UNIT-I TRAFFIC CHARACTERISTICS

1.0 TRAFFIC ENGINEERING

- A branch of Civil Engineering which deals with "*the improvement of traffic performance of road network and terminals*"
- This is achieved by systematic traffic studies, scientific analysis and engineering applications
- The method includes *planning and geometric design* on one hand and *regulation and control* on the other.

Traffic engineering therefore deals with "the application of scientific principles, tools, techniques and findings for the safe, rapid, convenient and economic movement of people and goods"

- Institute of Traffic Engineers, U.S.A defines "Traffic Engineering is that phase of engineering which deals with planning and geometric design of streets, highways, abutting lands and with traffic operation theories, as their use is related to the safe, convenient and economic transportation of persons and goods"

1.1 SCOPE OF TRAFFIC ENGINEERING

The basic objective of traffic engineering is to achieve free and rapid flow of traffic, with least number of traffic accidents.

- Factual studies of traffic operations provide the foundation for developing methods for improvement in general and for solving specific problems
- The study of traffic engineering may be divided into six major sections
  - ✓ Traffic characteristics
  - ✓ Traffic studies and analysis
  - ✓ Traffic operation, control and regulation
  - ✓ Planning and analysis
  - ✓ Geometric design
  - ✓ Administration and management

Study of traffic characteristics is the most essential prerequisites for any improvement of traffic facilities. The traffic characteristics are quite complex with various types of road users in the roads moving with different motives. The human psychology is to be given particular attention. The study of vehicular characteristics is an essential part.

The various studies to be carried out on the actual traffic include speed, volume, capacity, travel patterns, origin and destination, traffic flow characteristics, parking and accident studies.

Various aspects covered under traffic operations are regulations, control and the warrants for application of control. Regulations may be in the form of laws and ordinances or other traffic regulatory measures such as speed limit etc. Installation of traffic control devices like signs, signals and islands are most common means to regulate and control the traffic. Actual adoption of traffic management measures, such as traffic regulations and control need adequate attention.

Traffic planning is separate phase for major highways like express-ways, arterial roads, mass transit facilities and parking facilities. All the aspects such as cross section and surface details, sight distance requirements, horizontal and vertical alignment, maneuverer areas and intersections and parking facilities are to be suitably designed for better performance.

The various phases of traffic engineering are implemented with the help of Engineering, Enforcement and Education (3 E's). Enforcement is usually made through traffic laws, regulations and control. Education may be possible by sufficient publicity and through schools and television. It aims at improving the human factor in traffic performance. Engineering phase is the one which is constructive. It deals with improvement of road geometrics, providing additional road facilities and installation of suitably designed traffic control devices.

1.2 TRAFFIC CHARACTERISTICS

There are five critical components that interact in a traffic system:

1. Road users - drivers, pedestrians, bicyclists, and passengers
2. Vehicles - private and commercial
3. Streets and highways
4. Traffic control devices
5. The general environment

1.2.1 Road User Characteristics

The human element is involved in all actions of the road user either as pedestrian, cyclist, cart driver or motorist. The physical, mental and emotional characteristics of human beings effect their ability to operate motor vehicle safely or to service as a pedestrian. Hence it is important to study the characteristics and limitations of the road users.

The various factors which effect road user characteristic may be broadly be classified under four heads.

1. Physical
2. Mental
3. Psychological and
4. Environmental

1.2.1.1 Physical Characteristics

The physical characteristics of the road user may be either permanent or temporary.

The permanent characteristics are the vision, hearing, strength and the general reaction to traffic situations.

Vision plays the most important of all these. These include the acuity vision, peripheral vision and eye movement; glare vision, glare recovery and depth judgment. Field of clearest and acute vision is within a cone whose angle is only 3 degrees, though the vision is fairly satisfactory up to 10^o in general and even up to 20^o in the horizontal plane. However in the vertical plane the field of clear vision may be about two thirds of that in the horizontal plane. These factors are particularly taken care of while designing and installing control devices. As the field of clear vision is limited, the road user have to often shift their eyes with the peripheral field to obtain clear vision. The total time taken for the eye movement depends on some of the physical characteristics including the response to stimuli. The effect of glare adaptability to changes of light should also be studied. The depth judgment is important for a driver in judging distance and speed of vehicles and other objects ahead.

Hearing helps drivers in a way, though it is more important for pedestrians and cyclists. Though strength is not an important factor in general, lack of strength may make parking maneuvers difficult, particularly for heavy vehicles.

The reaction to traffic situation depends on the time required to perceive and understand the traffic situation and to take the appropriate action. This depends on many factors such as permanent and temporary physical factors, mental and psychological set up, speed and environmental actors. Also the time required to take appropriate action depends on the type of the problem and the familiarity.

The temporary physical characteristics of the road affecting their efficiency are fatigue, alcohol or drugs and illness. All these reduce alertness and increase the reaction time and also affect quality of judgment in some situations.

1.2.1.2 Mental Characteristics

Knowledge, skill, intelligence, experience and literacy can affect the road user characteristics. Knowledge of the vehicle characteristics, traffic behavior, driving practice, rules of road and psychology of road users will be quite useful for safe traffic operations. Reactions to certain traffic situations become more spontaneous with experience. Understanding the traffic regulation and special instruction and timely action depends on intelligence and literacy.

1.2.1.3 Psychological factors

These affect reaction to traffic situations of road users to a great extent. The emotional factors such as attentiveness, fear, anger, superstition, impatience, general attitude towards traffic and regulations and maturity also comes under this. Distractions by non-traffic events and worries reduce attentiveness to traffic situations. Dangerous actions are likely due to impatience. Some road users do not pay due regard to the traffic regulations and do not have the right attitude towards the traffic.

1.2.1.4 Environmental Factors

The various environmental conditions affecting the behavior of road users are traffic stream characteristics, facilities to the traffic, atmospheric conditions and the locality. The traffic stream may consist of mixed traffic or heavy traffic whereas the facilities to overtake for faster vehicles may be limited. The adaptability to different traffic stream characteristics depend on the driver's characteristics as well as the motivation. The purpose of entering the traffic stream can be social, recreational, business, routine movement or an emergency dash. The time, place and route are fundamentally chosen by the road user based on the needs. Whatever be the motive of moment, once the individual enters the traffic stream, the road user, is usually motivated by the desire for time-distance economy on one hand and comfort and safety on the other. Together with modifying factors of motivation there is a great variation among road users and their behavior in every traffic stream. The locality maybe is shopping center or a place with other distractions to the road users, thus affecting their behavior. The other environmental factors of importance are the weather visibility and other atmospheric conditions.

1.2.2 Vehicular Characteristics

It is quite important to study the various vehicular characteristics which effect the design and traffic performance because it is possible to design a road for any vehicle but not for an indefinite vehicle. The basic criterion of highway engineering is to cater for the needs of existing and anticipated traffic. It will not be economically feasible to keep on increasing the geometric standards and thickness of pavements from time to time to meet the needs of a few vehicles whose dimensions and weight are increased. The various vehicular characteristics affecting the road design may be classified as static and dynamic characteristic of the vehicle.

Static Characteristics of vehicle affecting road design are the dimensions, weight and maximum turning angle.

The height of vehicle affects the clearance of the overhead structures. The height of driver seat affects the visibility distance and the height of head light affects the headlight sight distance at valley curves. The field of vision ahead for the driver also depends on the design of wind shield and front portion of the vehicle body.

The clearance below the chassis, approach, departure and ramp angles of the vehicle affects the design of vertical profile of drive ways, humps and dips. The laden of the vehicle affects the capacity, overtaking distance and maneuverability of vehicles. The minimum turning radius depends on the length of wheel base and the features of the steering system and this effects design of sharp curves for the maneuver of vehicles at slow speeds. Gross weight, axle and wheel loads of vehicle govern the structural design of payments and cross drainage structures.

Dynamic characteristics of the vehicle affecting road design are speed, acceleration and breaking characteristics and some aspects of vehicle body design.

The speed and acceleration depends upon the power of the engine and the resistance to be overcome and are important in all the geometric design elements. The deceleration and breaking characteristics guide safe vehicle operation. The stability of vehicle and its safe movement on horizontal curves are affected by the width of wheel base and the height of center of gravity. The riding comfort on vertical curves depends on the design of suspension system of the vehicle. The impact characteristics on collision and the injuries to the occupants depends on the design of the bumper and body of vehicle. Some of the vehicle characteristics have been discussed below in detail.

1.2.2.1 Vehicle Dimensions

The dimensions to be mainly considered are the overall width, height and length of different vehicles, particularly of the largest ones. The width of the vehicle affects the width of the traffic lanes, shoulders and parking facilities. If the width of the lanes are not adequate in view of the widest vehicle using the roads, the capacity of road will decrease. Height of the vehicle effects the clearance to be provided under structures such as over bridges, under bridges, electric and other service lines. Length of the vehicle is an important factor in the design of horizontal alignment as it affects the extra width of pavement and minimum turning radius. Length affect the safe overtaking distance, capacity of a road and parking facilities. The length should be considered in the design of valley curves and dips. The maximum allowable width, height and length of the vehicle have been standardized by the Indian Road Congress (IRC).

Table: Maximum Dimensions of Road Vehicles

Dimension of Vehicle	Details	Maximum Dimension (m) excluding front and rare bumpers
Width	All Vehicles	2.50
Height	Single-Decked Vehicle	3.80
	Double-Decked Vehicle	4.75
Length	Single-unit truck with two or more axles	11.00
	Single-unit bus with two or more axles	12.00
	Semi-trailer tractor combinations	16.00
	Tractor and trailer combination	18.00

1.2.2.2 Weight of loaded Vehicle

The maximum weight of loaded vehicle affects the design of pavement thickness and gradients.

1.2.2.3 Power of Vehicle

The power of the heaviest vehicle and their loaded weights governs the permissible and limiting values of gradient on roads.

1.2.2.4 Speed of Vehicle

The vehicle speed affects

- Sight distance
- Superelevation, length of transition curve and limiting radius on the horizontal curves
- Length of transition curve on vertical valley curves and on humps
- Width of pavement and shoulders on straight and on horizontal curves
- Design gradient

- Capacity of traffic lane
- Design and control measures on intersections

Thus the design speed controls most of the geometric features of highways.

1.2.2.5 Braking Characteristics

The deceleration and breaking characteristics of vehicle depend on the design and type of breaking system and its efficiency. The safety of vehicle operation, stopping distance and the spacing between the two consecutive vehicles in a traffic stream are affected by the braking capacity.

$$\text{Breaking distance } L = \frac{u^2}{2gf}$$

1.2.2.6 Off Tracking

When a four or six wheeled vehicle, such as car or bus negotiates a horizontal curve at relatively slow speed, the rear wheels do not trace the same path as the corresponding front wheels. The difference in distance between the curved wheel path of a particular set of front and rear wheels is called off tracking or the mechanical widening for a vehicle which is equal to ${l^2}/{2R}$

Thus the off tracking depends on two factors

- The length of wheel base or the distance between the front and rear axles of the vehicle
- The turning angle or the mean radius of the horizontal curve traversed

1.2.3 Road Characteristics

1.2.3.1 Road Surface

The type of pavement is determined by the volume and composition of traffic, the availability of materials, and available funds. Some of the factors relating to road surface like road roughness, tire wear, tractive resistance, noise, light reflection, electrostatic properties etc. should be given special attention in the design, construction and maintenance of highways for their safe and economical operation. Unfortunately, it is impossible to build road surface which will provide the best possible performance for all these conditions. For heavy traffic volumes, a smooth riding surface with good all-weather anti-skid properties is desirable. The surface should be chosen to retain these qualities so that maintenance cost and interference to traffic operations are kept to a minimum.

1.2.3.2 Lightning

Illumination is used to illuminate the physical features of the road way and to aid in the driving task. A luminaire is a complete lighting device that distributes light into patterns much as a garden hose nozzle distributes water. Proper distribution of the light flux from luminaires is one of the essential factors in efficient roadway lighting. It is important that roadway lighting be planned on the basis of many traffic information such as night vehicular traffic, pedestrian volumes and accident experience.

1.2.3.3 Roughness

This is one of the main factors that an engineer should give importance during the design, construction, and maintenance of a highway system. Drivers tend to seek smoother surface when given a choice. On four-lane highways where the texture of the surface of the inner-lane is rougher than that of the outside lane, passing vehicles tend to return to the outside lane after execution of the passing maneuver. Shoulders or even speed-change lanes may be deliberately roughened as a means of delineation.

1.2.3.4 Pavement Colors

When the pavements are light colored (for example, cement concrete pavements) there is better visibility during day time whereas during night dark colored pavements like bituminous pavements provide more visibility. Contrasting pavements may be used to indicate preferential use of traffic lanes. A driver tends to follow the same pavement color having driven some distance on a light or dark surface, he expects to remain on a surface of that same color until he arrives a major junction point.

1.2.3.5 Night Visibility

Since most accidents occur at night because of reduced visibility, the traffic designer must strive to improve night time visibility in every way he can. An important factor is the amount of light which is reflected by the road surface to the drivers' eyes. Glare caused by the reflection of oncoming vehicles is negligible on a dry pavement but is an important factor when the pavement is wet.

1.2.3.6 Geometric aspects

The roadway elements such as pavement slope, gradient, right of way etc., affect transportation in various ways. Central portion of the pavement is slightly raised and is sloped to either sides so as to prevent the ponding of water on the road surface. This will deteriorate the riding quality since the pavement will be subjected to many failures like potholes etc. Minimum lane width should be provided to reduce the chances of accidents. Also the speed of the vehicles will be reduced and time consumed to reach the destination will also be more. Right of way width should be properly provided. If the right of way width becomes less, future expansion will become difficult and the development of that area will be adversely affected. One important other road element is the gradient. It reduces the tractive effort of large vehicles. Again the fuel consumption of the vehicles climbing a gradient is more. The other road element that cannot be avoided are curves. Near curves, chances of accidents are more. Speed of the vehicles is also affected.

1.3 Speed Studies

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 variation, 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.

1.3.1 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 enoscope, 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 travelling by all vehicles between a particular pair of frames.

1.3.2 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.

1.3.3 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. A uniformity between journey and running speeds denotes comfortable travel conditions.

1.3.4 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.

1.3.4.1 Time mean speed (v_t)

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

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

where v_i is the spot speed of ith 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,

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

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

1.3.4.2 Space mean speed (v_s)

The space mean speed also averages the spot speed, but spatial weightage is given instead of temporal. This is derived as below. Consider unit length of a road, and let v_i 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,

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

If t_s is the average travel time, then average speed $v_s = 1/t_s$.

Therefore, from the above equation, $v_s = \frac{n}{\sum_{i=1}^{n}\frac{1}{v_i}}$

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 v_i speed and n_i is the number of such observations.

1.3.4.3 Relation between time mean speed and space mean speed

The relation between time mean speed (v_t) and space mean speed (v_s) is given by the following relation: $v_t = v_s + \frac{\sigma^2}{v_s}$

where, σ^2 is the standard deviation of the spot speed. The standard deviation σ^2 can be computed in the following equation:

$$\sigma^2 = \frac{\sum q_i v_i^2}{\sum q_i} - (v_t)^2$$

where, q_i is the frequency of the vehicle having v_i speed.

1.3.5 Spot speed study purpose

- Establishing the speed zone of new or existing speed limit or enforcement practices.
- To determine speeds at the problem locations; to validate whether speeds are too high
- For traffic operation and control; - to establish speed limits - to determine safe speeds at curves
- Establishing speed trends at the local, state and national level to assess effectiveness of speed limit policy.

1.3.6 Factors affecting spot speed

- Driver - Age, Gender, motive of the journey, distance of his trip;
- Vehicle - type, age, weight, manufacturer and horse power;
- Roadways and environment - the graphical locations, grade, sight distance, no. of lanes, spacing of intersections; including time of day and weather
- Traffic – heavy or less volume, density, passing movements, speed regulations;

1.3.7 Locations for spot speed studies

- Speed Trend Locations: – Straight, level, open sections of rural highways – Midblock locations on urban streets
- Representative locations of different traffic conditions on a highway for basic data survey
- Problematic locations (Specific traffic engineering problem): – High accident frequency purposes – At points where the installation of traffic signals facility may be necessary

1.3.8 Methods of Measuring Spot Speeds:

The methods available for spot speed measurement may be classified as:

1. Direct observation of the time taken by a vehicle to cover a known distance.
2. Radar speedmeter method.
3. Electronic meter method
4. Photographic methods.

The direct observation method can be further classified to long-base method and short-base method.

***The long-base method is sub-divided to*:**

(i) Direct measurement of time
(ii) Enoscope
(iii) Pressure contact tubes.

1.3.8.1 Section of the Observation Point:

The criteria for this are:

1. Appropriate location for the specific purpose of study, intersection zones
2. Minimum influence of the observers and equipment on the driver and their speeds
3. Straight and level section of the highway to minimise the effect of geometric elements and roadside developments.

Selection of Base Length:
For long-base methods, the Institute of Traffic Engineers (1965) has recommended certain base lengths for spot speed determination at different average speed ranges of the traffic stream.

Table: Basic Lengths for Spot Speed Determination:

S.No	Average Speed of Traffic Stream (kmph)	Base Length (m)
1	< 40	27
2	40 – 65	54
3	> 65	810

(i) Direct-Timing Methods:

This is the simplest and most direct method for spot speed determination. Two observers are stationed at a convenient distance (50 m) such that they can see each other. The first one starts a stop-watch as a vehicle crosses the first reference point and stops it on a signal from his counterpart the moment the vehicle touches the other end of the section.

If the timing is done by a single observer, the measurement can be made from a convenient point in the section on one side of the road at a slightly higher elevation so that both the timing spots can be seen directly.

From the known distance and the measured time intervals, speeds can be calculated. A skilled observer can read a stop-watch to an accuracy of 0.2 second. If the observer can station themselves in an inconspicuous way, the speeds calculated are not influenced by the driver's reaction to work. The disadvantages of this approach are that the readings are influenced by the observer's reaction time and the parallax effect in observing the vehicle position.

(ii) Enoscope:

The parallax error of the observer can be eliminated by using a simple device called 'Enoscope', especially in the case of a single observer. Also known as 'Mirror box', it is an L-shaped box, open at both ends; a mirror is set inside it at 45° to both the arms as shown in figure 1.1.

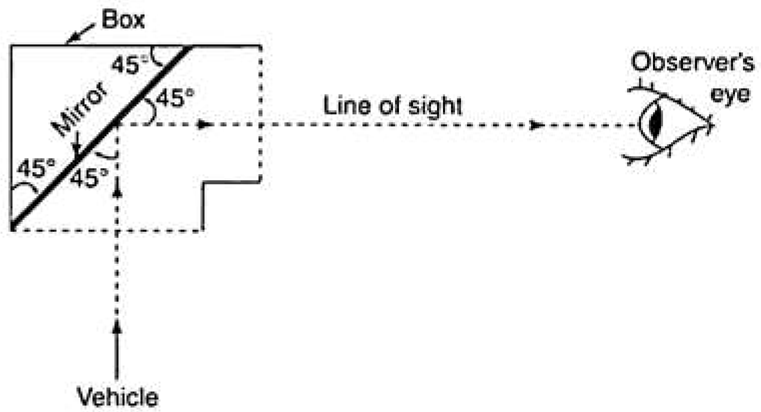


Figure 1.1 Principle of Enoscope

Light rays from the vehicle impinge on the mirror, get reflected and pass in a direction perpendicular to the incident ray. They reflected rays fall on the eye of the observer as shown. The observer can start and stop the stop-watch more accurately, with no parallax, because the line of sight is perpendicular to the direction of motion of the vehicle.

Either one enoscope can be used or two. If only one is used the device is placed directly opposite the first reference point and the observer is stationed at the other, as shown in figure. 1.2.

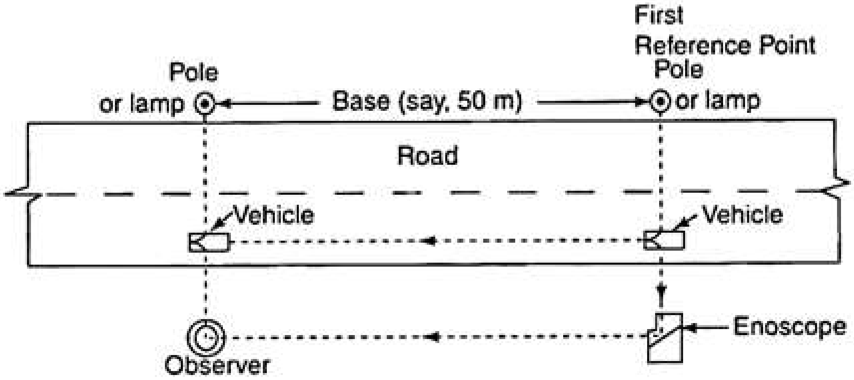


Figure 1.2 Spot Speed using Enoscope

The reference points are marked by fixing poles at the side of the road; a lamp may be used for night work. As soon as the vehicle passes the first reference point or the enoscope the timer is started and it is stopped as soon as it passes the observer. If two enoscopes are used, one each is placed at either end of the reference section and the observer will be positioned midway between the two as shown in figure 1.3.

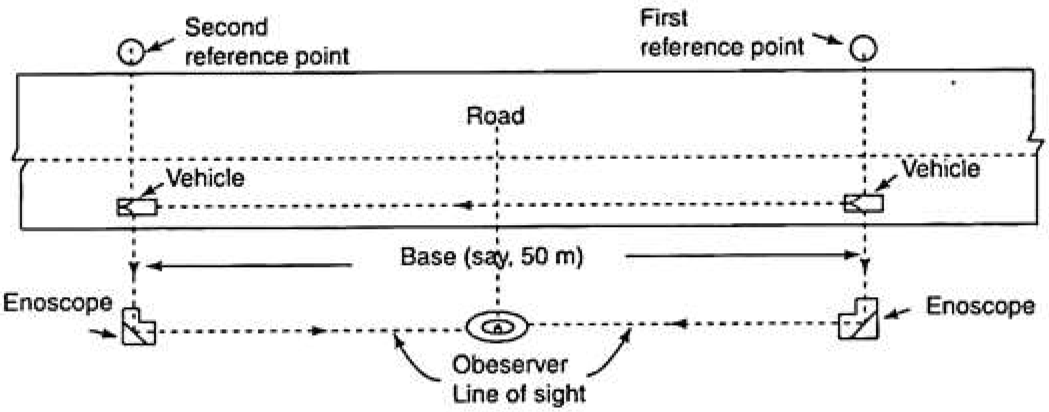


Figure 1.3: Spot Speed using two Enoscopes

The observer starts the timer when a vehicle crosses the first reference point and stops it as soon as the vehicle crosses the other end of the base by using the line of sight from each of the enoscopes. This method is not suitable for heavy multilane traffic because it is difficult to associate an observed shadow with a particular vehicle. Further, it is difficult to conceal the enoscope and the observer from the driver, whose attention would be distracted, giving scope for false readings.

(iii) Pressure Contact Tubes:

In this method, pneumatic tubes laid across the carriageway at the two reference act a detectors; when a vehicle passes over them, air impulses are sent to an electromagnetically controlled stop-watch in the hands of the observer, starting the time at the first reference point and stopping it at the second. The readings can be recorded by automatic date records also, reducing the manual work.

Short-Base Methods:

Here, the base length is very short, say 2 m to 3 m and electronic instruments are used along with pneumatic table detectors. Recording may be manual or automatic.

Radar Speedmeter Method:

The radar speedmeter works on the principle of Doppler Effect. Microwaves of radio frequency are transmitted to a moving vehicle. According to Doppler Effect, the speed of the vehicle is proportional to the change in the frequency of microwaves received back at the transmitter after being reflected by the vehicle.

The speedmeter is calibrated to read the speed directly in km/h, after the potential difference is amplified to enhance the accuracy of measurement to ± 3 km/h. The instrument is portable and battery-operated; it is set up near the edge of the road at about 1 m height above the road surface. This is used by the traffic police department for enforcing speed limits.

The operation zone can be around 50 m, and speeds can be measures for vehicles moving in both the directions.

Electronic Meter Method:

This requires the use of pneumatic tube and air switch, or electric contact stripes as detectors. On actuation, the current in milliamperes is allowed to accumulate in a condenser for a period of two electric pulses from the switches on the road. Vehicle speeds can be recorded only manually but the meter is calibrated to read the speed in km/h.

Photographic Methods:

Photography with time-lapse cameras has been successfully used to determine spot speeds of vehicles even in crowded zones. Photographs are taken at fixed intervals of time (say, one second per exposure) using a special camera. The passage of any vehicle can be traced with reference to time by projecting the exposed film on a screen. Video cameras also may be used for the purpose.

1.3.9 Presentation and Analysis of Speed Data:

Spot speed data can be analysed mathematically or graphically.

1.3.9.1 Mathematical Approach:

In this method, average speed or mean speed is obtained from a frequency distribution table by multiplying the number of vehicles in each speed class (30-40 km/h, 40 to 50 km/h, 50-65 km/h, and so on) by the mean speed of that class, summing up, and dividing the sum by the total number of vehicles observed.

Depending upon the instruments and techniques used for measuring spot speeds, the two kinds of average speeds, time-mean speed and space-mean speed, are obtained; these values give an idea of the traffic speeds in a certain stretch of the road to enable the traffic engineer to plan corrective measures, if necessary.

1.3.9.2 Graphical Approach:

The speed test data are used to form a frequency distribution table showing details of groups covering various speed ranges and number of vehicles in each range. From this table, both the histogram and the frequency distribution curve can be generated as shown in figure 1.4.

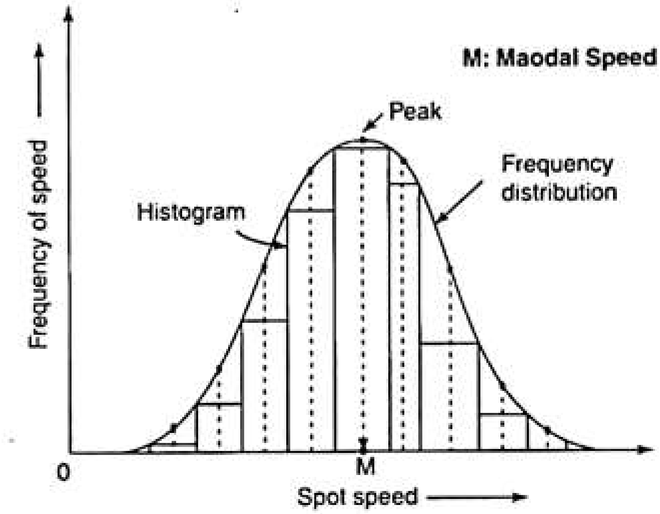


Figure 1.4: Frequency Distribution of Spot Speeds, of vehicles

For normally distributed data, the frequency curve is bell-shaped as shown. The speed corresponding to the peak is called the modal speed at which maximum number of vehicles travel.

Cumulative Spot Speeds of Vehicles:

If a graph is plotted with the average values of each speed group on the x-axis and the cumulative percentage of vehicles travelling at or below the different speeds on the y-axis, the graph appears somewhat as shown in figure. 1.5.

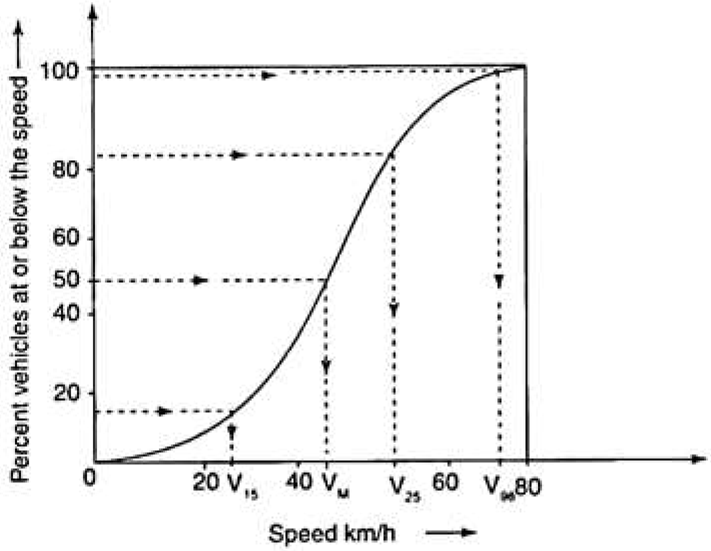


Figure 1.5: Cumulative Speed Distribution

This is very useful in determining the speed above or below which certain percentages of vehicles are moving.

1. **Design Speed:** A speed determined for design and correlation of the physical features of highway that influence vehicle operation.
2. **85th Percentile Speed:** This is the speed below which 85% of the vehicles are moving at the point considered on the highway. In other words, only 15% of the vehicles exceed this speed at the point. This is considered to be the safe speed limit under the existing conditions in that zone. However, for the purpose of geometric design, 98 percentile speed is considered.

   The speed below which 85% of all the vehicles travel is called 85th percentile speed and which is used for determining the speed limits for traffic regulation.
3. **Modal Speed:** It is the speed value occurring most frequently in a frequency distribution of speed obtained in a speed study. The modal speed would be the value with highest frequency of distribution.
4. **Median Speed:** It is the middle or 50 percentile speed. There are as many vehicles going faster than this speed as there are ones moving slower.

   It is the middle value of the set of speeds when they are arranged in an ascending order or descending order. By definition, the median equally divides the distribution. Therefore, 50% of all observed speeds should be less than the median. In the cumulative frequency curve, the 50th percentile speed is the median of the speed distribution. Median Speed = v_{50}
5. **98th Percentile Speed:** It is the speed below which 98% of all the vehicles travel. It is used as design speed in geometric design.
6. **15th Percentile Speed:** This is considered to represent the minimum speed on major highways. To decrease delay and congestion and to prevent accidents, traffic which moves at a speed less than this are generally prohibited. This provides good overtaking opportunities.

   It is the speed below which 15% of all the vehicles travel, is used to determine the lower speed limit on major facilities such as Expressways. Vehicles travelling below this speed cause interference with the traffic stream and may cause hazards.

1.4 Traffic Volume Studies

Systematic traffic surveys, traffic studies, and their scientific analysis are essential in traffic engineering and find wide application in planning for future needs of roads, improvement of existing facilities, geometric design aspects, pavement design, and traffic regulation and control.

Traffic surveys, also called traffic census, include types of traffic, size and weight, traffic flow, traffic volume per hour and per day, including seasonal variations/annual variations, distribution in different parts of a road network, and distribution in different directions at intersections.

1.4.1 Purposes of Traffic Volume Study

- To establish relative importance of any route or road facility.
- To decide the priority for improvement and expansion of a road and to allot the funds accordingly.
- To plan and design the existing and new facilities of traffic operations on the road.

- To make analysis of traffic pattern and trends on the road.
- To do structural design of pavements and geometrically design of roads by classified traffic volume study.
- To plan one-way street and other regulatory measures by volume distribution study.
- To do design of road intersections, planning signal timings and channelization by turning movement study.
- To do planning of sidewalks, cross walks and pedestrian signals by pedestrian volume study.
- To do economic studies after estimating the highway user's revenue.

1.4.2 Traffic volume counts can be obtained by the following methods:

(i) Manual Method

A team of observers can record not only traffic volume but also the types of vehicles, turning movements, directions of movements, laden weights of trucks and other such details that cannot be captured by using automatic methods.

However, it is not practicable to conduct manual counts for all the 24hours of the day and on all days of the year. But it is the most reliable method to obtain traffic volume by classified kinds of traffic and directional volume for short counts needed for intersection design. Statistical sampling techniques are used to extrapolate short-term counts.

Data may be recorded on prescribed sheets with appropriate tabular format or using multibank hand tally counters. Daily summary and weekly summary sheets are prepared.

Video Photographic Method

Video photographic method gives a permanent record of volume counts. Its analysis can be done conveniently by the use of the video which gives the required data for the analysis. By using video photographic method one can perform the classification of traffic volume easily by counting different type of vehicles. These vehicle classification counts are used in estimating structural and geometric design, computing expected highway user revenue and capacity.

However the data extraction can also be done using Traffic Data Extractor (TDE), software developed by IIT Bombay which contains tools for vehicle trajectory extraction, speed extraction and vehicle counting from a video based survey. It can be used for pedestrian data extraction also.

(ii) Automatic Counters:

Automatic counters use less number of observers and have the advantage of collecting a continuous record of traffic movement. The disadvantage is that details of classified traffic and other relevant information cannot be got.

Pneumatic Counters:

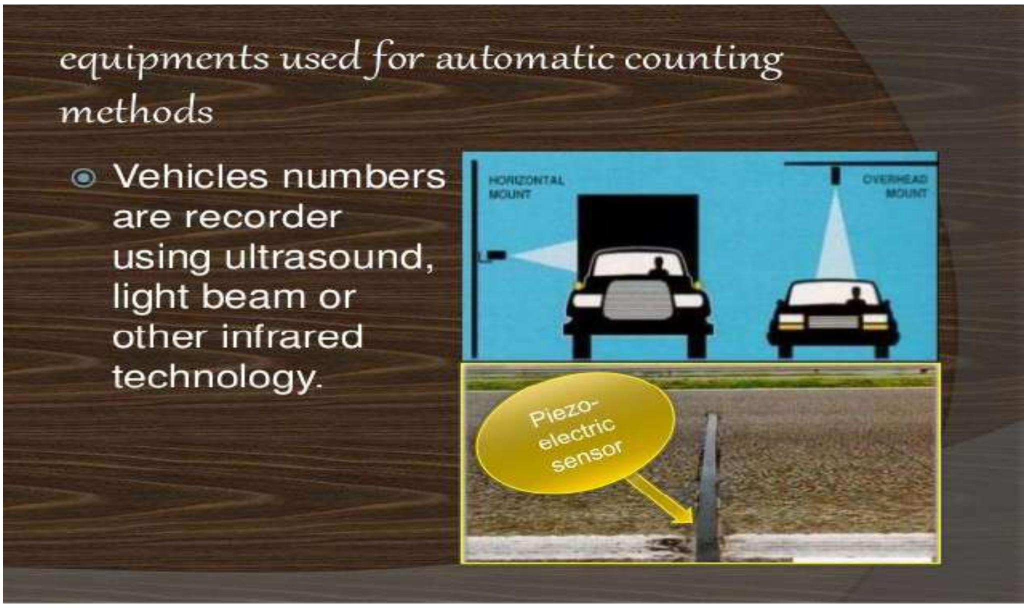
In this type, the counter is activated by an air switch attached to a flexible hose set across the road over which vehicles pass.

Electrical Counters:

In this method, the counter is activated by the closing of an electrical circuit by the moving vehicle.

Photo-Electric Cell Counters:

In this method, the counter is activated by the interruption of light rays falling on a photo-electric cell placed on the side of the road as the vehicle moves past it.



1.4.3 Counting Periods

The time and length that a specific location should be counted depends upon the data desired and the application in which the data are used. Counting periods vary from short counts at spot points to continuous counts at permanent stations. Hourly counts are generally significant in all engineering design, while daily and annual traffic is important in economic calculations, road system classification and investment programmes. Continuous counts are made to establish national and local highway use, trends of use and behaviour and for estimating purposes. Some of the more commonly used intervals are:

- 24-hour counts normally covering any 24-hour period between noon Monday and noon Friday. If a specific day count is desired, the count should be from midnight to midnight.
- 16 hour counts usually 5:30 am to 9:30 pm or 6 am to 9 pm.
- 12 hour counts usually from 7 am to 7 pm
- Peak Period counting times vary depending upon size of metropolitan area, proximity to major generators and the type of facility. Commonly used periods are 7 to 9 am and 4 to 6 pm.

1.4.4 Presentation of Traffic Volume Study Data:

The data obtained from traffic volume studies are presented in different forms for arriving at appropriate conclusions depending on the purpose of studies:

(a) Hourly, daily, weekly, seasonal, and annual variations of traffic in the form of charts or graphs. These will help in evaluating the existing facilities and for traffic regulation and control.

(b) Annual average daily traffic (AADT) of the total traffic as well as classified traffic are determined. The concept of ‘passenger car unit’ (PCU) is used to convert all types of traffic into an equivalent number of passenger cars. Continuous traffic counts are needed for this. Extrapolation from short counts needs the application of sampling techniques.

If the flow is measured only for short period, and not for an entire year, it is called the average daily traffic (ADT). These values help in assessing the relative importance of different routes in a road network, and also for planning improvements and phasing future development.

(c) Design hourly volume of traffic may be determined from a plot between hourly traffic volume (as percent of AADT or ADT) and the number of hours in a year when the particular traffic volume is exceeded.

(d) Traffic flow-lines are drawn along the route with the thickness of lines being proportional to the traffic volumes. This helps in knowing traffic distribution. Such lines help in fixing priorities for improvement of facilities along the routes.

(e) Traffic flow distribution at road intersections can be prepared, showing details of turning and crossing traffic volumes. This helps in the design of intersections and traffic control devices.

1.4.5 Design Hourly Volume of Traffic:

The peak hourly volume in a year will be so high that it will not be economical to design highway facilities to cater to the needs of this traffic. The average hourly volume found from annual average daily traffic (ADDT) data will be inadequate for a considerable period of the year.

It has been established from considerable research that if the highway is designed for the 30^{th} hourly traffic volume of the AADT plot, it will be satisfactory for a considerable period of the year. Since this volume will be exceeded only 29 times in the whole year, congestion will be caused only on these few occasions. This is designated as 30HV.

Thus, the thirtieth highest hourly volume is usually taken as the design hourly volume for achieving reasonable economy consistent with minimal inconvenience round the year. In some cases, this may not be strictly followed when spot study data are available and the traffic engineer uses his discretion. Sometimes, speed and origin-destination (O&D) studies may influence the decision.

Peak Flow: The peak flow is an indicative of design requirement, it is of vital concern. As used in design procedures in the United Kingdom it is usually the maximum hour's flow during a 7 day August traffic census. Since traffic is very near the year's peak in August, this maximum hour's flow is likely to approach the busiest hour of the year. However due to the influence of various factors, it is not as precise as often required.

An alternative method suggested by the Road Research Laboratory overcomes these defects by averaging the flows in a selected peak hour of each day during the highest 13 week period which, in the United Kingdom is June, July and August. This average is taken as the peak-flow hour and may be used for design purposes after suitable allowance is made for future growth.

Typical American practice is to select one of the most highly used hours of the year, often the 30th highest, and to use the volume in this hour, after expansion, for design. By definition, the 30th highest hour is that flow which is exceeded in only 29h of the year and if the correct expansion has been made for, say, a 20 year design period, 29 h of over loading would occur a year at the end of that period.

A design hourly volume of 8 to 10 per cent of the AADT has been suggested for Indian conditions (IRC: 64-1990), based on traffic surveys on some national highways.

A typical plot from which the 30th highest hourly volume of traffic is found is shown in figure. 1.6.

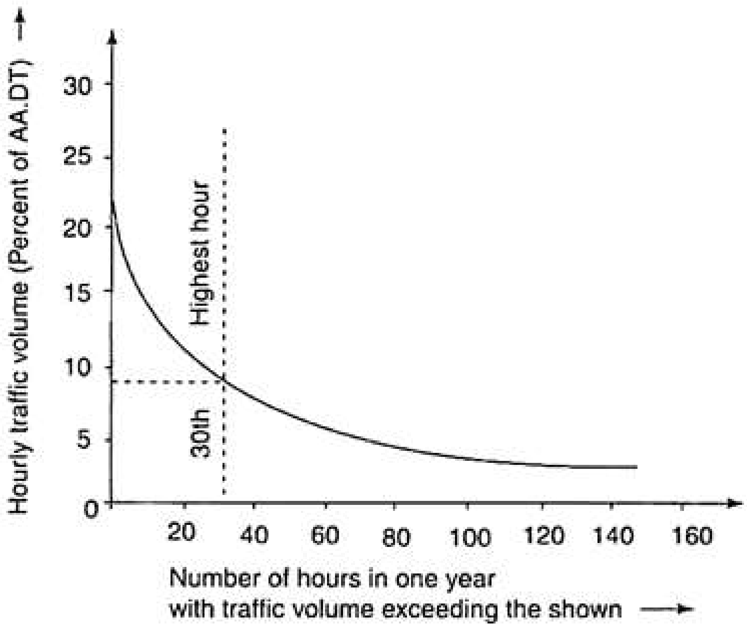


Figure 1.6 Design Hourly Traffic Volume from AADT

Peak hour factor (PHF): It is the relationship between the peak 15-minute flow rate and the peak hour volume. PHF lies between 0.25 and 1. Closer the value to unity, more uniform is the traffic and conversely closer the value to 0.25, more peaked demand will be there.

$$\text{Peak Hour Factor} = \frac{\text{Peak Hour Volume}}{\frac{60}{15} * \text{Maximum volume at 15 min. interval in Peak Hour}}$$

Passenger Car Unit (PCU):

Highway facilities in India are used by different classes of vehicles such as cars, buses, trucks, vans, auto-rickshaws, motor-cycles, bicycles, bullock-carts and so on. The characteristics of this heterogeneous or mixed traffic flow are complex compared to homogenous traffic consisting of passenger cars only.

It is rather difficult to estimate traffic volume and capacity of road way facilities under mixed traffic flow conditions. In order to facilitate the estimation of traffic volume and traffic capacity while dealing with mixed traffic conditions, it is imperative that a common standard vehicle is chosen and all other types are converted into this class of vehicle; the standard vehicle chosen for this purpose is the passenger car. The common unit, therefore, is the passenger car unit

(PCU). So the different vehicles classes are converted into one single class called passenger car unit (PCU).

If the addition of one particular vehicle per hour of a certain class affects the traffic flow to the same extent as the addition of x passenger cars, that particular vehicle is considered equivalent to x PCU.

The important factors that affect the PCU-value of any type of vehicle are:

1. Size – the length and width of the vehicle
2. Speed under the prevailing roadway and traffic
3. Clearances – transverse and longitudinal for ensuring safe traffic operation.
4. Regulation and control measures of traffic.
5. Road environment (urban, rural, signalized etc.)
6. Climatic and weather conditions.

Table: The IRC guidelines for capacity recommended the following PCU equivalent for different types of vehicles in India for rural conditions:

PCU-equivalents (IRC: 64–1990, Guidelines on capacity of rural roads)

S. No	Vehicle type	PCU-Equivalent factor
1	Motor cycle and scooter	0.50
2	Passenger car, van, auto rickshaw	1.00
3	Truck or bus	3.00
4	Truck-trailer / Tractor-trailer	4.50
5	Cycle	0.50
6	Cycle rickshaw	2.00
7	Handcart	3.00
8	Horse-drawn vehicle	4.00
9	Small bullock-cart	6.00
10	Big bullock-cart	8.00

Table: The latest IRC guidelines in this regard are given below:

PCU-equivalents (IRC: 64-2009, Guidelines for capacity of roads in rural areas)

S. No	Vehicle type	PCU-Equivalent factor	
		Single and two-lane	Multi-lane
1	Passenger car, pick-up van	1.0	1.0
2	Bus, / Truck	4.0	4.5
3	Multi-axle truck	5.0	6.0
4	Light commercial vehicle	2.5	2.8
5	Tractor	3.0	3.0
6	Tractor-trailer	4.5	4.5
7	Auto-rickshaw	1.4	1.6
8	Motorised two-wheeler	0.4	0.5
9	Pedal cycle	0.6	0.6
10	Pedal rickshaw	2.0	2.5
11	Horse cart	4.0	4.0
12	Bullock cart	7.0	7.0

Table: PCU Values (IRC: 86-1983)

Sl. No	Vehicle type	PCU
1	2 wheeler	0.5
2	3 wheeler	1
3	Car/jeep	1
4	Van/minibus	1
5	LCV	1.5
6	Truck/Bus/Tractor-trailer	3
7	Bicycle	0.5

SURVEY SHEETS:

Table 2: Survey Sheet for Traffic Volume Count Data

Time Interval	2W	3W	LCV	Car	Bus	Van/ Jeep	HCV	Tractor With Trailer	Bicycle	Total Volume	Total PCU
PCU	**0.5**	**1**	**1.5**	**1**	**3**	**1**	**4**	**3**	**0.5**		
0:0-0:15											
0:15-0:30											
0:30-0:45											
0:45-1:00											
1:0-1:15											
1:15-1:30											
1:30-1:45											
1:45-2:00											
TOTAL											

ANALYSIS:

Table 3: Traffic Volume for 1 Hour Interval

Time Interval	2W	3W	LCV	Car	Bus	Van/Jeep	HCV	Tractor	Bicycle	Total Volume	Total PCU
PCU	**0.75**	**1.2**	**2**	**1**	**3**	**3**	**4**	**4**	**0.5**	**PCU**	

OBSERVATIONS AND CALCULATIONS:

Peak hour period =

Peak 15 min period =

Maximum volume in peak 15 min period =

Maximum volume in peak hour =

Peak Hour Factor = $\frac{\text{Peak Hour Volume}}{\frac{60}{15} * \text{Maximum volume at 15 min. interval in Peak Hour}}$ =

1.4.6 Variation of Volume Counts and Peak Hour Factors

Variation of volume counts can be further sub-divided into daily, weekly and seasonal variation. For studying the daily variation, the flow in each hour has been expressed as percentage of daily flow. Weekdays, Saturdays and Sundays usually show different patterns. That's why comparing day with day is much more useful. Peak Hour Volume is very important factor in the design of roads and control of traffic, and is usually 2 - 2.5 times the average hourly volume. Apart from this there is one additional feature of this variation: two dominant peaks (morning and evening peak), especially in urban areas. These mainly include work trips and are not dependent on weather and other travel conditions.

Similar to daily variation, weekly variation gives volumes expressed as a percentage of total flow for the week. Weekdays flows are approximately constant but the weekend flows vary a lot depending upon the season, weather and socio-economic factors. Seasonal variation is the most consistent of all variation patterns and represents the economic and social condition of the area served.

Peak hour factors should be applied in most capacity analyses in accordance with the Highway Capacity Manual, which selected 15 minute flow rates as the basis for most of its procedures. The peak-hour factor (PHF) is descriptive of trip generation patterns and may apply to an area or portion of a street and highway system. The PHF is typically calculated from traffic counts. It is the average volume during the peak 60 minute period v_{av}^{60} divided by four times the average volume during the peak 15 minute's period v_{av}^{15}.

$$PHF = \frac{V_{av}^{60}}{4 \times V_{av}^{15}}$$

One can also use 5, 10, or 20 minutes instead of 15 minutes interval for the calculation of PHF. But in that case we have to change the multiplying factor in the denominator from 4. Generalizing,

$$PHF = \frac{V_{av}^{60}}{\frac{60}{n} \times V_{av}^{n}}$$

where $v_{av}^{n}$is the peak n minute flow. The Highway Capacity Manual advises that in absence of field measurements reasonable approximations for peak hour factor can be made as follows:

- 0.95 for congested condition

- 0.92 for urban areas
- 0.88 for rural areas

General guidelines for finding future PHF can be found in the Development Review Guidelines, which are as follows:

- 0.85 for minor street inflows and outflows
- 0.90 for minor arterial
- 0.95 for major streets

1.5 FUNDAMENTAL TRAFFIC FLOW 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.

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

1.5.1 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

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

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.

1. spot speed,
2. running speed,
3. journey speed,

4. time mean speed and
5. space mean speed

Spot Speed is the instantaneous speed of a vehicle at a specified location.

- 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 enoscope, pressure contact tubes or direct timing procedure or radar speedometer or by time-lapse photographic methods.

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. 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 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. A uniformity between journey and running speeds denotes comfortable travel conditions.

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. 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.

1.5.2 Flow

Flow 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, n_t, passing a particular point in one lane in a defined period t. Then the flow q expressed in $vehicles/hour$ is given by

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

The variation of volume with time, i.e. month to month, day to day, hour to hour and within a hour is also as important as volume calculation. Volume variations can also be observed from season to season.

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.

Volume in general is measured using different ways like manual counting, detector/sensor counting, moving-car observer method, etc.

Types of volume measurements

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.

1.5.3 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, n_x, in one lane of the road at that point of time and derive the density k as,

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

1.5.4 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. (figure 1.7).

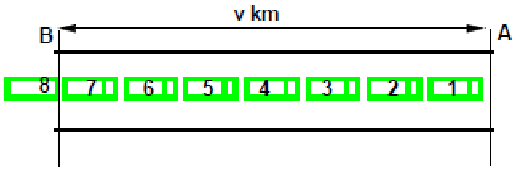


Figure 1.7: Illustration of relation between fundamental parameters of traffic flow

Let the number of vehicles counted by an observer at A for one hour be n_1. 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 n_2 in a road stretch of distance v will be $density \times distance$. Therefore,

$$n_2 = k \times v$$

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.(ie $n_1 = n_2$). Therefore,

$$q = k \times v$$

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

1.5.5 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.

1.5.5.1 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 is listed below:

1. When the density is zero, flow will also be zero, since there is no vehicles 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 1.8

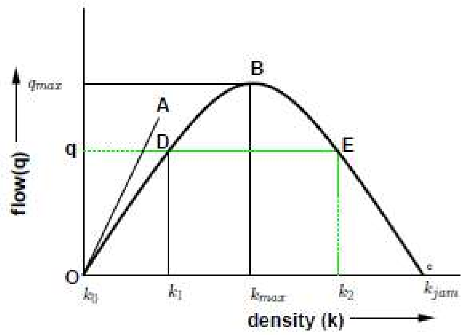


Figure1.8: Flow density curve

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 k_1 will be higher since there are less number of vehicles on the road.

1.5.5.2 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 1.9. Corresponding to the zero density, vehicles will be owing with their desire speed, or free flow speed. When the density is jam density, the speed of the vehicles becomes zero.

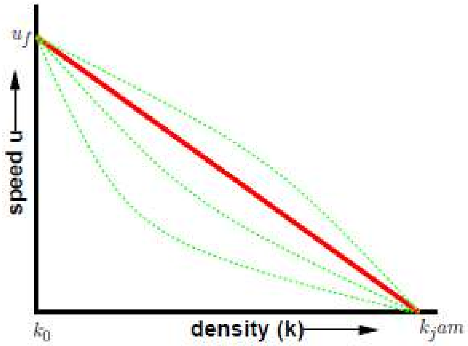


Figure 1.9: Speed-density diagram

1.5.5.3 Speed flow relation

The relationship between the speed and flow can be postulated as follows. The flow is zero either because there is 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 1.10. The maximum flow q_{max} occurs at speed u. It is possible to have two different speeds for a given flow.

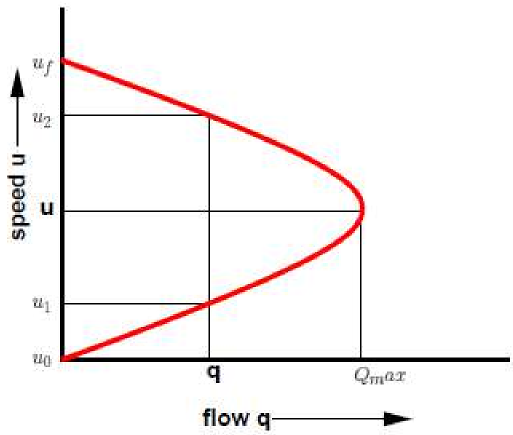


Figure 1.10: Speed-flow diagram

1.5.5.4 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 1.11

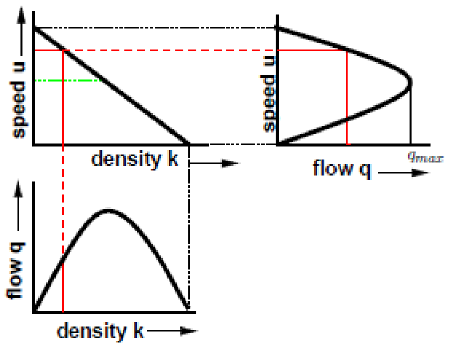


Figure 1.11: Fundamental diagram of traffic flow

- A linear speed-density relationship is illustrated in figure 1.9.

$$v \rightarrow v_f \text{ when } k \rightarrow 0$$
$$k \rightarrow k_j \text{ when } v \rightarrow 0$$

- The equation for this relationship is shown below.

$$v = v_f - \left[\frac{v_f}{k_j}\right].k$$

Where v is the mean speed at density k, v_f is the free speed and k_j is the jam density.

- we know that $q = kv$

  Therefore $q = v_f.k - \left[\frac{v_f}{k_j}\right].k^2$

- To find density at maximum flow, differentiate equation with respect to k and equate it to zero.

$$\frac{dq}{dk} = 0$$
$$v_f - \frac{v_f}{k_j}.2k = 0$$
$$k = \frac{k_j}{2}$$

- Denoting the density corresponding to maximum flow as k_0,

$$k_o = \frac{k_j}{2}$$

- Therefore, density corresponding to maximum flow is half the jam density. Once we get k_0, we can derive for maximum flow, q_{max}

$$q_{max} = v_f.\frac{k_j}{2} - \frac{v_f}{k_j}.[\frac{k_j}{2}]^2$$
$$= \frac{v_f k_j}{4}$$

- Thus the maximum flow is one fourth the product of free flow and jam density.
- The speed at maximum flow, v_0,

$$v_o = v_f - \frac{v_f}{k_j}.\frac{k_j}{2}$$

$$v_o = \frac{v_f}{2}$$

- Therefore, speed at maximum flow is half of the free speed.

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Numerical Examples

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 $v_t = \frac{\sum v_t}{n} = \frac{50+40+60+54+45}{5} = \frac{249}{5} = 49.8$

Space mean speed is the harmonic mean of spot speed.

Therefor $v_s = \frac{n}{\sum \frac{1}{v_t}} = \frac{5}{\frac{1}{50}+\frac{1}{40}+\frac{1}{60}+\frac{1}{54}+\frac{1}{45}} = \frac{5}{0.12} = 48.82$

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:

If the spot speeds are expressed as a frequency table, then

Time mean speed $v_t = \frac{\sum_{t=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i}$

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

S.No	Speed Range	Average speed (v_i)	Frequency (q_i)	$v_i q_i$	$\frac{q_i}{v_i}$
1	2 – 5	3.5	1	3.5	0.28
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**	**1.27**

Time mean speed $v_t = \frac{\sum_{t=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i} = \frac{142}{12} = 11.83$

Space mean speed $v_s = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n} \frac{q_i}{v_i}} = \frac{12}{1.27} = 9.45$

3. For the data given below, compute the time mean speed and space mean speed. Finally compute the density of the stream.

Speed Range	Frequency
0 – 10	5
10 – 20	15
20 – 30	20
30 – 40	25
40 – 50	30

Solution:

If the spot speeds are expressed as a frequency table, then

Time mean speed $v_t = \frac{\sum_{t=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i}$

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

S.No	Speed Range	Average speed (v_i)	Frequency (q_i)	$v_i q_i$	$\frac{q_i}{v_i}$
1					
2					
3					
4					
Total					

Time mean speed $v_t = \frac{\sum_{t=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i} = - =$

Space mean speed $v_s = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n} \frac{q_i}{v_i}} = - =$

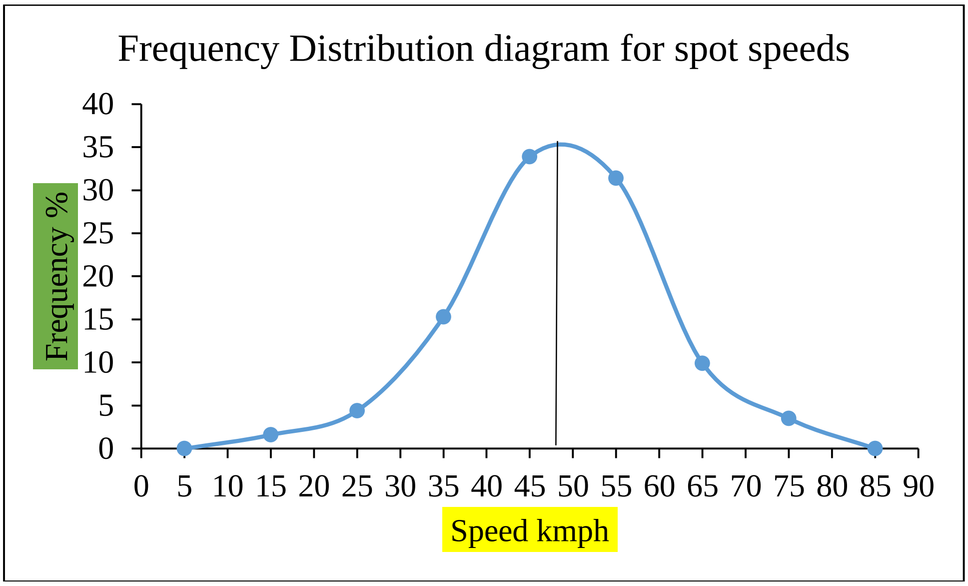
4. The table below gives the consolidated data of spot speed studies on a section of a road. Determine the most preferred speed at which maximum proportion f vehicles travel

Speed Range (kmph)	Frequency
0 – 10	0
10 – 20	11
20 – 30	30
30 – 40	105
40 – 50	233
50 – 60	216

60 – 70	68
70 – 80	24
80 – 90	0

Solution:

Speed Range (kmph)	Mean Speed (kmph)	Frequency	Percent frequency
A	B	C	D
0 – 10	5	0	0.0
10 – 20	15	11	1.6
20 – 30	25	30	4.4
30 – 40	35	105	15.3
40 – 50	45	233	33.9
50 – 60	55	216	31.4
60 – 70	65	68	9.9
70 – 80	75	24	3.5
80 – 90	85	0	0.0



The most preferred speed is the modal speed. It corresponds to the peak value and is found as 47kmph

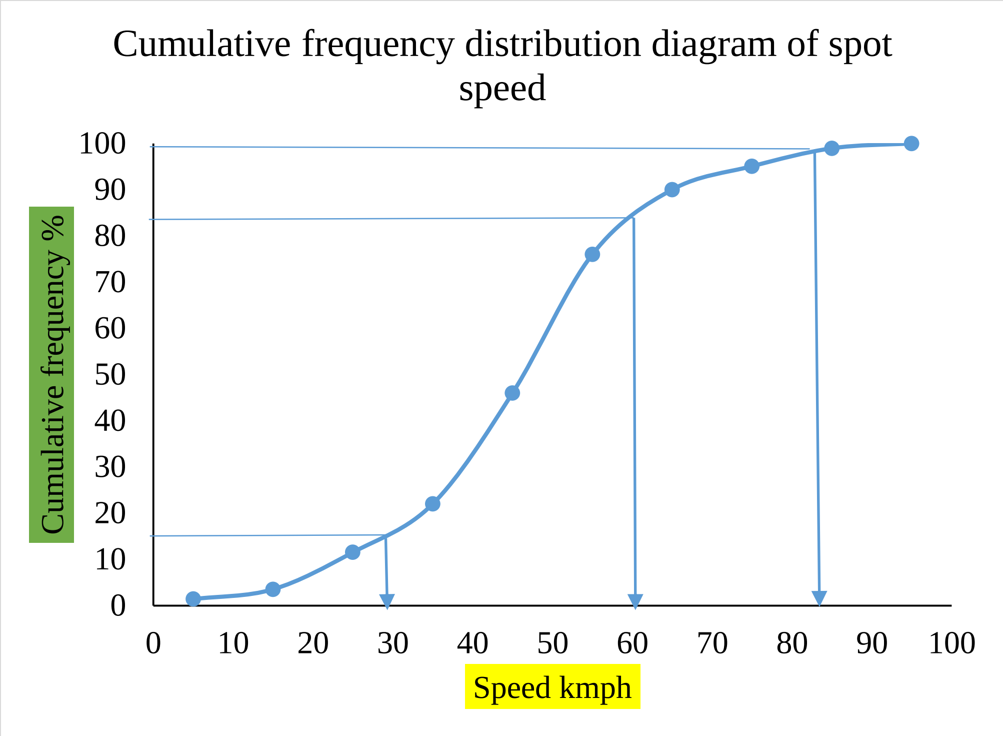
5. Spot speed studies were carried out at a certain stretch of a highway with mixed traffic flow and the consolidated data collected are given below.

Speed range, kmph	No of vehicles observed
0 - 10	12
10 - 20	18
20 - 30	68
30 - 40	89
40 - 50	204
50 - 60	255
60 - 70	119
70 - 80	43
80 - 90	33
90 - 100	9

Determine: (i) The upper and lower values or speed limits for installing speed regulation signs at this road stretch and (ii) the design speed for checking the geometric design elements of the highway.

Solution:

Speed range, kmph	**Mean Speed kmph**	**Frequency**	**% Frequency**	**Cumulative Frequency, (at or below the speed), %**
0 - 10	5	12	1.41	1.41
10 -20	15	18	2.12	3.53
20 - 30	25	68	8	11.53
30 - 40	35	89	10.47	22
40 - 50	45	204	24	46
50 - 60	55	255	30	76
60 - 70	65	119	14	90
70 - 80	75	43	5.06	95.06
80 - 90	85	33	3.88	98.94
90 - 100	95	9	1.06	100
Total		**850**	**100**	



(a) Upper speed limit for regulation = 85th percentile speed = 60 kmph

(b) Lower speed limit for regulation = 15th percentile speed = 30 kmph

(c) Speed to check geometric design elements = 98th percentile speed = 84 kmph

6. The free mean speed on a roadway is found to be 80kmph. Under stopped condition the average spacing between vehicles is 6.9m. Determine the capacity flow.

Solution:

Given Free mean speed $V_{sf} = 80kmph$

$$s_{jam} = 6.9m$$

Jam density $k_j = \frac{1000}{6.9} = 145\ veh/km$

Maximum flow $q_{max} = \frac{V_{sf}K_j}{4} = \frac{80\times145}{4} = 2900\frac{veh}{hr}/lane$

7. The table below shows the volumetric data observed at an intersection. Calculate the peak hour volume, peak hour factor (PHF), and the actual (design) flow rate for this approach

Time Interval	Cars
4:00 - 4:15	30
4:15 - 4:30	26
4:30 - 4:45	35
4:45 - 5:00	40

5:00 - 5:15	49
5:15 - 5:30	55
5:30 - 5:45	65
5:45 - 6:00	50
6:00 - 6:15	39
6:15 - 6:30	30

Solution:

- The peak hour volume is just the sum of the volumes of the four 15 minute intervals within the peak hour (219). The peak 15 minute volume is 65 in this case. The peak hour factor (PHF) is found by dividing the peak hour volume by four times the peak 15 minute volume. PHF = $\frac{219}{4\times65}$ = 0.84

- The actual (design) flow rate can be calculated by dividing the peak hour volume by the PHF, 219/0.84 = 260 vehicles/hr, or by multiplying the peak 15 minute volume by four, 4 × 65 = 260 vehicles per hour.

8. Find the peak hour factor for the 15-minute vehicle volumes given
    1) V15 = 190
    2) V30 = 200
    3) V45 = 190
    4) V60 = 190

Solution:

PHF = (190 + 200 + 190 + 190) / [(200 x 4)] = 0.96

9. Find the peak hour factor for the 15-minute vehicle volumes given
    1) V15 = 175
    2) V30 = 200
    3) V45 = 150
    4) V60 = 125

Solution:

PHF = (175 + 200 + 150 + 125) / [(200 x 4)] = 0.81

A PHF of 1 indicates that the traffic volume in every 15-minute interval is the same and therefore the traffic flow is consistent throughout the hour. Lower PHF values indicate more variable traffic flows and that the traffic volume has a spike during the peak 15-minute interval.

10. The table below shows flow rates that were measured for four 15-minute time periods for each of the 12 intersection movements. Find the peak hour factor

Time period	**Eastbound**			**Westbound**			**Northbound**			**Southbound**			**Total**
	LT	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	**LT**	**TH**	**RT**	
4:00 PM	40	55	175	50	50	75	120	815	45	40	700	55	**2,220**
4:15 PM	50	75	375	55	80	125	215	1,025	20	60	1,975	165	**4,220**

4:30 PM	30	75	125	45	75	115	20	975	35	55	1,200	145	**2,895**
4:45 PM	45	60	175	55	85	150	145	1,015	45	50	1,350	130	**3,305**

Solution:

Examination of this table shows that second time period, which begins at 4:15 pm, is the peak 15-minute period of the four that are shown here.

The total flow for this time period (15 min) is 4,220 veh,

The average flow rate for the hour is 12,640 veh/hr; this is the sum of the total volumes observed during each of the four 15-minute periods shown below.

The peak hour factor can then be computed as follows:

$$\text{Peak Hour Factor} = \frac{\text{Peak Hour Volume}}{\frac{60}{15} * \text{Maximum volume at 15 min. interval in Peak Hour}}$$

=12,640/16,880

=0.75

11. The Flow in each 5-minute interval from 4:30 – 6:00Pm is given in the table below. Determine when the peak hour begins and ends. What is the peak hour factor?

Time	Flow Rate
4:30 - 4:35	1200
4:35 - 4:40	1350
4:40 - 4:45	1490
4:45 - 4:50	1780
4:50 - 4:55	1720
4:55 - 5:00	1540
5:00 - 5:05	1670
5:05 - 5:10	1650
5:10 - 5:15	1700
5:15 - 5:20	1400
5:20 - 5:25	1500
5:25 - 5:30	1700
5:30 - 5:35	1300
5:35 - 5:40	1300
5:40 - 5:45	1550
5:45 - 5:50	1350
5:50 - 5:55	1780
5:55 - 6:00	1450

Solution:

Table: Flow in 15minute interval

Time	Flow Rate	15 Min Interval	15 Min flow Rate
4:30 - 4:35	1200	4:30 – 4:45	
4:35 - 4:40	1350		
4:40 - 4:45	1490		
4:45 - 4:50	1780	4:45 – 5:00	
4:50 - 4:55	1720		
4:55 - 5:00	1540		
5:00 - 5:05	1670	5:00 – 5:15	
5:05 - 5:10	1650		
5:10 - 5:15	1700		
5:15 - 5:20	1400	5:15 – 5:30	
5:20 - 5:25	1500		
5:25 - 5:30	1700		
5:30 - 5:35	1300	5:30 – 5:45	
5:35 - 5:40	1300		
5:40 - 5:45	1550		
5:45 - 5:50	1350	5:45 – 6:00	
5:50 - 5:55	1780		
5:55 - 6:00	1450		

Table: Flow in 1 Hour interval

1 Hour interval	1 Hour Volume
4:30 – 5:30	
4:45 – 5:45	
5:00 – 6:00	

Peak hour period =

Peak 15 min period =

Maximum volume in peak 15 min period =

Maximum volume in peak hour =

Peak Hour Factor = $\frac{\text{Peak Hour Volume}}{\frac{60}{15} * \text{Maximum volume at 15 min. interval in Peak Hour}}$ =

12. The table below shows the volumetric data collected at an intersection: Calculate the peak hour volume, peak hour factor (PHF), and the actual (design) flow rate for this approach.

Table: Volumetric Data Collected

Time	HCV	LCV	CAR	3W	2W
4:00 - 4:15	4	10	6	38	24
4:15 - 4:30	8	12	9	63	33
4:30 - 4:45	7	13	8	42	27
4:45 - 5:00	6	13	15	37	32

5:00 - 5:15	7	14	10	51	28
5:15 - 5:30	6	10	9	63	41
5:30 - 5:45	8	11	8	48	38
5:45 - 6:00	10	6	15	47	21
6:00 - 6:15	9	7	9	54	26
6:15 - 6:30	10	9	11	62	35
6:30 - 6:45	12	11	12	61	39
6:45 - 7:00	8	8	10	54	42

Table: PCU Values

HCV	3.5
LCV	2.2
CAR	1.0
3W	0.8
2W	0.5

Solution:

The first step in this solution is to find the total traffic volume for each 15 minute period in terms of passenger car units. For this purpose the PCU values given in the table are used. Once we have this, we can locate the hour with the highest volume and the 15 minute interval with the highest volume.

Time	HCV	LCV	CAR	3W	2W	Flow in PCU
PCU	3.5	2.2	1.0	0.8	0.5	
4:00 - 4:15						
4:15 - 4:30						
4:30 - 4:45						
4:45 - 5:00						
5:00 - 5:15						
5:15 - 5:30						
5:30 - 5:45						
5:45 - 6:00						
6:00 - 6:15						
6:15 - 6:30						
6:30 - 6:45						
6:45 - 7:00						

Table: Flow in 1 Hour interval

1 Hour interval	1 Hour Volume
4:00 – 5:00	
4:15 – 5:15	
4:30 – 5:30	
4:45 – 5:45	
5:00 – 6:00	
5:15 – 6:15	
5:30 – 6:30	
5:45 – 6:45	

6:00 – 7:00	

Peak hour period =

Peak 15 min period =

Maximum volume in peak 15 min period =

Maximum volume in peak hour =

Peak Hour Factor = $\frac{\text{Peak Hour Volume}}{\frac{60}{15} * \text{Maximum volume at 15 min. interval in Peak Hour}}$ =

The actual (design) flow rate can be calculated by dividing the peak hour volume by the PHF, or by multiplying the peak 15 minute volume by 4.

Therefore

The actual design flow rate = peak hour volume/PHF

Or

The actual design flow rate = peak 15min volume*4

13. Determine the time mean speed, space mean speed, and 85th percentile speed from the following speed (in m/s) data

Speed	**Frequency**
1- 5	9
6-10	16
11-15	32
16-20	48
21-25	23
26-30	9

14. For a given road following speed data is collected. 25, 31, 36, 39, 42, 44, 47, 48, 49, 51, 52, 52, 53, 54, 55, 56, 57, 57, 57, 58, 59, 60, 60, 62, 63, 64, 65, 66, 66, 68, 68, 69, 70, 70, 71, 73, 75, 79, 85, 89, 90. What is the speed you will recommend for designing sight distance or radius of circular curve?

15. The spot speeds of ten vehicles observed at a certain location are 55.1, 40.8, 32.2, 47.8, 64.5, 53.2, 58.2, 67.6, 36.4, and 53.2 kmph. Find the time mean speed, space mean speed and 85th percentile speed

16. Table below indicates the values of spot speeds observed at a certain location. Find (i) the 98th percentile speed (ii) 85th percentile speed (iii) 50th percentile speed and (iv) 15th percentile speed

Obs. No	**Speed (kmph)**
1	55.1
2	40.8

3	32.2
4	47.8
5	64.5
6	53.2
7	58.2
8	66.6
9	36.4
10	53.2

UNIT-II HIGHWAY CAPACITY AND LEVEL OF SERVICE

2.0 General

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.

2.1 Derived Characteristics

2.1.1 Time headway

The microscopic characteristic 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.

2.1.2 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.

2.1.3 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.

2.2 Gap acceptance and follow-up time

Gap acceptance is one of the most important components in microscopic traffic characteristic. The gap acceptance theory commonly used in the analysis of uncontrolled intersections based on the concept of defining the extent drivers will be able to utilize a gap of particular size or duration. A driver entering into or going across a traffic stream must evaluate the space between a potentially conflicting vehicle and decide whether to cross or enter or not. One of the most important aspects of traffic operation is the interaction of vehicles with in a single stream of traffic or the interaction of two separate traffic streams. This interaction takes place when a driver changes lanes merging in to a traffic stream or crosses a traffic stream. Inherent in the traffic interaction associated with these basic maneuvers is concept of gap acceptance.

2.2.1 Basic Terminologies

1. **Gap** means the time and space that a subject vehicle needs to merge adequately safely between two vehicles. Gap acceptance is the minimum gap required to finish lane changing safely. Therefore, a gap acceptance model can help describe how a driver judges whether to accept or not.
2. **Gap acceptance**: The process by which a minor stream vehicle accepts an available gap to maneuver.
3. **Critical gap**: The minimum major-stream headway during which a minor-street vehicle can make a maneuver.
4. **Lag**: Time interval between the arrival of a yielding vehicle and the passage of the next priority stream vehicle (Forward waiting time).
5. **Headway**: The time interval between the arrivals of two successive vehicles. Headway differs from gap because it is measured from the front bumper of the front vehicle to the front bumper of the next vehicle.
6. **Minimum Headway**: The minimum gap maintained by a vehicle in the major traffic stream.
7. **Follow-up time**: Time between the departure of one vehicle from the minor street and the departure of the next vehicle using the same gap under a condition of continuous queuing.
8. **Delay**: The additional travel time experienced by a driver, passenger or pedestrian.
9. **Conflicting movements**: The traffic streams in conflict at an intersection.
10. **Capacity**: The maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or a roadway during a given time period under prevailing roadway, traffic, and control conditions.

2.2.2 Critical Gap

The critical gap t_{cx} for movement x is defined as the minimum average acceptable gap that allows intersection entry for one minor street or major street. The term average acceptable means that the average driver would accept or choose to utilize a gap of this size. The gap is measured as the clear time in the traffic stream defined by all conflicting movements. Thus, the model assumes that all gaps shorter than t_{cx} are rejected or unused, while all gaps equal to or larger than t_{cx} would be accepted or used. The adjusted critical gap t_{cx} computed as follows.

$$t_{cx} = t_{cb} + t_{cHV} P_{HV} + t_G G + t_{c,T} + t_{3,LT}$$

where, t_{cx} is the critical gap for movement x, t_{cb} is the base critical gap from Table. 2.1 t_{cHV} is the adjustment factor for heavy vehicles P_{HV} is the proportion of heavy vehicles t_{cG} is the adjustment factor for grade G is the percent grade divided by 100, t_{cT} is the adjustment factor for each part of a two-stage gap acceptance process, and t_{3LT} is the critical gap adjustment factor for intersection geometry.

2.2.3 Follow-up time

The follow up time t_{fx} for movement x is the minimum average acceptable time for a second queued minor street vehicle to use a gap large enough admit two or more vehicles. Follow-up times were measured directly by observing traffic flow. Resulting follow-up times were analyzed to determine their dependence on different parameters such as intersection layout. This measurement is similar to the saturation flow rate at signalized intersection. Table 2.1 and 2.2 shows base or unadjusted values of the critical gap and follow up time for various movements. Base critical gaps and follow up times can be adjusted to account for a number of conditions, including heavy - vehicle presence grade, and the existence of two stage gap acceptance. Adjusted Follow up Time computed as:

$$t_{fx} = t_{fb} + t_{fHV} P_{HV}$$

where, t_{fx} is the follow-up time for minor movement x , t_{fb} is the base follow-up time from table 2.2, t_{fHV} is the adjustment factor for heavy vehicles, and P_{HV} is the proportion of heavy vehicles for minor movement.

Table 2.1 Base critical gap and follow up times

Vehicle Movement	Base Critical Gap, t_c,base (s)		Base Follow-up Time $t_{f,base}$ (s)
	Two-Lane Major Street	Four-Lane Major Street	
Left turn from major	4.1	4.1	2.2
Right turn from minor	6.2	6.9	3.3
Through traffic on minor	6.5	6.5	4.0
Left turn from minor	7.1	7.5	3.5

Table 2.2 Adjustments to base critical gap and follow up times

Adjustment Factor	Values(s)	
t_{cHV}	1.0	Two-lane major streets
	2.0	Four-lane major streets
t_{cG}	0.1	Movements 9 and 12
	0.2	Movements 7,8,10 and 11
	1.0	Otherwise
t_{cT}	1.0	First or second stage of two-stage process
	0.0	For one-stage process
T_{3LT}	0.7	Minor-street LT at T-intersection
	0.0	Otherwise
t_{fHV}	0.9	Two-lane major streets
	1.0	Four-lane major streets

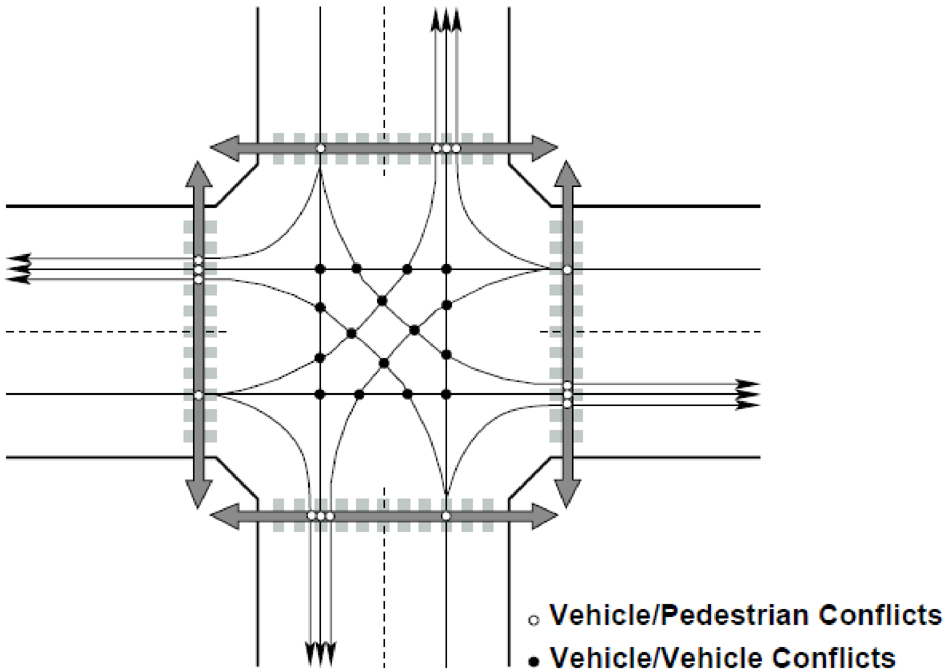


Figure 2.1 Conflicts at four legged intersection

2.2.4 Conflicting volume

The traffic flow process at un-controlled intersection is complicated since there are many distinct vehicular movements to be accounted for. Most of this movements conflict with opposing vehicular volumes. These conflicts result in decreasing capacity, increasing delay, and increasing potentials for traffic accidents. Consider a typical four-legged intersection as shown in Fig. 2.1. The numbers of conflicts for competing through movements are 4, while competing right turn and through movements are 8. The conflicts between right turn traffics are 4, and between left turn and merging traffic are 4. The conflicts created by pedestrians will be 8 taking into account all the four approaches. Diverging traffic also produces about 4 conflicts. Therefore, a typical four legged intersection has about 32 different types of conflicts. Conflicts at an intersection are different for different types of intersection. The essence of the intersection control is to resolve these conflicts at the intersection for the safe and efficient movement of both vehicular traffic and pedestrians.

2.3 Capacity and Level of Service LOS

Often it is required to ascertain how much a transport facility can accommodate. Such information is useful in the design of traffic facility. Capacity analysis helps in answering the question. It is a quantitative assessment of the ability of a traffic facility to handle vehicles or people for which it is designed.

A related question is, what is the performance level of the system at various operating conditions. Or in other words, how good is the operation of the traffic facility. Level of Service analysis tries to answer this question which is essentially a qualitative analysis. Capacities and Level of Services are therefore closely related analysis of a traffic facility.

Capacity and Level of service are two related terms. Capacity analysis tries to give a clear understanding of how much traffic a given transportation facility can accommodate. Level of service tries to answer how good is the present traffic situation on a given facility. Thus it gives a qualitative measure of traffic, whereas capacity analysis gives a quantitative measure of a facility. Capacity and level of service varies with the type of facility, prevailing traffic and road conditions etc.

Importance of the Concept of Highway Capacity

The concept of highway capacity is important for the following reasons:

1. The capacity of a highway should be adequate to serve the needs of the projected traffic.

2. The class of highway, lane width, number of lanes and intersections are dependent on capacity.

3. Improvements on geometric elements, traffic control devices and traffic management measures can be effectively planned based on the studies of highway capacity.

4. The adequacy of the existing highway network for the existing traffic volume can be assessed by capacity studies; transportation planning can be done effectively using this information.

2.3.1 Capacity

Capacity of a transport facility 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. The Highway Capacity Manual (HCM 2010) defines the capacity 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.

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

UNIT-II HIGHWAY CAPACITY AND LEVEL OF SERVICE

Basic capacity is the maximum number of passenger cars that can pass a given point on a Lane or roadway during one hour under nearly ideal roadway and traffic conditions which can possibly be attained. Two roads having the same physical features will have the same basic capacity irrespective of traffic conditions, as they are assumed to have ideal conditions. Thus basic capacity is the *theoretical capacity*.

Possible capacity is the maximum number of vehicles that can pass a given point on a Lane or roadway during one hour under prevailing roadway and traffic conditions. The possible capacity of a road is generally much lower than the basic capacity as the prevailing roadway and traffic conditions are seldom ideal. In a worst case when the prevailing traffic condition is so bad that due to traffic condition, the traffic may come to a stand-still condition and in such a situation the possible capacity of the road may approach zero.

When the prevailing roadway and traffic conditions approach the ideal conditions, the possible capacity would also approach the basic capacity. Thus the value of possible capacity varies from zero to basic capacity. For the purpose of design neither basic capacity nor possible capacity can be adopted as they represent two extreme cases of roadway and traffic conditions.

Practical capacity is the maximum number of vehicles that can pass a given point on a Lane or roadway during one hour without traffic density being so high as to cause unreasonable delay, hazard or restriction to the driver's freedom to manoeuver under the prevailing roadway and traffic conditions. It is the practical capacity which is of primary interest to the designers who strive to provide adequate highway facilities and hence this is also called *design capacity*

The capacity measure depends on these operating conditions. The first is the traffic conditions and the factors that influence the capacity includes vehicle composition, turning, movements, etc. The second factor is the roadway conditions and it includes geometrical characteristics such as lane width, shoulder width, horizontal alignment, vertical alignment. The third factor is the control conditions such as the traffic signal timings, round-about characteristics.

Determination of theoretical maximum capacity

An estimate of a theoretical maximum or basic capacity of a single Lane may be made from the relation:

$$= \frac{1000V}{S}$$

Here,

q_c = capacity of a single lane, vehicles per hour per lane

V = speed, Kmph

S = average centre to centre spaceing of vehicles when they follow one behind the other as a queue or space headway, m

Thus the capacity depends upon the speed V and spacing S. The average spacing between centre to centre vehicles is equal to the average length of vehicle plus the average clear gap between the vehicles in the stream and this spacing is also equal to the space headway. The minimum clear gap between vehicles are allowed for safe stopping of the rare vehicle in case the vehicle ahead suddenly stops. It is also found that drivers follow the vehicle ahead at a closer gap at a lower speeds and the clear gap and the spacing H_s gets increased instinctively at higher speed of the traffic stream.

Thus the space gap allowed by the driver of a following vehicle depends on several factors such as,

a) Speed of leading and following vehicles
b) Type and characteristics of the two vehicles
c) Driver characteristics of the following vehicle
d) Traffic volume to capacity ratio of the road stretch at the instant or the ‘level of service’
e) The proportion of different vehicle classes in the stream
f) Roadway geometrics and
g) Environmental factors such as weather conditions, lighting, etc.

The assumption that space gap increases in direct proportion to the speed of the vehicle or that of the traffic stream gives only an approximate average value of the space gap between vehicles in the traffic stream. The space gap between the vehicle ahead and the following vehicle in a traffic stream is sometimes assumed to be equal to the distance travelled during the reaction time of the driver, with a further assumption that the breaking distance of the lead vehicle and the following vehicle is approximately equal. If the reaction time is t sec, the minimum space gap S_g is given by

$$S_g = vt, m = 0.278Vt, m$$

The minimum space headway, S in a traffic stream is therefore equal to the minimum space gap plus average length of vehicle L in the stream.

$$S = S_g + L = 0.278Vt + L$$

In a stream flow, as the driver of the following vehicle is quite alert, the average reaction time is found to be low; this value is often assumed to be 0.70 to 0.75 sec. In the analysis of overtaking sight distance, the value of reaction time has been assumed as 0.7 sec in the empirical relation for spacing, S given by,

$$S = (0.7V + L) = (0.2V + L), m$$

Thus a suitable value of spacing $\boldsymbol{S}$ maybe adopted in above equation to estimate the theoretical capacity of a traffic Lane with the homogeneous traffic flow.

It has been observed (as explained earlier) that with increase in speed of the traffic stream the time headway decreases and after reaching a minimum value at an optimum speed, starts increasing. The maximum theoretical capacity of a traffic lane may therefore be obtained if the minimum time headway H_t is known.

$$q_c = \frac{3600}{H_t}$$

Here q_c is the capacity, vehicles per hour (or 3600sec), and the minimum time headway in seconds.

The peak value of theoretical capacity is reached at an optimum speed. As the speed is increase further, the maximum capacity flow of the lane starts decreasing due to increase in headway at the higher speed range.

Factors affecting practical capacity

Some of the important factors that affect the practical capacity of a traffic lane or is Highway are listed below:

a) *Lane width:* As the Lane width decreases, the capacity also decreases. The practical capacity of 3.0m wide Lane or a two-lane road in rural areas may decrease to 76% of the capacity of a 3.5m lane.
b) *lateral clearance:* vertical obstructions such as retaining walls, raised culvert walls or Parked vehicles near the traffic lane reduces the effective width of a lane and thus result in a reduction in the capacity of the adjacent lane. Further restricted lateral clearance affects driving comfort and increases accident rate. As minimum clearance of 1.85m from the pavement edge to the obstruction is considered desirable so that capacity is not affected adversely. When the distance from payment edge to an obstruction decreases to 0.75m on one side only, the capacity decreases to 96% and when this obstruction is on both sides, the percentage further decreases to 80% of standard design capacity.
c) *Width of shoulders:* Narrow shoulders reduce the effective width of adjacent traffic lanes as a vehicles travel towards the center of the payment. When vehicles in emergency (like that of a tyre puncture or other break down) have to park on the shoulders of insufficient width, there is a reduction in effective width of the adjacent lane, resulting in a considerable reduction in the capacity of the lane.
d) *Commercial vehicles:* Large commercial vehicles like a truck and buses occupy greater space and influence the other traffic in the same lane as well as the vehicles along the adjoining lanes. Also these heavy commercial vehicles may travel at lower speeds especially on ascending grades.
e) *Alignment:* If the alignment and geometrics are not up to their desired standards, the capacity will decrease. Particularly restrictions to sight distance requirements cause reduction in capacity. Steep and long grades affect the capacity. When 60% of the road

length has sub-standard OSD, the capacity decreases to 65% of the standard design capacity.

f) *Road Geometrics:* Presence of sharp horizontal curves, steep gradients, summit and Valley curves necessitate speed changes and consequently result in lower highway capacity.

g) *Presence of intersections at grade:* Intersections restrict free flow of traffic and thus adversely affect the capacity. The capacity of an intersection of two roads crossing at grade will be slightly less than the road with the lower capacity of the two. At signalized intersections as the vehicles have to stop alternately to allow crossing traffic, The capacity of the intersections will be further decreased. In order to provide consistent traffic flow and maximum capacity on important highways, is necessary to plan them as controlled access highways with grade separated intersections.

h) Other factors which affect the capacity are the stream speed, one or two way traffic movement, number of traffic lanes, vehicular and driver characteristics, composition of traffic and the traffic volume.

2.3.2 Level of service

Level-of-Service (LOS) of a traffic facility is a concept introduced to relate the quality of traffic service to a given flow rate. Level-of-Service is introduced by HCM to denote the level of quality one can derive from a local under different operation characteristics and traffic volume. HCM proposes LOS as a letter that designate a range of operating conditions on a particular type of facility. Six LOS letters are defined by HCM, namely A, B, C, D, E, and F, where A denote the best quality of service and F denote the worst. These definitions are based on Measures of Effectiveness (MoE) of that facility. Typical measure of effectiveness include speed, travel-time, density, delay etc. There will be an associated service volume for each of the LOS levels. A service volume or service flow rate 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 LOS.

2.3.3 Type of Facilities

HCM has developed the capacities standard and LOS measure for various facilities. Each traffic facility has its own unit for the capacity and measure of effectiveness for each item will also vary. The traffic facilities can be divided into three, namely: the uninterrupted facilities, interrupted facilities, and others. Uninterrupted facilities include freeway (basic freeway, weaving sections, and ramps), multi-lane highways (unidirectional), two-lane highways (bidirectional). Freeways normally have density as the measure of effectiveness, while multi-lane and two-lane highways have delay/speed as the MoE. Interrupted facilities include un-signalized intersection, signalized intersection, and arterials or corridors. They have respectively control delay, total delay and average travel speed as the measure of effectiveness. Other facilities may include pedestrian pathways, bicycle tracks, bus-transit system, rail-transit system and air-transportation system. Each of them have facility specific measure of effectiveness.

UNIT-II HIGHWAY CAPACITY AND LEVEL OF SERVICE

Factors affecting level of service

The level of service can be derived from a road under different operating characteristics and traffic volumes. The factors affecting level of service (LOS) can be listed as follows:

a) Speed and travel time
b) Traffic interruptions/restrictions
c) Freedom to travel with desired speed
d) Driver comfort and convenience
e) Operating cost.

3 Illustrations

For a typical freeway mid-block section the capacity and LOS can be defined for an ideal section. An ideal section has uninterrupted flow from both sides and has only passenger cars and the drivers are regular travelers who are familiar with the facility. The lane width is 3.65m wide with proper shoulder and 1.8m lateral clearance is available from the edge of the pavement. The free flow speed of 115kmph is achievable on the multi-lane and 100kmph on the two-lane highway.

3.1 Capacity

Such a facility is considered as an ideal facility and for such facilities the following values can be taken as capacity.

a) A capacity of 2000 vehicle per hour per lane for a speed of 115kmph
b) A capacity of 1900 vehicles per hour per lane for a speed of 80kmph
c) A capacity of 2800 vehicle per hour for both direction at 100kmph

Note that the above values are not analytical or experimentally derived, but, statistically derived from the observed field values from large number of such sections. Needly to say that it is possible to have a flow higher than this capacity measure, but not necessary.

3.2 Level of service

The above capacity value drop due to various 'non-ideal condition' which includes changes in speed or travel time, traffic interruptions or restriction etc. Accordingly HCM has defined various levels of services for the traffic facility. Assigning quality value is based on several user surveys capturing the perception of drivers on the quality of the traffic under various operating condition. The Figure 2.2 illustrate the quality of services or Level-of-Services (A to F) and the various operating conditions. The same can be shown in the Table 2.3.

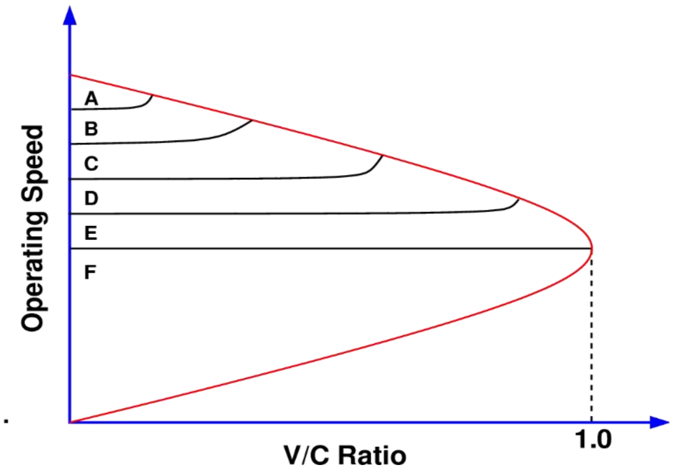


Figure 2.2 The Level of Service of a mid-block section is expressed in terms of the operating speed and volume to capacity (v/c) ratio

Table 2.3 LOS of a Mid-Block Section

LOS	Quality	Speed (kmph)	V/C	Description
A	Free-flow	80	0.6	High level of physical and psychological comfort
B	Reasonable free-flow	70	0.7	Reasonable level of physical and psychological comfort
C	Near free-flow	60	0.8	Local deterioration possible with blockages
D	Medium flow	50	0.85	Non-recoverable local disruptions
E	At capacity flow	40	0.9	Minor disturbances resulting breakdown
F	Congested flow	15	1	Break down of flow capacity drops

Level of service A represents the zone of free flow. Here the traffic volume will be less, traffic will be experiencing free flow 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 define operation at capacity. At this level, the stream reaches its 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.

2.4 Multilane Highways

2.4.1 Introduction

Increasing traffic flow has forced engineers to increase the number of lanes of highways in order to provide good maneuvering facilities to the users. The main objectives is to analyze LOS which is very important factor for a traffic engineer because it describes the traffic operational conditions within a traffic stream. Also we are going to study the characteristics and capacity for multilane highways. Free-flow speed is an important parameter that is being used extensively for capacity and level-of- service analysis of various types of highway facilities.

2.4.2 Multilane Highways

A highway is a public road especially a major road connecting two or more destinations. A highway with at least two lanes for the exclusive use of traffic in each direction, with no control or partial control of access, but that may have periodic interruptions to flow at signalized intersections not closer than 3.0 km is called as multilane highway. They are typically located in suburban areas leading to central cities or along high-volume rural corridors that connect two cities or important activity centers that generate a considerable number of daily trips.

2.4.2.1 Highway Classification

There are various ways of classification of highways; we will see classification of highways according to number of lanes.

- Two lane highways.
- Multilane highways

2.4.2.2 Highway Characteristics

Multilane highways generally have posted speed limits between 60 km/h and 90 km/h. They usually have four or six lanes, often with physical medians or two-way right turn lanes (TWRTL), although they may also be undivided. The traffic volumes generally varies from 15,000 - 40,000 vehicles per day. It may also go up to 100,000 vehicles per day with grade separations and no cross-median access. Traffic signals at major intersections are possible for multilane highways which facilitate partial control of access. Typical illustrations of multilane highway configurations are provided in Figure 2.3 and 2.4

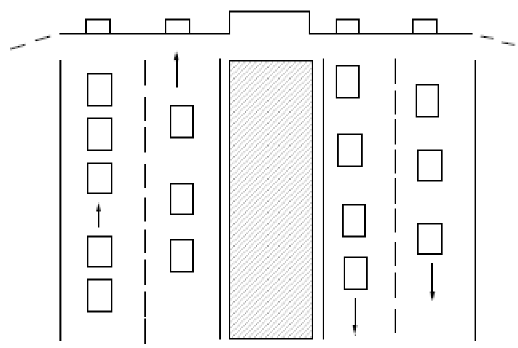


Figure2.3 Divided multilane highway in a rural/suburban environment

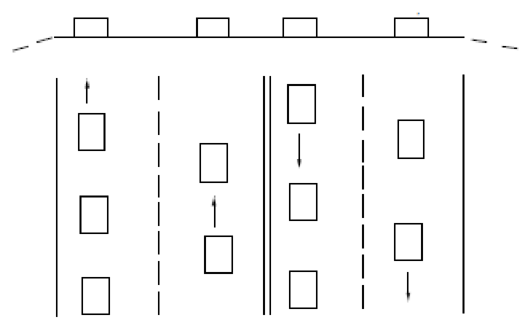


Figure 2.4 Undivided multilane highway in a rural/suburban environment

2.4.3 Highway Capacity

An important operation characteristic of any transport facility including the multilane highways is the concept of capacity. Capacity may be defined as the maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, traffic, environmental, and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour. There are two types of capacity, possible capacity and practical capacity. Possible capacity is defined as the maximum number of vehicles that can pass a point in one hour under prevailing roadway and traffic condition. Practical capacity on the other hand is the maximum number that can pass the point without unreasonable delay restriction to the average driver’s freedom to pass other vehicles. Procedure for computing practical capacity for the uninterrupted flow condition is as follows:

1. Select an operating speed which is acceptable for the class of highways the terrain and the driver.
2. Determine the appropriate capacity for ideal conditions from table 2.4.
3. Determine the reduction factor for conditions which reduce capacity (such as width of road, alignment, sight distance, heavy vehicle adjustment factor).
4. Multiply these factors by ideal capacity value obtained from step 2.

Table 2.4 Free flow speed and capacity for multilane highway

Types of facility	Free flow speed(kmph)	Capacity (pcphpl)
Multilane	100	2200
	90	2100
	80	2000
	70	1900

BASE CONDITIONS FOR CAPACITY ESTIMATION (Multilane divided interurban highways as per INDO-HCM 2017)

The base conditions for capacity estimation of multilane divided interurban highways are given below:

- Plain and level terrain
- No horizontal curvature or vertical gradient
- Traffic lanes 3.5 m wide [As per IRC: SP-84 (2014) and IRC: SP-87 (2013), the standard lane width of highways in India should be 3.5 m.]
- Minimum 1.5 m wide paved shoulders, followed by unpaved shoulders/crash barriers, the latter necessarily required in case of sections on an embankment of more than 3 m height
- Minimum of 2.5 m wide median
- No pavement defects that can adversely affect traffic operations. Roughness, in terms of International Roughness Index (IRI), is less than 2.7 m/km.
- No direct access points
- No side friction in terms of public transport stops, bus bays and truck lay-byes coupled with absence of significant pedestrian activity or slow-moving vehicles such as bicycles, rickshaws and animal carts.
- No work zone activity at or near the section.
- No incidents or crashes at the time of observation at or near the section.

BASE CONDITIONS FOR CAPACITY ESTIMATION (Two lane as per INDO-HCM 2017)

UNIT-II HIGHWAY CAPACITY AND LEVEL OF SERVICE

The basic parameters of traffic flow, namely speed, volume and density are used to estimate the capacity of road. For the identification of base section, predefined conditions followed for bidirectional carriageways covering varying road typologies are as follows:

- The carriageway width should be 7.0 m with a minimum of 1.0 m soft shoulder to facilitate two-way traffic movement in the case of two lane bidirectional roads. Similarly, in the case of intermediate lane road, being a road with restricted carriageway width, the carriageway width should be 5.5 m with a minimum of 1.0 m soft shoulder to facilitate two-way traffic movement at reduced speeds. In the case of single lane roads, the carriageway width should be 3.75 m with soft shoulder of 1.0 m.
- The section should be straight and level.
- The section should not be influenced by interruptions such as intersections, steep gradients and curvatures as well as any other adjoining roads.
- There must not be any physical barrier on at least 500 m section such as speed breakers, rumble strips, as it may affect the traffic stream.
- Section must be free from any form of roadside friction activities.
- Section should be free from any form of work activity for at least 1 km on either side.
- No incidents or crashes at the time of observation for at least 1 km on either side.

2.4.4 Level of Service

Level of service (LOS) is a qualitative term describing the operational performance of any transportation facility. The qualitative performance measure can be defined using various quantitative terms like:

1. Volume to capacity ratio,
2. Mean passenger car speed,(in km/h)
3. Density, (in p/kmln).

Basically any two of the following three performance characteristics can describe the LOS for a multilane highway. Each of these measures can indicate how well the highway accommodates the traffic demand. Since speed does not vary over a wide range of flows, it is not a good indicator of service quality. Density which is a measure of proximity of other vehicles in the traffic stream and is directly perceived by drivers and does not vary with all flow levels and therefore density is the most important performance measure for estimating LOS. Based on the quantitative parameter, the LOS of a facility can be divided into six qualitative categories, designated as LOS A,B,C,D,E,F The definition of each level of service, is given below:

Level of Service A

Travel conditions are completely free flow. The only constraint on the operation of vehicles lies in the geometric features of the roadway and individual driver preferences. Lane changing, merging and diverging manoeuvre within the traffic stream is good, and minor disruptions to traffic are easily absorbed without an effect on travel speed. Average spacing between vehicles is a minimum of 150 m or 24 car lengths. Figure 2.5 shows LOS A.

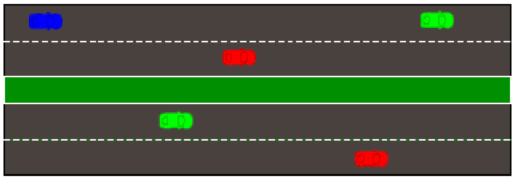


Figure 2.5 LOS A

Level of Service B

Travel conditions are at free flow. The presence of other vehicles is noticed but it is not a constraint on the operation of vehicles as are the geometric features of the roadway and individual driver preferences. Minor disruptions are easily absorbed, although localized reduction in LOS are noted. Average spacing between vehicles is a minimum of 150 m or 24 car lengths. Figure 2.6 below shows LOS B.

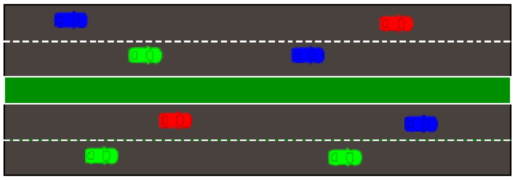


Figure 2.6 LOS B

Level of Service C

Traffic density begins to influence operations. The ability to manoeuvre within the traffic stream is affected by other vehicles. Travel speeds show some reduction when free-flow speeds exceed 80 km/h. Minor disruptions may be expected to cause serious local deterioration in service, and queues may begin to form. Average spacing between vehicles is a minimum of 150m or 24 car length. Figure 2.7 shows LOS C.

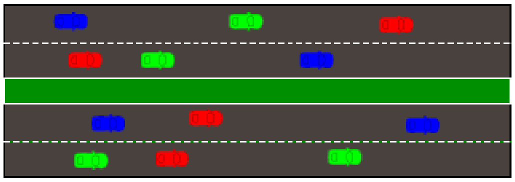


Figure 2.7 LOS C

Level of Service D

The ability to manoeuvre is severely restricted due to congestion. Travel speeds are reduced as volumes increase. Minor disruptions maybe expected to cause serious local deterioration in service, and queues may begin to form. Average spacing between vehicles is a minimum of 150m or 24 car length. Figure 2.8 shows LOS D.

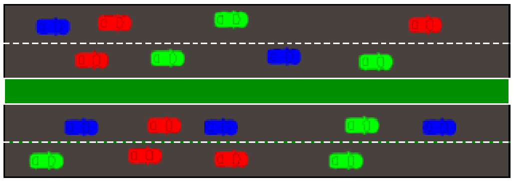


Figure 2.8 LOS D

Level of Service E

Operations are unstable at or near capacity. Densities vary, depending on the free-flow speed. Vehicles operate at the minimum spacing for which uniform flow can be maintained. Disruptions cannot be easily dissipated and usually result in the formation of queues and the deterioration of service to LOS F. For the majority of multilane highways with free-flow speed between 70 and 100km/h, passenger-car mean speeds at capacity range from 68 to 88 km/h but are highly variable and unpredictable. Average spacing between vehicles is a minimum of 150 m or 24 car length. Figure 2.9 shows LOS E.

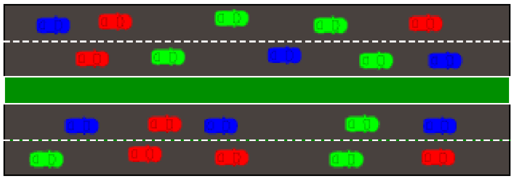


Figure 2.9 LOS E

Level of Service F

A forced breakdown of flow occurs at the point where the numbers of vehicles that arrive at a point exceed the number of vehicles discharged or when forecast demand exceeds capacity. Queues form at the breakdown point, while at sections downstream they may appear to be at capacity. Operations are highly unstable, with vehicles experiencing brief periods of movement followed by stoppages. Travel speeds within queues are generally less than 48 km/h. Note that the term LOS F may be used to characterize both the point of the breakdown and the operating condition within the queue. Figure 2.10 shows LOS F.

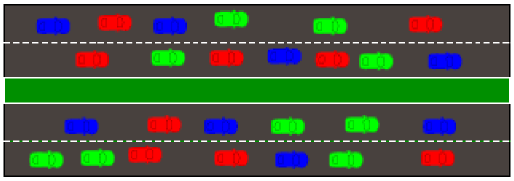


Figure 2.10 LOS F

2.5 Determination of Level of Service

The determination of level of service for a multilane highway involves three steps:

1. Determination of free-flow speed
2. Determination of flow rate
3. Determination of level of service

Free-flow speed

Free-flow speed is the theoretical speed of traffic density, when density approaches zero. It is the speed at which drivers feel comfortable travelling under the physical, environmental and traffic conditions existing on an uncongested section of multilane highway. In practice, free-flow speed is determined by performing travel-time studies during periods of low-to-moderate flow conditions. The upper limit for low to moderate flow conditions is considered 1400 passenger cars per hour per lane(pc/h/ln) for the analysis. Speed-flow and density-flow relationships are shown in figure 2.11 and figure 2.12. These relationships hold for a typical uninterrupted-flow segment on a multilane highway under either base or no base conditions in which free-flow speed is known. Figure 2.11 indicates that the speed of traffic volume up to a flow rate of 1400 pc/h/ln. It also shows that the capacity of a multilane highway under base conditions is 2200 pc/h/ln for highways with a 90 km/h free-flow speed. At flow rates between 1400 and 2200 pc/h/ln, the speed on a multilane highway drops. Figure 2.12 shows that density varies continuously throughout the full range of flow rates. The capacity value of 2200 pc/h/ln is representative of the maximum 15-min flow rate that can be accommodated under base conditions for highways with 90 km/h free-flow speed. From various studies of the flow characteristics, base conditions for multilane highways are defined as follows:

1. Lane widths are 3.6 m.
2. Lateral clearance is 1.8 m.
3. A minimum of 3.6 m of total lateral clearance in the direction of travel. Clearances are measured from the edge of the outer travelled lanes (shoulders included) and lateral clearance of 1.8 m or greater are considered to be equal to 1.8 m.
4. No direct access points along the highway.
5. A divided highway.
6. Only passenger cars in the traffic stream.
7. A free-flow speed of 90 km/h or more.

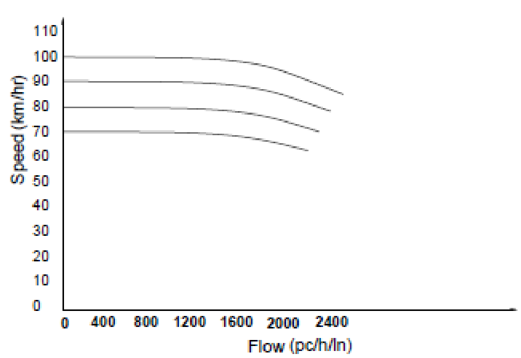


Figure 2.11 Speed-Flow relationship on multilane highway

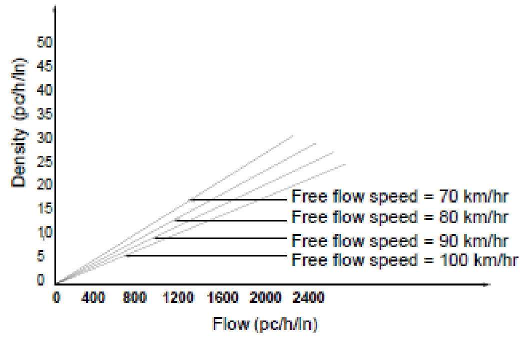


Figure 2.12 Density-flow relationships on multilane highways

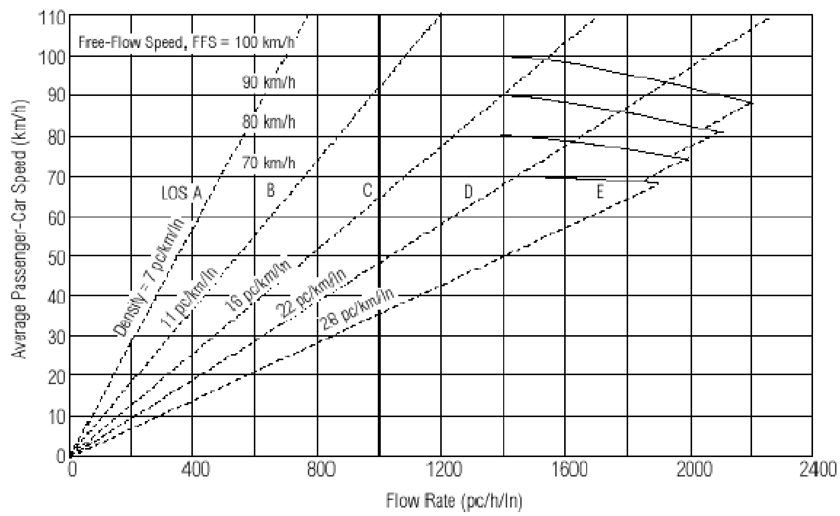


Figure 2.13 Speed-Flow curve with LOS Criteria for multilane highways

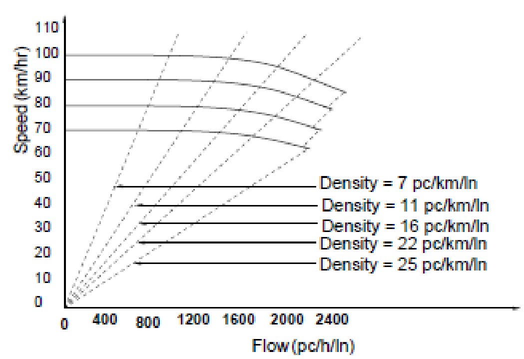


Figure 2.14 Flow chart showing step by step procedure to find density and LOS

The average of all passenger-car speeds measured in the field under low volume conditions can be used directly as the free-flow speed if such measurements were taken at flow rates at or below 1400 pc/h/ln. No adjustments are necessary as this speed reflects the net effect of all conditions at the site that influence speed, including lane width, lateral clearance, type of median, access points, posted speed limits, and horizontal and vertical alignment. Free-flow speed also can be estimated from 85th-percentile speed or posted speed limits, research suggests that free-flow speed under base conditions is 11 km/h higher than the speed limit for 65 km/h to 70 km/h speed limits and 8 km/h higher for 80 km/h to 90 km/h speed limits. Fig. 2.14 shows speed- flow curves with LOS criteria for multilane highways, here LOS is easily determined for any value of speed simply by plotting the point which is an intersection of flow and corresponding speed. Note that density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.

Determination of free-flow speed

When field data are not available, the free-flow speed can be estimated indirectly as follows:

$$FFS = BFFS - f_{LW} - f_{LC} - f_m - f_A \qquad \text{eq (1)}$$

where, FFS is the estimated FFS (km/h), $BFFS$ = base FFS (km/h), f_{LW}= adjustment for lane width, from Table 2.5 (km/h), f_{LC}= adjustment for lateral clearance, from Table 2.6 (km/h), f_m = adjustment for median type, from Table 2.7 (km/h), and f_A= adjustment for access points, from Table 2.8 (km/h). FFS on multilane highways under base conditions is approximately 11 km/h higher than the speed limit for 65 and 70 km/h speed limits, and it is 8 km/h higher for 80 and 90 km/h speed limits. $BFFS$ is approximately equal to 62.4 km/h (i.e decrease in 1.6 km/h) when the 85th percentile speed is 64 km/h, and it is 91.2 km/h (i.e decrease in 4.8 km/h) when the 85th percentile speed is 96 km/h and the in between speed values is found out by interpolation. According to Table 2.5, the adjustment in km/h increase as the lane width decreases from a base lane width of 3.6 m. No data exist for lane widths less than 3.0m.

The adjustment for lateral clearance (T_{LC}) is given as:

$$T_{LC} = L_{CL} + L_{CR}$$

where, T_{LC}= Total lateral clearance (m), L_{CL}= Lateral clearance (m), from the right edge of the travel lanes to roadside obstructions (if greater than 1.8 m, use 1.8 m), and L_{CR}= Lateral clearance (m), from the left edge of the travel lanes to obstructions in the roadway median (if the lateral clearance is greater than 1.8m, use 1.8 m). Once the total lateral clearance is computed, the adjustment factor is obtained from Table 2.6. For undivided highways, there is no adjustment for the right-side lateral clearance as this is already accounted for in the median type. Therefore, in order to use Table 2.7 for undivided highways, the lateral clearance on the left edge is always 1.8 m, as it for roadways with TWRTL's. The access-point density, which is use in Table 2.8, for a divided roadway is found by dividing the total number of access points (intersections and driveways) on the right side of the roadway in the direction of travel being studied by the length of the segment in kilometers. The adjustment factor for access-point density is given in Table 2.8. Thus the free flow speed can be computed using equation 1 and applying all the adjustment factors.

Table 2.5 Adjustment for lane width (Source: HCM, 2000)

Lane Width (m)	Reduction in FFS(km/h)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Table 2.6 Adjustment for lateral clearance (Source: HCM, 2000)

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance a (m)	Reduction in FFS (km/h)	Total Lateral Clearance a (m)	Reduction in FFS (km/h)
3.6	0.0	3.6	0.0
3.0	0.6	3.0	0.6
2.4	1.5	2.4	1.5
1.8	2.1	1.8	2.1
1.2	3.0	1.2	2.7
0.6	5.8	0.6	4.5
0.0	8.7	0.0	6.3

Table 2.7 Adjustment to free flow speed for median type (Source: HCM, 2000)

Median Type	Reduction in FFS (km/h)
Undivided highways	2.6
Divided highways	0.0

Table 2.8 Adjustment to free flow speed for Access-point density (Source: HCM, 2000)

Access Points/Kilometer	Reduction in FFS (km/h)
0	0.0
6	4.0
12	8.0
18	12.0
≥ 24	16.0

Determination of Flow Rate

The next step in the determination of the LOS is the computation of the peak hour factor. The fifteen minute passenger-car equivalent flow rate (pc/h/ln), is determined by using following formula:

$$v_p = \frac{V}{(PHF \times N \times f_{HV} \times f_p)}$$

where, v_p is the 15-min passenger-car equivalent flow rate (pc/h/ln), V is the hourly volume (veh/h), PHF is the peak-hour factor, N is the number of lanes, f_{HV} is the heavy-vehicle adjustment factor, and f_p is the driver population factor. PHF represents the variation in traffic flow within an hour. Observations of traffic flow consistently indicate that the flow rates found in the peak 15-min period within an hour are not sustained throughout the entire hour. The PHFs for multilane highways have been observed to be in the range of 0.75 to 0.95. Lower values are typical of rural or off-peak conditions, whereas higher factors are typical of urban and suburban peak-hour conditions. Where local data are not available, 0.88 is a reasonable estimate of the PHF for rural multilane highways and 0.92 for suburban facilities. Besides that, the presence of heavy vehicles in the traffic stream decreases the FFS, because base conditions allow a traffic stream of passenger cars only. Therefore, traffic volumes must be adjusted to reflect an equivalent flow rate expressed in passenger cars per hour per lane (pc/h/ln). This is accomplished by applying the heavy-vehicle factor (f_{HV}). Once values for $E_T$and E_R have been determined, the adjustment factors for heavy vehicles are applied as follows:

$$f_{HV} = \frac{1}{(1 + P_T(E_T - 1) + P_R(E_R - 1))}$$

where, E_T and E_R are the equivalents for trucks and buses and for recreational vehicles (RVs), respectively, P_T and P_R are the proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction), f_{HV} is the adjustment factor for heavy vehicles. Adjustment for the presence of heavy vehicles in traffic stream applies for three types of vehicles: trucks, buses and recreational vehicles (RVs). Trucks cover a wide range of vehicles, from lightly loaded vans and panel trucks to the most heavily loaded coal, timber, and gravel haulers. An individual truck's operational characteristics vary based on the weight of its load and its engine performance. RVs also include a broad range: campers, self-propelled and towed; motor homes; and passenger cars or small trucks towing a variety of recreational equipment, such as boats, snowmobiles, and motorcycle trailers. There is no evidence to indicate any distinct differences between buses and trucks on multilane highways, and thus the total population is combined.

Table 2.9 Passenger-car equivalent on extended general highway segments (Source: HCM, 2000)

Factor	Type of Terrain		
	Level	Rolling	Mountainous
ET (Trucks and Buses)	1.5	2.5	4.5
ER (RVs)	1.2	2.0	4.0

Determination of Level of Service

The level of service on a multilane highway can be determined directly from figure 2.14 or Table 2.10 based on the free-flow speed (FFS) and the service flow rate (v_p) in pc/h/ln.

Table 2.10 Level of Service criteria for a typical free flow speed of 100 kmph proposed in HCM 2000.

Free-Flow Speed	Criteria	(LOS) A	(LOS) B	(LOS) C	(LOS) D	(LOS) E
100 km/h	Max. density (pc/km/ln)	7	11	16	22	25
	Average speed (kmph)	100	100	98.4	91.5	88
	Max. volume capacity ratio	0.32	0.50	0.72	0.92	1.00
	Max. service flow rate (pc/h/ln)	700	1100	1575	2015	2200

The procedure is as follows:

1. Define a segment on the highway as appropriate. The following conditions help to define the segmenting of the highway,

   - Change in median treatment
   - Change in grade of 2% or more or a constant upgrade over 1220 m
   - Change in the number of travel lanes
   - The presence of a traffic signal
   - A significant change in the density of access points
   - Different speed limits
   - The presence of bottleneck condition

In general, the minimum length of study section should be 760 m, and the limits should be no closer than 0.4 km from a signalized intersection.

2. On the basis of the measured or estimated free-flow speed on a highway segment, an appropriate speed-flow curve of the same as the typical curves is drawn.

3. Locate the point on the horizontal axis corresponding to the appropriate flow rate (vp) in pc/hr/ln and draw a vertical line.
4. Read up the FFS curve identified in step 2 and determine the average travel speed at the point of intersection.
5. Determine the level of service on the basis of density region in which this point is located. Density of flow can be computed as

$$D = \frac{v_p}{S}$$

where, D is the density (pc/km/ln), v_p is the flow rate (pc/h/ln), and S is the average passenger-car travel speed (km/h). The level of service can also be determined by comparing the computed density with the density ranges shown in table given by HCM. To use the procedures for a design, a forecast of future traffic volumes has to be made and the general geometric and traffic control conditions, such as speed limits, must be estimated. With these data and a threshold level of service, an estimate of the number of lanes required for each direction of travel can be determined.

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UNIT-II NUMERICAL EXAMPLES

Numerical example 1

A segment of undivided four-lane highway on level terrain has field-measured FFS 74.0km/h, lane width 3.4-m, peak-hour volume 1,900-veh/h, 13 percent trucks and buses, 2 percent RVs, and 0.90 PHF. What is the peak-hour LOS, speed, and density for the level terrain portion of the highway?

Solution:

1. ***Data given:***
   - Level terrain, field measured FFS = 74 km/h,
   - lane width is 3.4 m,
   - peak-hour volume = 1900 veh/h,
   - percent trucks and buses P_T = 0.13,
   - percent RV's P_R = 0.02, and
   - PHF=0.90.

2. ***Determination of flow rate (v_p):***

   LOS can be calculated by knowing flow rate and free flow speed.

   Flow rate (v_p) is calculated from the equation

$$v_p = \frac{V}{(PHF \times N \times f_{HV} \times f_p)}$$

Since f_{HV} is unknown, it is calculated from the equation

$$f_{HV} = \frac{1}{(1 + P_T(E_T - 1) + P_R(E_R - 1))}$$

where, E_T and E_R are passenger-car equivalents for trucks and buses and for recreational vehicles (RVs) respectively P_T and P_R are proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction)

$$f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(1.2 - 1)}$$

Assume no RVs, since none is indicated.

$$V_p = \frac{1900}{(0.90 * 2 * 0.935 * 1)}$$

$$= 1129 \text{ pc/hr/ln}$$

3. ***Determination of free flow speed(S):***

In this example the free flow speed (FFS) measured at the field is given and hence no need to compute free flow speed by indirect method. Therefore, FFS = S = 74.0km/h.

4. ***Determination of density(D):***

The density of flow is computed from the equation

$$D = \frac{V_p}{S} = 15.3$$

5. ***Determination of LOS:***

LOS determined from the speed-flow diagram. LOS = C.

Numerical example 2

A segment of an east-west five-lane highway with two travel lanes in each direction separated by a two-way left-turn lane (TWLTL) on a level terrain has 83.0-km/h 85th-percentile speed, 3.6-m lane width, 1,500-veh/h peak-hour volume, 6 % trucks and buses, 8 access points/km (WB), 6 access points/km (EB), 0.90 PHF, 3.6-m and greater lateral clearance for westbound and eastbound. What is the LOS of the highway on level terrain during the peak hour?

<u>Solution:</u>

1. ***Data given:***

Level terrain,
85^{th}-percentile speed is 83.0 km/h,
lane width is 3.6 m,
peak-hour volume, V=1500 veh/h
Proportion of trucks and buses P_T= 0.06,
8 access points/km in WB,
6 access points/km in EB,
PHF = 0.90, and

Lateral clearance for westbound and eastbound is more than 3.6 m.

2. ***Determination of flow rate (v_p):***

LOS can be calculated by knowing flow rate and free flow speed. Flow rate (v_p) is calculated from the equation

$$v_p = \frac{V}{(PHF \times N \times f_{HV} \times f_p)}$$

where, v_p = 15-min passenger-car equivalent flow rate (pc/h/ln), V = hourly volume (veh/h), PHF = peak-hour factor, N = number of lanes, f_{HV} = heavy-vehicle adjustment factor, and f_p = driver population factor Since f_{HV} is unknown it is calculated from the equation

$$f_{HV} = \frac{1}{(1 + P_T(E_T - 1) + P_R(E_R - 1))}$$

where, E_T and E_R = passenger-car equivalents for trucks and buses and for recreational vehicles (RVs), respectively P_T and P_R = proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction) Assume no RVs, since none is indicated.

$$f_{HV} = \frac{1}{1 + 0.06(1.5 - 1) + 0}$$

$$= 0.970$$

$$V_p = \frac{1500}{(0.90 * 2 * 0.970 * 1)}$$

3. ***Determination of free flow speed(S):***

BFFS is approximately equal to 62.4 km/h when the 85th percentile speed is 64 km/h, and it is 91.2 km/h when the 85th percentile speed is 96 km/h and the in between speed values is found out by interpolation. Hence,

BFFS = 80 km/h.

Now, compute east bound and west bound free-flow speeds

$$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_m$$

$$= 80 - 0 - 0 - 4 - 0$$

$$= 76 \text{ kmph (WB)}$$

$$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_m$$

$$= 80 - 0 - 0 - 5.3 - 0$$

$$= 74.7 \text{ kmph (EB)}$$

4. Determination of LOS: LOS determined from the speed-flow diagram. LOS = C (for EB) LOS = C (for WB)

Numerical example 3

A 10 km long 4 lane undivided multilane highway in a suburban area has a segment 1 km long with a 3% upgrade and a segment 1 km long with a 3% downgrade. The section has a volume of 1900 vehicles/hr in each direction with 13% trucks and buses and 2% recreational vehicles. The 85 th percentile speed of passenger car is 80 km/hr on upgrade and 86km/hr on downgrade. There are total of 12 access points on both sides of the roadway. The lane width is 3.6 m, PHF is 0.90 and having a 3m lateral clearance. Determine the LOS of the highway section (upgrade and downgrade) during the peak hour? From HCM, For a 3% upgrade and 1 km length (ET=1.5 , ER=3) For a 3% downgrade and 1 km length(ET=1.5 , ER=1.2)

<u>**Solution:**</u>

1. ***Data given:***

   3% upgrade and 3% downgrade
   No. of lanes = 4, N = 4,
   80.0 km/h 85^{th} percentile speed for upgrade,
   86 km/h 85^{th} percentile speed for downgrade,
   3.6m lane width,
   1,900-veh/h peak-hour volume, (V =1900 veh/h)
   13 % trucks and buses, (P_T=0.13)
   2 % Recreational vehicles, (P_R=0.02)
   12 access points/km,

PHF = 0.90

lateral clearance = 3 m

2. ***Determination of flow rate (v_p):***

LOS can be calculated by knowing flow rate and free flow speed.

For upgrade: Flow rate is calculated from the equation

$$v_p = \frac{V}{(PHF \times N \times f_{HV} \times f_p)}$$

where, v_p = 15-min passenger-car equivalent flow rate (pc/h/ln), V = hourly volume (veh/h), PHF = peak-hour factor, N = number of lanes, f_{HV} = heavy-vehicle adjustment factor, and f_p = driver population factor Since f_{HV} is unknown it is calculated from the equation

$$f_{HV} = \frac{1}{(1 + P_T(E_T - 1) + P_R(E_R - 1))}$$

where, E_T and E_R = passenger-car equivalents for trucks and buses and for recreational vehicles (RVs), respectively P_T and P_R = proportion of trucks and buses, and RVs, respectively, in the traffic stream (expressed as a decimal fraction) Assume no RVs, since none is indicated.

$$f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(3 - 1)} = 0.905$$

$$V_p = \frac{1900}{0.90 * 2 * 0.905 * 1)} = 1166 \text{ pc/hr/ln}$$

For downgrade:

$$f_{HV} = \frac{1}{1 + 0.13(1.5 - 1) + 0.02(1.2 - 1)} = 0.935$$

$$V_p = \frac{1900}{0.90 * 2 * 0.905 * 1)} = 1128 \text{ pc/hr/ln}$$

3. ***Determination of free flow speed(S):***

For upgrade: BFFS is approximately equal to 62.4 km/h when the 85th percentile speed is 64 km/h, and it is 91.2 km/h when the 85th percentile speed is 96 km/h and the in between speed values is found out by interpolation. Hence for 86 km/hr 85th percentile speed from interpolation we get, BFFS = 77.0 km/h Now, Compute east bound and west bound free-flow speeds

$$FFS = BFFS - f_{LW} - f_{LC} - f_m - f_A$$

$$= 77 - 0 - 0.6 - 8.0 - 2.6$$

$$= 65.8 \text{ kmph}$$

For downgrade:

BFFS is approximately equal to 62.4 km/h when the 85th percentile speed is 64 km/h, and it is 91.2 km/h when the 85th percentile speed is 96 km/h and the in between speed values is found out by interpolation. Hence for 86 km/hr 85th percentile speed from interpolation we get, BFFS= 82.0 km/h Now, Compute the free-flow speed

$$FFS = BFFS - f_{LW} - f_{LC} - f_m - f_A$$

$$= 82 - 0 - 0.6 - 8.0 - 2.6$$

$$= 71 \text{ kmph}$$

4. ***Determination of LOS***

LOS determined from the speed-flow diagram. LOS = D (for upgrade) LOS = D (for downgrade)

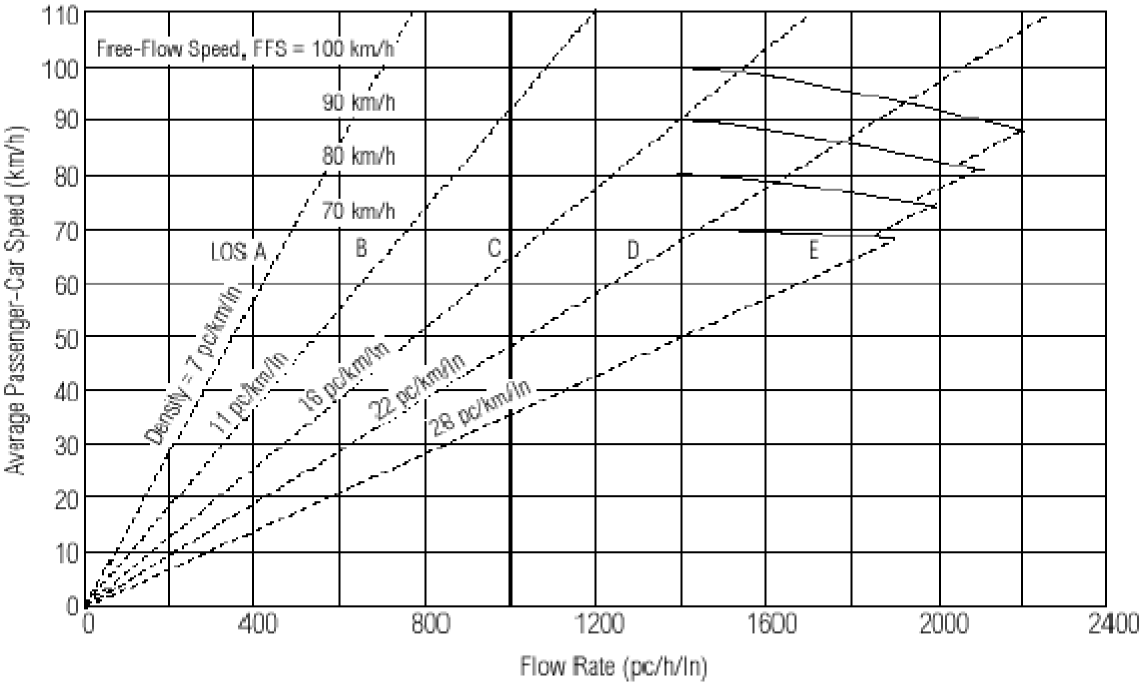

Figure: Speed-Flow curve with LOS Criteria for multilane highways

PARKING STUDIES

3.1 General

Parking is one of the major problems that is created by the increasing road traffic. It is an impact of transport development. The availability of less space in urban areas has increased the demand for parking space especially in areas like Central business district (CBD). This affects the mode choice also. This has a great economic impact.

3.1.1 Ill effects of parking

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

1. **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.
2. **Accidents**: Careless manoeuvring of parking and unparking 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.
3. **Environmental pollution**: They also cause pollution to the environment because stopping and starting of vehicles while parking and unparking results in noise and fumes. They also affect the aesthetic beauty of the buildings because cars parked at every available space creates a feeling that building rises from a plinth of cars.
4. **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.

3.1.2 Types of parking facilities

3.1.2.1 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 5× 2.5 meters and that for a truck is 3.75× 7.5 meters.

1. **Parallel parking**: The vehicles are parked along the length of the road. Here there is no backward movement involved while parking or unparking the vehicle. Hence, it is the safest parking from the accident perspective. However, it consumes the maximum kerb 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 3.1.

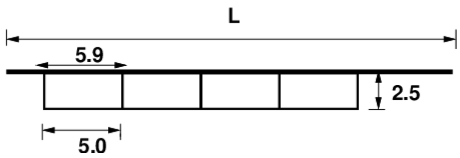

Figure 3.1: Illustration of parallel parking

The length available to park *N* number of vehicles, $L = N * 5.9$

2. **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 manoeuvrability. Delay caused to the traffic is also minimum in this type of parking. An example is shown in figure 3.2. From the figure,

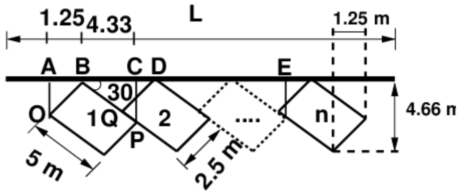

Figure 3.2: Illustration of 30° parking

$$AB = OB \sin 30 = 1.25$$
$$BC = OP \cos 30 = 4.33$$
$$BD = DQ \cos 60 = 5$$
$$CD = BD - BC = \ 5 - 4.33 = 0.67$$
$$AB + BC = 1.25 + 4.33 = 5.58$$

For *N* vehicles, $L = AC + (N - 1)CE$

$$= 5.58 + (N - 1)5$$

Therefor, $L = 5N + 0.58$

3. **45° 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 3.3, length of parking space available for parking *N* number of vehicles in a given kerb is $L = 3.54N + 1.77$

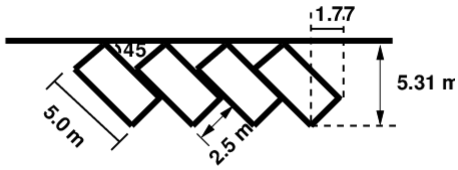

Figure 3.3: Illustration of 45° parking

4. **60° 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 3.4, length available for parking *N* vehicles, $L = 2.89N + 2.16$

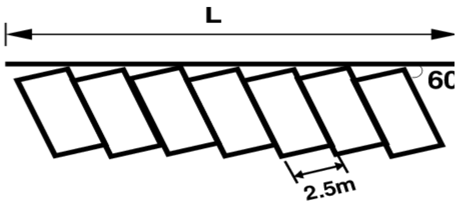

Figure 3.4: Illustration of 60° parking

5. **Right angle parking**: In right angle parking or 90° 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 manoeuvring 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 3.5. Length available for parking N number of vehicles is$L = 2.5N$

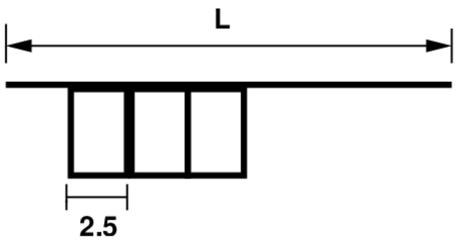

Figure 3.5: Illustration of 90° parking

3.1.2.2 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 firms. A typical layout of an off-street parking is shown in figure 3.6.

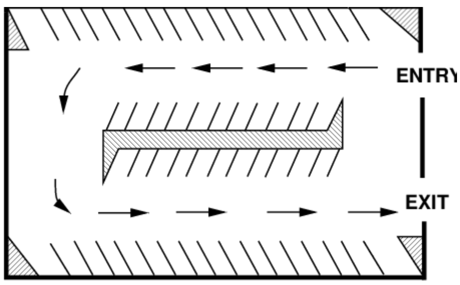

Figure 3.6: Illustration of off-street parking

It includes (a). Surface car parking, (b). Multi-storey car parking, (c). Roof parking, (d). Mechanical car parking, (e). Underground car parking.

- Surface car parks: This type of parking is used at super market, complex & office.
- Multi-storey car parks: This type of parking design for 400 – 500 car parking. In this type of parking, parking design for max 4 – 5 floor. This parking is use for large area.

- Roof parks: Because of less space in many cities parking facility provided on roof of the building. For transportation of vehicle arrangement of ramp or mechanical lift is there.
- Mechanical car parks: In this method with the help of lift cars are lifted from one floor to another floor. Cars are parked in stall with the help of mechanical trolley. Maintenance cost is more.
- Underground car parks: Basement of building.
  Costly: foundation
  Ventilation
  Lighting

3.2 Parking studies and analysis

3.2.1 Parking requirements

There are some minimum parking requirements for different types of building. For residential plot area less than 300sq.m require only community parking space. For residential plot area from 500 to 1000sq.m, minimum one-fourth of the open area should be reserved for parking. Offices may require at least one space for every 70sq.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.

3.2.2 Parking statistics

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. The following parking statistics are normally important.

1. **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.

2. **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.

3. **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.

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

$$parking\ duration = \frac{parking\ load}{parking\ volume} \qquad \text{eq(1)}$$

5. **Parking turnover**: It is the ratio of number of vehicles parked in a duration to the number of parking bays available. This can be expressed as number of vehicles per bay per time duration.

$$parking\ turnover = \frac{parking\ volume}{no.of\ bays\ available} \qquad eq(2)$$

6. **Parking index**: Parking index is also called occupancy or efficiency. It is defined as the ratio of number of bays occupied in a 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

$$parking\ index = \frac{parking\ load}{parking\ capacity} \times 100 \qquad eq\ (3)$$

3.3 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.

3.3.1 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 labour required is very less. Only one person may be enough. But we won't get any data regarding the time duration for which a particular vehicle used that parking lot. Parking duration and turnover is not obtained. Hence we cannot estimate the parking fare from this survey. For quick survey purposes, a fixed period sampling can also be done. 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 1 hour, the count is again taken. Here there are chances of missing the number of vehicles that were parked for a short duration.

3.3.2 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 labour intensive.

ACCIDENT STUDIES

3.4 General

The problem of accident is a very acute in highway transportation due to complex flow pattern of vehicular traffic, presence of mixed traffic along with pedestrians. Traffic accident leads to loss of life and property. Thus the traffic engineers have to undertake a big responsibility of providing safe traffic movements to the road users and ensure their safety. Road accidents cannot be totally prevented but by suitable traffic engineering and management the accident rate can be reduced to a certain extent. For this reason systematic study of traffic accidents are required to be carried out. Proper investigation of the cause of accident will help to propose preventive measures in terms of design and control.

3.4.1 Objectives of accident studies

Some objectives of accident studies are listed below:

1. To study the causes of accidents and suggest corrective measures at potential location
2. To evaluate existing design
3. To compute the financial losses incurred
4. To support the proposed design and provide economic justification to the improvement suggested by the traffic engineer
5. To carry out before and after studies and to demonstrate the improvement in the problem.

3.4.2 Causes of road accidents

The various causes of road accidents are:

1. **Road Users** - Excessive speed and rash driving, violation of traffic rules, failure to perceive traffic situation or sign or signal in adequate time, carelessness, fatigue, alcohol, sleep etc.
2. **Vehicle** - Defects such as failure of brakes, steering system, tyre burst, lighting system.
3. **Road Condition** - Skidding road surface, pot holes, ruts.
4. **Road design** - Defective geometric design like inadequate sight distance, inadequate width of shoulders, improper curve design, improper traffic control devices and improper lighting,.
5. **Environmental factors** - Unfavourable weather conditions like mist, snow, smoke and heavy rainfall which restrict normal visibility and makes driving unsafe.
6. **Other causes** - Improper location of advertisement boards, gate of level crossing not closed when required etc.

3.5 Accident Analysis

3.5.1 Accident data collection

The accident data collection is the first step in the accident study. The data collection of the accidents is primarily done by the police. Motorist accident reports are secondary data which are filed by motorists themselves. The data to be collected should comprise all of these parameters:

1. **General** - Date, time, person involved in accident, classification of accident like fatal, serious, minor
2. **Location** - Description and detail of location of accident
3. **Details of vehicle involved** - Registration number, description of vehicle, loading detail, vehicular defects
4. **Nature of accident** - Details of collision, damages, injury and casualty

5. **Road and traffic condition** - Details of road geometry, surface characteristics, type of traffic, traffic density etc.
6. **Primary causes of accident** - Details of various possible cases which are the main causes of accident.
7. **Accident cost** - Financial losses incurred due to property damage, personal injury and casualty

These data collected need proper storing and retrieving for the following purpose. The purposes are as follows:

1. Identification of location of points at which unusually high number of accident occur.
2. Detailed functional evaluation of critical accident location to identify the causes of accidents.
3. Development of procedure that allows identification of hazards before large number of accidents occurs.
4. Development of different statistical measures of various accident related factors to give insight into general trends, common casual factors, driver profiles, etc.

3.5.2 Accident investigation

The accident data collection involves extensive investigation which involves the following procedure:

1. **Reporting:** It involves basic data collection in form of two methods:
    a. **Motorist accident report -** It is filed by the involved motorist involved in all accidents fatal or injurious.
    b. **Police accident report -** It is filed by the attendant police officer for all accidents at which an officer is present. This generally includes fatal accidents or mostly accidents involving serious injury required emergency or hospital treatment or which have incurred heavy property damage.
2. **At Scene-Investigation:** It involves obtaining information at scene such as measurement of skid marks, examination of damage of vehicles, photograph of final position of vehicles, examination of condition and functioning of traffic control devices and other road equipment's.
3. **Technical Preparation:** This data collection step is needed for organization and interpretation of the study made. In this step measurement of grades, sight distance, preparing drawing of after accident situation, determination of critical and design speed for curves is done.
4. **Professional Reconstruction:** In this step effort is made to determine from whatever data is available how the accident occurs from the available data. It is professionally referred as determining behavioral or mediate causes of accident.
5. **Cause Analysis:** It is the effort made to determine why the accident occurred from the data available and the analysis of accident reconstruction studies.

3.5.3 Accident data analysis

The purpose is to find the possible causes of accident related to driver, vehicle, and roadway. Accident analyses are made to develop information such as:

1. Driver and Pedestrian - Accident occurrence by age groups and relationships of accidents to physical capacities and to psychological test results.

2. Vehicle - Accident occurrence related to characteristic of vehicle, severity, location and extent of damage related to vehicles.
3. Roadway conditions - Relationships of accident occurrence and severity to characteristics of the roadway and roadway condition and relative values of changes related to roadways.

It is important to compute accident rate which reflect accident involvement by type of highway. These rates provide a means of comparing the relative safety of different highway and street system and traffic controls. Another is accident involvement by the type of drivers and vehicles associated with accidents.

1. ***Accident Rate per Kilometer:***
   On this basis the total accident hazard is expressed as the number of accidents of all types per km of each highway and street classification.

$$R = \frac{A}{L} \qquad (1)$$

where, R = total accident rate per km for one year, A = total number of accident occurring in one year, L = length of control section in kms

2. ***Accident involvement Rate:***
   It is expressed as numbers of drivers of vehicles with certain characteristics who were involved in accidents per 100 million vehicle-kms of travel.

$$R = \frac{N \times 100000000}{V} \qquad (2)$$

where, R = accident involvement per 100 million vehicle-kms of travel, N = total number of drivers of vehicles involved in accidents during the period of investigation and V = vehicle-kms of travel on road section during the period of investigation

3. ***Death rate based on population:***
   The traffic hazard to life in a community is expressed as the number of traffic fatalities per 100,000 populations. This rate reflects the accident exposure for entire area.

$$R = \frac{B \times 100000}{P} \qquad (3)$$

where, R = death rate per 100,000 population, B = total number of traffic death in one year and P = population of area

4. ***Death rate based on registration:***
   The traffic hazard to life in a community can also be expressed as the number of traffic fatalities per 10,000 vehicles registered. This rate reflects the accident exposure for entire area and is similar to death rate based on population.

$$R = \frac{B \times 10000}{M} \qquad (4)$$

where, R = death rate per 10,000 vehicles registered, B = total number of traffic death in one year and M = number of motor vehicles registered in the area

5. ***Accident Rate based on vehicle-kms of travel:***
   The accident hazard is expressed as the number of accidents per 100 million vehicle km of travel. The true exposure to accident is nearly approximated by the miles of travel of the motor vehicle than the population or registration.

$$R = \frac{C \times 100000000}{V} \qquad (5)$$

where, R = accident rate per 100 million vehicle kms of travel, C = number of total accidents in one year and V = vehicle kms of travel in one year

3.6 Safety measures

The ultimate goal is to develop certain improvement measures to mitigate the circumstances leading to the accidents. The measures to decrease the accident rates are generally divided into three groups engineering, enforcement and education. Some safety measures are described below:

3.6.1 Safety measures related to engineering

The various measures of engineering that may be useful to prevent accidents are enumerated below

1. Visual guidance to driver

There is consecutive change of picture in drivers mind while he is in motion. The number of factors that the driver can distinguish and clearly fix in his mind is limited. So using the laws of visual perception certain measures have been suggested:

1. Contrast in visibility of the road should be achieved by provision of elements that differ from its surrounding by colors, pattern such as shoulder strips, shoulder covered with grass, edge markings.
2. Providing road side vegetation is an effective means.
3. The visibility of crown of trees from a distant location is also very useful in visual guiding.
4. The provision of guard rails of different contrasting colors also takes drivers attention and prevent from monotonous driving.

Figure 3.8 and 3.9 is a visual guidance measure. Planting trees along side of roadway which has a turning angle attracts attention of the driver and signals that a turn is present ahead.

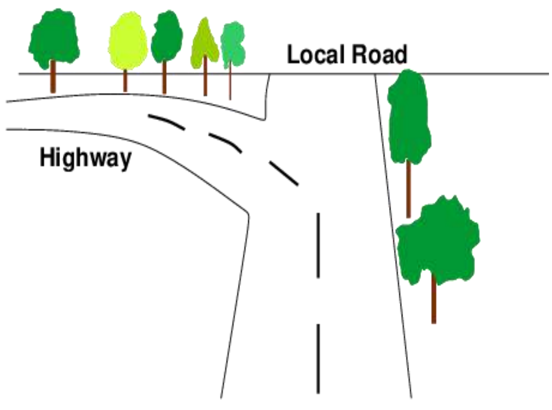

Figure 3.8 Bifurcation of the highway

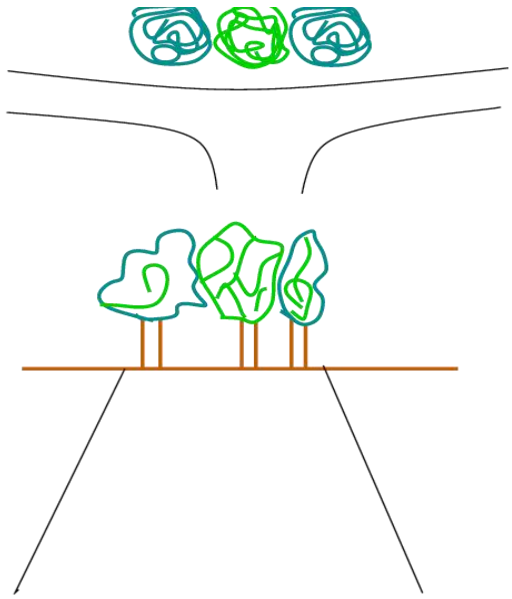

Figure 3.9 Road seemed to be stopped by a dense forest

2. Road reconstruction

The number of vehicles on the road increases from year to year, which introduces complications into organization of traffic, sharply reduces the operation and transportation characteristic of roads and lead to the growth of accident rate. This leads to the need of reconstructing road. The places of accidents need to be properly marked so that the reconstruction can be planned accordingly.

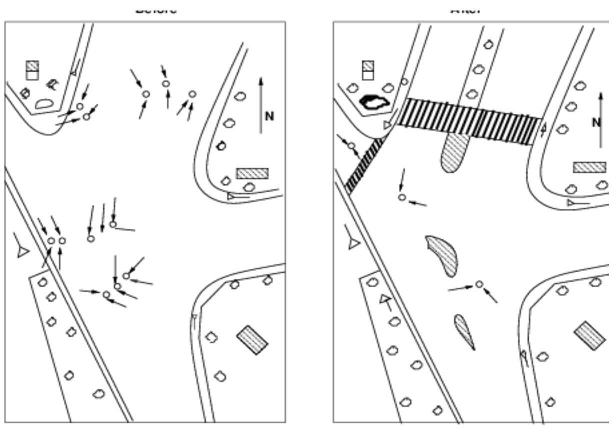

Figure 3.10 Diagram of accidents before and after reconstruction

The Figure 3.10 shows that there were too many conflict points before which reduced to a few number after construction of islands at proper places. Reconstruction process may also include construction of a new road next to the existing road, renewal of pavement without changing the horizontal alignment or profile of the road, reconstruction a particular section of road.

3. Channelization

The Channelization of traffic at intersection separates the traffic stream travelling in different direction, providing them a separate lane that corresponds to their convenient path and spreading as far as possible the points of conflict between crossing traffic streams. The traffic lanes are separated by marking relevant lines or by constructing slightly elevated islands as shown in Figure 3.12.

The principles of proper channelized intersection are:-

1. The layout of intersection should be visibly clear, simple and understandable by driver.
2. Should ensure superiority to the vehicles using road of higher class.
3. Layout of intersection makes it necessary for a driver running through it to choose at each moment of time one of not more than two possible direction of travel. This is achieved by visual guidance, islands and markings.
4. The island provided should separate high speed, through and turning traffic flows.
5. The width of traffic lane should ensure unhampered turning to the big vehicles.
6. Pedestrian crossing should be provided

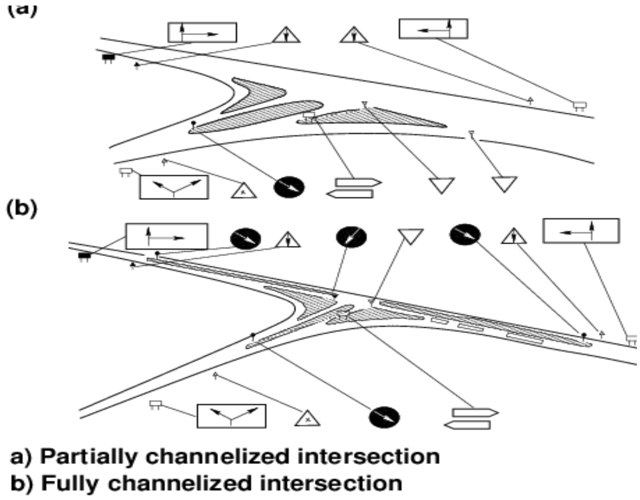

Figure 3.12 Channelized Intersection ensuring safety

4. ***Road signs***

Road signs are integral part of safety as they ensure safety of the driver himself (warning signs) and safety of the other vehicles and pedestrians on road (regulatory signs). Driver should be able to read the sign from a distance so that he has enough time to understand and respond. It is essential that they are installed and have correct shape, colour, size and location.

Other methods

Various other methods of traffic accident mitigation are described below:

1. **Street lighting:** Street lightning of appropriate standard contributes to safety in urban area during night time due to poor visibility.
2. **Improvement in skid resistance**: If road is very smooth then skidding of the vehicles may occur or if the pavement is wet then wet weather crashes occur. Thus it is important to improve the skid resistance of the road. Various ways of increasing the skid resistance of road are by constructing high-friction overlay or cutting of grooves into the pavement.
3. **Road markings**: Road markings ensure proper guidance and control to the traffic on a highway. They serve as supplementary function of road sign. They serve as psychological barrier and delineation of traffic path and its lateral clearance from traffic

hazards for the safe movement of traffic. Thus their purpose is to provide smooth and safe traffic flow.

4. **Guide posts with or without reflector**: They are provided at the edge of the roadway to prevent the vehicles from being off tracked from the roadway. Their provision is very essential in hilly road to prevent the vehicle from sliding from top. Guide posts with reflector guide the movement of vehicle during night.
5. **Guard rail**: Guard rail have similar function as of guide post. On high embankments, hilly roads, road running parallel to the bank of river, shores of lake, near rock protrusion, trees, bridge, abutments a collision with which is a great hazard for a vehicle. It is required to retain the vehicle on the roadway which has accidentally left the road because of fault or improper operation on the part of the driver. Driver who has lost control create a major problem which can be curbed by this measure.
6. **Driver reviver stop**: Driver reviver stop are generally in use in countries like U.S.A where driver can stop and refresh himself with food, recreation and rest. They play a very important part in traffic safety as they relieve the driver from the mental tension of constant driving. These stops are required to be provided after every 2 hour travel time.
7. **Constructing flyovers and bypass**: In areas where local traffic is high bypasses are required to separate through traffic from local traffic to decrease the accident rate. To minimize conflicts at major intersections flyovers are required for better safety and less accident rate
8. **Regular accident studies**: Based on the previous records of accidents the preventive measures are taken and after that the data related to accidents are again collected to check the efficiency of the measures and for future implementation of further preventive measures.

3.6.2 Safety measures related to enforcement

The various measures of enforcement that may be useful to prevent accidents at spots prone to accidents are enumerated below. These rules are revised from time to time to make them more comprehensive.

1. Speed control

Checks on spot speed of all vehicles should be done at different locations and timings and legal actions on those who violate the speed limit should be taken

2. Training and supervision

The transport authorities should be strict while issuing licence to drivers of public service vehicles and taxis. Driving licence of the driver may be renewed after specified period, only after conducting some tests to check whether the driver is fit

3. ***Medical check***

The drivers should be tested for vision and reaction time at prescribed intervals of time

3.6.3 Safety measures related to education

The various measures of education that may be useful to prevent accidents are enumerated below.

1. ***Education of road users***

The passengers and pedestrians should be taught the rules of the road, correct manner of crossing etc. by introducing necessary instruction in the schools for the children and by the help of posters exhibiting the serious results due to carelessness of road users.

2. ***Safety drive***

Imposing traffic safety week when the road users are properly directed by the help of traffic police as a means of training the public. Training courses and workshops should be organized for drivers in different parts of the country.

3.6.4 Safety audit

It is the procedure of assessment of the safety measures employed for the road. It has the advantages like proper planning and decision from beforehand ensures minimization of future accidents, the long term cost associated with planning is also reduced and enables all kinds of users to perceive clearly how to use it safely. Safety audit takes place in five stages as suggested by Wrisberg and Nilsson, 1996. Five Stages of Safety Audit are:

1. **Feasibility Stage** - The starting point for the design is determined such as number and type of intersection, relationship of the new scheme to the existing road, the relevant design standards.
2. **Draft Stage** - In this stage horizontal and vertical alignment, junction layout are determined. After the completion of this stage decision about land acquisition is taken.
3. **Detailed design stage** - Signing, marking, lighting, other roadside equipment and landscaping are determined.
4. **Pre-opening stage** - Before opening a new or modified road should be driven, walked or cycled. It should be done at different condition like bad weather, darkness.
5. **Monitoring of the road in use** - Assessment is done at the final stage after the road has been in operation for few months to determine whether the utilization is obtained as intended and whether any adjustment to the design are required in the light of the actual behavior of road users.

References

1. https://www.civil.iitb.ac.in/tvm/nptel/581_Parking/web/web.html
2. https://www.civil.iitb.ac.in/tvm/nptel/582_Accident/web/web.html

4.0 Intersection

The term junction or intersection describes all roadway situations where two or more roads meet or cross one another at the same or different elevations.

The design and layout of road junctions demand careful consideration from the view point of traffic management because it is very essential to have safety of vehicular traffic and pedestrians at such places. The accidents generally occur at road junctions and hence, proper precautions should be taken in their design and layout. They should be properly signalled and it is essential to have proper segregation and control of the traffic.

4.1 Uncontrolled intersection: Are the most common type of intersection usually occurs where the intersecting roads are relatively equal importance and found in areas where there is not much traffic shown in Figure 4.1. Uncontrolled intersections are the traffic junctions where there is no explicit traffic control measures are adopted.

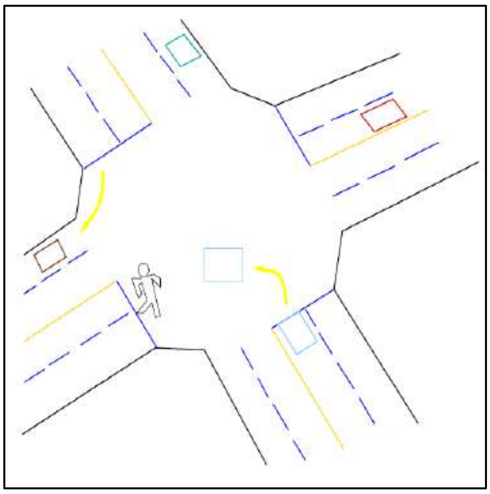

Figure 4.1: Examples showing uncontrolled intersection

4.2 Definitions and Important Terms

1. Channelization - It is the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement marking to facilitate the safe and orderly movements of both vehicles and pedestrians.
2. Conflict - It is defined as the demand for the same highway space by two or more users of the highway. Conflicts are classified into mainly three types:
    (a) Crossing conflicts
    (b) Diverging conflicts
    (c) Merging conflicts
3. Angle of Intersection - The angle of intersection is that formed by the centerlines of the intersecting streets. Where the angle of intersection departs significantly (more than approximately 20^{o}) from right angles, the intersection is referred to as a skewed intersection. Figure 4.2 shows the angle made between the center lines of the major and minor legs.
4. Refuge Areas - The area which is used to give refuge to the pedestrians crossing a street (the open area between two medians) is known as a refuge area.

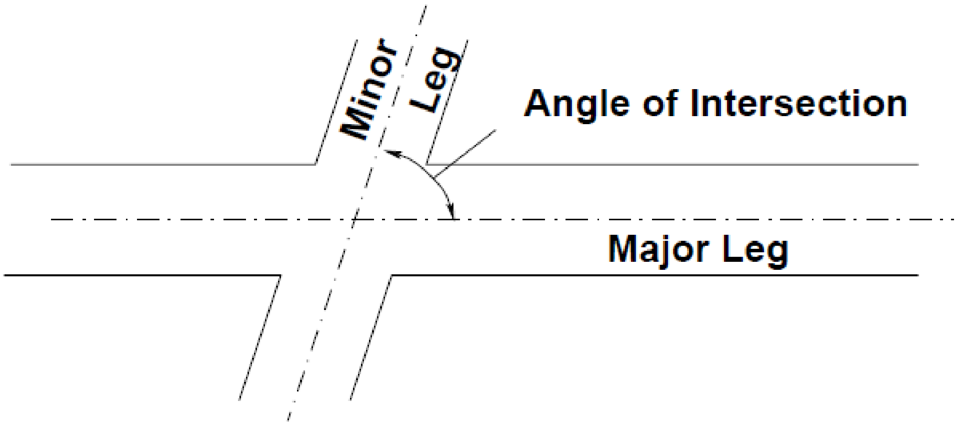

Figure 4.2: Angle of Intersection

4.3 Conflicts at an intersection

Conflicts at an intersection are different for different types of intersection. Consider a typical four-legged intersection as shown in figure. The number of conflicts for competing through movements are 4, while competing right turn and through movements are 8. The conflicts between right turn traffics are 4, and between left turn and merging traffic is 4. The conflicts created by pedestrians will be 8 taking into account all the four approaches. Diverging traffic also produces about 4 conflicts. Therefore, a typical four legged intersection has about 32 different types of conflicts. This is shown in figure 4.3.

The essence of the intersection control is to resolve these conflicts at the intersection for the safe and efficient movement of both vehicular traffic and pedestrians.

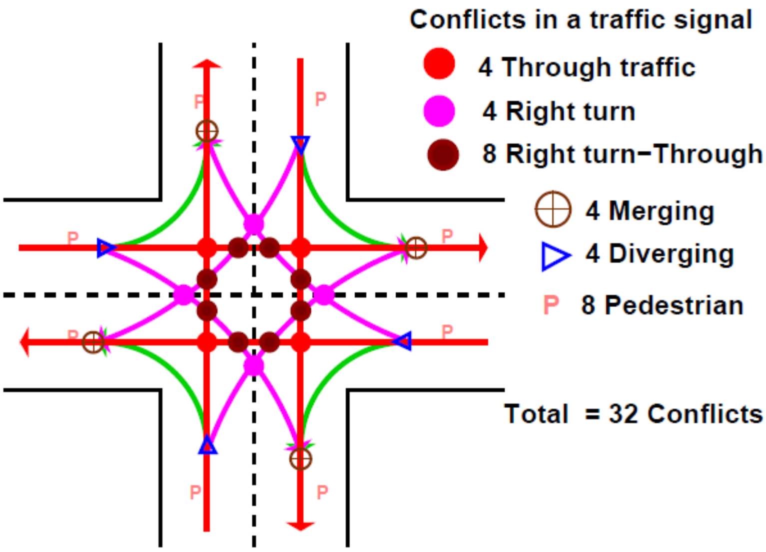

Figure 4.3: Conflicts at an intersection

4.4 Types of Intersections

Road intersections can be grouped in the following two categories:

1. At-grade intersections
2. Grade separated

4.4.1 At-grade intersections

This is the most common type of intersection and it indicates the road junctions at the same elevation. The traffic movement like merging, diverging, crossing and weaving are carried out at the same level.

Following are the *three* types of at-grade intersections:

1. All-paved or unchannelized intersection
2. Channelized intersections
3. Roundabouts or rotaries

All-paved or unchannelized intersections: The unchannelized intersections are paved for the whole area and as such, there is no restriction to vehicles to use any part of the intersection area. These intersections are of the lowest order in the sense that traffic operations become complex in nature and for their smooth functioning they have to be controlled by traffic police or signals. Figure 4.4 shows the common varieties of all-paved intersections.

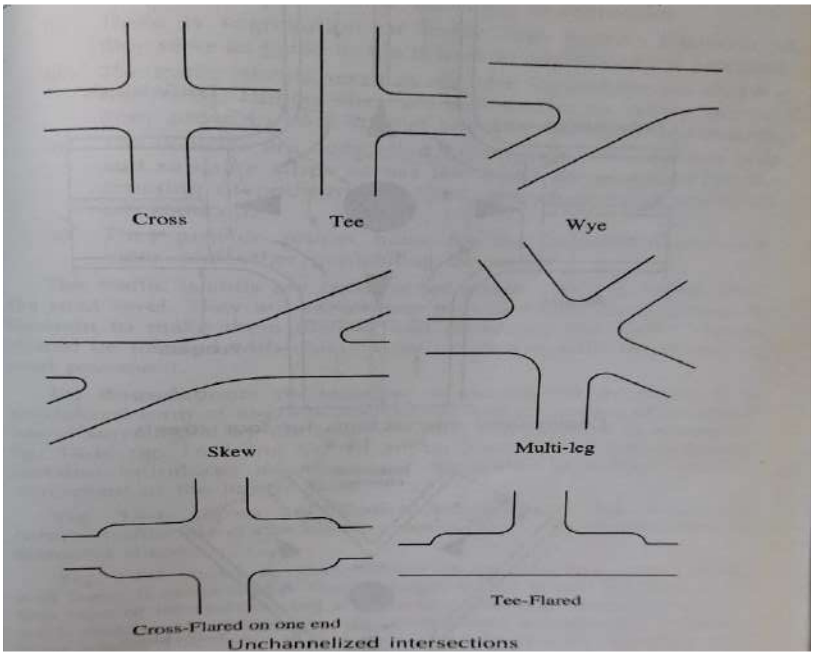

Figure 4.4 Unchannelized Intersections

Channelized intersections: In order to handle large volumes of traffic at the intersection, it becomes necessary to introduce traffic islands to channelize that turning traffic. The space at a road junction over which traffic is not allowed to make move is known as a *traffic island*. Figure 4.5 shows the arrangement of traffic islands for road junction with the *four* streets and *three* streets.

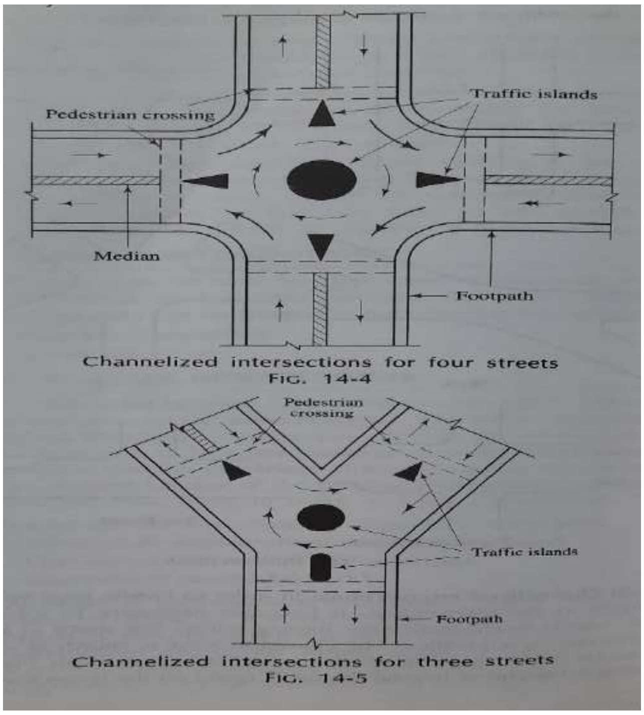

Figure 4.5: Traffic Islands for Road Junctions

The arrangement at road junction in the form of traffic islands serves the following five objectives:

1. The efficiency of traffic handling is increased.
2. There is segregation of traffic into proper channels as they serve as guide to the drivers in negotiating the junctions.
3. The traffic islands serve as shelters for pedestrians crossing the roads. Hence, they are referred to as *refugee islands*. They prove to be a special boon for the aged and infants.
4. The vehicles are compelled to move in one direction only and separate strips across the roads are provided for the crossing of pedestrians. Thus, the chance of accidents are reduced.
5. They provide proper place for the installation of traffic signs and other controlling devices.

Channelizing Devices

A channelizing device can be defined as any structure which helps in providing Channelization. These can be wide raised medians, non-traversable road islands, traversable raised curbs or even flush channelizing devices.

1. Wide Raised Medians

In this form of channelizing device, a raised wide separator is constructed between the two opposing lanes. Figure 4.6 shows a typical wide raised median on a freeway.

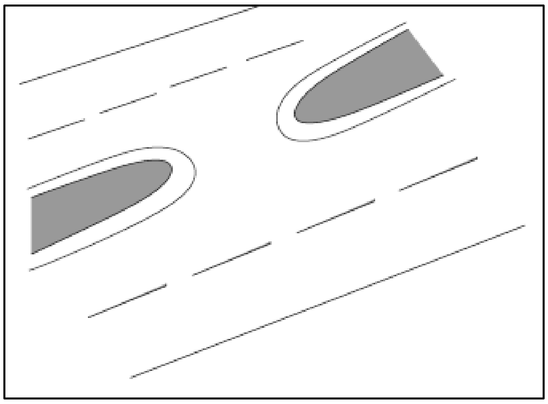

Figure 4.6: Wide Raised Median

2. Non- traversable Raised Islands

In this type of device, a narrower and a higher median than the traversable island is constructed between the opposing lanes. Due to the height, most of the vehicles are not able to cross the median, and hence the name. Figure 4.7 shows a non-traversable raised island constructed on a roadway.

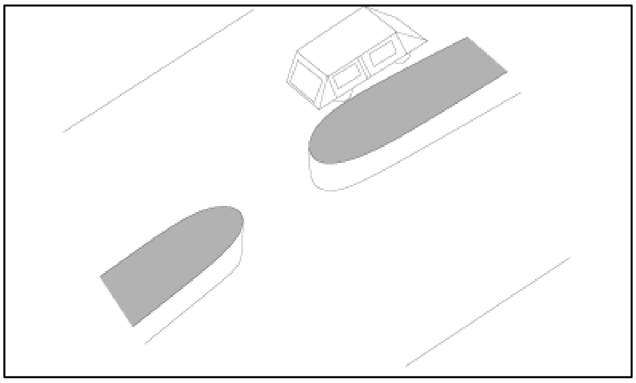

Figure 4.7: Non-traversable Raised Island

3. Traversable Raised Curb Systems

In this device, a narrow and mountable type of raised curb is constructed to separate the traffic moving in the opposing lanes. This class of channelizing device is the narrowest, and therefore the easiest to fit in a wide range of roadway cross-section widths. Figures 4.8 and 4.9 shows traversable raised curbs with and without vertical panels.

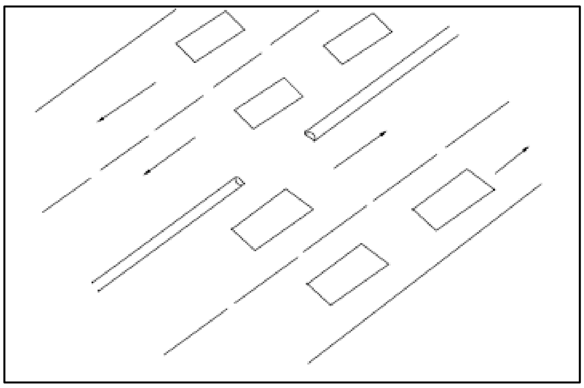

Figure 4.8: Traversable Raised Curb System (Without vertical panels)

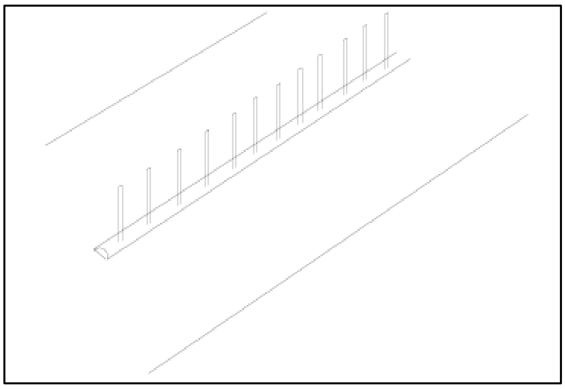

Figure 4.9: Traversable Raised Curb System (With vertical panels)

4. Flush Channelization

In this type of Channelization, a variety of treatments, including raising them above the pavement just slightly (2 to 5 cm); the application of pavement markings and other types of contrasting surfaces etc., are possible. The area seen flushed with the road surface in Figure 4.10 is the flush island.

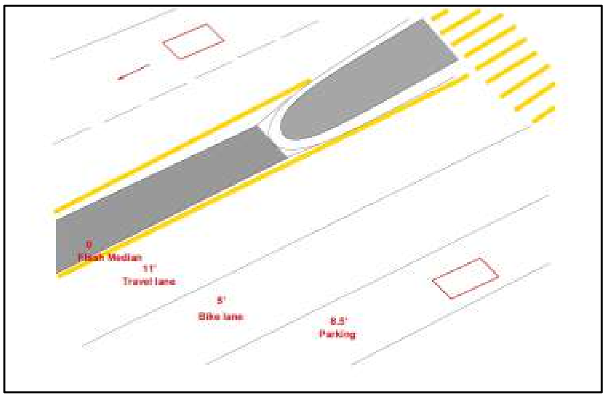

Figure 4.10 Flush Island providing Channelization objectives

Roundabouts or rotaries: A *roundabout or rotary* is a specialized form of at grade intersection and it consists of a central island surrounded by the roads forming the junction as shown in the figure 4.11. The provision of a roundabout junction introduces uni-directional (clockwise direction) circular movement at the intersection.

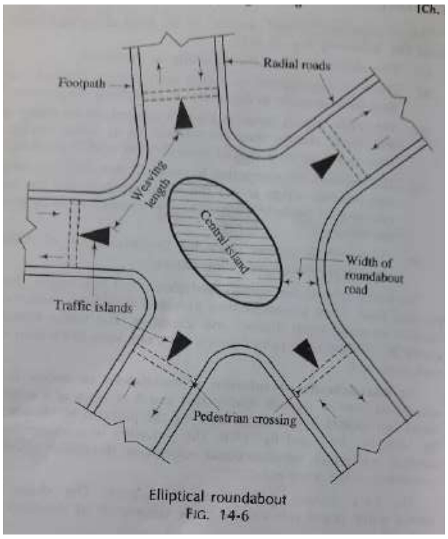

Figure 4.11: Roundabout

Following are the advantages of roundabouts:

1. It provides a simple solution for a road junction where more than four roads made
2. There is a little loss in traffic capacity as there is continuous flow of traffic through the roundabout. A well designed rotary can accommodate a traffic of about 3000 vehicles per hour ~~and it also enables radial streets to carry traffic to their full capacity.~~
3. There is smooth and orderly flow of traffic with a little delay.
4. The vehicles as they approach the roundabouts are merging and weaving in the traffic stream. It thus provides a higher degree of safety and hence, there are less chances of serious collision or accidents.
5. The wear and tear of vehicles using the roundabouts are reduced as stopping and starting of the vehicles are less frequent.
6. The maintenance cost is considerably reduced due to the fact that the rotary can be made a self-controlled traffic intersection avoiding the necessity of traffic police or signals.

Following are the disadvantages of roundabouts

1. If traffic is to be stopped from time to time for the crossing of pedestrians, the orderly movement of traffic is seriously upset.
2. It becomes congested and hazardous under fog conditions.
3. It may confuse the drivers who are not familiar with such type of construction.
4. It requires large area of a flat land and hence, it cannot be adopted where land values are high.
5. It requires the installation of complicated traffic signs.
6. It proves to be unsuitable for high speed roads.

4.4.2 Grade separations

A grade separated is the arrangement of taking one road over or under another by means of bridge. It is also known as a fly-over junction. There is no physical connection between the separated roadways in a grade separation.

The term *interchange* is used to indicate a grade separation having facility for traffic to pass from one intersection road to the other. Thus, connecting roads, known as *ramps* or *turning roadways* or provided to enable limited or full movement between the separated roads at an interchange. As shown in figure 4.12, the ramps can be classified in the following *three* categories:

(1) Direct Ramp: The direct interchange ramp involves diverging rightside and merging from the right side
(2) Semi-direct ramp: The semi-direct interchange ramp allows diverging on left, but merging is from the right side.
(3) Indirect ramp: In the indirect interchange ramp the diverging is to the left and merging involved is also from the left side. This ramp proves to be easy, simple and less dangerous for the accidents. But the distance to be traversed for the transfer of rout is more as compared to the previous two types.

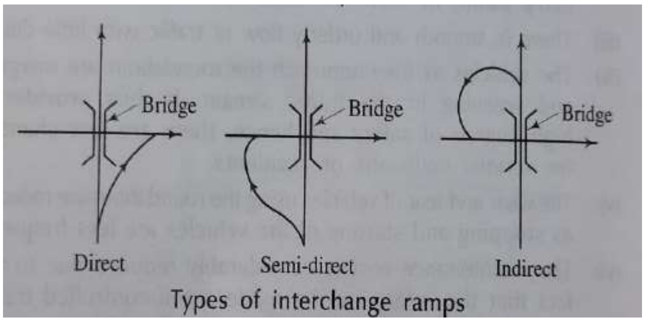

Figure 4.12 Types of interchange ramps

Classification of Grade Separated Intersection

As we discussed earlier, grade-separated intersections are provided to separate the traffic in the vertical grade. Different types of grade-separators are flyovers and interchange. Flyovers itself are subdivided into overpass and underpass. When two roads cross at a point, if the road having major traffic is elevated to a higher grade for further movement of traffic, then such structures are called overpass. Otherwise, if the major road is depressed to a lower level to cross another by means of an under bridge or tunnel, it is called under-pass. Interchange is a system where traffic between two or more roadways flows at different levels in the grade separated junctions. Common types of interchange include trumpet interchange, diamond interchange, and cloverleaf interchange.

1. ***Trumpet interchange***: Trumpet interchange is a popular form of three leg interchange. If one of the legs of the interchange meets a highway at some angle but does not cross it, then the interchange is called trumpet interchange. A typical layout of trumpet interchange is shown in figure 4.13.

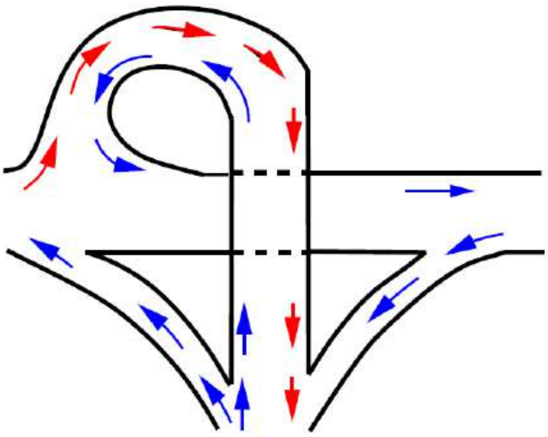

Figure 4.13 Trumpet Interchange

2. ***Diamond interchange***: Diamond interchange is a popular form of four-leg interchange found in the urban locations where major and minor roads crosses. The important feature of this interchange is that it can be designed even if the major road is relatively narrow. A typical layout of diamond interchange is shown in figure 4.14.

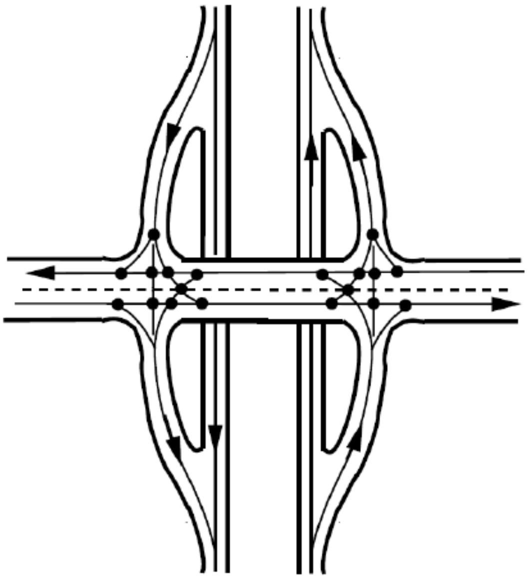

Figure 4.14: Diamond Interchange

3. ***Cloverleaf interchange***: It is also a four leg interchange and is used when two highways of high volume and speed intersect each other with considerable turning movements. The main advantage of cloverleaf intersection is that it provides complete separation of traffic. The disadvantage is that large area of land is required. Therefore, cloverleaf interchanges are provided mainly in rural areas. A typical layout of this type of interchange is shown in figure 4.15.

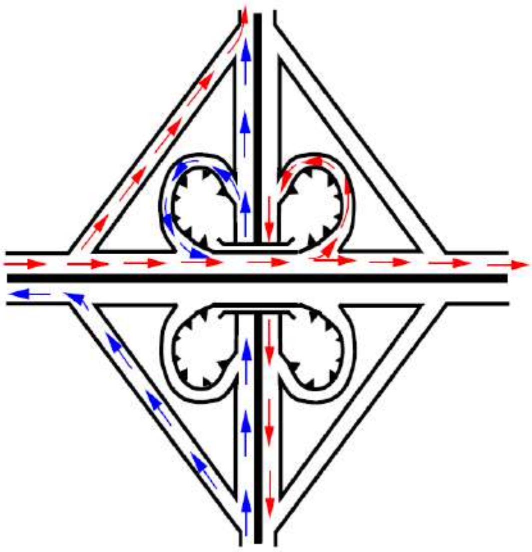

Figure 4.15: Cloverleaf interchange

Advantages of Grade Separator

The advantages of providing grade separator are as follows:

1) Grade separator provides maximum facility to the crossing traffic and avoids the accident while crossing.
2) They provide increased safety for turning traffic.
3) Grade separation is an essential part of controlled access highway like an expressway.
4) It is possible to adopt grade separation for all likely angles and layout of intersecting roads.
5) Stage construction of additional ramps is possible after the grade separation structure between main roads is construction.
6) Traffic capacity is increased.

Disadvantages of Grade Separator

The disadvantages of providing grade separator are as follows:

1) The construction cost is very high.
2) Construction of grade separator is costly, difficult and undesirable where there is limited right of way or where the topography is not favorable.
3) In flat or plain terrains, grade separation may introduce undesirable crests and sags in the vertical alignment.

4.5 Traffic Rotaries

Rotary intersections or roundabouts are special form of at-grade intersections laid out for the movement of traffic in one direction around a central traffic island. Essentially all the major conflicts at an intersection namely the collision between through and right-turn movements are converted into milder conflicts namely merging and diverging. The vehicles entering the rotary are gently forced to move in a clockwise direction in orderly fashion. They then weave out of the rotary to the desired direction. The benefits, design principles, capacity of rotary etc. will be discussed in this chapter.

Guidelines for the selection

Because of the above limitation, rotaries are not suitable for every location. There are few guidelines that help in deciding the suitability of a rotary. They are listed below.

1. Rotaries are suitable when the traffic entering from all the four approaches are relatively equal.
2. A total volume of about 3000 vehicles per hour can be considered as the upper limiting case and a volume of 500 vehicles per hour is the lower limit.
3. A rotary is very beneficial when the proportion of the right-turn traffic is very high; typically if it is more than 30 percent.
4. Rotaries are suitable when there are more than four approaches or if there is no separate lanes available for right-turn traffic. Rotaries are ideally suited if the intersection geometry is complex.

Traffic operations in a rotary

As noted earlier, the traffic operations at a rotary are three; diverging, merging and weaving. All the other conflicts are converted into these three less severe conflicts.

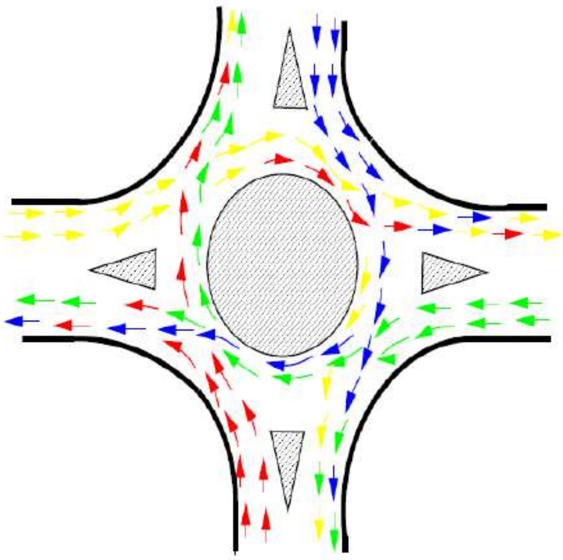

Figure 16 Traffic Operations in a rotary

1. Diverging: It is a traffic operation when the vehicles moving in one direction is separated into different streams according to their destinations.
2. Merging: Merging is the opposite of diverging. Merging is referred to as the process of joining the traffic coming from different approaches and going to a common destination into a single stream.
3. Weaving: Weaving is the combined movement of both merging and diverging movements in the same direction.

These movements are shown in figure 16. It can be observed that movements from each direction split into three; left, straight, and right turn.

Design elements

The design elements include design speed, radius at entry, exit and the central island, weaving length and width, entry and exit widths. In addition the capacity of the rotary can also be determined by using some empirical formula. A typical rotary and the important design elements are shown in figure 17.

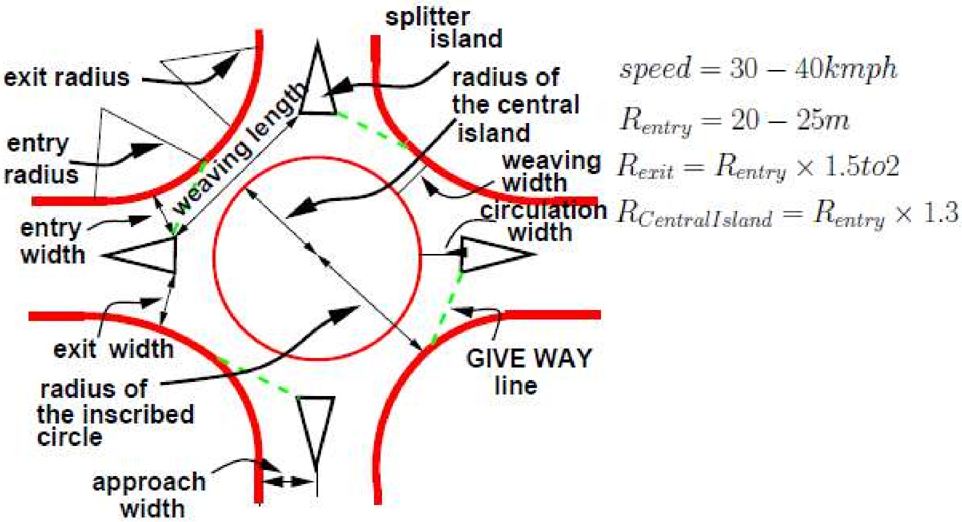

Figure 17 Design Elements of a rotary

Design speed

All the vehicles are required to reduce their speed at a rotary. Therefore, the design speed of a rotary will be much lower than the roads leading to it. The normal practice is to keep the design speed as 30 and 40 kmph for urban and rural areas respectively.

Entry, exit and island radius

The entry radius of about 20 and 25 meters is ideal for an urban and rural design respectively.

The exit radius should be higher than the entry radius and the radius of the rotary island so that the vehicles will discharge from the rotary at a higher rate. A general practice is to keep the exit radius as 1.5 to 2 times the entry radius.

The radius of the central island which is about 1.3 times that of the entry curve is adequate for all practical purposes.

Width of the rotary

The width of the carriageway at entry and exit will be lower than the width of the carriageway at the approaches to enable reduction of speed. IRC suggests that a two lane road of 7 m width should be kept as 7 m for urban roads and 6.5 m for rural roads. Further, a three lane road of 10.5 m is to be reduced to 7 m and 7.5 m respectively for urban and rural roads.

The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus weaving width is given as,

$$W_{weaving} = \left(\frac{e_1 + e_2}{2}\right) + 3.5\ m$$

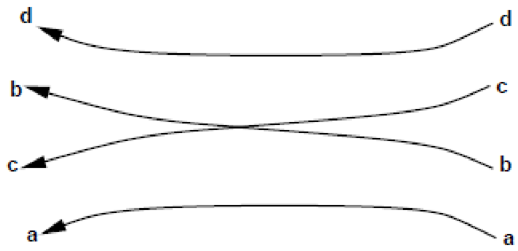

Figure 18 Weaving operations in a Rotary

where e_1 is the width of the carriageway at the entry and e_2 is the carriageway width at exit. Weaving length determines how smoothly the traffic can merge and diverge. It is decided based on many factors such as weaving width, proportion of weaving traffic to the non-weaving traffic etc. This can be best achieved by making the ratio of weaving length to the weaving width very high. A ratio of 4 is the minimum value suggested by IRC. Very large weaving length is also dangerous, as it may encourage over-speeding.

Capacity

The capacity of rotary is determined by the capacity of each weaving section. Transportation Road Research lab (TRL) proposed the following empirical formula to find the capacity of the weaving section.

$$Q_w = \frac{280w\left[1 + \frac{e}{w}\right]\left[1 - \frac{p}{3}\right]}{1 + \frac{w}{l}}$$

where e is the average entry and exit width, i.e, $(e_1+e_2)/2$, w is the weaving width, l is the length of weaving, and p is the proportion of weaving traffic to the non-weaving traffic. Figure 18 shows four types of movements at a weaving section, a and d are the non-weaving traffic and b and c are the weaving traffic. Therefore,

$$p = \frac{b + c}{a + b + c + d}$$

This capacity formula is valid only if the following conditions are satisfied.

1. Weaving width at the rotary is in between 6 and 18 meters.
2. The ratio of average width of the carriage way at entry and exit to the weaving width is in the range of 0.4 to 1.
3. The ratio of weaving width to weaving length of the roundabout is in between 0.12 and 0.4.

4. The proportion of weaving traffic to non-weaving traffic in the rotary is in the range of 0.4 and 1.
5. The weaving length available at the intersection is in between 18 and 90 m.

4.6 Signalized intersection

The increasing of traffic volume at our intersection has been arise a problems like road accidents, conflicts and congestions. These problems can solved by providing an efficient traffic signal control at the intersection for continuous and efficient movement of vehicles through the intersection.

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 types of intervals - change interval and clearance interval. *Change interval* is also called the *yellow time indicates* the interval between the green and red signal indications for an approach. *Clearance interval* is also called *all red* is included 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 G_i. 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 R_i. 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 here before he moves.

- *Saturation Flow (S):* This indicates the number of vehicles passing an intersection with minimum headway during the whole of a 'green' period.
  For new signal installations, the RRL recommends the use of the following formula for determining saturation flow –

  $S = 525\, w$ passenger car units (PCU) per hour

Where,

S = Saturation flow

w = Width of approach road in metros.

This works out to approximately 160 PCU for every 0.3 m width of the road and is applicable for w ranging from 5.50m to 18m. For smaller widths, reduced values of S are recommended.

Methods for the Design of Traffic Signals:

The following methods are commonly used for the design of traffic signals:

(a) Trial cycle method
(b) Webster's minimum delay method
(c) IRC method

Webster's method is a rational approach for signal design. The design is simple and is totally based on formulae's laid down by Webster. In this method, the total cycle of the signal is determined which forms a total least delay occurring at signal.

The steps in the design procedure are:

1) The saturation flow of traffic, S_1, S_2,… on the approach roads are obtained from field studies by noting the number of vehicles in the stream of flow during the green aspects and the corresponding time intervals.
2) In the absence of data, the values are determined using RRL recommendations already given under the definition for 'saturation flow'. S = 525 w passenger car units (PCU) per hour
3) The normal flows q_1, q_2, … on the approach roads, during the design peak hour traffic are also obtained from field observations
4) The ratios $y_1 = q_1/S_2$, $y_2 = q_2/S_2$, … are calculated.
5) In the case of mixed traffic, all the q- and S-values are to be obtained after converting to equivalent PCU values.
6) The optimum signal cycle, C_0, is given by

$$C_o = \frac{1.5L + 5}{1 - Y}$$

Here, $L = total\ lost\ time\ per\ cycle\ in\ seconds = nl + R$

Where n is the number of phases based on traffic signal installations on the approach road and l is the lost time for the phase (as defined in 'lost time' earlier) and R is the all-red time in seconds.

If $Y = y_1 + y_2 + \ldots$

Then $G_1 = \frac{y_1}{Y}(C_o - L)$

$$G_2 = \frac{y_2}{Y}(C_o - L)$$

And so on

Providing suitable amber times, the times of red, green and amber aspects are obtained.

If there are pedestrian signals, the 'Walk' and 'Don't Walk' times can also be calculated based on the red aspect times on the particular roads and extra times for starting delays. The results may be summarized in the form of a timing diagram or a phasing diagram.

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1. The width of a carriage way approaching an intersection is given as 15 m. The entry and exit width at the rotary is 10 m. The traffic approaching the intersection from the four sides is shown in the figure below. Find the capacity of the rotary using the given data.

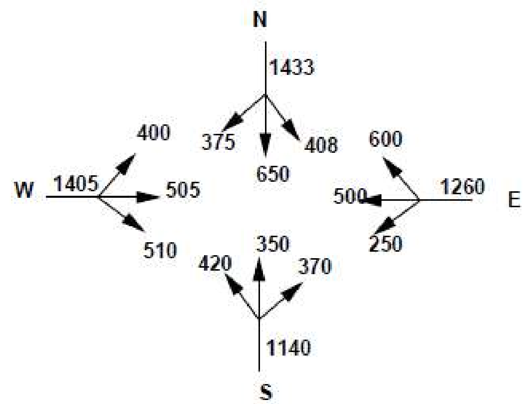

Figure: Traffic approaching the rotary

Solution

The traffic from the four approaches negotiating through the roundabout is illustrated in figure

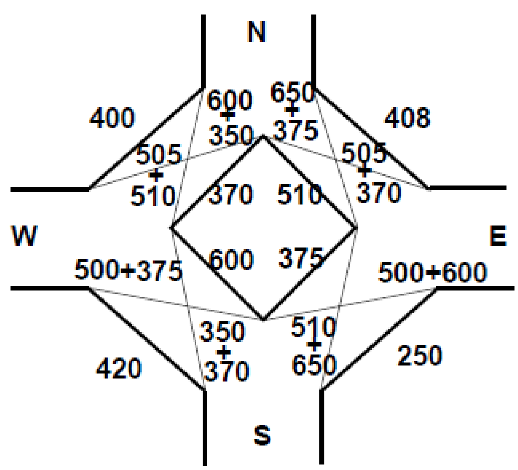

Figure: Traffic negotiating a rotary

- Weaving width is calculated as, $w = \left[\frac{e_1+e_2}{2}\right] + 3.5 = 13.5m$
- Weaving length, l is calculated as, $l = 4 \times w = 54m$
- The proportion of weaving traffic to the non-weaving traffic in all the four approaches is found out first.
- It is clear from equation, that the highest proportion of weaving traffic to non-weaving traffic will give the minimum capacity. Let the proportion of weaving traffic to the non-

weaving traffic in West-North direction be denoted as p_{WN}, in North-East direction as p_{NE} , in the East-South direction as p_{ES} , and finally in the South-West direction as p_{SW} .

- The weaving traffic movements in the East-South direction is shown in figure 6. Then using equation,

$$p_{ES} = \frac{510 + 650 + 500 + 600}{510 + 650 + 500 + 600 + 250 + 375} = \frac{2260}{2885} = 0.783$$

$$p_{WN} = \frac{505 + 510 + 350 + 600}{505 + 510 + 350 + 600 + 400 + 370} = \frac{1965}{2735} = 0.718$$

$$p_{NE} = \frac{650 + 375 + 505 + 370}{650 + 375 + 505 + 370 + 510 + 408} = \frac{1900}{2818} = 0.674$$

$$p_{SW} = \frac{350 + 370 + 500 + 375}{350 + 370 + 500 + 375 + 420 + 600} = \frac{1595}{2615} = 0.6099$$

- Thus the proportion of weaving traffic to non-weaving traffic is highest in the East-South direction.

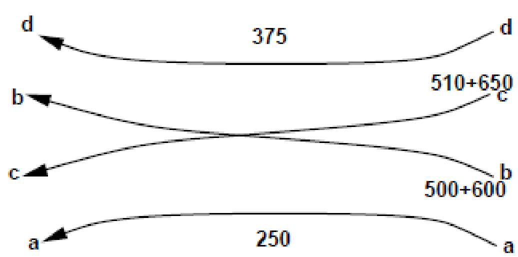

Figure: Traffic weaving in East-South direction

Therefore, the capacity of the rotary will be capacity of this weaving section. From equation,

$$Q_{ES} = \frac{280 \times 13.5 \left[1 + \frac{10}{13.5}\right] \left[1 - \frac{0.783}{3}\right]}{1 + \frac{13.5}{54}} = 2161.164\ veh/hr$$

2. The width of approaches for a rotary intersection is 12 m. The entry and exit width at the rotary is 10 m. Table below gives the traffic from the four approaches, traversing the intersection. Find the capacity of the rotary.

Approach	Left turn	Straight	Right turn
North	400	700	300
South	350	370	420
East	200	450	550

West	350	500	520

Solution

The traffic from the four approaches negotiating through the roundabout is illustrated in figure

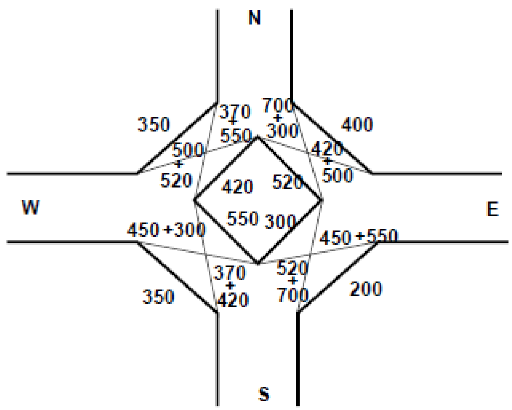

Figure: Traffic negotiating a rotary

- Weaving width is calculated as, $w = \left[\frac{e_1+e_2}{2}\right] + 3.5 = 13.5m$
- Weaving length, l is calculated as, $l = 4 \times w = 54m$
- The proportion of weaving traffic to the non-weaving traffic in all the four approaches is found out first.
- It is clear from equation, that the highest proportion of weaving traffic to non-weaving traffic will give the minimum capacity. Let the proportion of weaving traffic to the non-weaving traffic in West-North direction be denoted as p_{WN}, in North-East direction as p_{NE} , in the East-South direction as p_{ES} , and finally in the South-West direction as p_{SW} .

$$p_{ES} = \frac{450 + 550 + 700 + 520}{200 + 450 + 550 + 700 + 520 + 300} = \frac{2220}{2720} = 0.816$$

$$p_{WN} = \frac{370 + 550 + 500 + 520}{350 + 370 + 550 + 500 + 520 + 420} = \frac{1740}{2510} = 0.690$$

$$p_{NE} = \frac{420 + 500 + 700 + 300}{520 + 400 + 420 + 500 + 700 + 300} = \frac{1920}{2840} = 0.676$$

$$p_{SW} = \frac{450 + 300 + 370 + 420}{550 + 450 + 370 + 420 + 350} = \frac{1540}{2540} = 0.630$$

- Thus the proportion of weaving traffic to non-weaving traffic is highest in the East-South direction.

- Therefore, the capacity of the rotary will be the capacity of this weaving section. From equation,

$$Q_{ES} = \frac{280 \times 13.5\left[1 + \frac{10}{13.5}\right]\left[1 - \frac{0.816}{3}\right]}{1 + \frac{13.5}{54}} = 380.56\; veh/hr$$

3. The average normal flow of traffic on cross roads A and B during design perios are 400 and 250 PCU/hr; the saturation flow values on these roads are estimated as 1250 and 1000 PCU/hr respectively. The all-red time required for pedestrian crossings is 12 sec. Design two phase traffic signal with pedestrian crossing by Webster's method.

Solution

Given: normal flow on roads A & B: $q_a = 400\ {}^{PCU}/_{hr}$ and $q_b = 250\ {}^{PCU}/_{hr}$

Saturation flow, $S_a = 1250\ {}^{PCU}/_{hr}$ and $S_b = 1000\ {}^{PCU}/_{hr}$;

All-red time, $R = 12\ sec$

Number of Phases, $n = 2$

$$Y_a = \frac{q_a}{S_a} = \frac{400}{1250} = 0.32$$

$$Y_b = \frac{q_b}{S_b} = \frac{250}{1000} = 0.25$$

$$Y = y_a + y_b = 0.32 + 0.25 = 0.57$$

Total Lost Time, $L = 2n + R = 2 \times 2 + 12 = 16\ sec$

Optimum Cycle time,

$$C_o = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 16 + 5}{1 - 0.57} = \frac{29}{0.43} = 67.4\ \cong 67.5\ sec$$

$$G_a = \frac{y_a}{Y}(C_o - L) = \frac{0.32}{0.57}(67.5 - 16) = 29\ sec$$

$$G_b = \frac{y_b}{Y}(C_o - L) = \frac{0.25}{0.57}(67.5 - 16) = 22.5\ sec$$

Provide an all-red time, R for pedestrian crossing = 12 Sec

Providing Amber times of 2.0 sec each for clearance, total cycle time

$$= 29 + 22.5 + 12 + 2 + 2 = 67.5\ sec$$

4. The average normal flow of traffic on cross roads 1 and 2 during design periods are 440 and 280 PCU/hr; the saturation flow values on these roads are estimated as 1300 and 1100 PCU/hr respectively. The all-red time required for pedestrian crossings is 12 sec. Design two phase traffic signal with pedestrian crossing by Webster's method.

Solution

Given: normal flow on roads A & B: $q_1 = 440\ {}^{PCU}/_{hr}$ and $q_2 = 280\ {}^{PCU}/_{hr}$

Saturation flow, $S_1 = 1300\ {}^{PCU}/_{hr}$ and $S_2 = 1100\ {}^{PCU}/_{hr}$;

All-red time, $R = 12\ sec$

Number of Phases, $n = 2$

$$Y_1 = \frac{q_1}{S_1} = \frac{440}{1300} =$$

$$Y_2 = \frac{q_2}{S_2} = \frac{280}{1100} =$$

$$Y = y_1 + y_2 =$$

Total Lost Time, $L = 2n + R = 2 \times 2 + 12 = 16\ sec$

Optimum Cycle time,

$$C_o = \frac{1.5L + 5}{1 - Y} =$$

$$G_1 = \frac{y_1}{Y}(C_o - L) =$$

$$G_2 = \frac{y_2}{Y}(C_o - L) =$$

Provide an all-red time, R for pedestrian crossing = 12 Sec

Providing Amber times of 2.0 sec each for clearance, total cycle time

$$=$$

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Unit- V TRAFFIC REGULATION AND SIGNALS

5.0 Need for regulation of traffic

The motor vehicle is a machine in charge of a human being and this makes it necessary for the formulation of suitable regulations for safe operation of traffic and enforcement of regulations. The regulations should be framed so as to achieve safe and efficient movement of traffic and pedestrians.

5.1 Traffic Regulations

5.1.1 Regulations concerning the driver

Regulations concerning the driver cover the following aspects;

I. Licensing of the driver
II. Requirements of physical fitness
III. Age of drivers
IV. Disqualification and endorsement of licenses

Licensing of the driver

Driving of a motor vehicle without the driver having a valid driving license is an offense. The license is usually granted after the driver passes a test of competence.

Physical fitness

In India the following diseases and disabilities disqualify a person from obtaining a license

I. Heart disease
II. Inadequate perception
III. Deafness
IV. Inability to distinguish red and green colors
V. Night blindness

Age of driver

The minimum age to drive a motor vehicle is 18 years and the minimum is to drive a transport vehicle is 20 years in India.

Disqualification and endorsement of license

Habitual drinking and dangerous driving render a driver to be disqualified from holding driving license.

Offenses and penalties

The drivers are expected not to drive at excessive speed and to avoid careless and dangerous driving. Driving under the influence of liquor or drugs and driving when mentally or physically unfit are also punishable offenses.

5.1.2 Regulation of vehicle

The regulation of vehicles broadly covers the aspects indicated below

I. Vehicle registration
II. Construction and equipment of vehicles
III. Size, weight and loads of vehicle
IV. Lighting of Vehicles
V. Inspection of vehicles
VI. Control of transport vehicles
VII. Insurance

Vehicle registration

Vehicle registration is a basic requirement and the data accumulated provides guidance to administrators, planners, traffic police, economists and traffic engineers on total number of vehicles in use, their different types and use, taxation name of the owner and license plate number.

Construction and equipment of vehicles

It is essential that the major vehicles be constructed and equipped in such a manner as to promote safe and efficient traffic.

Control of transport vehicle

Rules are framed to govern the use of commercial transport vehicles. These rules are intended to grant permit for the playing of goods vehicles on specified routes and regions.

Insurance

Most of the countries have laws requiring the vehicles to be insured against third party risks. The insurance is intended to cover liability in respect of death or injury to person or damage to any property of a third party arising out of the use of the vehicle.

5.1.3 Regulations concerning traffic

In India, the traffic is mixed in character and consists of a more motley of motorized vehicles, animal drawn vehicles, cycles, cycle-rickshaws and hand-carts. Any city or town will have to, develop a system of rules to regulate such traffic and enforce them strictly. Some of the regulations that are possible are outlined here.

Cycles

The following rules promote safety of cycle traffic

I. Cycling while under the influence of alcohol or drugs shall be considered an offense.
II. Riding off more than one person on a cycle shall be considered an offense.
III. Wherever separate cycle tracks are provided, the cyclist shall ride on such tracks compulsorily.
IV. All cycles shall be provided with the good brakes, night lamps, a red reflector at the rare and bells or horns.
V. Cycles shall be parked only at designated places

Motor Cycles and Scooters

The following are some of special provisions for regulating the safe movement of motorcycles and scooters;

I. Motor cycle and scooter riders shall wear compulsorily crash helmets.
II. All motor cycles and scooters shall be provided with the rear view mirror.
III. All motor cycles and scooters shall have a screen provided on the rear wheel to prevent loose garments getting entangled in the spokes.
IV. Not more than one rider and a pillion rider shall be carried on a motorcycle or scooter.
V. A rider with a learner's license shall not carry a pillion rider.
VI. A footrest shall be compulsorily provided for the pillion rider.

Rules for pedestrian traffic

The following are some of this simple safety rules which the pedestals should observe:

I. Pedestrians shall obey the traffic signals and any violations shall be considered an offense.
II. Pedestrians shall use the footways wherever they are provided, the street being used only for crossing.
III. Pedestrians shall cross the streets only at crosswalks wherever they are provided.
IV. Where footways are not provided separately, pedestrians shall walk on the right hand side of road facing traffic.

Rules for animal vehicles

The following are some of the regulations that are possible for animal drawn vehicles:

I. The animal drawn vehicles traffic shall be prohibited from carrying long pipes, rods, bamboos etc. more than 5 meters in length.
II. The height, length and width of loads shall be restricted to safe limits, depending upon the size of the carriage
III. The animal drawn traffic shall invariably keep to the extreme left of the carriage way having mixed traffic.

5.1.4 General rules concerning traffic

There are some fundamental traffic laws which every road user must be conversant with.

"Keep to the left" rule

India is one of the country which still added to the "Keep to the left rule". According to the "Keep to the left" rule, the drivers must keep to the left and stay on the left side except when overtaking another vehicle or making a right turn.

Overtaking rules

Normal rules in countries with the left side rule prescribe overtaking on the right. When there are multiple lanes, this rule is not usually enforced.

Turning rules

In countries with the left side rule, left turning manoeuvres must be made from the lane nearest to the left hand side curb of the street and into the left lane of the street concerned nearest to the left side curb. Similarly, a right turning manoeuvre must be made from the lane nearer to the central line of the street and into the left lane nearest to the center line of the street concerned. The correct turning manoeuvres are indicated in figure 5.1.

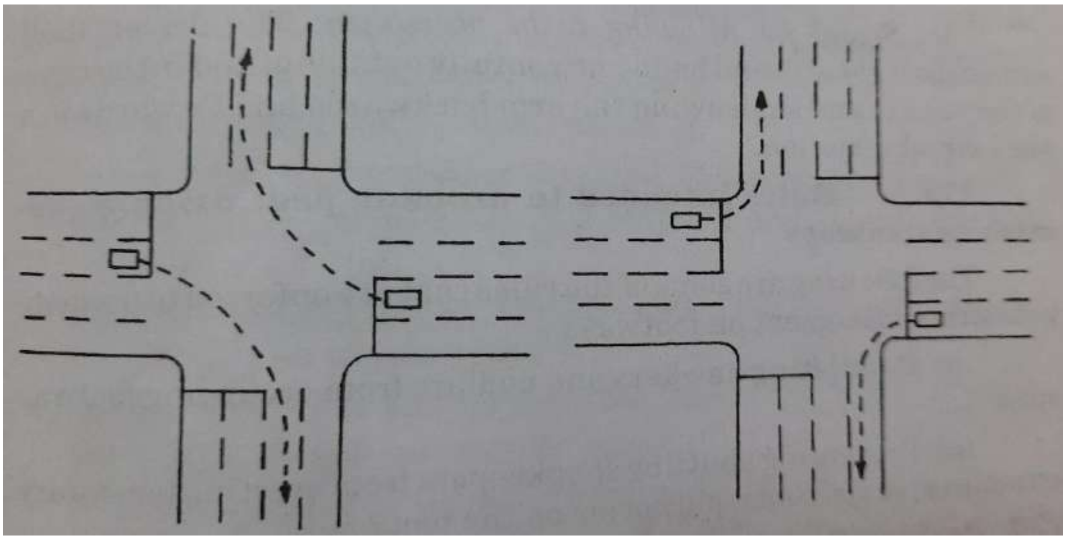

Figure 5.1: Correct left and right turning manoeuvres

Priority rules at intersections

The usual rule at an intersection is that the vehicle which arrives at an intersection first has the right of way. When two vehicles arrive simultaneously at an intersection, priority is to be given to the vehicle on the right.

5.2 Traffic Signals

To control traffic at the important road junctions or intersections the automatic traffic signals are installed in big towns. There are usually three colors namely red, yellow or Amber, and green included in the traffic signals. The red and green lights indicate stoppage and movement respectively. The yellow light signifies impending change or clearance time. Sometimes arrows indicating the directions are included in the light signals at complicated road junctions.

Advantages of traffic signals: Following are the advantages of traffic signals:

1. There is increase in the traffic handling capacity at the road junctions.
2. There is overall improvement in the quality of traffic flow at the road junctions
3. They allow safe crossing of the heavy traffic
4. They help in reducing certain types of accidents especially those at right angle collisions
5. They permit the pedestrians to cross the roads safely and with confidence
6. They proved to be economical as compared to the manual control they provide for the orderly movement of traffic

Limitations of traffic signals: It is found that many traffic signals have been installed where no actual need exists. The installation of an unwarranted signal generally leads to increasing hazards and traffic delays. The disadvantages are:

1. If the design and location of signals are improper it may lead to violation of control system.
2. If the signals stopped working due to electric power failure or any other reason there is confusion among the road users.
3. There are chances of rear end collisions

5.2.1 TYPES OF TRAFFIC SIGNALS

Traffic signals are the control devices which alternately direct the traffic to stop and proceed at intersections using red and green traffic light signal automatically.
The signals are classified into the following types:

1. Traffic Control Signals
    - ✓ Fixed time signals
    - ✓ Manually operated signals
    - ✓ Traffic actuated (automatic) signals
2. Pedestrian signals
3. Special traffic signals

1. Traffic Control Signals

- These are provided with three colored light glows facing each direction of traffic flow.
- Red light indicates STOP
- Yellow amber light indicates the clearance time for the vehicles which have entered the intersection area by the end of green signal
- Green light indicates GO
- Traffic control signal are further classified into the following 3 types.

A typical traffic signal showing the arrangement of three light glows is shown in this figure 5.2.

Figure 5.2: Traffic Signals

A. Fixed Time Signals

- These signals are set to repeat regularly a cycle of red, amber yellow and green lights. Depending upon the traffic intensities, the timings of each phase of the cycle is predetermined. Fixed time signals are the simplest type of automatic traffic signals which are electrically operated.
- **Draw backs of the signals**: The cycle of red, yellow and green goes on irrespective whether on any road, there is any traffic or not. Traffic in the heavy stream has to stop at end phase.

B. Traffic Actuated Signals

- In these signals the timings of the phase and cycle are changed according to traffic demand.
- In fully-actuated signals, computers assign the right of way for the traffic movement on turn basis of traffic flow demand.

C. Manually Operated Signals

- In these types of signals, the traffic police watches the traffic demand from a suitable point during the peak hours at the intersection and varies the timings of these phases and cycle accordingly.

2. Pedestrian Signals

- When the vehicular traffic remains stopped by red or stop signal on the traffic signals of the road intersection, these signals give the right of way of pedestrians to cross a road during the walk period.

3. Special Signals Or Flashing Beacons

- These signals are used to warn the traffic.
- When there is a red flashing signal, the drivers of vehicles must stop before entering the nearest cross walk at the intersection or at a stop line where marked.
- Flashing of yellow signals are used to direct the drivers of the vehicular traffic to proceed with caution.

5.2.2 Pre-Timed and Traffic Actuated Traffic Signals (Fixed Time Signals and Vehicle-Actuated Signals)

Traffic signals operate in either pre-timed or actuated mode or some combination of the two. Pre-timed control consists of a series of intervals that are fixed in duration. They repeat a preset constant cycle. In contrast to pre-timed signals, actuated signals have the capability to respond to the presence of vehicles or pedestrians at the intersection. Actuated control consists of intervals that are called and extended in response to vehicle detectors. The controllers are capable of not only varying the cycle length & green times in response to detector actuation, but of altering the order and sequence of phases.

Pre-timed (Fixed Time) Signals

Pre-timed control is ideally suited to closely spaced intersections where traffic volumes and patterns are consistent on a daily or day-of-week basis. They are better suited to intersections where three or fewer phases are needed. Pre-timed control has several advantages. For example, it can be used to provide efficient coordination with adjacent pre-timed signals. It does not require detectors. Finally, it requires a minimum amount of training to set up and maintain.

Advantages

- Simple
- Can be coordinated
- Easy to field adjust
- Can handle peak and off peak conditions

Disadvantages

- Cannot react to short term demand changes
- Can cause excessive delay
- Sometimes result in disrespect

Traffic-Actuated (Vehicle-Actuated) Signals

Basic Principles

Vehicle-Actuated Signals are equipped with detectors and the necessary control logic to respond to the demands placed on them. Vehicle-actuated control uses information on current demands and operations, obtained from detectors within the intersection, to alter one or more aspects of the signal timing on a cycle-by-cycle basis. Timing of the signals is controlled by traffic demand.

Advantages of Actuated Signals

- They can reduce delay.
- They are adaptable to short-term fluctuations in traffic flow.
- Usually increase capacity.
- Provide continuous operation under low volume conditions.
- Especially effective at multiple phase intersections.

Disadvantages of Actuated Signals

- If traffic demand pattern is very regular, the extra benefit of adding local actuation is minimal.
- Installation cost is two to three times the cost of a pre-timed signal installation.
- Actuated controllers are much more complicated than pre-timed controllers, increasing maintenance costs.
- They require careful inspection & maintenance to ensure proper operation.

5.3 Design of Signal setting

5.3.1 Phase design

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.

There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, flow pattern especially the turning movements, 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 5.3. 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.

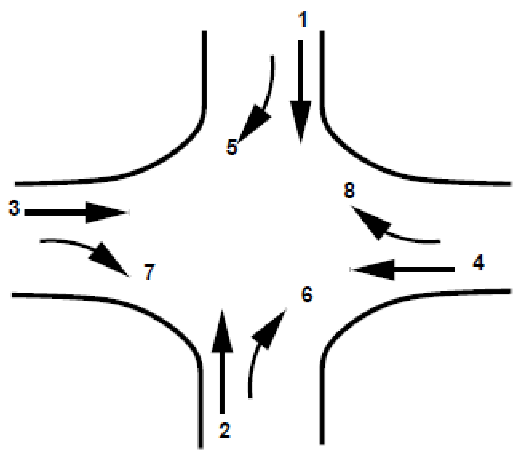

Figure 5.3: Four legged intersection

Two phase signals

Two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in figure 5.4, 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 adopted.

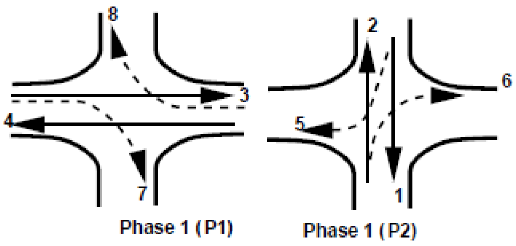

Figure 5.4: Two Phase signal

Four phase signals

There are at least three possible phasing options. For example, figure 5.5 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.

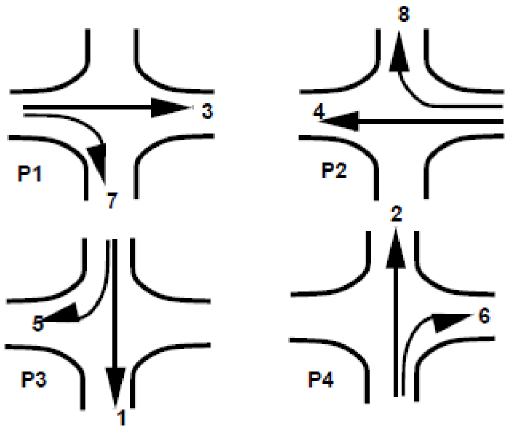

Figure 5.5: One way of providing four phase signal

Figure 5.6 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.

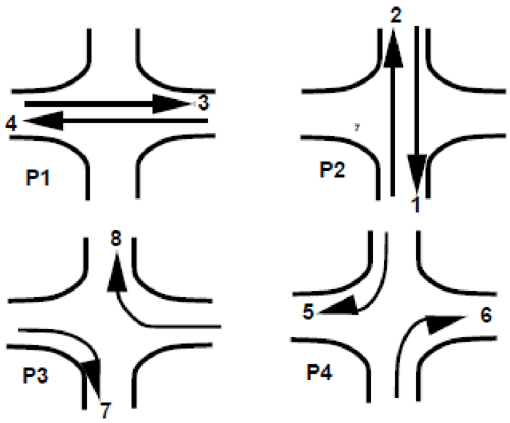

Figure 5.6: Second possible way of providing a four phase signal

Figure 5.7 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.

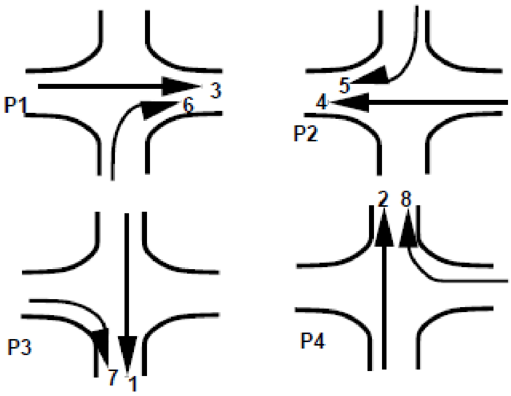

Figure 5.7: Third possible way of providing a four-phase signal

5.3.2 Timing diagram

A typical signal timing plan is a graphical representation of the traffic light phases similar to a GANTT chart.

This is a pictorial representation of the time cycles of the phases, on which the times of the signal indications – red, amber and green are marked in the correct sequence. A typical timing diagram for a simple two-phase traffic system is shown in Figure 5.8 & 5.9.

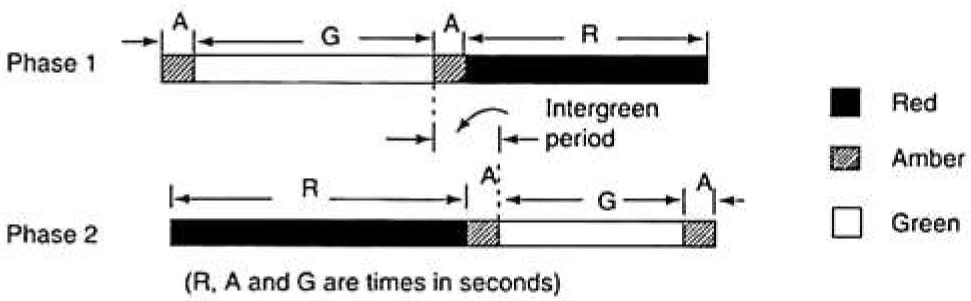

Figure 5.8: Timing Diagram

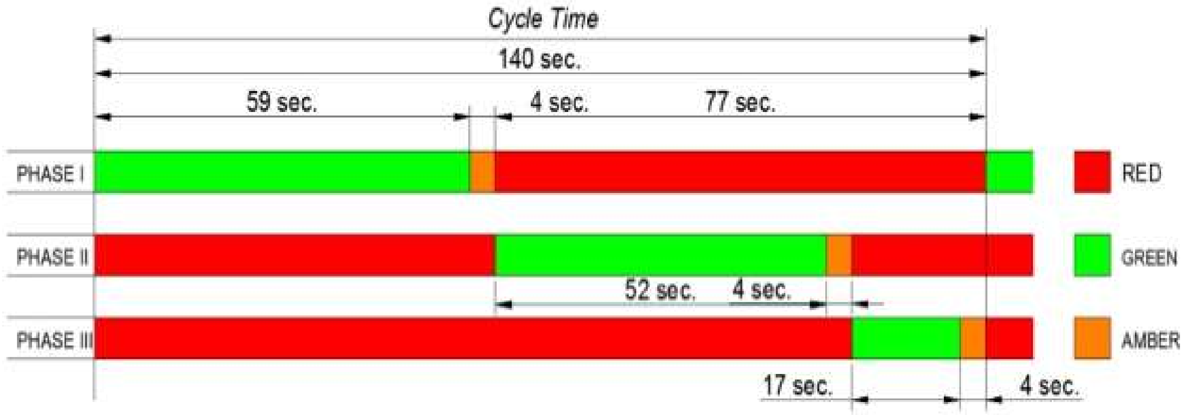

Figure 5.9: Timing Diagram

5.3.3 Warrants for signalization/Traffic Signal Warrants (IRC: 93-1985)

Traffic control signals should not be installed, unless one or more of the signal warrants specified herein are met. If these requirements are not met, a traffic signal should neither be put into operation not continued in operation (if already installed).

An investigation of the need for traffic signal control should include where applicable, at least an analysis of factors contained in the following warrants:

Warrant 1 — Minimum vehicular volume

Warrant 2 — Interruption of continuous traffic

Warrant 3 — Minimum pedestrian volume

Warrant 4 — Accident experience

Warrant 5 — Combination of warrants

WARRANT 1 — Minimum Vehicular Volume

The minimum vehicular volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of signal installation. The warrant is satisfied when for each of any 8 hours of an average day, the traffic volume given in Warrant-I of IRC: 93-1985 exists on major street and on the minor street approach to the intersection.

These major street and minor street volumes are for the same 8 hours. Each traffic lane marked at the intersection, shall be minimum 2.8 metre wide.

WARRANT 2 — Interruption of Continuous Traffic

The interruption of continuous traffic warrant applied to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street.

WARRANT 3—Minimum Pedestrian Volume

A signal installed under this warrant at an isolated intersection or mid-block, should be of the traffic actuated type with push buttons for pedestrains crossing the main street. If experience proves that it is being tampered with or misuse anticipated, they can be of the usual fixed time cycle and phases.

WARRANT 4—Accident Experience

The accident experience warrant is satisfied when: (i) Adequate trial of less restrictive remedies with satisfactory observance and enforcement have failed to reduce the accident frequency, (ii) The signal installation will not seriously disrupt traffic flow.

WARRANT 5—Combination of Warrants

In exceptional cases, signals may be justified occasionally where no signal warrant is satisfied but where two or more of warrants 1, 2 and 3 are satisfied to the extent of 80 per cent or more of the stated volume.

Adequate trial or other remedial measure which causes less delay and inconvenience to traffic should precede installation of signals under this warrant.

5.3.4 Optimum Cycle Length and Signal Setting for intersection

The objective in setting signal timings for a fixed-time signal is to minimize overall vehicular delay.

The least delay to traffic at an intersection is obtained when the green periods of the phases are set in proportion to the corresponding ratios of flow to saturation flow, on the dominant (or critical) approaches

Webster developed a relatively simple expression to determine optimal cycle length – based on total lost time and the sum of the y values at all approaches (recall that y is the ratio of the arrival flow rate to the saturation flow rate at an approach):

$$C_o = \frac{1.5L + 5}{1 - Y}\ sec$$

Where Y is the sum of the y values for all phases and refers to the intersection as a whole and L is the total lost time per cycle in seconds.

The lost time value in the optimal cycle length equation can be expressed by

$$L = nl + R$$

Where:

n is the number of phases

l is the average lost time per phase (excluding any all-red periods)

R is the total time during each cycle when all signals display red simultaneously.

When traffic is of a truly random character, the minimum cycle time will result in nearly infinite delay

The optimal cycle length (i.e. the cycle length that results in the minimum amount of total delay at the intersection) is roughly two times the minimum cycle length, therefore:

$$C_{opt} \cong 2C_{min} = \frac{2L}{1-Y}$$

5.4 Effects of Traffic on the Environment

The following detrimental effects of the traffic on our surrounding have been recognized to be of importance to merit serious study:

i. Safety
ii. Noise
iii. Air Pollution
iv. Vibration
v. Visual intrusion and degrading the aesthetics
vi. Severance

Safety

With the number of cars on the roads increasing every year, governments are constantly working to find new ways to reduce traffic congestion and improve road safety. As automotive and smart technologies advance, there are many promising new innovations that can help improve motorist safety while reducing traffic congestion around the world.

Reliable Traffic Data- Using the information provided through improved technologies like radar-based systems, traffic can be re-routed and better managed to avoid congestion and improve driver safety.

Integrated Traffic Management Systems- When managed through an integrated traffic management system, traffic flow can be monitored and improved based on real-time indicators.

Traffic Signal Systems- Traffic signal systems are a key factor in traffic management and motorist safety. New features, like adaptive traffic signals that collect information from current traffic conditions and make adjustments to the signals in real-time to match the traffic needs.

Air Pollution

Pollution of the atmosphere by fumes and smell emitted by the motor vehicle makes the urban streets extremely unpleasant.

Noise Pollution

Noise in cities is the result of a number of activities such as road traffic, aircrafts, railways and industries and constructional works. The traffic engineer is concerned with the abatement of noise generated by road traffic which is often the predominant source of the annoyance.

Vibration

A vehicle moving on a road surface induces vibrations in the surroundings these are of the following types

i. vibration generated in the contained area air
ii. surface vibrations
iii. underground vibrations

On a narrow streets flanked by buildings the air contained between the buildings is vibrated when vehicles move on the streets such vibrations rarely cause structural damages but may be annoying to the people. Surface vibrations are those set up on structures above the ground whereas underground vibrations are set up in the soil mass and the foundation resting thereon.

Visual Intrusion and Degrading the Aesthetics

In the urban sphere, the motor vehicle has been competing for space for movement and it appears that buildings seem to rise from a plinth of cars. Service stations, garages and petrol filling stations have sprung up along the road and added their mite to the degradation of the general scene.

To attract the attention of the motorist numerous signs, signals and billboards has sprung up all along the streets. Destruction of vegetation causing landslides and soil erosion are some of the common bad effects.

The visual ill effects of parking can be got over by designing suitable off-street facilities for parking and enforcing regulations for on-street parking.

Landscaping of rural highways can preserve and enhance the aesthetics. Proper care is needed in route location on geometric design of highways to preserve the natural beauty.

Some of the measures recommended are

1. Acquisition of adequate right of way
2. Control of access
3. Construction of bypass and congested town
4. Provision of parallel service roads to meet the needs of local traffic
5. Prevention and removal of encroachments

Severance and Land Consumption

Severance is the general term denoting the psychological, cultural and physical disturbance caused by a traffic facility on the neighbourhoods, the land, the society and its lifestyles. The amount of land devoured by streets and highways is so large that it has created problems of rehabilitation and relocation. There are other competing sectors where land would be greatly needed, for example urban slump clearance, housing and agriculture.

The following guidelines can be kept in view in planning new facilities or improvement of existing ones to keep the effects of severance and land consumption as low as possible:

1. Historic and cultural sites areas must be preserved
2. Severance of school playgrounds from the school precincts should be avoided.
3. Recreational areas, virgin forest lands and conservation lands should not be disturbed by Highway location.
4. Where severance is unavailable suitable provision should be made for people to cross the road. Underpasses and over-bridges should be provided to mitigate the hardships.

5. The highways should be planned such that they have the least impact on ecological system.

5.5 Air Pollution

5.5.1 Air Pollutants and Effects of Air Pollutants

The major sources of the pollutants is the exhaust gas emitted by the internal combustion engine. The following are the major components of the exhaust gas:

- Carbon dioxide
- Water Vapour
- Unburnt Petrol
- Organic Compounds produced from the petrol
- Carbon monoxide
- Oxides of nitrogen
- Lead Compounds
- Carbon particulates (smoke)

Effect of Pollutants

Carbon Dioxide, CO_2, is the most important contributor to climate change. Carbon monoxides, oxides of nitrogen and lead compounds are substances which are of concern from the point of view of the road user and his health. Small doses of carbon monoxides present in the air due to road traffic may not be a medical danger, but can cause minor effects. The concentration of nitrogen oxides due to road traffic being small, their presence does not appear to be a danger to health, but the effect of long-term exposure might cause anxiety. Lead compounds in small concentrations as are present in the city streets may not be toxic, but the increase in the concentration may ultimately affect the well-being of the residents. Smog is a result of the combination of smoke and fog and can cause hazards to driving and irritation to eyes.

5.5.2 Measures for Controlling Air Pollution

The following are some of the measures for controlling air pollution from road traffic:

1. Reducing the pollutants at the source, which is the exhaust, the evaporation losses and crank case losses by improving the vehicle design and maintenance
2. Use of small cars instead of bigger ones
3. Patronage of public transport system especially tubes and railways
4. Use of alternative fuels and methods of propulsion
5. Staggering work hours to reduce peak hour traffic
6. Institutions of parking restraint to promote public transport
7. Restraining traffic through road pricing
8. Controlling idling engines, by insisting that engine should be stopped during traffic delays
9. By constructing bypasses and ring roads to reduce traffic in the mid towns

5.6 Noise Pollution

5.6.1 Generation of Noise by Road Traffic

The generation of noise caused by rod traffic can be considered under the following categories

i. Noise generated by various parts of the vehicle
ii. Noise contributed by the interaction between the vehicle and road surface
iii. Noise dependent on the speed, flow and density of traffic

- Motor cycles and scooters are generally noisier than passenger cars.
- Because of the large horsepower of the diesel engines and the heavy loads they carry, commercial trucks are a main source of noise.
- As vehicles grow older and their mechanical conditions deteriorates, the noise generated becomes more.
- That tyre-road surface interaction is a major generator of noise. Smooth surface is generally produces less noise than rough ones.
- As the traffic volume increases the noise level inevitable rises. Higher speeds also are known to cause higher noise level.

5.6.2 Effects of Noise

The detrimental effects of traffic noise can be considered under the following three major groups

i. ***Subjective Effects*** - *Subjective Effects* can be described by terms such as annoyance, disturbance, dissatisfaction, bother and noisiness.
ii. ***Behavioral Effects*** - *Behavioral Effects* cover interference with sleep, speech or any general tasks. Disturbance in sleep caused by noise is common in high noise areas.
iii. ***Psychological Effects*** - *Psychological Effects* are those that cause startle or fright phenomena, and can result in harmful effects on various parts of the body.

5.6.3 Measurement of Noise Levels

The unit of measurement of noise is the decibel (dB) which is the unit of sound pressure level. In order to account for the ear's response at low and high frequencies, different weighing filters, A, B and C are used. A weighted decibel, dB(A), is commonly employed for measuring the relative levels of noise produced by different traffic conditions. The instrument used for recording sound levels is the sound level meter. People's judgment of what acceptable noises and what is not varies. Normally noise having a level of not more than 60 dB(A) will be rated by many as quite. Noise levels at 90 dB(A) and above will be rated by many as extremely noise.

5.6.4 Control of Traffic Noise

Techniques available for control of traffic noise can be considered under the following headings

I. Changing design of vehicle
II. Changing tyres or road surfaces
III. Elimination of noisier vehicles
IV. Modifications in traffic operations

Changing design of vehicles

Legislative measure in enforcing vehicle manufacturers to design the vehicles for a maximum noise level can prove effective if they are enforced properly.

Changing tyre/surface characteristics

Change entire tyre tread design and composition can bring about a reduction in the noise levels. Smoother surface results in less noisier roads.

Elimination of noisier vehicles

As vehicles become old, their noise levels increases. Legislative measures can prevent such vehicles from being used on the road.

Modifications in traffic operations

Some of the measures that are possible under this heading are:

i. Rerouting of commercial vehicles and buses away from the predominantly residential areas
ii. Prohibiting blowing horns by proper signage and enforcement measures.

5.7 valuation Procedures

Measures to protect and improve the environmental condition cost money. At the same time, bad environmental conditions cost the society money in terms of economic loss. If scare resources have to be allotted to any scheme that scheme should be economically justifiable/ Difficulties arise in assigning monetary values to benefits from schemes aimed at improving the environment. In recent times, considerably thought is being given to quantify the benefits into monetary terms, and evaluation processes are becoming easier.

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UNIT - VI: Intelligent Transportation Systems

6.0 General

An important metric for economic growth of any country is its rapidly increasing vehicle ownership. However, the indirect effect of vehicle ownership is acute traffic congestion. India has in the past decade seen an astronomical increase in vehicle ownership and associated roadblocks and traffic snarls in its metropolitan cities. The variety of vehicles in India – two, three and four wheelers, in addition to a large pedestrian population complicates the situation.

The principal reason for traffic condition in India is that the road space and infrastructure have not improved on par with the traffic. The direct solution for this problem by improvement in infrastructures is constrained by space availability and other logistic problems. There is, therefore, an urgent need to explore and a lot better traffic management options to ease traffic condition.

6.1 ITS Definition and Objective

Intelligent transportation systems (ITS) is a tested route to mitigate traffic congestion problems. ITS can be broadly defined as the use of technology for improving transportation systems. The major objective of ITS is to evaluate, develop, analyze and integrate new technologies and concepts to achieve traffic efficiency, improve environmental quality, save energy, conserve time and enhance safety and comfort for drivers, pedestrians and other traffic groups.

State-of-art data acquisition and evaluation technology, communication networks, digital mapping, video monitoring sensors and variable message signs are creating new trends in traffic management throughout the world.

The synergy of data acquisition, analysis, evaluation, and information dissemination helps in developing an all-encompassing system of traffic organization that enables information sharing among the managers and users of traffic.

6.2 ITS Aim

ITS activities aim at the development of sustainable, multi-modal surface transportation system that will establish a connected transportation environment among vehicles, the infrastructure and portable devices. Such a cooperative setup leverages technology in order to maximize driver safety and mobility while improving environmental performance and focusing on development.

ITS encompasses all modes of transportation – air, sea, road and rail and intersects various components of each mode – vehicles, infrastructure, communication and operational systems, Various countries develop strategies and techniques based on their geographic, cultural, social-economic and environmental background to integrate the various components into an interrelated system.

6.3 ITS Taxonomy

The commonly adopted functional taxonomy of the ITS is as follows

<u>Advanced Traffic Management Systems (ATMS)</u>: It integrates various sub-systems (such as CCTV, vehicle detection, communications, variable message systems, etc.) into a coherent single interface that provide real time data on traffic status and predict traffic conditions for more efficient planning and operations. Dynamic traffic control systems, freeway operations

management systems, incident response systems etc. respond in real time to changing conditions.

<u>Advances Traveler Information Systems (ATIS)</u>: It provide to users of transportation systems, travel-related information to assist decision making on route choices, estimate travel times, and avoid congestion. This can be enabled by providing different information using various technologies such as:

- GPS enables in-vehicle navigation systems

- Dynamic road message signs for real time communication of information on traffic congestions, bottlenecks, accidents, and alternate route information during road closures and maintenance
- Website to provide a colour-coded network map showing congestion levels on highways

Advanced Vehicle Control Systems's (AVCS): These are tools and concepts that enhance the driver's control of the vehicle to make travel safer and more efficient. For example, in vehicle collision warning systems alert the driver to a possible imminent collision. In more advanced AVCS applications, the vehicle could automatically brake or steer away from a collision, based on inputs from sensors on the vehicle. Both systems are autonomous to the vehicle and can provide substantial benefits by improving safety and reducing accident induced congestion. The installation of high-tech gadgets and processors in vehicles allow incorporation of software applications and artificial intelligence systems that could control internal operations ubiquitous computing, and other programs to be integrated into a greater transportation system.

Commercial Vehicle Operations (CVO): It comprises an assembly of satellite navigation system, a small computer and a digital radio, which can be used in commercial vehicles such as trucks, vans, and taxes. This system affords constant monitoring of truck operations by the central office and provide traceability and safety.

Advanced Public Transportation Systems (APTS): It applies state-of-art transportation management and information technology to public transit systems to enhance efficiency of operation and improves safety. It includes real-time passenger information systems, automatic vehicle location systems, bus arrival notification systems, and systems providing priority of passage to buses at signalized intersections.

Advanced Rural Transportation Systems (ARTS): It provide information about remote road and other transportation systems. Examples include automated road and weather conditions reporting and directional information. This type of information is valuable to motorists traveling to remote or rural areas.

6.4 Components of ITS

A traffic management center (TMC) is a hub of transport administration where data is collected and analyzed and combined with other operational and control concepts to manage the complex transportation network. It is the focal point for communicating transportation related information to the media and the motoring public, a place where agencies can coordinate their responses to transportation situations and conditions. Typically, several agencies share the administration of transport infrastructure, through a network of traffic operation centers. There is, often, a localized distribution of data and information and the centres adopt different criteria to achieve the goals of traffic management. This is an inter-dependent autonomy in operations and decision-making is essential because of the heterogeneity of demand and performance characteristics of interacting subsystems.

The effective functioning of the TMC, and hence the efficiency of the ITS, depend critically on the following components:

- Automated data acquisition
- Fast data communication to traffic management centres
- Accurate analysis of data at the management centres
- Reliable information to public travelers

6.4.1 Data acquisition

Rapid, exhaustive and accurate data acquisition and communication is critical for real time monitoring and strategy planning. A good data acquisition-management-communication system combines tested hardware and efficient software that can collect reliable data on which to base further ITS activities. The different ITS hardware/equipment commonly used include sensors, cameras, automatic vehicle identifiers (AVI), GPS based automatic vehicle locators (AVL) and servers that can store huge amount of data for meaningful interpretation. A few of the state-of-art, critical components are described below.

a. *Sensors*

Sensors and detectors have been used for highway traffic counts, surveillance, and control. Early sensors related on visuals (e.g. optical detectors), sound (acoustic detectors), and vehicle weight induced pressure/vibrations (seismic/piezoelectric sensors) on the road surface. Advances in detectors technologies now enable use a variety of detectors such as magnetic detectors (based on geomagnetism), infrared, ultrasonic, radar, and microwave detctors (based on reflection of radiation), inductive loop detectors (based on electromagnetic induction), seismic, and inertia-switch detectors (based on vibration), and video based detectors, in addition to the more traditional sensors used over the years. Many of these detectors are intrusive and are placed in the subsurface of roadways and provide real time traffic information on that point of the road. The volume, occupancy and speed of the vehicle are the commonly obtained traffic parameters. The three main types of vehicle detectors used in current practice are inductive loop detectors, magnetic detectors, and magnetometers.

The advantages of the above sensors/detectors is that, unlike technologies such as AVI, GPS etc., these are autonomous detectors and do not require voluntary participation by the traveling public. However, these sensors and detectors require periodic maintenance, replacement and repair due to deterioration of data quality overtime. In addition, many of them are intrusive in nature and require cutting of roadsurfaces for installation and maintenance making the cost of installation and maintenance prohibitively high. This is leading to greater use of visual detectors such as video cameras in recent years. Video cameras were introduced to traffic management for roadway surveillance based on their ability to transmit closed circuit television imagery to a human operator for interpretation. Present day traffic management applications utilized video image processing to automatically analyze the scene of focus and extract information for traffic surveillance and control.

b. *Automatic Vehicle Identifiers (AVI) and Automatic Vehicle Locators (AVL)*

The AVI system uses a combination of AVI readers, AVI tags or transponders in the vehicle, and a central computer system. AVI readers/antennas are located on the roadside or overhead structures or as a part of an electronic toll collection booth. The antennas emit radio frequency signals within a capture range across one or more freeway lanes. When a probe vehicle enters the antenna's capture range, the transponders in the probe vehicle respond to the radio signal and its unique ID is assigned a time and date stamp by the reader. This data is then transmitted to a central computer facility where it is processed and stored.

c. *GPS*

The Global Positioning System (GPS) is a worldwide satellite navigation system that provides a fast, flexible and relatively inexpensive data to determine a vehicle's position and velocity in real time. It provides fundamental location data in terms of latitude, longitude, elevation and coordinated universal time (UTC). Based on the spatial and temporal data, traffic engineers can determine the most useful traffic information, including travel time, travel speed, travel distance and delay.

6.4.2 Communication tools

The efficiency of the ITS system depends not only on the collection and analysis of traffic related data, but also on quick and reliable communication, both data from field to TMC and information derived using the data and models from TMC to the public. This involves communication between data collection centres to TMC and travel and traffic related announcements to vehicles.

- Dedicated Short-Range Communication (DSRC) provide communication between the vehicle and the roadside in specific locations (for example- toll plazas).
- Wireless Communications Systems dedicated to Intelligent Transport Systems and Road Transport and Traffic Telematics provide network connectivity to vehicles.
- Continuous Air interface Long and Medium range (CALM) provides continuous communication between a vehicle and the roadside using a variety of communication media, including cellular and infra-red links.

6.4.3 Data analysis

Data analysis includes data cleaning, fusion, and analysis. The data from sensors and other collection devices that are transmitted to the centre must be checked. Inconsistent data must be weeded out and clean data has to be retained. Further data from different devices may need to be combined or fused for further analysis. The clean and fused traffic data will be analyzed to estimate and forecast traffic states. These traffic state estimation methods will be used to provide sustainable information to users.

6.5 ITS Overview and Benefits

6.5.1 Electronic Toll Collection (ETC) is designed to determine if a car is registered in a toll payment program, alert enforcers to toll payment violations, and debit the participating account. With ETC, these transactions can be performed while vehicles travel at near highway cruising speed. ETC is a fast becoming a globally accepted method of toll collection, a trend greatly aided by the growth of interoperable ETC technologies. Technologies used in ETC are Automatic Vehicle Identification (AVI), Automatic Vehicle classification (AVC), Video Enforcement Systems (VES) and Vehicle Positioning System (VPS).

6.5.2 Ramp Meter (RM) - Traffic signals on freeway ramp meters alternate between red and green signals to control the flow of vehicles entering the freeway. Metering rates can be altered based on freeway traffic conditions.

6.5.3 Red Light Camera (RLC) - RLCs detect a motor vehicle that passes over sensors in the pavement after a traffic signal has turned red. The sensors connect to computers in high-speed cameras, which take two photographs of the violation. Typically, the first photo is taken of the front of the vehicle when it enters the intersection, and the second photo is taken of the rear of the vehicle when the vehicle is in the intersection. Law enforcement officials review the photograph, and a citation is mailed to the registered owner of the vehicle. RLCs' benefits appear primarily to be in the area of safety.

6.5.4 Traffic Signal Coordination (TSC) - TSC provides the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system. Some examples include arterial streets, downtown networks, and closely spaced intersections such as diamond interchanges.

6.5.5 Transit Signal Priority (TSP) - TSP gives special treatment to transit vehicles at signalized intersections. TSP systems use sensors to detect approaching transit vehicles and alter signal timings to improve transit performance. For example, some systems extend the duration of green signals for public transportation vehicles when necessary.

6.5.6 Traveler Information Systems (TIS) - Developing Traveler Information Systems support many categories of drivers and travelers. Traveler information applications use a variety of technologies, including Internet websites, telephone hotlines, and television and radio, to allow users to make informed decisions regarding trip departures, routes, and mode of travel.

References

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