the stop watch when the vehicle passes in front of him. The working of the enoscope is shown in figure An alternative method is to use pressure contact tube which gives a pressure signal when vehicle moves at either end. Another most widely used method is inductive loop detector which works on the principle of magnetic inductance. Road will be cut and a small magnetic loop is placed. When the metallic content in the vehicle passes over it, a signal will be generated and the count of the vehicle can be found automatically. The advantage of this detector is that the counts can be obtained throughout the life time of the road. However, chances of errors are possible because noise signals may be generated due to heavy vehicle passing adjacent lanes. When dual loops are used and if the spacing between them is known then speed also can be calculated in addition to the vehicle cost.

Measurements over long section

This is normally used to obtain variations in speed over a stretch of road. Usually the stretch will be having a length more than 500 metres. We can also get density. Most traditional method uses aerial photography. From a single frame, density can be measured, but not speed or volumes. In time lapse photography, several frames are available. If several frames are obtained over short time intervals, speeds can be measured from the distance covered between the two frames and time interval between them.

Moving observer method for stream measurement

Determination of any of the two parameters of the traffic flow will provide the third one by the equation
$q = u.k$. Moving observer method is the most commonly used method to get the relationship between the fundamental stream characteristics. In this method, the observer moves in the traffic stream unlike all other previous methods. Consider a stream of vehicles moving in the north bound direction. Two different cases of motion can be considered. The first case considers the traffic stream to be moving and the observer to be stationary. If no is

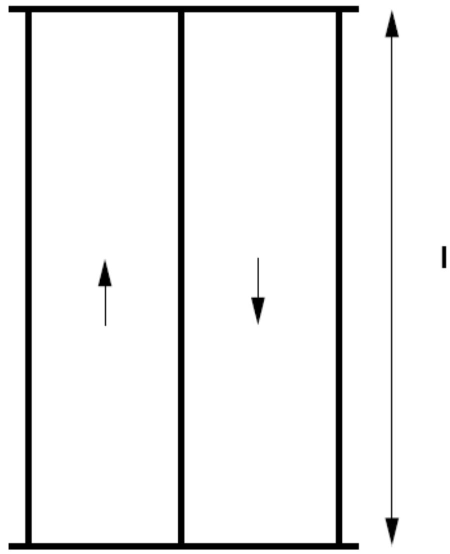


Illustration of moving observer method

the number of vehicles overtaking the observer during a period, t, then flow q is n_0/t , or

$$n_0 = q\ X\ t$$

The second case assumes that the stream is stationary and the observer moves with speed v_o. If n_p is the number of vehicles overtaken by observer over a length l, then by definition, density k is n_p/l , or

$$n_p = k\ X\ l$$

$$n_p = k.v_0.t$$

Where v_0 is the speed of the observer and t is the time taken for the observer to cover the road stretch. Now consider the case when the observer is moving within the stream. In that case mo vehicles will overtake the observer and mp vehicles will be overtaken by the observer in the test vehicle. Let the difference m is given by m_0 - m_p, then from equation

$$m = q.t - k.v_o.t$$

This equation is the basic equation of moving observer method, which relates q; k to the counts m, t and v_o that can be obtained from the test. However, we have two unknowns, q and k, but only one equation. For generating another equation, the test vehicle is run twice once with the traffic stream and another one against traffic stream, i.e.

$$m_w = q.t_w + k.v_w$$
$$= q.t_w + k.l$$
$$m_a = q.t_a - k.v_a.t_a$$
$$= q.t_a - k.l$$

where, a,w denotes against and with traffic flow. It may be noted that the sign of equation is negative, because test vehicle moving in the opposite direction can be considered as a case when the test vehicle is moving in the stream with negative velocity. Further, in this case, all the vehicles will be overtaking, since it is moving with negative speed. In other words, when the test vehicle moves in the opposite direction, the observer simply counts the number of vehicles in the opposite direction. Adding equation 32.5 and 32.5, we will get the first parameter of the stream, namely the flow (q) as:

$$q = \frac{m_w + m_a}{t_w + t_a}$$

Now calculating space mean speed from equation 32.5,

$$\begin{aligned}
\frac{m_w}{t_w} &= q - k.v_w.t \\
&= q - \frac{q}{v} v_w \\
&= q - \frac{q}{v}\left[\frac{l}{t_w}\right] \\
&= q(1 - \frac{l}{v} \times \frac{1}{t_w}) \\
&= q(1 - \frac{t_{avg}}{t_w})
\end{aligned}$$

If v_s is the mean stream speed, then average travel time is given by $t_{avg} = \frac{l}{v_s}$. Therefore,

$$\begin{aligned}
\frac{m_w}{q} &= t_w(1 - \frac{t_{avg}}{t_w}) = t_w - t_{avg} \\
t_{avg} &= t_w - \frac{m_w}{q} = \frac{l}{v},
\end{aligned}$$

Rewriting the above equation, we get the second parameter of the traffic flow, namely the mean speed v_s and can be written as,

$$v_s = \frac{l}{t_w - \frac{m_w}{q}}$$

Thus two parameters of the stream can be determined. Knowing the two parameters the third parameter of traffic flow density (k) can be found out as

$$K = \frac{q}{v_s}$$

For increase accuracy and reliability, the test is performed a number of times and the average results are to be taken.

Example 1

The length of a road stretch used for conducting the moving observer test is 0.5 km and the speed with which the test vehicle moved is 20 km/hr. Given that the number of vehicles encountered in the stream while the test

Sample no.	m_a	m_o	m_p	$m(m_o - m_p)$	t_a	t_w	$q = \frac{m_a + m_w}{t_a + t_w}$	$u = \frac{l}{t_w - \frac{m_a}{q}}$	$k = \frac{q}{v}$
1	107	10	74	-64	0.025	0.025	860	5.03	171
2	113	25	41	-16	0.025	0.025	1940	15.04	129
3	30	15	5	10	0.025	0.025	800	40	20
4	79	18	9	9	0.025	0.025	1760	25.14	70

vehicle was moving against the traffic stream is 107, number of vehicles that had overtaken the test vehicle is 10, and the number of vehicles overtaken by the test vehicle is 74, find the flow, density and average speed of the stream.

Solution Time taken by the test vehicle to reach the other end of the stream while it is moving along with the traffic is $t_w = \frac{0.5}{20} = 0.025$ hr Time taken by the observer to reach the other end of the stream while it is moving against the traffic is $t_a = t_w = 0.025$ hr Flow is given by equation, q $= \frac{107+(10-74)}{0.025+0.025} = 860$ veh/hr Stream speed v_s can be found out from equation$v_s = \frac{0.5}{0.025-\frac{10.74}{860}} = 5$ km/hr Density can be found out from equation as k $= \frac{860}{5} = 172$veh/km

Example 2

The data from four moving observer test methods are shown in the table. Column 1 gives the sample number, column 2 gives the number of vehicles moving against the stream, column 3 gives the number of vehicles that had overtaken the test vehicle, and last column gives the number of vehicles overtaken by the test vehicle. Find the three fundamental stream parameters for each set of data. Also plot the fundamental diagrams of traffic flow.

Sample no.	1	2	3
1	107	10	74
2	113	25	41
3	30	15	5
4	79	18	9

Solution From the calculated values of flow, density and speed, the three fundamental diagrams can be plotted as shown in figure 32:3.

Capacity and Level of service

Capacity:

Capacity is defined as the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under given conditions with a reasonable expectation of occurrence. Some of the observations that are found from this definition can be now discussed. Capacity is independent of the demand. It speaks about the physical amount of vehicles and passengers a road can afford. It does not depend on the total number of vehicles demanding service. On the other hand, it depends on traffic conditions, geometric design of the road etc. For example, a curved road has lesser capacity compared to a straight road. Capacity is expressed in terms of units of some specific thing (car, people, etc.), so it also does depend on the traffic composition. In addition, the capacity analysis depends on the environmental conditions too. Capacity is a probabilistic measure and it varies with respect to time and position. Hence it is not always possible to completely derive analytically the capacity. In most cases it is obtained, through field observations.

Level of service:

A term closely related to capacity and often confused with it is service volume. When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a qualitative measure. A service volume is the maximum number of vehicles, passengers, or the like, which can be accommodated by a given facility or system under given conditions at a given level of service.

For a given road or facility, capacity could be constant. But actual flow will be different for different days and different times in a day itself. The intention of LOS is to relate the traffic service quality to a given flow rate of traffic. For a given road or facility, capacity could be constant. But actual flow will be different for different days and different times in a day itself. The intention of LOS is to relate the traffic service quality to a given flow rate of traffic. It is a term that designates a range of operating conditions on a particular type of facility. Highway capacity manual (HCM) developed by the transportation research board of USA provides some procedure to determine level of service. It divides the quality of traffic into six levels ranging from level A to level F. Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed and level F represents the worst quality of traffic. Level of service is defined based on the measure of effectiveness or (MOE). Typically three parameters are used under this and they are speed and travel time, density, and delay. One of the important measures of service quality is the amount of time spent in travel. Therefore, speed and travel time are considered to be more effective in defining LOS of a facility. Density gives the proximity of other vehicles in the stream. Since it affects the ability of drivers to maneuver in the traffic stream, it is also used to describe LOS. Delay is a term that describes excess or unexpected time spent in travel. Many specific delay measures are defined and used as MOE's in the highway capacity manual.

Types of facilities

Most important classification of transportation facilities from the engineering perspective is based on the continuity of flow, that is uninterrupted flow and interrupted flow. Uninterrupted flow is the flow of traffic in which there is no obstructions to the movement of vehicles along the road. Freeway is one example for this type of facility. In a freeway, when a vehicle enters a freeway, there is no need for the vehicle to stop anywhere till it leaves the freeway. There are three sections in a freeway - basic unit, weaving section and ramps(on/off). Vehicles will be entering the freeway through ramps. Ramps used for entering the freeway are called on-ramps and those used for exiting the freeway are called off-ramps. Freeways generally have 4, 6, or 8 lane alignments. Multi lanes also provide uninterrupted flow. HCM defines the levels of service of freeway sections based on density, as described in tables

LOS	K (veh/km/lane)	FFS (Km/hr)	v/c
A	0-7	120	0.35
B	7-11	120	0.55
C	11-16	114	0.77
D	16-22	99	0.92
E	22-28	85	1.0
F	> 28	< 85	> 1.0

In many roads, there will be signalized as well as unsignalized intersections. Uninterrupted ow is possible in sections of rural and suburban multilane highways between signalized intersections where signal spacing is sufficient to allow for uninterrupted flow. Two lane highways also provide uninterrupted ow facilities. Interrupted flow refers to the condition when the traffic flow on the road is obstructed due to some reasons. This is experienced in signalized intersections, unsignalized intersections, arterials etc. At signalized intersections, there will be some kind of active control and the vehicle will have to stop or sometimes to reduce its speed and the flow of traffic is interrupted. Thus the capacity is defined in terms of control delay i.e. sec/veh. Arterials are roads of long stretches with many intersections in between and obviously there will be interruption to the flow of traffic. Here, the capacity is expressed in terms of average travel speed. Some other facilities are facilities for pedestrians, bicycles, bus-transit, rail-transit etc. Example for pedestrian facility is a provision of subway exclusively for the use of pedestrians. Here, the capacity may be expressed in terms of number of passengers. In bus transit system, the buses have to stop at the bus bays and also it has to share the road with the other vehicles. Hence the capacity will be affected by the control characteristics and the traffic conditions prevailing in the road. Since trains have exclusive right of way, the capacity is strictly governed by the control characteristics. It has two types of capacities - line capacity and station capacity. Line capacity is based on the number of tracks available between two stations. Station capacity refers to the facilities available in the platform of the station, and other facilities.

For uninterrupted flow of traffic, measure of effectiveness (MOE) is density in freeways. Speed also becomes important in two-lane highways and multilane highways. In the case of interrupted flow, MOE is delay. The delay of travel time becomes an important factor in calculating the capacity.

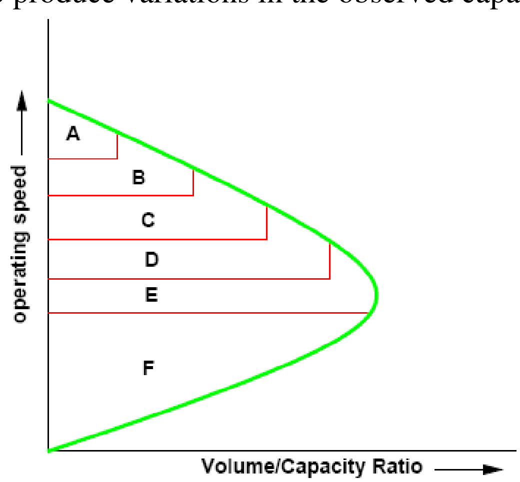
LOS	Control Delay sec/veh(signalised)	Delay sec/veh (unsignalised)
A	≤ 10	≤ 10
B	10-20	10-15
C	20-35	15-25
D	35-55	25-35
E	55-80	35-50
F	> 80	> 50

Highway capacity:

Highway capacity is defined by the Highway Capacity Manual as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions. The highway capacity depends on certain conditions as listed below;

1. **Traffic conditions**: It refers to the traffic composition in the road such as the mix of cars, trucks, buses etc in the stream. It also includes peaking characteristics, proportions of turning movements at intersections and the like.
2. **Road way characteristics**: This points out to the geometric characteristics of the road. These include lane width, shoulder width, lane configuration, horizontal alignment and vertical alignment.
3. **Control conditions**: This primarily applies to surface facilities and often refers to the signals at intersections etc.

Again capacity can be defined for a point or uniform section. Capacity is estimated for segments having uniform conditions. Points where these conditions change represent the boundaries where separate analysis may be required. Capacity is the maximum flow rate that a facility can afford. This maximum flow rate is taken for the worst 15 minutes of the peak hours while finding out the capacity. Capacity is measured as a reasonably expected value and not the maximum flow rate ever observed in the facility. This is because the measured capacity at a single location will show significant variation from day to day. Further, local driving habits also produce variations in the observed capacity.



Level of Services A to F

Factors affecting level of service:

The level of service can be derived from a road under different operating characteristics and traffic volumes.

The factors a_ecting level of service (LOS) can be listed as follows:

1. Speed and travel time
2. Traffic interruptions/restrictions
3. Freedom to travel with desired speed
4. Driver comfort and convenience
5. Operating cost.

Highway Capacity Manual (HCM) used travel speed and volume by capacity ratio (v/c ratio) to distinguish between various levels of service. The value of v/c ratio can vary between 0 and 1. Depending upon the travel speed and v/c ratio, HCM has defined six levels of service, level A to level F based on a graph between operating speed and v/c ratio as shown in the figure. Level of service A represents the zone of free flow. Here the traffic volume will be less, traffic will be experiencing free ow also. The drivers will be having the complete freedom to choose their desired speed. Even at maximum density, for this LOS the average spacing between vehicles is 167 m. Lane changes within the traffic stream, as well as merging and diverging movements, are made relatively easy. The effect of minor incidents and point breakdowns are easily aborted at this level. Level of service B represents zone of reasonably free flow. Free flow speeds are still maintained at this level of service. The drivers freedom to choose their desired speed is only slightly restricted. The lowest average spacing between vehicles is about 100 m. The effects of small incidents and point breakdowns are still easily contained.

At level of service C, the presence of other vehicles begins to restrict the maneuverability within the traffic stream. Average speeds remain at or near the free flow speed level, but significant increase in driver vigilance is required at this level. Minimum average spacing between the vehicles is in the range of 67 m. Queues may be expected to form behind any significant blockage. At level of service D, the average speeds begin to decline with increasing flows. Freedom to maneuver within the traffic stream is noticeably restricted. At this level, density deteriorates more quickly with flow. The spacing between the vehicles is about 50 m. As the traffic stream has little space to absorb disruptions, minor incidents can lead to queuing of vehicles. Level of service E defines operation at capacity. At this level, the stream reaches it's maximum density limit. There will be no usable gaps in the stream and even slight disruptions will cause a breakdown, with queues forming rapidly behind the disruption. Maneuvering within the traffic stream becomes extremely difficult. Level of service F describes conditions in a queue that has formed behind a point of breakdown or disruption. As vehicles shuffle through the queue, there may be periods when they move quickly, and others when they are stopped completely. Thus this level of service is used to describe the point of breakdown as well, even though operations downstream of such a breakdown may appear good. Level of service F represents the region of forced flow, having low speed, and complete breakdown of the system.

Traffic signs

Requirements of traffic control devices

1. **The control device should fulfill a need**: Each device must have a specific purpose for the safe and efficient operation of traffic flow. The superior's devices should not be used.

2. **It should command attention from the road users**: This affects the design of signs. For commanding attention, proper visibility should be there. Also the sign should be distinctive and clear. The sign should be placed in such a way that the driver requires no extra effort to see the sign.

3**. It should convey a clear, simple meaning**: Clarity and simplicity of message is essential for the driver to properly understand the meaning in short time. The use of color, shape and legend as codes becomes important in this regard. The legend should be kept short and simple so that even a less educated driver could understand the message in less time.

4. **Road users must respect the signs**: Respect is commanded only when the drivers are conditioned to expect that all devices carry meaningful and important messages. Overuse, misuse and confusing messages of devices tend the drivers to ignore them.

5. **The control device should provide adequate time for proper response from the road users:** This is again related to the design aspect of traffic control devices. The sign boards should be placed at a distance such that the driver could see it and gets sufficient time to respond to the situation. For example, the STOP sign which is always placed at the stop line of the intersection should be visible for at least one safe stopping sight distance away from the stop line.

Communication tools:

A number of mechanisms are used by the traffic engineer to communicate with the road user. These mechanisms recognize certain human limitations, particularly eyesight. Messages are conveyed through the following elements.

1. **Color:** It is the first and most easily noticed characteristics of a device. Usage of different colors for different signs is important. The most commonly used colors are red, green, yellow, black, blue, and brown. These are used to code certain devices and to reinforce specific messages. Consistent use of colors helps the drivers to identify the presence of sign board ahead.

2. **Shape**: It is the second element discerned by the driver next to the color of the device. The categories of shapes normally used are circular, triangular, rectangular, and diamond shape. Two exceptional shapes used in traffic signs are octagonal shape for STOP sign and use of inverted triangle for GIVE WAY (YIELD) sign. Diamond shape signs are not generally used in India.

3. **Legend:** This is the last element of a device that the drive comprehends. This is an important aspect in the case of traffic signs. For the easy understanding by the driver, the legend should be short, simple and specific so that it does not divert the attention of the driver. Symbols are normally used as legends so that even a person unable to read the language will be able to understand that. There is no need of it in the case of traffic signals and road markings.

4. **Pattern**: It is normally used in the application of road markings, complementing traffic signs. Generally solid, double solid and dotted lines are used. Each pattern conveys different type of meaning. The frequent and consistent use of pattern to convey information is recommended so that the drivers get accustomed to the different types of markings and can instantly recognize them.

Types of traffic signs:

There is several hundreds of traffic signs available covering wide variety of traffic situations. They can be classified into three main categories.

1. **Regulatory signs**: These signs require the driver to obey the signs for the safety of other road users.
2. **Warning signs**: These signs are for the safety of oneself who is driving and advice the drivers to obey these signs.
3. **Informative signs**: These signs provide information to the driver about the facilities available ahead, and the route and distance to reach the specific destinations

In addition special type of traffic sign namely work zone signs are also available. These type of signs are used to give warning to the road users when some construction work is going on the road. They are placed only for short duration and will be removed soon after the work is over and when the road is brought back to its normal condition. The first three signs will be discussed in detail below.

Regulatory signs:

These signs are also called mandatory signs because it is mandatory that the drivers must obey these signs. If the driver fails to obey them, the control agency has the right to take legal action against the driver. These signs are primarily meant for the safety of other road users. These signs have generally black legend on a white background. They are circular in shape with red borders. The regulatory signs can be further classified into:

1. Right of way series: These include two unique signs that assign the right of way to the selected approaches of an intersection. They are the STOP sign and GIVE WAY sign For example, when one minor road and major road meets at an intersection, preference should be given to the vehicles passing through the major road. Hence the give way sign board will be placed on the minor road to inform the driver on the minor road that he should give way for the vehicles on the major road. In case two major roads are meeting, then the traffic engineer decides based on the traffic on which approach the sign board has to be placed. Stop sign is another example of regulatory signs that comes in right of way series which requires the driver to stop the vehicle at the stop line.

2. Speed series: Number of speed signs may be used to limit the speed of the vehicle on the road. They include typical speed limit signs, truck speed, minimum speed signs etc. Speed limit signs are placed to limit the speed of the vehicle to a particular speed for many reasons. Separate truck speed limits are applied on high speed roadways where heavy commercial vehicles must be limited to slower speeds than passenger cars for safety reasons. Minimum speed limits are applied on high speed roads like expressways, freeways etc. where safety is again a predominant reason. Very slow vehicles may present hazard to themselves and other vehicles also.

3. Movement series: They contain a number of signs that aspect specific vehicle maneuvers. These include turn signs, alignment signs, exclusion signs, one way signs etc. Turn signs include turn prohibitions and lane use control signs. Lane use signs make use of arrows to specify the movements which all vehicles in the lane must take. Turn signs are used to safely accommodate turns in unsignalized intersections.

4. Parking series: They include parking signs which indicate not only parking prohibitions or restrictions, but also indicate places where parking is permitted, the type of vehicle to be parked, duration for parking etc.

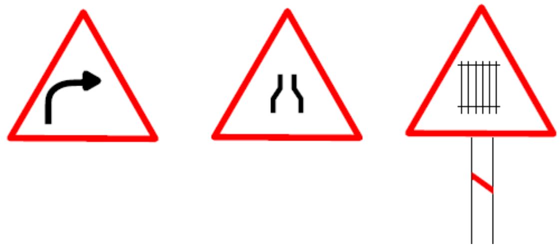
5. Pedestrian series: They include both legend and symbol signs. These signs are meant for the safety of pedestrians and include signs indicating pedestrian only roads, pedestrian crossing sites etc.

6. Miscellaneous: Wide varieties of signs that are included in this category are: a "KEEP OF MEDIAN" sign, signs indicating road closures, signs restricting vehicles carrying hazardous cargo or substances, signs indicating vehicle weight limitations etc. Some examples of the regulatory signs are shown in figure. They include a stop sign, give way sign, signs for no entry, sign indicating prohibition for right turn, vehicle width limit sign, speed limit sign etc.

Warning signs:

Warning signs or cautionary signs give information to the driver about the impending road condition. They advice the driver to obey the rules. These signs are meant for the own safety of drivers. They call for extra vigilance from the part of drivers. The color convention used for this type of signs is that the legend will be black

Examples of regulatory signs (stop sign, give way sign, signs for no entry, sign indicating prohibition for right turn, vehicle width limit sign, speed limit sign)



Examples of cautionary signs (right hand curve sign board, signs for narrow road, sign indicating railway track ahead)

in color with a white background. The shape used is upward triangular or diamond shape with red borders. Some of the examples for this type of signs are given in fig. and includes right hand curve sign board, signs for narrow road, sign indicating railway track ahead etc.

Informative signs:

Informative signs also called guide signs, are provided to assist the drivers to reach their desired destinations. These are predominantly meant for the drivers who are unfamiliar to the place. The guide signs are redundant for the users who are accustomed to the location. Some of the examples for these type of signs are route markers, destination signs, mile posts, service information, recreational and cultural interest area signing etc. Route markers are used to identify numbered highways. They have designs that are distinctive and unique. They are written black letters on yellow background. Destination signs are used to indicate the direction to the critical destination points, and to mark important intersections. Distances in kilometers are sometimes marked to the right side of the destination. They are, in general, rectangular with the long dimension in the horizontal direction. They are color coded as white letters with green background. Mile posts are provided to inform the driver about the progress along a route to reach his destination. Service guide signs give information to the driver regarding various services such as food, fuel, medical assistance etc. They are written with white letters on blue background. Information on historic, recreational and other cultural area is given on white letters with brown background. In the figure we can see some examples for informative signs which include route markers, destination signs, mile posts, service centre information etc.

Examples of informative signs (route markers, destination signs, mile posts, service centre information etc)

Design Principles of Traffic Signal or Webster method of traffic signal design

Definitions and notations:

A number of definitions and notations need to be understood in signal design. They are discussed below:

- Cycle: A signal cycle is one complete rotation through all of the indications provided.
- Cycle length: Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of green for one approach till the next

time the green starts. It is denoted by C.

- Interval: Thus it indicates the change from one stage to another. There are two typesofintervals-changeintervalandclearanceinterval.Changeintervalisalsocalledtheyellowtimeindicatestheintervalbet weenthegreenandredsignalindicationsforanapproachClearance interval is also called all red and is provided after each yellow interval indicating a period during which all signal faces show red and is used for clearing off the vehicles in the intersection.
- Green interval: It is the green indication for a particular movement or set of movements and is denoted by Gi . This is the actual duration the green light of a traffic signal is turned on.
- Red interval: It is the red indication for a particular movement or set of movements and is denoted by Ri . This is the actual duration the red light of a traffic signal is turned on.
- Phase: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.
- Lost time: It indicates the time during which the intersection is not effectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is in the front of the queue will take some time to perceive the signal (usually called as reaction time) and some time will be lost before vehicle actually moves and gains speed.

Phase design:

The signal design procedure involves six major steps. They include:

(1) Phase design,

(2) Determination of amber time and clearance time,

(3) Determination of cycle length,

(4) Apportioning of green time,

(5) Pedestrian crossing requirements, and

(6) Performance evaluation of the design obtained in the previous steps.

The objective of phase design is to separate the conflicting movements in an intersection into various phases, so that movements in a phase should have no conflicts. If all the movements are to be separated with no conflicts, then a large number of phases are required. In such a situation, the objective is to design phases with minimum conflicts or with less severe conflicts. There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, the flow pattern especially the turning movements, and the relative magnitudes of flow. Therefore, a trial and error procedure is often adopted. However, phase design is very important because it affects the further design steps. Further, it is easier to change the cycle time and green time when flow pattern changes, where as a drastic change in the flow pattern may cause considerable confusion to the drivers. To illustrate various phase plan options, consider a four legged intersection with through traffic and right turns. Left turn is ignored. See Figure 34:1. The first issue is to decide how many phases are required. It is possible to have two, three, four or even more number of phases

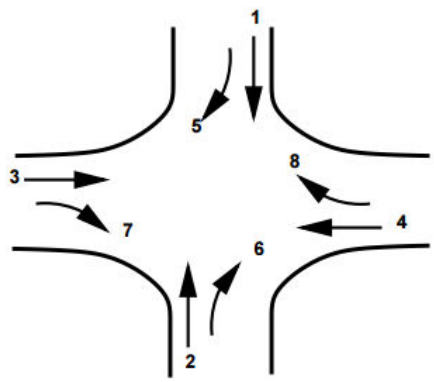
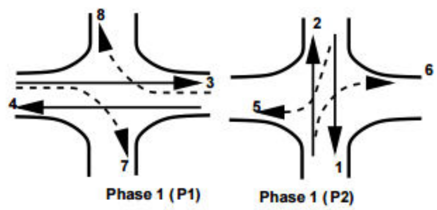


Figure 34:1: Four legged intersection

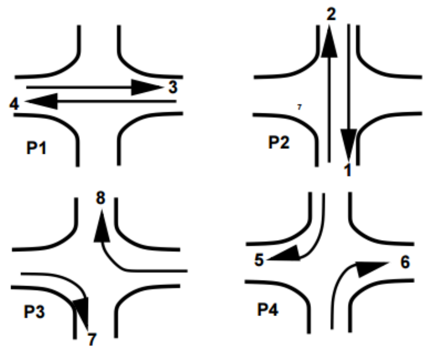


Movements in two phase signal system

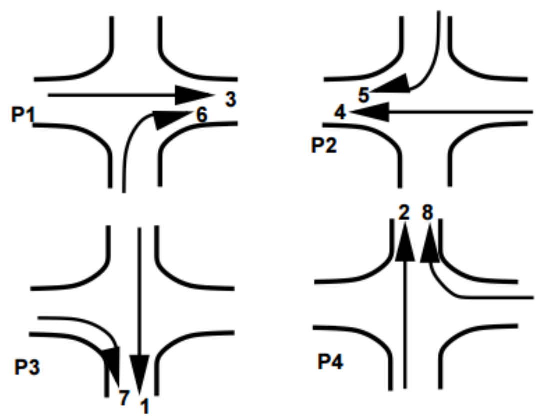
Two phase signals two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in Figure 34:2, non-conflicting through traffic 3 and 4 are grouped in a single phase and non-conflicting through traffic 1 and 2 are grouped in the second phase. However, in the first phase flow 7 and 8 offer some conflicts and are called permitted right turns. Needless to say that such phasing is possible only if the turning movements are relatively low. On the other hand, if the turning movements are significant, then a four phase system is usually.

Four phase signals:

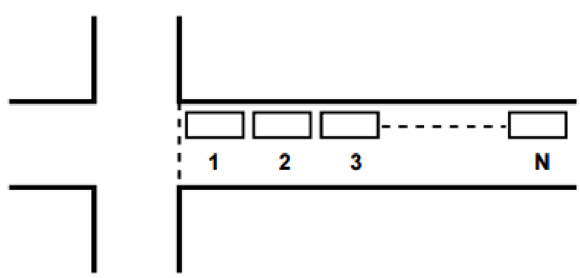
There are at least three possible phasing options. For example, figure 34:3 shows the most simple and trivial phase plan. Where, flow from each approach is put into a single phase avoiding all conflicts. This type of phase plan is ideally suited in urban areas where the turning movements are comparable with through movements and when through traffic and turning traffic need to share same lane. This phase plan could be very inefficient when turning movements are relatively low. Figure 34:4 shows a second possible phase plan option where opposing through traffic are put into same phase. The non-conflicting right turn flows 7 and 8 are grouped into a third phase. Similarly flows 5 and 6 are grouped into fourth phase. This type of phasing is very efficient when the intersection geometry permits to have at least one lane for each movement, and the through traffic volume is significantly high. Figure 34:5 shows yet another phase plan. However, this is rarely used in practice. There are five phase signals, six phase signals etc. They are normally provided if the intersection control is adaptive, that is, the signal phases and timing adapt to the real time traffic conditions.



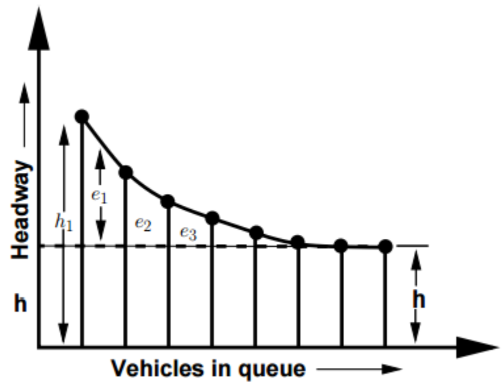
Movements in four phase signal system: option 2



Movements in four phase signal system: option 3



Group of vehicles at a signalized intersection waiting for green signal



Headways departing signal

Cycle time

Cycle time is the time taken by a signal to complete one full cycle of iterations. i.e. one complete rotation through all signal indications. It is denoted by C. The way in which the vehicles depart from an intersection when the green signal is initiated will be discussed now. Figure 34:6 illustrates a group of N vehicles at a signalized intersection, waiting for the green signal. As the signal is initiated, the time interval between two vehicles, referred as headway, crossing the curb line is noted. The first headway is the time interval between the initiation of the green signal and the instant vehicle crossing the curb line. The second headway is the time interval between the first and the second vehicle crossing the curb line. Successive headways are then plotted as in figure 34:7. The first headway will be relatively longer since it includes the reaction time of the driver and the time necessary to accelerate. The second headway will be comparatively lower because the second driver can overlap his/her reaction time with that of the first driver's. After few vehicles, the headway will become constant. This constant headway which characterizes all headways beginning with the fourth or fifth vehicle, is defined as the saturation headway, and is denoted as h. This is the headway that can be achieved by a stable moving platoon of vehicles passing through a green indication. If every vehicles require h seconds of green time, and if the signal were always green, then s vehicles per hour would pass the intersection. Therefore,

$$S=3600/h$$

where s is the saturation flow rate in vehicles per hour of green time per lane, h is the saturation headway in seconds. As noted earlier, the headway will be more than h particularly for the first few vehicles. The difference between the actual headway and h for the i th vehicle and is denoted as ei shown in figure. These differences for the first few vehicles can be added to get start up lost time, l_1 which is given by,

$$l_1 = \sum_{i=1}^{n} e_i$$

The green time required to clear N vehicles can be found out as,

$$T = l_1 + h.N$$

Where T is the time required to clear N vehicles through signal, l_1 is the start-up lost time, and h is the saturation headway in seconds.

Effective green time Effective green time is the actual time available for the vehicles to cross the intersection. It is the sum of actual green time (G_i) plus the yellow minus the applicable lost times. This lost time is the sum of start-up lost time (l_1) and clearance lost time (l_2) denoted as t_L. Thus effective green time can be written as,

$$g_i = G_i + Y_i - t_L$$

Lane capacity:

The ratio of effective green time to the cycle length (g_i C)is defined as green ratio. We know that saturation flow rate is the number of vehicles that can be moved in one lane in one hour assuming the signal to be green always. Then the capacity of a lane can be computed as,

$$c_i = s_i(g_i/ C)$$

Where c_i is the capacity of lane in vehicle per hour, s_i is the saturation flow rate in vehicle per hour per lane, C is the cycle time in seconds.

Numerical example:

Let the cycle time of an intersection is 60 seconds, the green time for a phase is 27 seconds, and the corresponding yellow time is 4 seconds. If the saturation headway is 2.4 seconds per vehicle, the start-up lost time is 2 seconds per phase, and the clearance lost time is 1 second per phase, find the capacity of the movement per lane?

Solution Total lost time, t_L = 2+1 = 3 seconds. From equation 34.4 effective green time, g_i = 27+4-3 = 28 seconds. From equation 34.1 saturation flow rate, $s_i = \frac{3600}{h} = \frac{3600}{2.4}$ = 1500 veh per hr. Capacity of the given phase can be found out from equation 34.5 as $C_i = 1500 \times \frac{28}{60}$ = 700 veh per hr per lane.

Critical lane

During any green signal phase, several lanes on one or more approaches are permitted to move. One of these will have the most intense traffic. Thus it requires more time than any other lane moving at the same time. If sufficient time is allocated for this lane, then all other lanes will also be well accommodated. There will be one and only one critical lane in each signal phase. The volume of this critical lane is called critical lane volume.

Determination of cycle length

The cycle length or cycle time is the time taken for complete indication of signals in a cycle. Fixing the cycle length is one of the crucial steps involved in signal design.

If t_{Li} is the start-up lost time for a phase i, then the total start-up lost time per cycle, $L = \sum_{i=1}^{N} t_{Li}$, where N is the number of phases. If start-up lost time is same for all phases, then the total start-up lost time is $L = N t_L$. If C is the cycle length in seconds, then the number of cycles per hour $= \frac{3600}{C}$. The total lost time per hour is the number of cycles per hour times the lost time per cycle and is $= \frac{3600}{C} L$. Substituting as $L = N t_L$, total lost time per hour can be written as $= \frac{3600\ N\ t_l}{C}$. The total effective green time T_g available for the movement in a hour will be one hour minus the total lost time in an hour. Therefore,

$$\begin{aligned} T_g &= 3600 - \frac{3600\ N\ t_L}{C} \\ &= 3600 \left[1 - \frac{N\ t_L}{C}\right] \end{aligned}$$

Let the total number of critical lane volume that can be accommodated per hour is given by V_c, then $V_c = \frac{T_g}{h}$. Substituting for T_g from equation 34.9 and s_i from equation 34.1 in the expression for the the maximum sum of critical lane volumes that can be accommodated within the hour and by rewriting, the expression for C can be obtained as follows:

$$\begin{aligned} V_c &= \frac{T_g}{h}, \\ &= \frac{3600}{h}\left[1 - \frac{N\ t_L}{C}\right], \\ &= s_i\left[1 - \frac{N\ t_L}{C}\right], \\ \therefore\ C &= \frac{N\ t_L}{1 - \frac{V_c}{s}}. \end{aligned}$$

The above equation is based on the assumption that there will be uniform flow of traffic in an hour. To account for the variation of volume in an hour, a factor called peak hour factor, (PHF) which is the ratio of hourly volume to the maximum flow rate, is introduced. Another ratio called v/c ratio indicating the quality of service is also included in the equation. Incorporating these two factors in the equation for cycle length, the final expression will be,

The above equation is based on the assumption that there will be uniform flow of traffic in an hour. To account for the variation of volume in an hour, a factor called peak hour factor, (PHF) which is the ratio of hourly volume to the maximum flow rate, is introduced. Another ratio called v/c ratio indicating the quality of service is also included in the equation. Incorporating these two factors in the equation for cycle length, the final expression will be,

$$C = \frac{N\ t_L}{1 - \frac{V_c}{s_i \times PHF \times \frac{v}{c}}}$$

Highway capacity manual (HCM) has given an equation for determining the cycle length which is a slight modification of the above equation. Accordingly, cycle time C is given by,

$$C = \frac{N\ L\ X_C}{X_C - \sum\left(\frac{V_{c_i}}{s_i}\right)}$$

where N is the number of phases, L is the lost time per phase, $\left(\frac{V_{c_i}}{s_i}\right)$ is the ratio of critical volume to saturation flow for phase i, X_C is the quality factor called critical $\frac{v}{c}$ratio where v is the volume and c is the capacity.

Numerical example The traffic flow in an intersection is shown in the figure 34:8. Given start-up lost time is 3 seconds, saturation head way is 2.3 seconds, compute the cycle length for that intersection. Assume a two-phase signal.

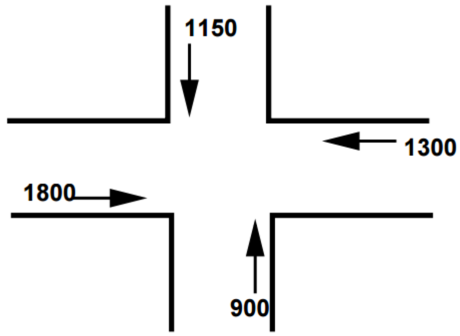
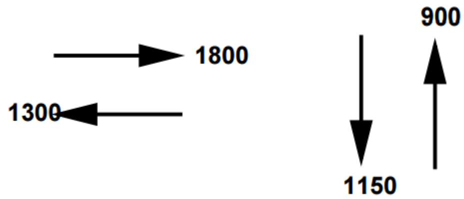


Figure 34:8: Traffic flow in the intersection

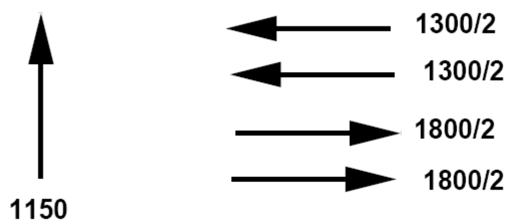


One way of providing phases

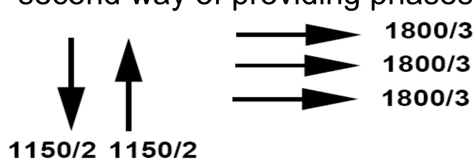
Solution 1 : If we assign two phases as shown below figure 34:9, then the critical volume for the first phase which is the maximum of the flows in that phase = 1150 vph. Similarly critical volume for the second phase = 1800 vph. Therefore, total critical volume for the two signal phases = 1150+1800 = 2950 vph.

2. Saturation flow rate for the intersection can be found out from the equation as si = 3600 2.3 = 1565.2 vph. This means, that the intersection can handle only 1565.2 vph. However, the critical volume is 2950 vph . Hence the critical lane volume should be reduced and one simple option is to split the major traffic into two lanes. So the resulting phase plan is as shown in figure

3. Here we are dividing the lanes in East-West direction into two, the critical volume in the first phase is 1150 vph and in the second phase it is 900 vph. The total critical volume for the signal phases is 2050 vph which is again greater than the saturation flow rate and hence we have to again reduce the critical lane volumes.



second way of providing phases



Third way of providing phases

4. Assigning three lanes in East-West direction, as shown in figure, the critical volume in the first phase is 575 vph and that of the second phase is 600 vph, so that the total critical lane volume = 575+600 = 1175 vph which is lesser than 1565.2 vph.

5. Now the cycle time for the signal phases can be computed from equation as:

C = (2 × 3) / (1 – (1175/1565.2)) = 24 seconds

Green splitting

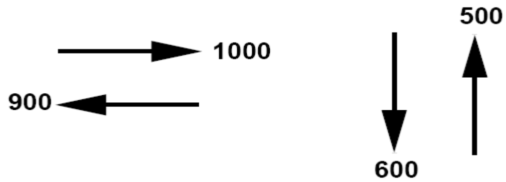
Green splitting or apportioning of green time is the proportioning of effective green time in each of the signal phase. The green splitting is given by,

$$g_i = \left[\frac{V_{c_i}}{\sum_{i=1}^{N} V_{c_i}} \right] \times t_g$$

where V_{ci} is the critical lane volume and tg is the total effective green time available in a cycle. This will be cycle time minus the total lost time for all the phases. Therefore,

$$t_g = C - N\, t_L$$

where C is the cycle time in seconds, n is the number of phases, and t_L is the lost time per phase. If lost time is different for different phases, then effective green time can be computed as follows:



Phase diagram for an intersection

$$t_g = C \sum_{i=1}^{N} t_{Li}$$

where t_{Li} is the lost time for phase i, N is the number of phases and C is the cycle time in seconds. Actual green time can be now found out as,

$$G_i = g_i - y_i + t_{Li}$$

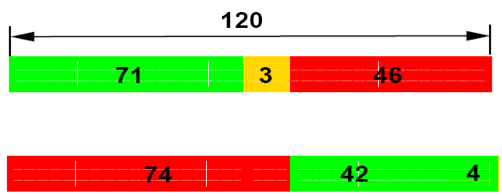
where G_i is the actual green time, g_i is the effective green time available, y_i is the amber time, and L_i is the lost time for phase i.

Numerical example

The phase diagram with flow values of an intersection with two phases is shown in figure 34:12. The lost time and yellow time for the first phase is 2.5 and 3 seconds respectively. For the second phase the lost time and yellow time are 3.5 and 4 seconds respectively. If the cycle time is 120 seconds, find the green time allocated for the two phases.

Solution

1. Critical lane volume for the first phase, VC1 = 1000 vph.
2. Critical lane volume for the second phase, VC2 = 600 vph.
3. Total critical lane volumes, VC = VC1 + VC2 = 1000+600 = 1600 vph.
4. Effective green time can be found out from equation 34.9 as Tg=120-(2.5-3.5)= 114 seconds.
5. Green time for the first phase, g1 can be found out from equation 34.8 as g1 = (1000/1600)×114 = 71.25 seconds.



Timing diagram

6. Green time for the second phase, g_2 can be found out from equation 34.8 as g_2 = (600/1600) ×114= 42.75 seconds.
7. Actual green time can be found out from equation 34.11. Thus actual green time for the first phase, G_1 = 71.25-3+2.5 = 71 seconds (rounded).
8. Actual green time for the second phase, G_2 = 42.75-4+3.5 = 42 seconds (rounded).
9. The phase diagram is as shown in figure

Road markings

Classification of road markings:

The road markings are defined as lines, patterns, words or other devices, except signs, set into applied or attached to the carriageway or kerbs or to objects within or adjacent to the carriageway, for controlling, warning, guiding and informing the users. The road markings are classified as longitudinal markings, transverse markings, object markings, word messages, marking for parking, marking at hazardous locations etc.

Longitudinal markings:

Longitudinal markings are placed along the direction of traffic on the roadway surface, for the purpose of indicating to the driver, his proper position on the roadway. Some of the guiding principles in longitudinal markings are also discussed below. Longitudinal markings are provided for separating traffic flow in the same direction and the predominant color used is white. Yellow color is used to separate the traffic flow in opposite direction and also to separate the pavement edges. The lines can be either broken, solid or double solid. Broken lines are permissive in character and allows crossing with discretion, if traffic situation permits. Solid lines are restrictive in character and does not allow crossing except for entry or exit from a side road or premises or to avoid a stationary obstruction. Double solid lines indicate severity in restrictions and should not be crossed except in case of emergency. There can also be a combination of solid and broken lines. In such a case, a solid line may be crossed with discretion, if the broken line of the combination is nearer to the direction of travel. Vehicles from the opposite directions are not permitted to cross the line. Different types of longitudinal markings are centre line, traffic lanes, no passing zone, warning lines, border or edge lines, bus lane markings, cycle lane markings.

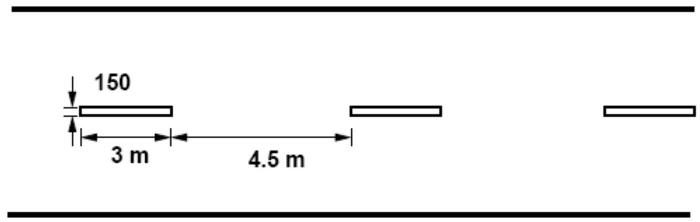
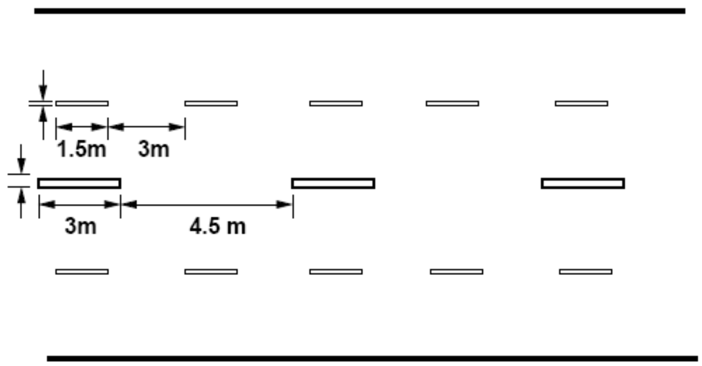


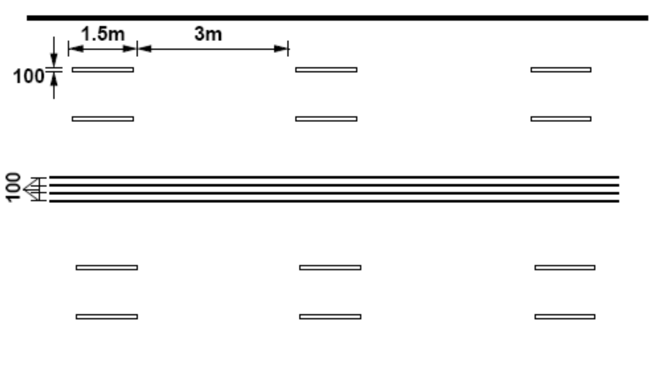
Figure 37:1: Centre line marking for a two lane road



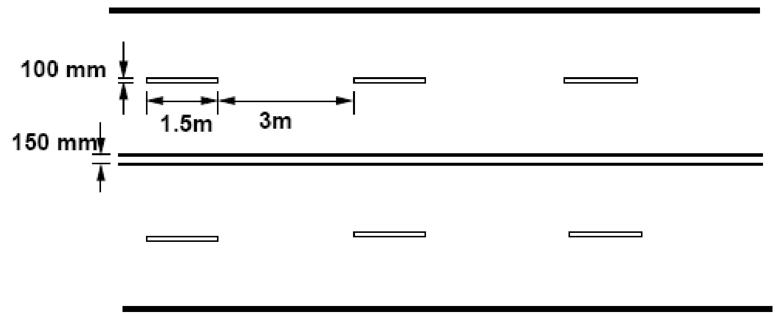
Centre line and lane marking for a four lane road

Centre line

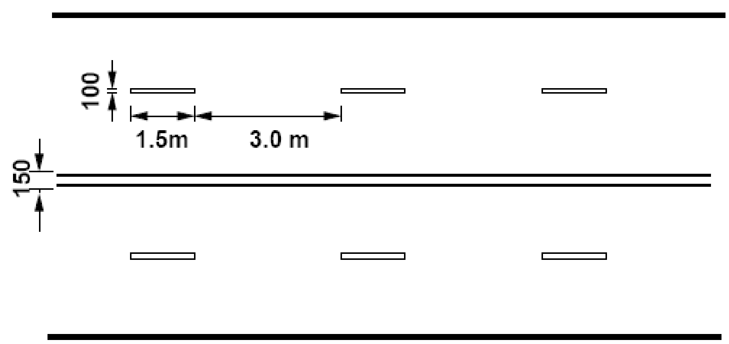
Centre line separates the opposing streams of traffic and facilitates their movements. Usually no centre line is provided for roads having width less than 5 m and for roads having more than four lanes. The centre line may be marked with single broken line, single solid line, double broken line, or double solid line depending upon the road and traffic requirements. On urban roads with less than four lanes, the centre line may be single broken line segments of 3 m long and 150 mm wide. The broken lines are placed with 4.5 m gaps. On curves and near intersections, gap shall be reduced to 3 metres. On undivided urban roads with at least two traffic lanes in each direction, the centre line marking may be a single solid line of 150 mm wide as in fig, or double solid line of 100 mm wide separated by a space of 100 mm as shown in figure. The centre barrier line marking for four lane road is shown in figure



Double solid line for a two lane road



Centre barrier line marking for four lane road



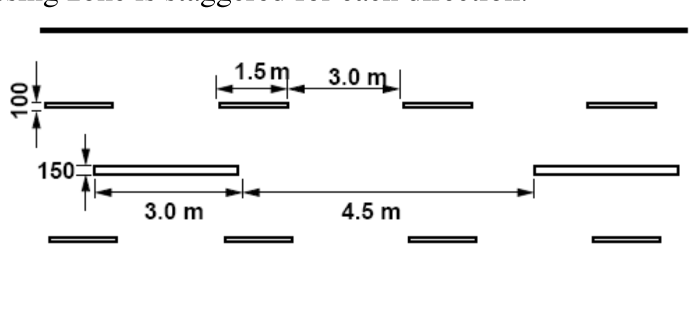
Lane marking for a four lane road with solid barrier line

Traffic lane lines

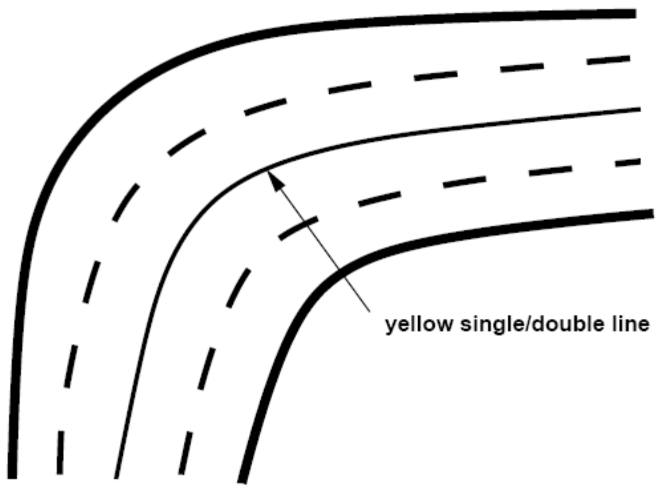
The subdivision of wide carriageways into separate lanes on either side of the carriage way helps the driver to go straight and also curbs the meandering tendency of the driver. At intersections, these traffic lane lines will eliminate confusion and facilitates turning movements. Thus traffic lane markings help in increasing the capacity of the road in addition ensuring more safety. The traffic lane lines are normally single broken lines of 100 mm width. Some examples are shown in figure.

No passing zones

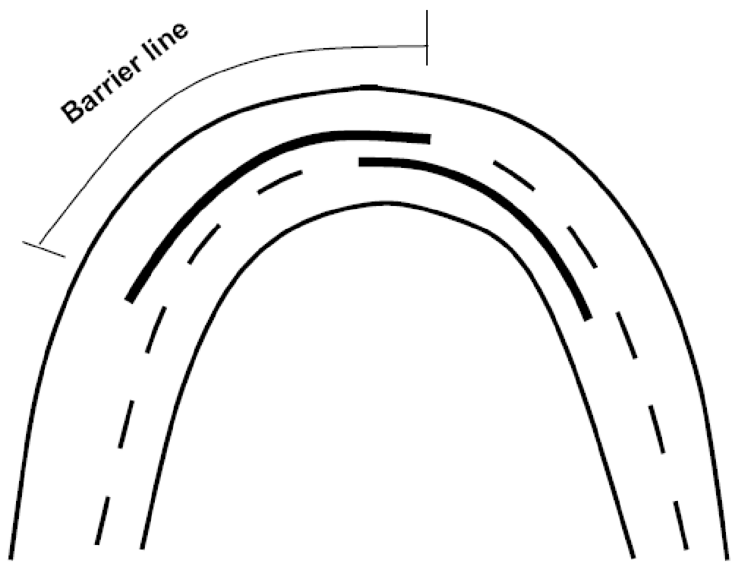
No passing zones are established on summit curves, horizontal curves, and on two lane and three lane highways where overtaking maneuvers are prohibited because of low sight distance. It may be marked by a solid yellow line along the centre or a double yellow line. In the case of a double yellow line, the left hand element may be a solid barrier line, the right hand may be a either a broken line or a solid line . These solid lines are also called barrier lines. When a solid line is to the right of the broken line, the passing restriction shall apply only to the opposing traffic. Some typical examples are shown in figure. In the latter case, the no passing zone is staggered for each direction.



Traffic lane marking for a four lane road with broken centre line



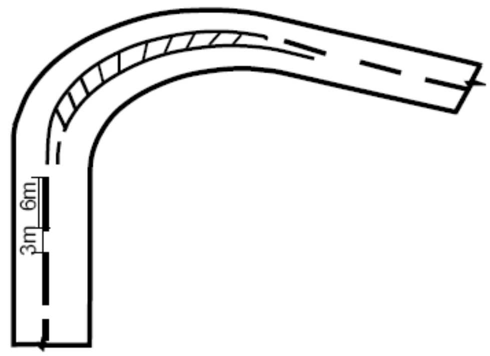
Barrier line marking for a four lane road



No passing zone marking at horizontal curves

Warning lines:

Warning lines warn the drivers about the obstruction approaches. They are marked on horizontal and vertical curves where the visibility is greater than prohibitory criteria specified for no overtaking zones. They are broken lines with 6 m length and 3 m gap. A minimum of seven line segments should be provided. A typical example is shown in figure



Warning line marking for a two lane road

Edge lines:

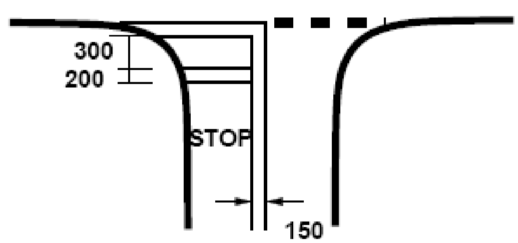
Edge lines indicate edges of rural roads which have no kerbs to delineate the limits upto which the driver can safely venture. They should be at least 150 mm from the actual edge of the pavement. They are painted in yellow or white.

Transverse markings:

Transverse markings are marked across the direction of traffic. They are marked at intersections etc. The site conditions play a very important role. The type of road marking for a particular intersection depends on several variables such as speed characteristics of traffic, availability of space etc. Stop line markings, markings for pedestrian crossing, direction arrows, etc. are some of the markings on approaches to intersections.

Stop line:

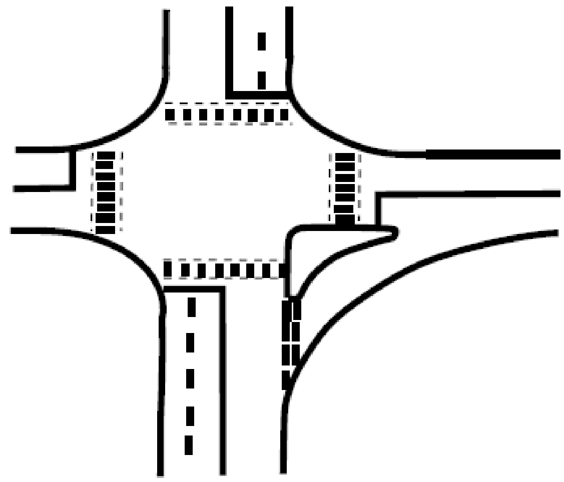
Stop line indicates the position beyond which the vehicles should not proceed when required to stop by control devices like signals or by traffic police. They should be placed either parallel to the intersecting roadway or at right angles to the direction of approaching vehicles. An example for a stop line marking is shown in figure.



Stop line marking near an intersection

Pedestrian crossings

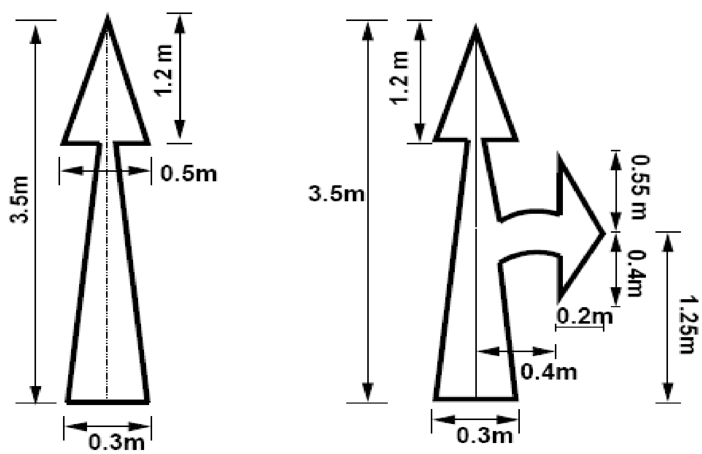
Pedestrian crossings are provided at places where the conflict between vehicular and pedestrian traffic is severe. The site should be selected that there is less inconvenience to the pedestrians and also the vehicles are not interrupted too much. At intersections, the pedestrian crossings should be preceded by a stop line at a distance of 2 to 3m for unsignalized intersections and at a distance of one metre for signalized intersections. Most commonly used pattern for pedestrian crossing is Zebra crossing consisting of equally spaced white strips of 500 mm wide. A typical example of an intersection illustrating pedestrian crossings is shown in figure



Pedestrian marking near an intersection

Directional arrows

In addition to the warning lines on approaching lanes, directional arrows should be used to guide the drivers in advance over the correct lane to be taken while approaching busy intersections. Because of the low angle at which the markings are viewed by the drivers, the arrows should be elongated in the direction of traffic for adequate visibility. The dimensions of these arrows are also very important. A typical example of a directional arrow is shown in figure.



Directional arrow marking

Object marking:

Physical obstructions in a carriageway like traffic island or obstructions near carriageway like signal posts, pier etc. cause serious hazard to the flow of traffic and should be adequately marked. They may be marked on the objects adjacent to the carriageway.

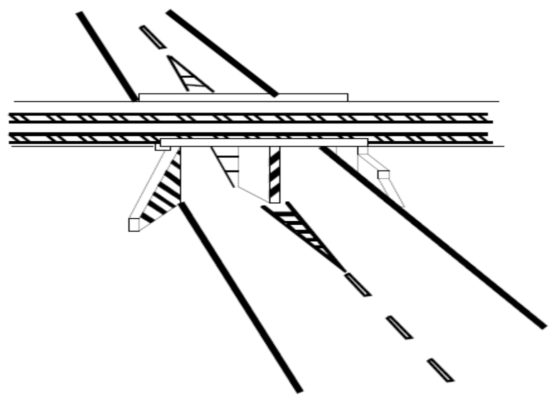
Objects within the carriageway:

The obstructions within the carriageway such as traffic islands, raised medians, etc. may be marked by not less than five alternate black and yellow stripes. The stripes should slope forward at an angle of 45^0 with respect to the direction of traffic. These stripes shall be uniform and should not be less than 100 m wide so as to provide sufficient visibility.

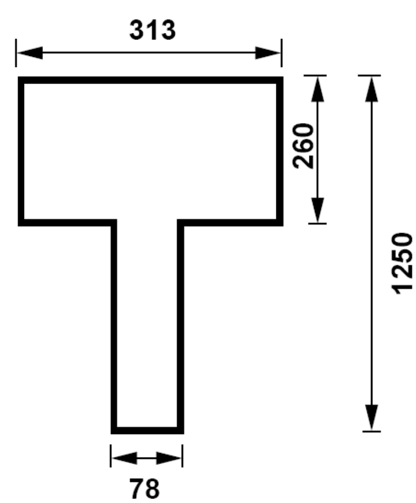
Objects adjacent to carriageway

Sometimes objects adjacent to the carriageway may pose some obstructions to the flow of traffic. Objects such as subway piers and abutments, culvert head walls etc. are some examples for such obstructions.

They should be marked with alternate black and white stripes at a forward angle of 45_ with respect to the direction of traffic. Poles close to the carriageway should be painted in alternate black and white up to a height of 1.25 m above the road level. Other objects such as guard stones, drums, guard rails etc. where chances of vehicles hitting them are only when vehicle runs o_ the carriageway should be painted in solid white. Kerbs of all islands located in the line of traffic flow shall be painted with either alternating black and white stripes of 500 mm wide or chequered black and white stripes of same width. The object marking for central pier and side walls of an underpass is illustrated in figure.



Word messages:
Information to guide, regulates, or warns the road user may also be conveyed by inscription of word message on road surface. Characters for word messages are usually capital letters. The legends should be as brief as possible and shall not consist of more than three words for any message. Word messages require more and important time to read and comprehend than other road markings. Therefore, only few and important ones are usually adopted. Some of the examples of word messages are STOP, SLOW, SCHOOL, RIGHT TUN ONLY etc. The character of a road message is also elongated so that driver looking at the road surface at a low angle can also read them easily. The dimensioning of a typical alphabet is shown in figure.



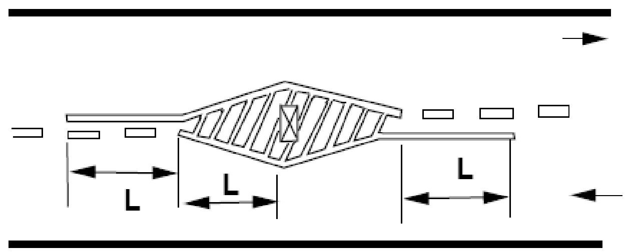
Typical dimension of the character T used in road marking

Parking:
The marking of the parking space limits on urban roads promotes more efficient use of the parking spaces and tends to prevent encroachment on places like bus stops, _re hydrant zones etc. where parking is undesirable. Such parking space limitations should be indicated with markings that are solid white lines

100 mm wide. Words TAXI, CARS, SCOOTERS etc. may also be written if the parking area is specific for any particular type of vehicle. To indicate parking restriction, kerb or carriage way marking of continuous yellow line 100 mm wide covering the top of kerb or carriageway close to it may be used.

Hazardous location

Wherever there is a change in the width of the road, or any hazardous location in the road, the driver should be warned about this situation with the help of suitable road markings. Road markings showing the width transition in the carriageway should be of 100 mm width. Converging lines shall be 150 mm wide and shall have a taper length of not less than twenty times the off-set distance. Typical carriageway markings showing transition from wider to narrower sections and vice-versa is shown in figure. In the _gure, the driver is warned about the position of the pier through proper road markings.



Approach marking for obstructions on the road way

Parking

Parking studies

Before taking any measures for the betterment of conditions, data regarding availability of parking space, extent of its usage and parking demand is essential. It is also required to estimate the parking fares also. Parking surveys are intended to provide all these information. Since the duration of parking varies with different vehicles, several statistics are used to access the parking need.

Parking statistics

Parking accumulation: It is defined as the number of vehicles parked at a given instant of time.
Normally this is expressed by accumulation curve. Accumulation curve is the graph obtained by plotting the number of bays occupied with respect to time.

Parking volume: Parking volume is the total number of vehicles parked at a given duration of time.
This does not account for repetition of vehicles. The actual volume of vehicles entered in the area is recorded.

Parking load: Parking load gives the area under the accumulation curve. It can also be obtained by simply multiplying the number of vehicles occupying the parking area at each time interval with the time interval. It is expressed as vehicle hours.

Average parking duration: It is the ratio of total vehicle hours to the number of vehicles parked.

$$\text{parkingduration} = \frac{\text{parking load}}{\text{parking volume}}$$

Parking turnover: It is the ratio of number of vehicles parked in duration to the number of parking bays available.

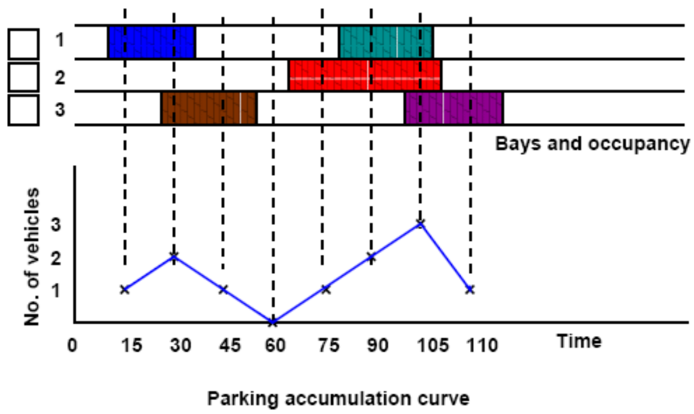
$$\text{parkingturnover} = \frac{\text{parkingvolume}}{\text{No: ofbaysavailable}}$$

This can be expressed as number of vehicles per day per time duration.

Parking index: Parking index is also called occupancy or efficiency. It is defined as the ratio of number of bays occupied in time duration to the total space available. It gives an aggregate measure of how effectively the parking space is utilized. Parking index can be found out as follows

$$\text{parking index } = \frac{\text{parking load}}{\text{parking capacity}} \text{ X } 100$$

To illustrate the various measures, consider a small example in _gure 38:1, which shows the duration for which each of the bays are occupied (shaded portion). Now the accumulation graph can be plotted by simply noting the number of bays occupied at time interval of 15, 30, 45 etc. minutes is shown in the figure.



Parking bays and accumulation curve

The various measures are calculated as shown below:

Parking volume= 5 vehicles.

Parking load = $(1+2+1+0+1+2+3+1)\frac{15}{60} = \frac{11\times 15}{60} = 2.75$ veh hour.

Average parking duration $= \frac{2.75 \ veh \ hours}{5veh} = 33$ minutes.

Parking turnover $= \frac{5 \ veh/2 \ hours}{3bays} = 0.83$ veh/hr/bay.

Parking index $= \frac{2.75 \ veh \ hour}{3\times 2 \ veh \ hours} \times 100 = 45.83\%$

Parking surveys

Parking surveys are conducted to collect the above said parking statistics. The most common parking surveys conducted are in-out survey, fixed period sampling and license plate method of survey.

1. In-out survey: In this survey, the occupancy count in the selected parking lot is taken at the beginning. Then the number of vehicles that enter the parking lot for a particular time interval is counted. The number of vehicles that leave the parking lot is also taken. The final occupancy in the parking lot is also taken. Here the labor required is very less. Only one person may be enough. But we wont get any data regarding the time duration for which a particular vehicle used that parking lot. Parking duration and turn over is not obtained. Hence we cannot estimate the parking fare from this survey.

2. Fixed period sampling: This is almost similar to in-out survey. All vehicles are counted at the beginning of the survey. Then after a fixed time interval that may vary between 15 minutes to i hour, the count is again taken. Here there are chances of missing the number of vehicles that were parked for a short duration.

3. License plate method of survey: This results in the most accurate and realistic data. In this case of survey, every parking stall is monitored at a continuous interval of 15 minutes or so and the license plate number is noted down. This will give the data regarding the duration for which a particular vehicle was using the parking bay. This will help in calculating the fare because fare is estimated based on the duration for which the vehicle was parked. If the time interval is shorter, then there are less chances of missing short-term parkers. But this method is very labor intensive.

Ill effects of parking

Parking has some ill-effects like congestion, accidents, pollution, obstruction to fire-fighting operations etc.

Congestion: Parking takes considerable street space leading to the lowering of the road capacity. Hence, speed will be reduced; journey time and delay will also subsequently increase. The operational cost of the vehicle increases leading to great economical loss to the community.

Accidents: Careless maneuvering of parking and un parking leads to accidents which are referred to as parking accidents. Common type of parking accidents occur while driving out a car from the parking area, careless opening of the doors of parked cars, and while bringing in the vehicle to the parking lot for parking.

Environmental pollution: They also cause pollution to the environment because stopping and starting of vehicles while parking and un parking results in noise and fumes. They also affect the aesthetic beauty of the buildings because a car parked at every available space creates a feeling that building rises from a plinth of cars. Obstruction to fire-fighting operations: Parked vehicles may obstruct the movement of fire-fighting vehicles. Sometimes they block access to hydrants and access to buildings.

Parking requirements:

There are some minimum parking requirements for different types of building. For residential plot area less than 300 sq.m require only community parking space. For residential plot area from 500 to 1000 sq.m, minimum one-fourth of the open area should be reserved for parking. Offices may require at least one space for every 70 sq.m as parking area. One parking space is enough for 10 seats in a restaurant where as theatres and cinema halls need to keep only 1 parking space for 20 seats. Thus, the parking requirements are different for different land use zones.

On street parking

On street parking means the vehicles are parked on the sides of the street itself. This will be usually controlled by government agencies itself. Common types of on-street parking are as listed below. This classification is based on the angle in which the vehicles are parked with respect to the road alignment. As per IRC the standard dimensions of a car is taken as 5X 2.5 metres and that for a truck is 3.75X 7.5 metres.

Parallel parking: The vehicles are parked along the length of the road. Here there is no backward movement involved while parking or un parking the vehicle. Hence, it is the safest parking from the accident perspective. However, it consumes the maximum curb length and therefore only a minimum number of vehicles can be parked for a given kerb length. This method of parking produces least obstruction to the on-going traffic on the road since least road width is used. Parallel parking of cars is shown in figure. The length available to park N number of vehicles,

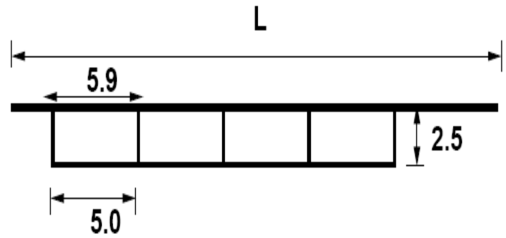


Illustration of parallel parking

$$L = \frac{N}{5.9}$$

30 parking: In thirty degree parking, the vehicles are parked at 30_ with respect to the road alignment. In this case, more vehicles can be parked compared to parallel parking. Also there is better maneuverability. Delay caused to the traffic is also minimum in this type of parking. An example is shown in figure 38:3. From the figure,

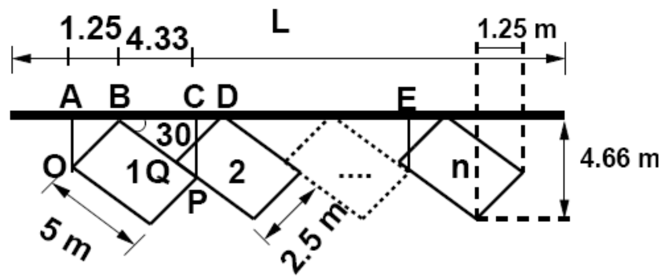


Illustration of 30° parking

$$\begin{aligned} AB &= OBsin30^\circ = & 1.25, \\ BC &= OPcos30^\circ = & 4.33, \\ BD &= DQcos60^\circ = & 5, \\ CD &= BD - BC = 5 - 4.33 = & 0.67, \\ AB + BC &= 1.25 + 4.33 = & 5.58 \end{aligned}$$

For N vehicles, L = AC + (N-1)CE =5.58+(N-1)5 =0.58+5N

45^0 parking: As the angle of parking increases, more number of vehicles can be parked. Hence compared to parallel parking and thirty degree parking, more number of vehicles can be accommodated in this type of parking. From figure, length of parking space available for parking N number of vehicles in a given kerb is L = 3.54 N+1.77

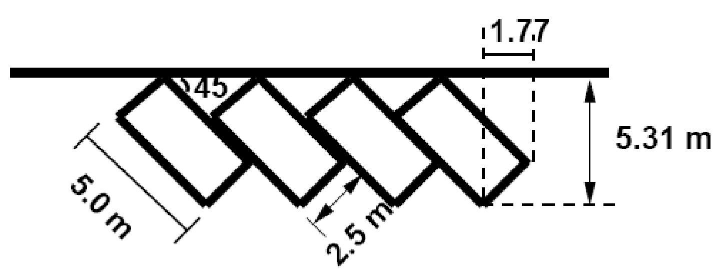


Illustration of 45^0 parking

60^0 parking: The vehicles are parked at 60_ to the direction of road. More number of vehicles can be accommodated in this parking type. From the figure, length available for parking N vehicles =2.89N+2.16.

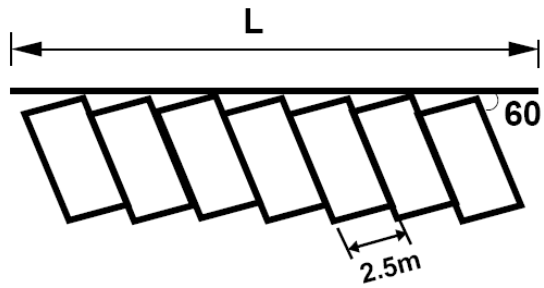


Illustration of 60^0 parking

Right angle parking: In right angle parking or 90^0 parking, the vehicles are parked perpendicular to the direction of the road. Although it consumes maximum width kerb length required is very little. In this type of parking, the vehicles need complex maneuvering and this may cause severe accidents. This arrangement causes obstruction to the road traffic particularly if the road width is less. However, it can accommodate maximum number of vehicles for a given kerb length. An example is shown in figure. Length available for parking N number of vehicles is L = 2.5N.

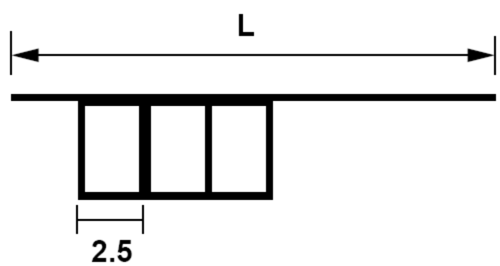


Illustration of 90^0 parking

Off street parking

In many urban centers, some areas are exclusively allotted for parking which will be at some distance away from the main stream of traffic. Such a parking is referred to as off-street parking. They may be operated by either public agencies or private _rms. A typical layout of an o_-street parking is shown in figure

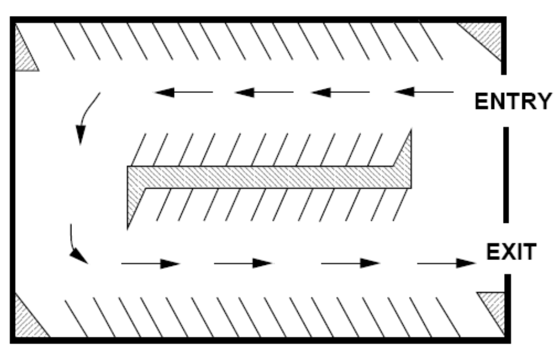


Illustration of off-street parking

Example 1

From an in-out survey conducted for a parking area consisting of 40 bays, the initial count was found to be

25. Table gives the result of the survey. The number of vehicles coming in and out of the parking lot for a time interval of 5 minutes is as shown in the table. Find the accumulation, total parking load, average occupancy and efficiency of the parking lot.

Time	In	Out
5	3	2
10	2	4
15	4	2
20	5	4
25	7	3
30	8	2
35	2	7
40	4	2
45	6	4
50	4	1
55	3	3
60	2	5

Accumulation can be found out as initial count plus number of vehicles that entered the parking lot till that time minus the number of vehicles that just exited for that particular time interval. For the first time interval of 5 minutes, accumulation can be found out as 25+3-2 = 26. It is being tabulated in column 4.
Occupancy or parking index is given by equation for the first time interval of five minutes, Parking index =26/40*100= 65%. The occupancy for the remaining time slot is similarly calculated and is tabulated in column 5.

Table 38:2: In-out parking survey solution

Time (1)	In (2)	Out (3)	Accumulation (4)	Occupancy (5)	Parking load (6)
5	3	2	26	65	130
10	2	4	24	60	120
15	4	2	26	65	130
20	5	4	27	67.5	135
25	7	3	31	77.5	155
30	8	2	37	92.5	185
35	2	7	32	80	160
40	4	2	34	85	170
45	6	4	36	90	180
50	4	1	39	97.5	195
55	3	3	39	97.5	195
60	2	5	36	90	180
Total					1735

Average occupancy is the average of the occupancy values for each time interval. Thus it is the average of all values given in column 5 and the value is 80.63%.
Parking load is tabulated in column 6. It is obtained by multiplying accumulation with the time interval.

For the first time interval, parking load = 26 X 5 = 130 vehicle minutes.
Total parking load is the summation of all the values in column 5 which is equal to 1935 vehicle minutes or 32.25 vehicle hours.

Example 2

The parking survey data collected from a parking lot by license plate method is s shown in the table below. Find the average occupancy, average turnover, parking load, parking capacity and efficiency of the parking lot.

Bay	Time			
	0-15	15-30	30-45	45-60
1	1456	9813	-	5678
2	1945	1945	1945	1945
3	3473	5463	5463	5463
4	3741	3741	9758	4825
5	1884	1884	-	7594
6	-	7357	-	7893
7	-	4895	4895	4895
8	8932	8932	8932	-
9	7653	7653	8998	4821
10	7321	-	2789	2789
11	1213	1213	3212	4778
12	5678	6678	7778	8888

Solution

See the following table for solution Columns 1 to 5 are the input data. The parking status in every bay is coded first. If a vehicle occupies that bay for that time interval, then it has a code 1. This is shown in columns 6, 7, 8 and 9 of the table corresponding to the time intervals 15, 30, 45 and 60 seconds.
Accumulation for a time interval is the total of number of vehicles in the bays 1 to 12 for that time interval. Accumulation for first time interval of 15 minutes = 1+1+1+1+1+0+0+1+1+1+1+1 = 10
Parking volume = Sum of the turnover in all the bays = 27 vehicles
Average duration is the average time for which the parking lot was used by the vehicles. It can be calculated as sum of the accumulation for each time interval X time interval divided by the parking volume =(10+11+9+11)X15/27 = 22.78 minutes/vehicle.
Occupancy for that time interval is accumulation in that particular interval divided by total number of bays. For first time interval of 15 minutes, occupancy = (10_100)/12 = 83% Average occupancy is found out as the average of total number of vehicles occupying the bay for each time interval. It is expressed in percentage. Average occupancy = (0.83+0.92+0.75+0.92 4) /4*100 = 85.42%.
Parking capacity = number of bays X number of hours = 12X1 = 12 vehicle hours
Parking load = total number of vehicles accumulated at the end of each time interval X time = (10+11+9+11) X 15/60 = 10.25 vehicle hours

Efficiency = Parking load/Total number of bays = 10:25/12 = 85.42%

Table 38:4: Licence plate parking survey solution

Bay	Time				Time				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	15	30	45	60	15	30	45	60	Turn over
1	1456	9813	-	5678	1	1	0	1	3
2	1945	1945	1945	1945	1	1	1	1	1
3	3473	5463	5463	5463	1	1	1	1	2
4	3741	3741	9758	4825	1	1	1	1	3
5	1884	1884	-	7594	1	1	0	1	2
6	-	7357	-	7893	0	1	0	1	2
7	-	4895	4895	4895	0	1	1	1	1
8	8932	8932	8932	-	1	1	1	0	1
9	7653	7653	8998	4821	1	1	1	1	3
10	7321	-	2789	2789	1	0	1	1	2
11	1213	1213	3212	4778	1	1	1	1	3
12	5678	6678	7778	8888	1	1	1	1	4
	Accumulation				10	11	9	11	
	Occupancy				0.83	0.92	0.75	0.92	2.25