Fundamental parameters of traffic flow

Prepared by

Anil kumar chhotu

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➢ Traffic stream parameters

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

- Thus the traffic stream itself is having some parameters on which the characteristics can be predicted. The parameters can be mainly classified as : measurements of quantity, which includes **density** and **flow of traffic** and measurements of quality which includes speed.
- The traffic stream parameters can be macroscopic which characterizes the traffic as a whole or microscopic which studies the behaviour of individual vehicle in the stream with respect to each other.
- As far as the macroscopic characteristics are concerned, they can be grouped as measurement of quantity or quality as described above, i.e. flow, density, and speed.
- While the microscopic characteristics include the measures of separation, i.e. the headway or separation between vehicles which can be either time or **space headway**. The fundamental stream characteristics are speed, flow, and density and are discussed below.

Speed

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

$$V=d/t$$

where, v is the speed of the vehicle in m/s, d is distance travelled 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.

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 traveling by all vehicles between a particular pair of frames.

Running speed

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

Journey speed

- Journey speed is the effective speed of the vehicle on a journey between two points and is the distance between the two points divided by the total time taken for the vehicle to complete the journey including any stopped time.
- If the journey speed is less than running speed, it indicates that the journey follows a stop-go condition with enforced acceleration and deceleration.
- The spot speed here may vary from zero to some maximum in excess of the running speed. A uniformity between journey and running speeds denotes comfortable travel conditions.

Time mean speed and space mean speed

- Time mean speed is defined as the average speed of all the vehicles passing **a point on a highway** over some specified time period.
- Space mean speed is defined as the average speed of all the vehicles occupying **a given section of a highway** over some specified time period.
- Both mean speeds will always be different from each other except in the unlikely event that all vehicles are traveling at the same speed.
- Time mean speed is a point measurement while space mean speed is a measure relating to length of highway or lane, i.e. the mean speed of vehicles over a period of time at a point in space is time mean speed and the mean speed over a space at a given instant is the space mean speed.

Flow

- There are practically two ways of counting the number of vehicles on a road. One is flow or volume, which is defined as **the number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specific time interval.**
- The measurement is carried out by counting the number of vehicles, nt, passing a particular point in one lane in a defined period t. Then the flow q expressed in vehicles/hour is given by

$$q = n_t / t$$

- Flow is expressed in planning and design field taking a day as the measurement of time.

Variations of Volume

- The variation of volume with time, i.e. month to month, day to day, hour to hour and within a hour is also as important as volume calculation.
- Volume variations can also be observed from season to season. Volume will be above average in a pleasant motoring month of summer, but will be more pronounced in rural than in urban area.
- But this is the most consistent of all the variations and affects the traffic stream characteristics the least. Weekdays, Saturdays and Sundays will also face difference in pattern. But comparing day with day, patterns for routes of a similar nature often show a marked similarity, which is useful in enabling predictions to be made.
- The most significant variation is from hour to hour. The peak hour observed during mornings and evenings of weekdays, which is usually 8 to 10 per cent of total daily flow or 2 to 3 times the average hourly volume.
- These trips are mainly the work trips, which are relatively stable with time and more or less constant from day to day.

Types of volume measurements

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.

Daily Volumes (contd.)

- AADT and AAWT are used for several transportation analyses:
  - Computation of accident rates in terms of 100 million vehicles miles
  - Establishment of traffic volume trends
  - Evaluation of the economic feasibility of highway projects
  - Development of freeway and major arterial street systems
  - Development of improvement and maintenance programs

- ADT and AWT are used for several transportation analyses:
  - Measurement of current demand
  - Evaluation of existing traffic flow

Illustration of Daily Volume Parameters

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

AADT = 5,445,000 / 365 = 14,918 veh/day

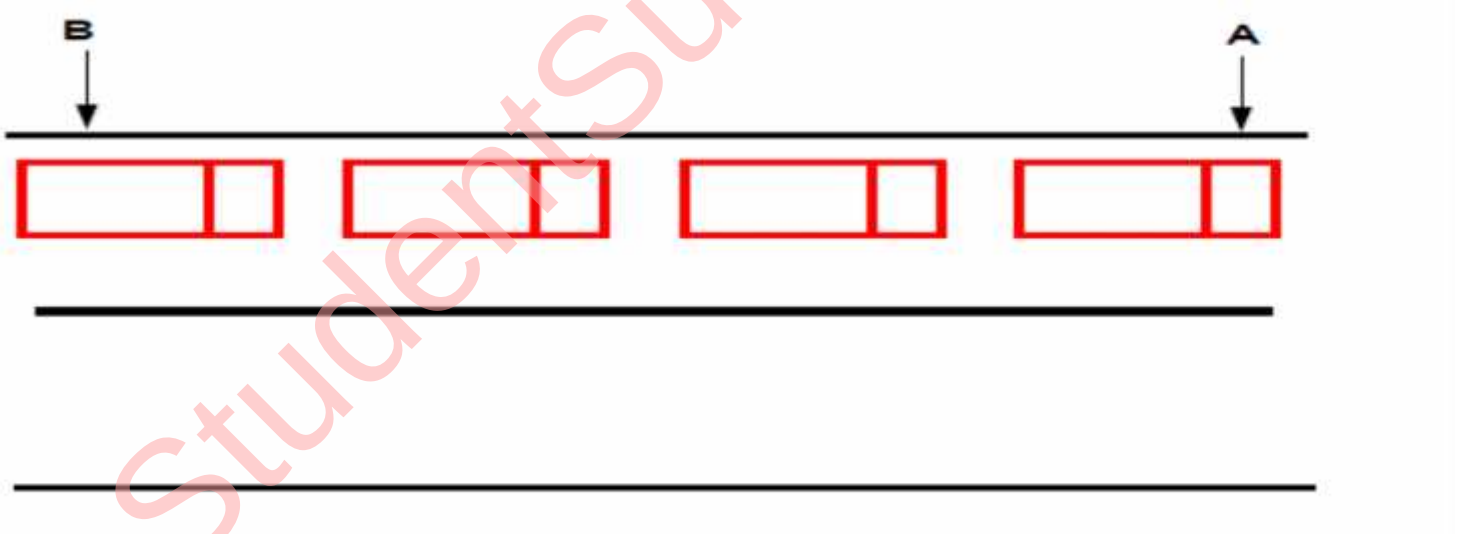
AAWT = 2,583,000 / 260 = 9,935 veh/day

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,

$$K = n_x / x$$

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



Time headway

- The microscopic character related to volume is the time headway or simply headway. **Time headway is defined as the time difference between any two successive vehicles when they cross a given point .**
- 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.

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

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

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

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

Distance headway

- 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,

$$\sum_{1}^{n_x} s_i = x \tag{30.6}$$

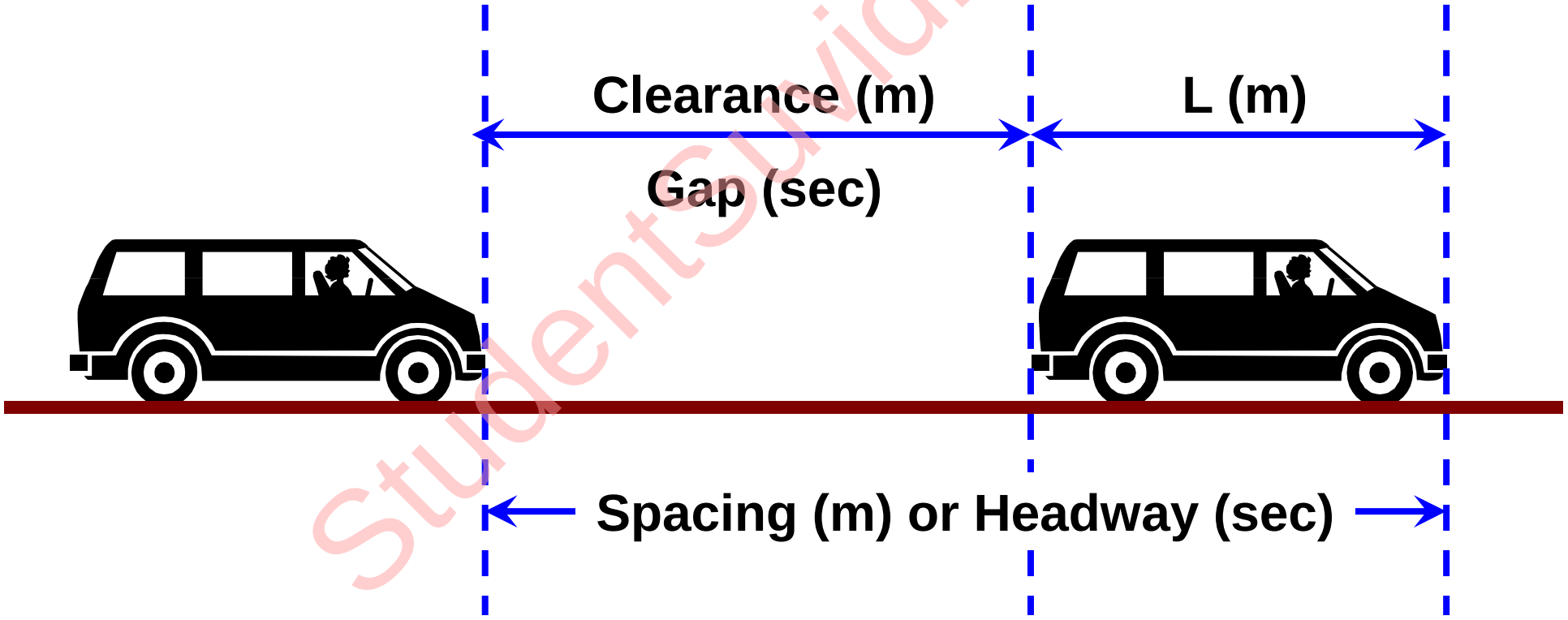
But the density (k) is the number of vehicles n_x at a distance of x, that is

$$k = \frac{n_x}{x} = \frac{n_x}{\sum_1^{n_x} s_i} = \frac{1}{s_{av}} \tag{30.7}$$

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

CLEARANCE AND GAP

- Correspond to parameters of spacing (m) and headway (sec)



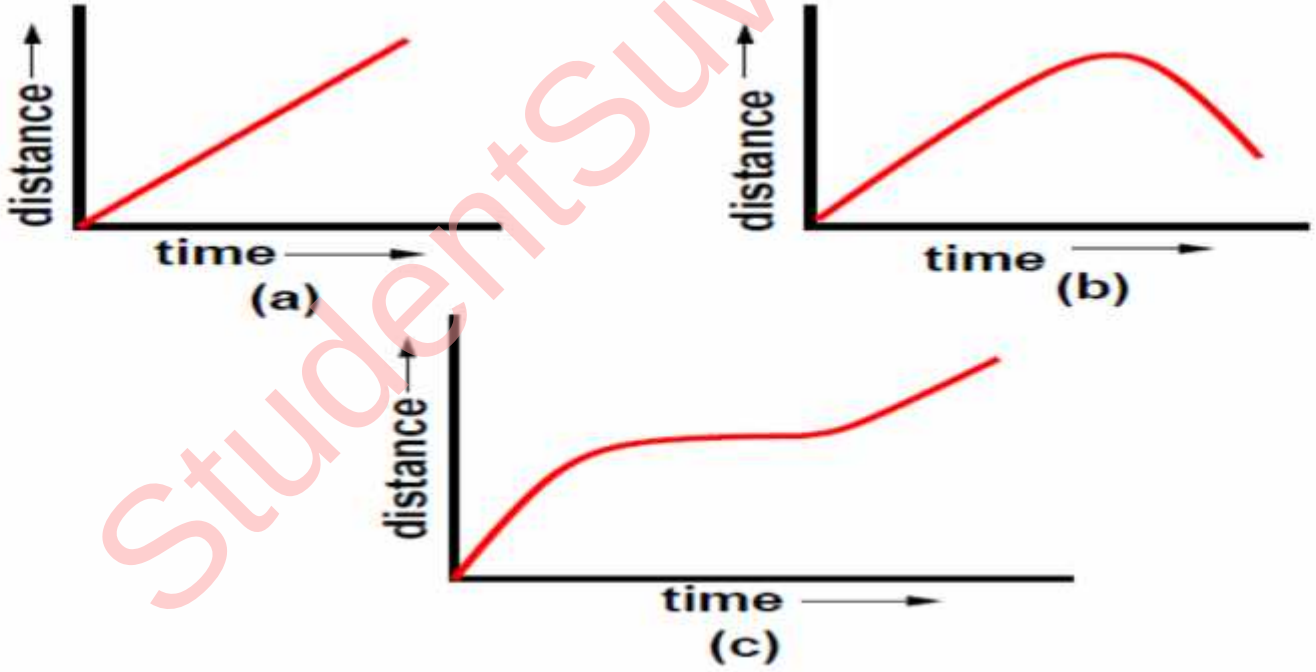
CLEARANCE AND GAP

$$g = h - (L/v)$$

$$c = g \times v$$

- g = mean gap (sec)
- L = mean length of vehicles (m)
- c = mean clearance (m)
- h = mean headway (sec)
- v = mean speed (m/sec)

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



Capacity and Level of service

- 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 LOS gives a qualitative measure of traffic, where as 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.

Capacity

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

Level of service

- A term closely related to capacity and often confused with it is service volume. When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a qualitative measure.
- A service volume is the maximum number of vehicles, passengers, or the like, which can be accommodated by a given facility or system under given conditions at a given level of service.
- For a given road or facility, capacity could be constant. But actual flow will be different for different days and different times in a day itself.
- The intention of LOS is to relate the traffic service quality to a given flow rate of traffic. It is a term that designates a range of operating conditions on a particular type of facility.
- Highway capacity manual (HCM) developed by the transportation research board of USA provides some procedure to determine level of service**. It divides the quality of traffic into six levels ranging form level A to level F**

- Level A represents the best quality of traffic where the driver has the freedom to drive with free flow speed and level F represents the worst quality of traffic.
- Level of service is defined based on the measure of effectiveness or(MOE).Typically three parameters are used under this and they are speed and travel time, density, and delay.
- One of the important measures of service quality is the amount of time spent in travel. Therefore, speed and travel time are considered to be more effective in defining LOS of a facility.
- Density gives the proximity of other vehicles in the stream. Since it affects the ability of drivers to maneuver in the traffic stream, it is also used to describe LOS.
- Delay is a term that describes excess or unexpected time spent in travel. Many specific delay measures are defined and used as MOE's in the highway capacity manual.

LOS for a basic freeway segment

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

LOS for a basic freeway segment

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

- In many roads, there will be signalized as well as unsignalized intersections. Uninterrupted flow is possible in sections of rural and suburban multilane highways between signalized intersections where signal spacing is sufficient to allow for uninterrupted flow. Two lane highways also provide uninterrupted flow facilities. Interrupted flow refers to the condition when the traffic flow on the road is obstructed due to some reasons.
- This is experienced in signalized intersections, unsignalized intersections, arterials etc. At signalized intersections, there will be some kind of active control and the vehicle will have to stop or sometimes to reduce its speed and the flow of traffic is interrupted. Thus the capacity is defined in terms of control delay ie sec/veh.
- Arterials are roads of long stretches with many intersections in between and obviously there will be interruption to the flow of traffic. Here, the capacity is expressed in terms of average travel speed. Some other facilities are facilities for pedestrians, bicycles, bus-transit, rail-transit etc. Example for pedestrian facility is a provision of subway exclusively for the use of pedestrians. Here, the capacity may be expressed in terms of number of passengers.

LOS for an intersection

- In bus transit system, the buses has to stop at the bus bays and also it has to share the road with the other vehicles. Hence the capacity will be affected by the control characteristics and the traffic conditions prevailing in the road. Since trains have exclusive right of way, the capacity is strictly governed by the control characteristics. It has two types of capacities - line capacity and station capacity. Line capacity is based on the number of tracks available between two stations. Station capacity refers to the facilities available in the
- platform of the station , and other facilities. For uninterrupted flow of traffic, measure of effectiveness (MOE) is density in freeways. Speed also becomes
- important in two-lane highways and multilane highways. In the case of interrupted flow, MOE is delay. The delay of travel time becomes an important factor in calculating the capacity

LOS for an intersection

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

Highway capacity

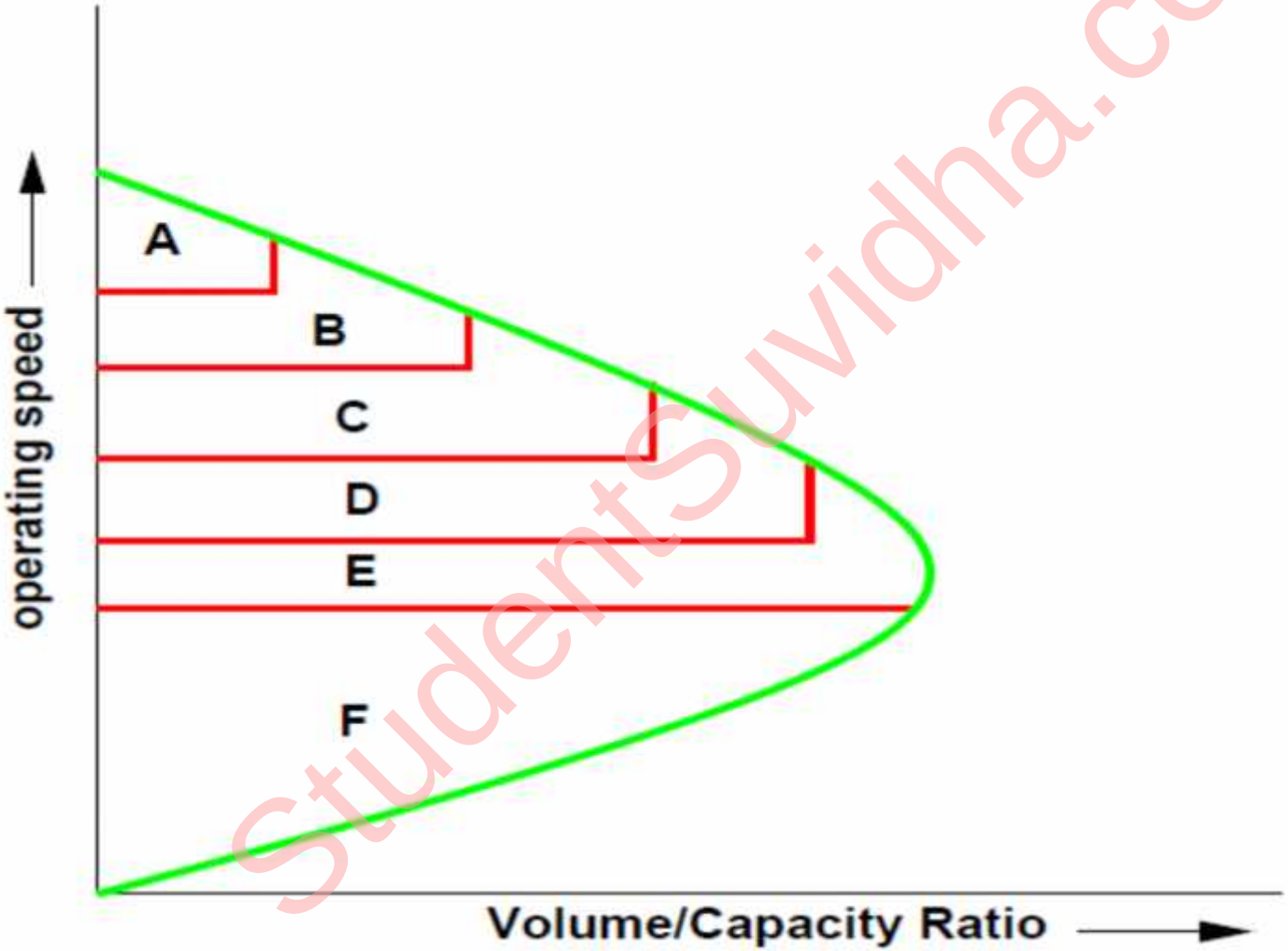
- Highway capacity is defined by the Highway Capacity Manual as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions

1. **Traffic conditions**: It refers to the traffic composition in the road such as the mix of cars, trucks, buses etc in the stream. It also include peaking characteristics, proportions of turning movements at intersections and the like.

2. **Road way characteristics:** This points out to the geometric characteristics of the road. These include lane width, shoulder width, lane configuration, horizontal alignment and vertical alignment.

3. **Control conditions:** This primarily applies to surface facilities and often refer to the signals at intersections etc.

Level of service A to F



Factors affecting level of service

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

- Highway Capacity Manual(HCM) used travel speed and volume by capacity ratio (v/c ratio) to distinguish between various levels of service. The value of v/c ratio can vary between 0 and 1. Depending upon the travel speed and v/c ratio, HCM has defined six levels of service, level A to level F based on a graph between operating speed and v/c ratio as shown in the figure
- Level of service A represents the zone of free flow. Here the traffic volume will be less, traffic will be experiencing free .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 maneuver ability 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 it's maximum density limit. There will be no usable gaps in the stream and even slight disruptions will cause a breakdown, with queues forming rapidly behind the disruption. Maneuvering within the traffic stream becomes extremely difficult.
- Level of service F describes conditions in a queue that has formed behind a point of breakdown or disruption. As vehicles shuffe 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, 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

Freeway Level Of Service

- LOS A

- LOS B

Freeway Level Of Service

- LOS C

- LOS D

Freeway Level Of Service

- LOS E

- LOS F

Macroscopic Parameters

- Flow (Q)
  - number of vehicles traversing a point of roadway per unit time (vehicles/hour)
- Density (K)
  - number of vehicles occupying a given length of lane or roadway averaged over time (vehicles/mile)
- Speed (U)
  - distance traversed by a vehicle per unit time (miles/hour)

Q-K-U Relationship

Flow, Q (veh/hr)

= Density, K (veh/mile) x Speed, U (miles/hr)

For example, say,

Flow, Q = 1200 veh/hour

Speed, U = 30 miles/hour

Density, K = Q/U = 1200/30 = 40 veh/mile

Fundamental Diagram of Traffic Flow

- Density zero, flow also zero
- Density increases, flow also increases
- When density reached maximum (jam density), flow is equal to zero (car line up end to end)
- Density increases from zero, flows also increases up to a maximum value. After this value, density keeps increasing but flow decreases

Fundamental Diagram of Traffic Flow

- Space mean speed-flow diagram: flow very low, speed is high and it is know as free flow speed.
- Increase in flow at to his maximum value, means decrease in speed. After this value, flow and speed decrease

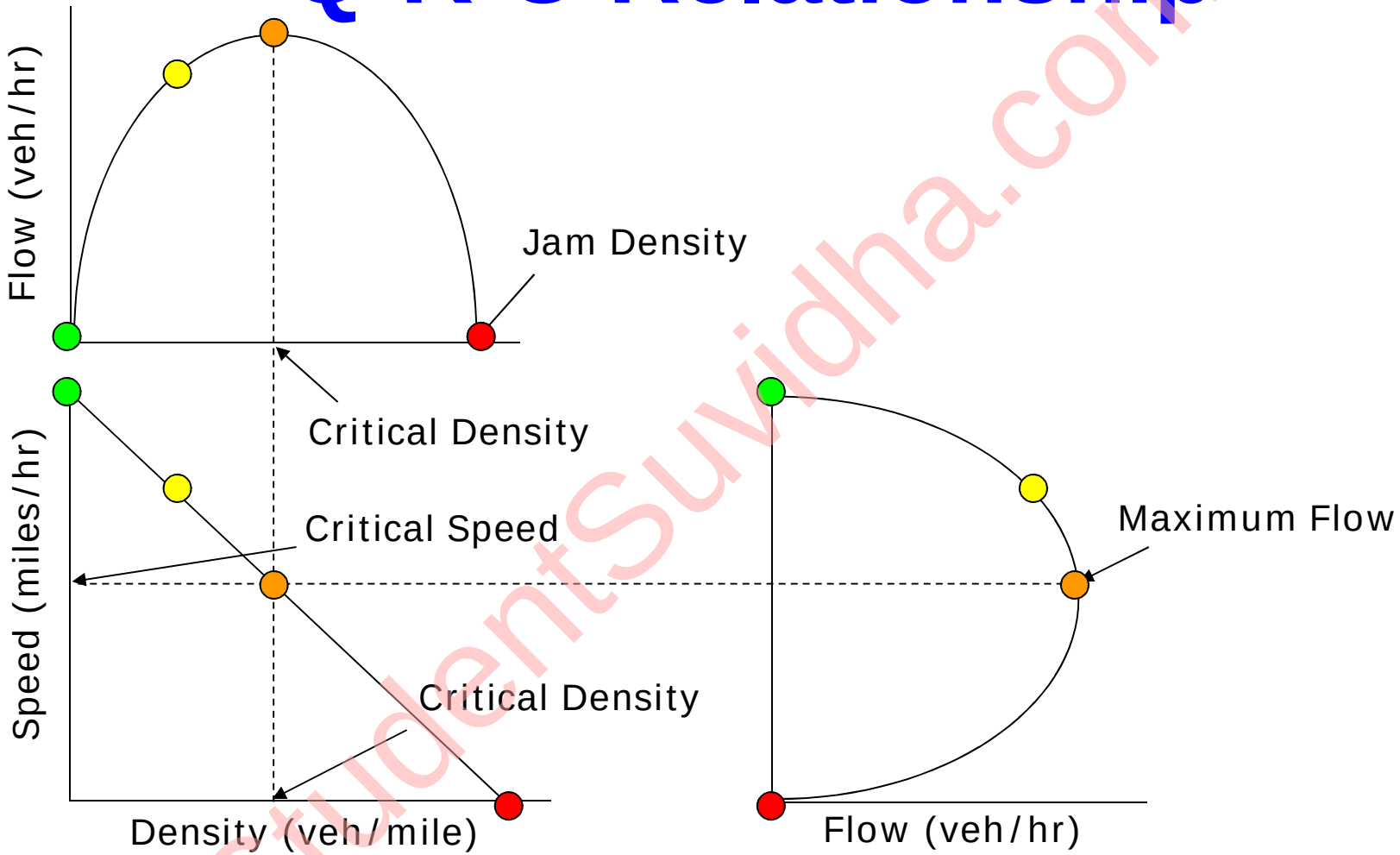
DENSITY

- Number of vehicles occupying a given length of lane or roadway, averaged over time, usually expressed as vehicles per km (veh/km)
- $q = v \times k$
- q = rate of flow (veh/hr)
- v = average travel speed (kph)
- k = average density (veh/km)

DENSITY

- A highway segment with a rate of flow of 1.350 veh/hr and an average travel speed of 45 kph would have a density of ***k*** = 1.350 / 45 = 30 veh/km.
- The proximity of vehicles in a traffic stream is given by density, which is a critical parameter in describing freedom of maneuverability.

Q-K-U Relationship



SPEED, FLOW, AND DENSITY RELATIONSHIP

- $q = u \times k$

  $q = Ak - Bk^2$

  $q = (A - Bk) \times k$
- $u = A - Bk$
- $k = (A - u) / B$
- $q = u \times [(A - u) / B]$

  $q = [u \times (A - u)] / B$
- $M = 1 / k$
- $q = (A/M) - (B/M^2)$