GATE – CIVIL ENGINEERING

TRANSPORTATION ENGINEERING

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TRANSPORTATION ENGINEERING

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15.6 TRAFFIC ENGINEERING

Basic object of traffic engineering is to achieve efficient free and rapid flow of traffic with least number of accidents.

Traffic characteristics:

a. **Road user characteristics:**

Road users - pedestrian, cyclist, car drivers or motorists

i. Physical characteristics

- Permanent or temporary
- Permanent characteristics - vision, hearing, strength and general reaction to traffic situations.
- Temporary characteristics - fatigue, alcohol or drugs and illness.
- Reduce alertness and increase the reaction time and also affect the quality of judgment in some situations.

ii. Mental characteristics.

- Knowledge, skill, intelligence, experience, literacy.

iii. Psychological factors

- Affect reaction to traffic situations of road users to a great extent.
- Emotional factors - attentiveness, fear, anger, superstition, impatience, general attitude towards traffic and regulations and maturity.

iv. Environmental factors

- Traffic stream characteristics, facilities to the traffic, atmospheric conditions and the locality.

b. **Vehicular characteristics**:

- Static characteristics of vehicles affecting road design are the dimensions, weight and maximum turning angle.
- Dynamic characteristics of vehicles affecting road design are speed, acceleration and braking characteristics and some aspects of vehicle body design.

Vehicle dimensions

Maximum width of vehicle = 2.50 m

Height - single decked = 3.80 m

Double decked = 4.75 m

Length: 11 to 18 m

Weight of loaded vehicle

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

Speed of vehicle:

The vehicle speeds affects

- sight distance
- superelevation
- length of transition curves on valley curves and on humps.
- width of pavement and shoulders on straight and horizontal curves
- design gradient
- capacity of traffic lane
- design and control measures on intersections.

Braking characteristics:

The deceleration and braking characteristics of vehicles depends on the design and type of braking system and its efficiency.

c. Traffic studies:

- Carried out to analyse the traffic characteristics
- Traffic surveys for collecting traffic data are called traffic census.
- The various traffic studies generally carried out are

  i. Traffic volume study

  ii. Speed studies
    - Spot speed study
    - Speed and delay study

  iii. Origin and destination study

  iv. Traffic flow characteristics

  v. Traffic capacity study

  vi. Parking study

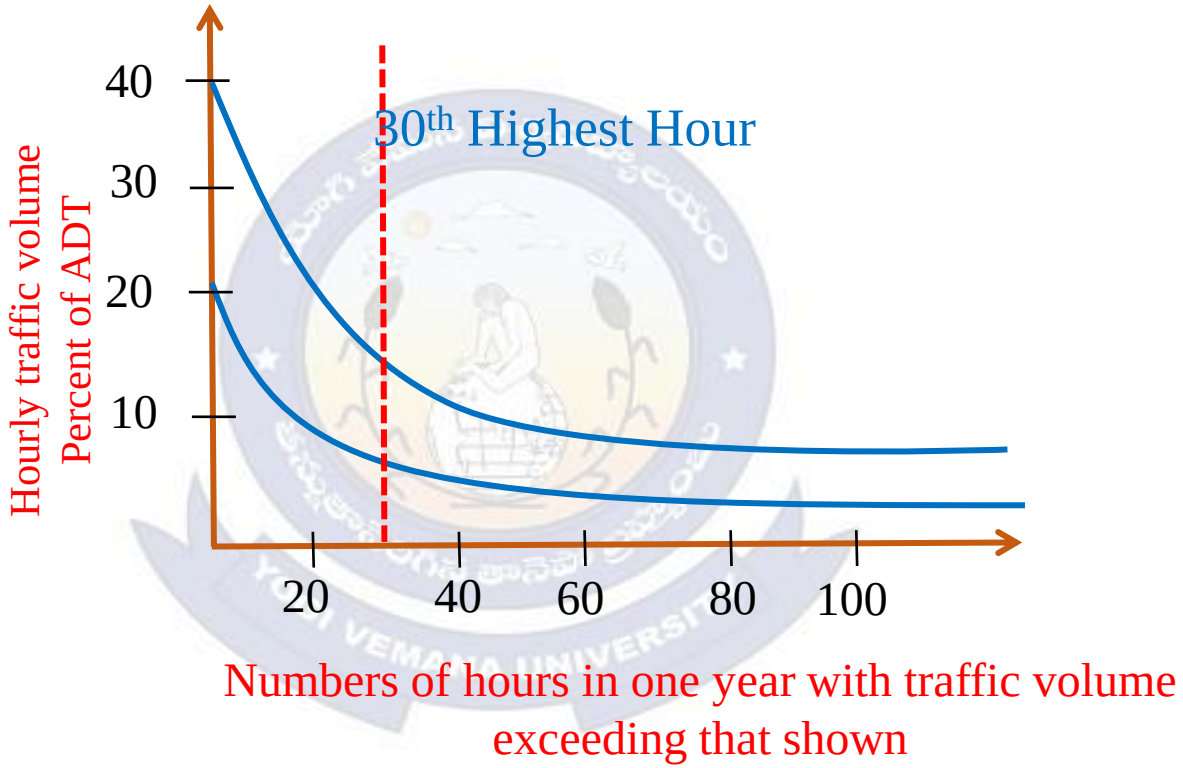
  vii.Accident studies or the traffic flop.

Traffic volume study

Traffic volume is the number of vehicles crossing a section of road per unit time at any selected period.

- traffic volume is used as a quantity measure of flow
- unit – vehicles per hour and vehicles per day.
- Traffic volume counts may be done by mechanical counters or manually.
- AADT or ADT - Annual Average Daily Traffic.
- In order to convert the different vehicle classes to one class such as passenger car, conversion factors known as Passenger Car Units (PCU) are used.
- AADT helps in deciding the relative importance of a route and in phasing the road development programme.
- Thirtieth highest hourly volume or the design hourly volume is found from the plot between hourly volume and the number of hours in an year that the traffic volume is exceeded.

- 30^{th} highest hourly volume is the hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the year will be less than this value.



- Design based on the highest or peak hourly volume of the year is uneconomical.
- The annual average hourly volume (AAHV) based on AADT will not be sufficient.

- The high facilities designed with capacity for 30th highest hourly traffic volume in the assumed year is found to be satisfactory from both facility and economic considerations.
- 30th highest hourly volume is generally taken as the hourly volume for design.

$$AADT = T \times DAF \times MAF$$

T: Traffic count at a road section for 24 hours

DAF: Daily Adjustment Factor

MAF: Monthly Adjustment Factor

AADT: Average Annual Daily Traffic

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Speed studies: Actual speed of vehicles depends on geometric features, traffic conditions, time, place, environment and driver.

Travel time: is the reciprocal of speed

Spot speed: is the instantaneous speed of a vehicle at a specified section or location can be found using Enoscope.

Average speed: is the average of the spot speeds of all vehicles passing a given point on the highway.

Space mean speed: represents the average speed of vehicles in a certain road length at any time. It is obtained from the observed travel time of the vehicles over a relatively long stretch of the road

$$\text{Space mean speed } V_s = \frac{3.6\, d.n}{\sum_{i=1}^{n} t_i}$$

where V_s : Space mean speed, kmph

d : Length of road, m

n : Number of individual vehicle observations

t_i : Observed travel time (sec) for i^{th} vehicle to travel distance d, m

The average travel time of all the vehicles is obtained from the reciprocal of space mean speed.

Time mean speed: represents the speed distribution of vehicles at a point on the roadway and it is the average of instantaneous speeds of observed vehicles at the spot.

$$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

V_t : Time-mean-speed, kmph

V_i : Observed instantaneous speed of i^{th} vehicle, kmph.

n : Number of vehicles observed.

The space mean speed is slightly lower than time mean speed under typical speed conditions on rural highways.

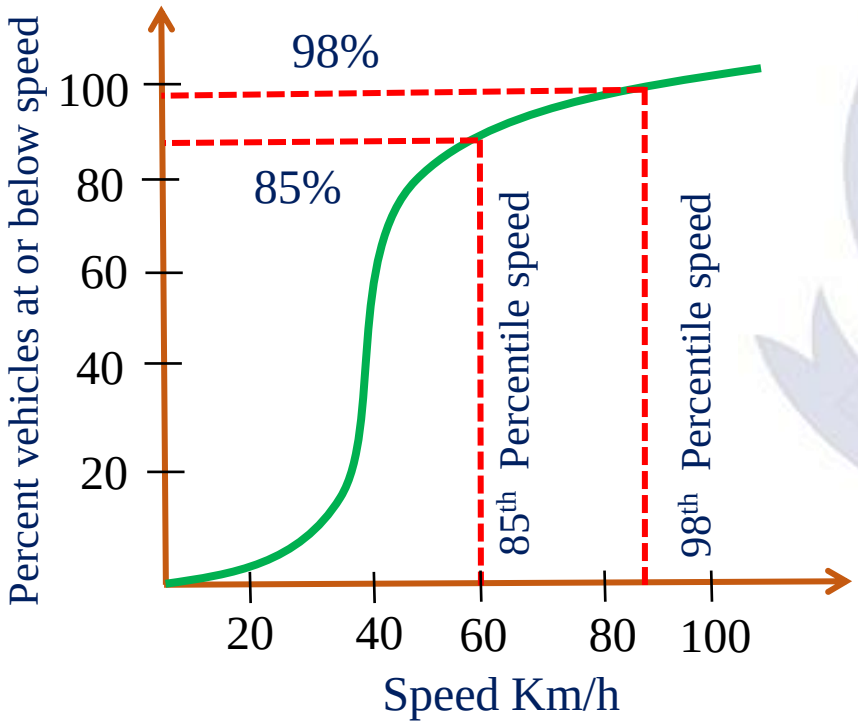
Running speed: is the average speed maintained by a vehicle over a particular stretch of road.

Overall speed or travel speed: is the effective speed with which a vehicle traverses a particular route between two terminals.

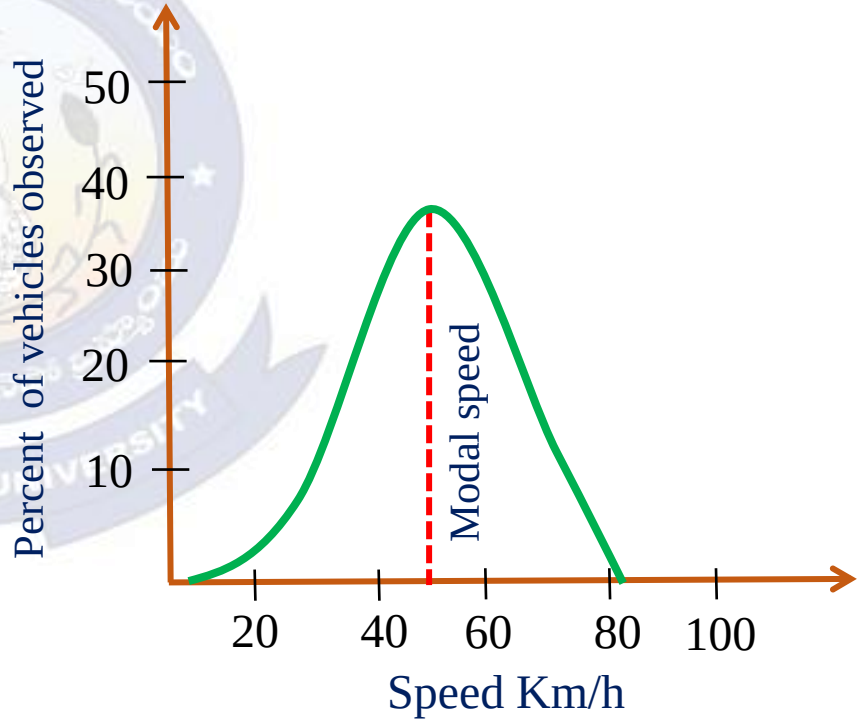
- 85^{th} percentile speed is the speed at or below which 85% of the vehicles are passing the point on the highway or only 15% of the vehicles exceed the speed at that spot.

The drivers exceeding 85th percentile speed are usually considered to drive faster than the safe speed under existing conditions and hence this speed is adopted for the safe speed limit at this zone.

- 98th percentile speed is taken for the purpose of highway geometric design.
- Speed distribution curve follows the normal distribution curve.



Cumulative Speed Distribution



Frequency Distribution curve of the spot speeds

Speed and delay study:

- to detect the spots of congestion
- to find the travel time and in benefit-cost analysis
- to judge the efficiency of the road way from the travel time.

The average journey time $(\bar{t})$ in a traffic stream in the direction of flow q is given by

$$\bar{t} = t_w - \frac{n_y}{q} \qquad q = \frac{n_a + n_y}{t_a + t_w}$$

where q : Flow of vehicles (volume per minute) in one direction of the stream

n_a : Average number of vehicles counted in the direction of steam when the test vehicle travels in the opposite direction

n_y : Average number of vehicles overtaking the test vehicle minus number of vehicles overtaken when the test is in the direction of q

t_w: Average journey time when the test vehicle is traveling with the stream.

t_a : Average journey time when test vehicle is running against the stream

Origin and destination studies:

Carried out to i. plan the road network and other facilities for vehicular traffic

ii. plan the schedule of different modes of transportation for the trip demand of commuters.

Methods for collecting the Origin and Destination data:

a. Road side interview method

b. License plate method

c. Return post card method

d. Tag-on-car method

e. Home interview method

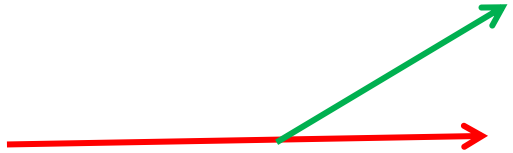
Desire lines is a graphical representation in O & D surveys.

Pie charts - representation of the relative magnitude of the generated traffic and geometrical relationships of the zones.

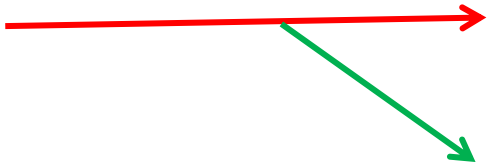
Traffic flow characteristics:

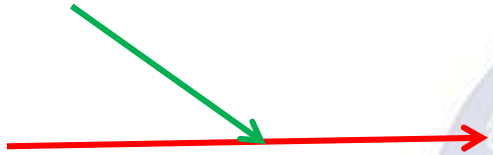
Basic traffic maneuvers – diverging, merging, crossing, weaving.

- **Diverging** on the left is the easiest movement causing least problem of the traffic conflicts
- lane change is the transfer of a vehicle from one traffic lane to the next adjacent traffic lane. It involves diverging and merging.
- **Weaving**: when a vehicle moves obliquely across the path of another vehicle moving in the same direction at relatively small angle of crossing. It consists of merging and diverging operations.
- **Time headway:** The time interval between the passage of successive vehicles moving in the same lane and measured from head to head as they pass a point on the road.
- **Space headway:** The distance between successive vehicles moving in the same lane measured from head to head at any instance.

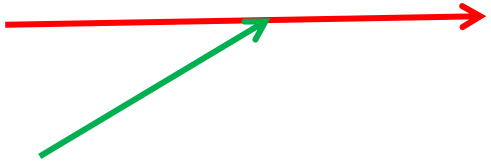


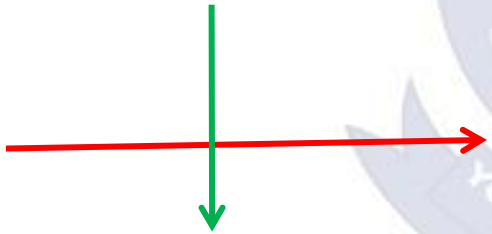
Diverging



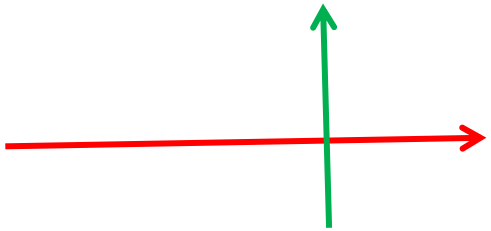


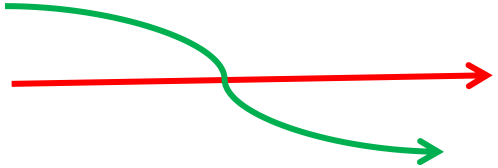
Merging



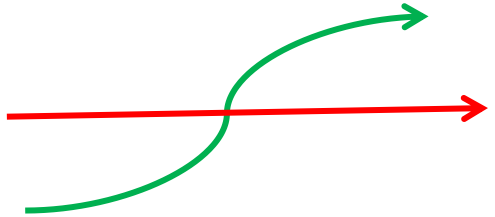


Crossing





Weaving



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Traffic capacity studies:

Traffic volume: Traffic volume is the number of vehicles moving in a specified direction on a given lane or roadway that pass a given point or cross section during specified unit of time.

- expressed as vehicles per hour or vehicles per day.

Traffic density: Traffic density is the number of vehicles occupying a unit length of lane of roadway at a given instant.

- expressed as vehicles per kilometer.
- traffic volume = traffic density × traffic speed
- the highest traffic density occur when the vehicles are at a stand still on a given route. The traffic volume approach to zero.

Traffic capacity: is the ability of a roadway to accommodate traffic volume.

- expressed as the maximum number of vehicles in a lane or road that can pass a given point in unit time ie., vehicles per hour per lane.
- volume represents an actual rate of flow
- capacity indicates a capability or maximum rate of flow.

Basic capacity: is the maximum number of passenger cars that can pass a given point on a lane or roadway during 1 hour.

- 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 1 hour.

- the possible capacity of a road is much lower than the basic capacity.
- if the traffic is stand still, the possible capacity of the road approach zero.

Practical capacity: is the maximum number of vehicles that can pass a given point on a lane or roadway during 1 hour.

- it is also called design capacity.

Theoretical maximum capacity: The theoretical maximum or basic capacity of a single lane is $C = \frac{1000\,V}{S}$

C : Capacity of a single lane, vehicles per hour.

V : Speed of vehicle, kmph

S : Average centre to centre spacing of vehicles, m

Minimum space headway, S = Minimum space gap + average length of vehicle

$$S = S_g + L$$

$$= 0.278\,V.t + L$$

The average reaction time is assumed as 0.7 sec.

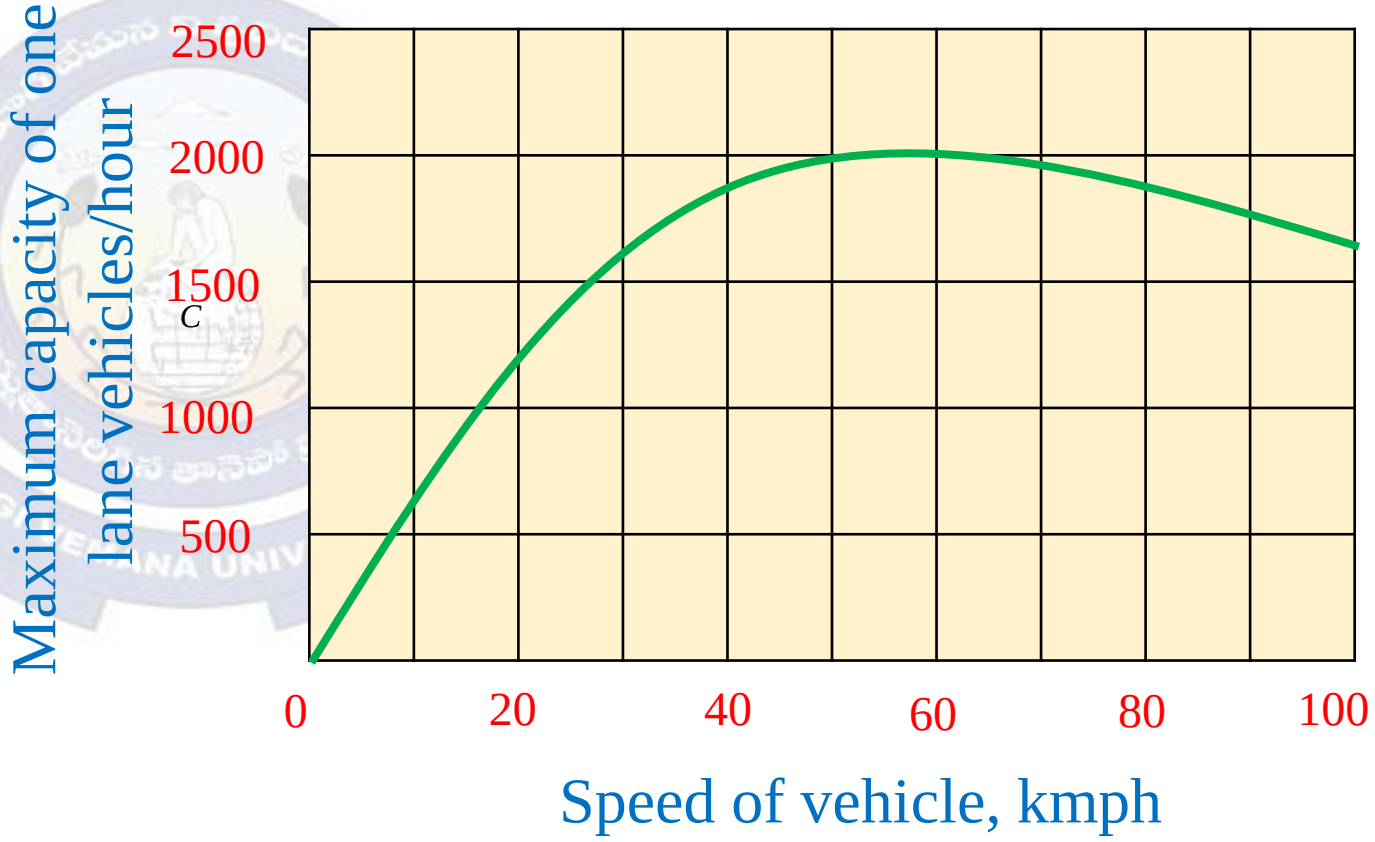
$$S = 0.7v + L = 0.2V + L$$

- With increase in speed of the traffic stream, the time headway decreases and after reaching a minimum value at an optimum speed, starts increases.
- The maximum theoretical capacity of a traffic lane

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

C :Maximum theoretical capacity, Vehicles/hour/lane

H_t : Minimum time headway in sec.



Passenger Car Unit (PCU):

- PCU is the standard vehicle unit to convert the other vehicle classes.
- Traffic volume and capacity expressed as PCU per lane per hour.
- Traffic density is expressed as PCU per km length of lane.

Tentative equivalency factors suggested by IRC.

S.No.	Vehicle class	Equivalency factor
1.	Passenger car, tempo, Auto rickshaw, Agricultural tractor.	1.0
2.	Bus, truck, Agricultural tractor-trailer unit	3.0
3.	Motor cycle, scooter, pedal cycle	0.5
4.	Cycle rickshaw	1.5
5.	Horse drawn vehicles	4.0
6.	Small bullock cart and hand cart	6.0
7.	Large bullock cart	8.0

Capacity of different types of Roads in Rural Areas

S.No.	Type of road	Capacity CPU per day
1.	Single lane with 3.75 in wide carriageway and normal earthen shoulders	1000
2.	Single lane with 3.75 m wide carriageway and 1.0 m wide hard shoulders	2500
3.	Roads with intermediate lanes of width 5.5 m and normal earthen shoulders	5000
4.	Two lane roads with 7.0 m wide carriageway and earthen shoulders	10,000
5.	Four lane divided highway	20,000 to 30,000

Condition diagram: A condition diagram is a drawing to scale showing all important physical conditions of an accident location to be studied.

Collision diagram: Collision diagrams showing the approximate path of vehicles and pedestrians involved in the accidents.

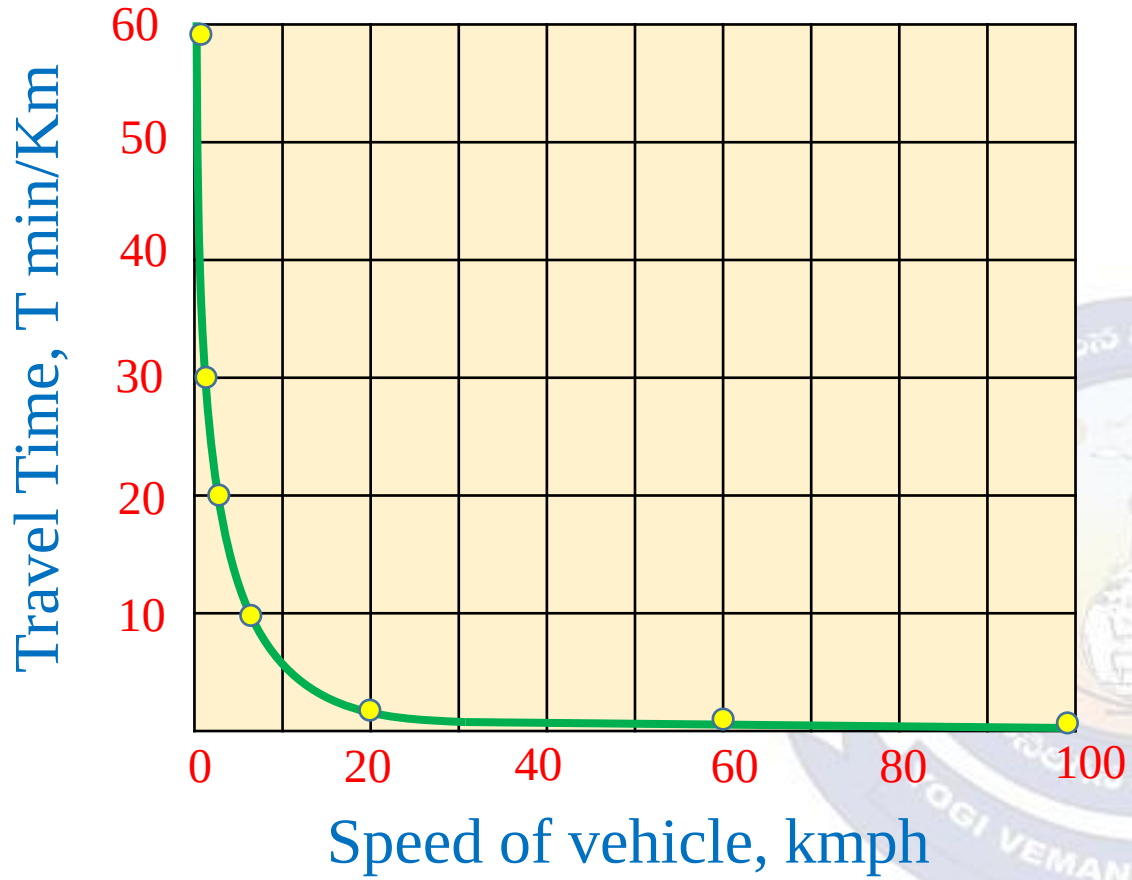
Relationship between Speed, Travel time, Volume, Density and Capacity:

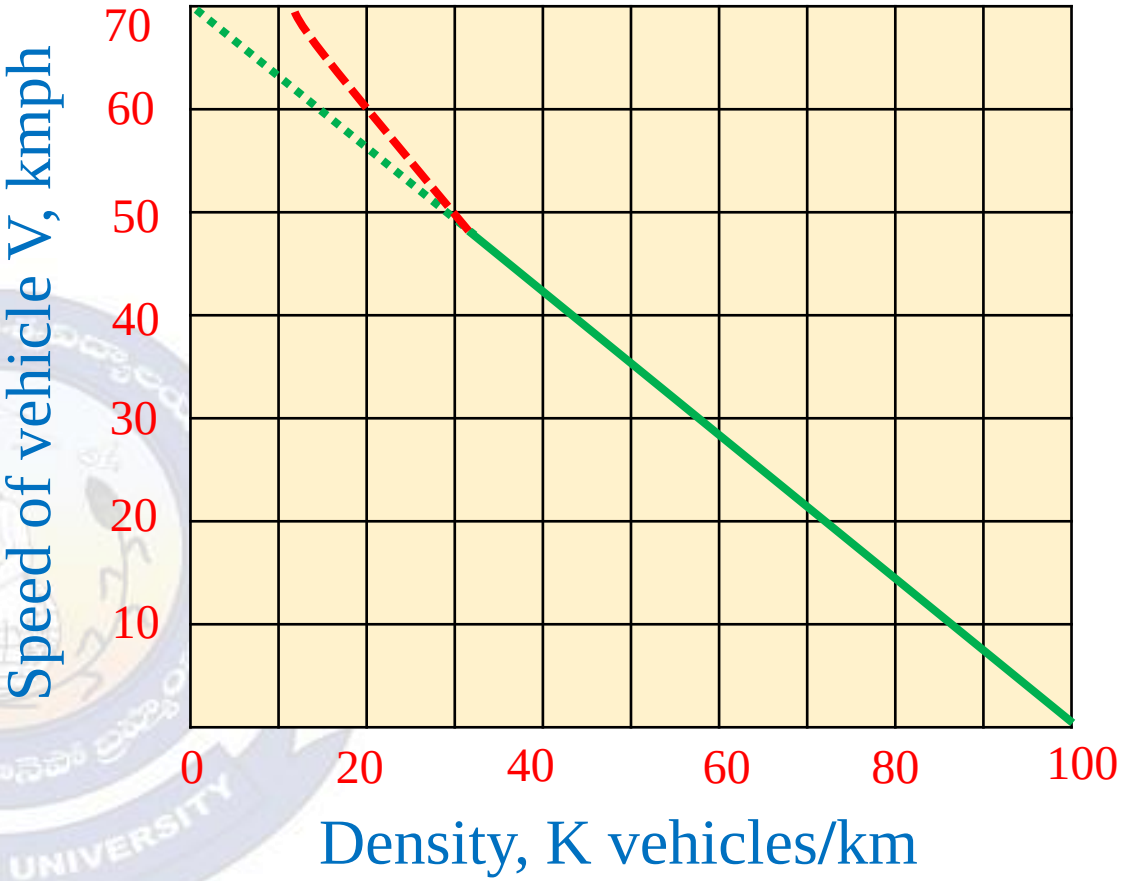
Travel time per unit length of road in inversely proportional to the speed.

If T : Travel time

V : Speed, kmph

$$T : (\text{min/km}) = \frac{60}{V} \; ; \qquad T : (\text{Sec/km}) = \frac{3600}{V}$$





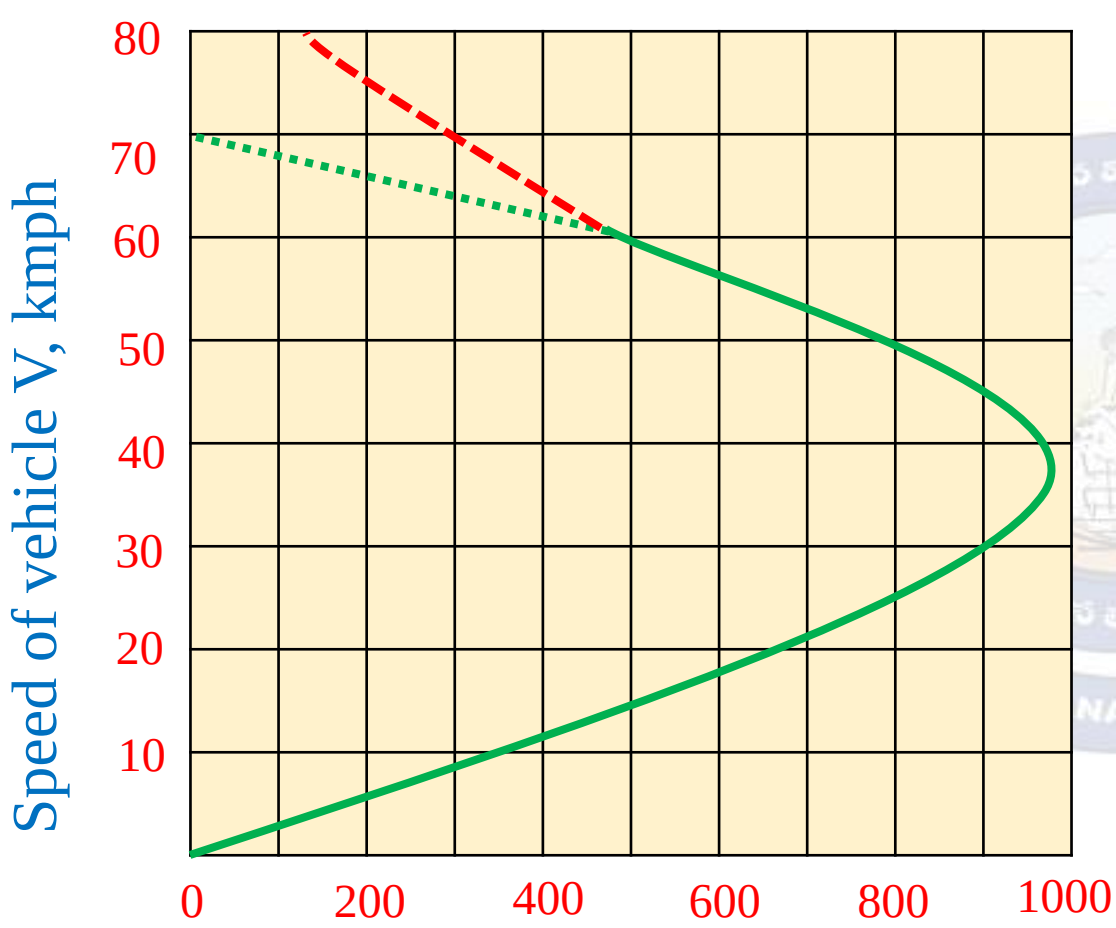
$$q = k.V_s$$

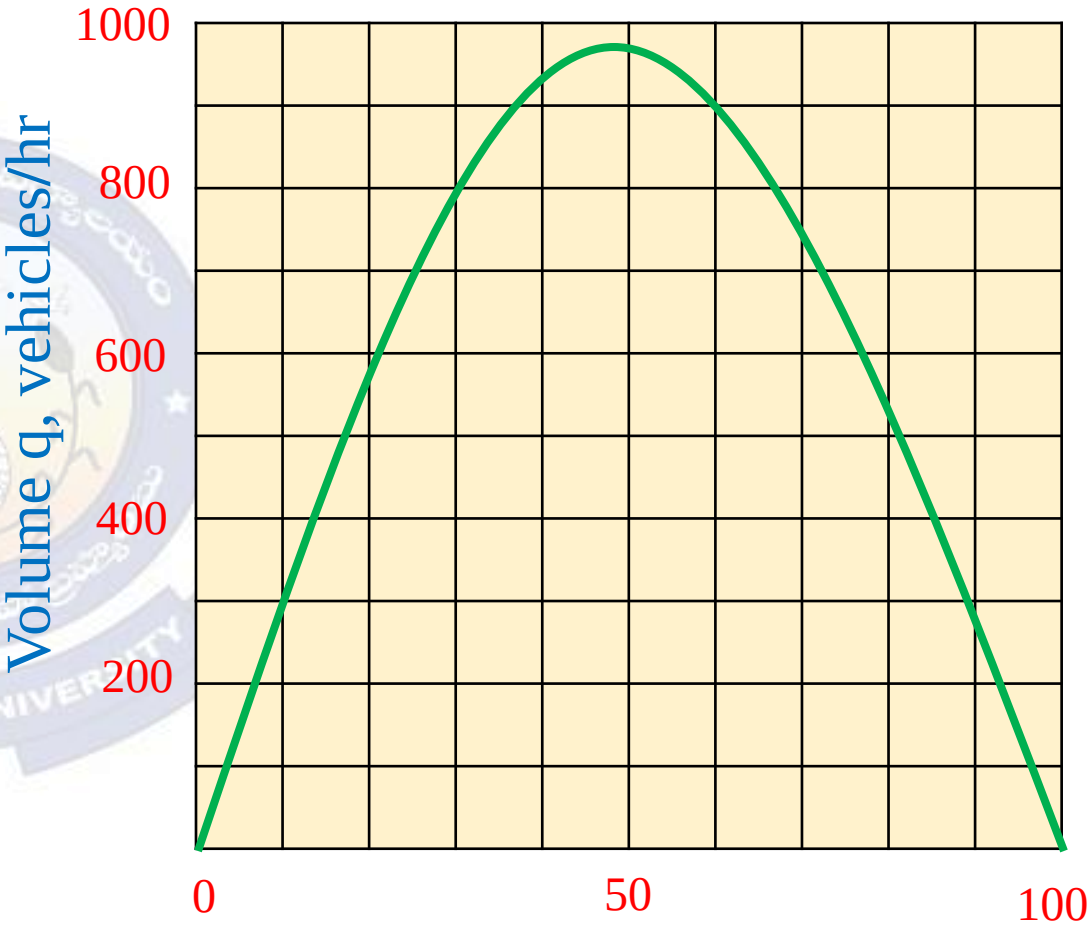
q : Average volume of vehicles passing a point during a specified period of time (vehicles/hour)

k : Average density or number of vehicles occupying a unit length of roadway at a given instant (Vehicles/km)

V_s : Space mean speed of vehicles in a unit roadway length (kmph)

$$k\left(\text{vehicles/km}\right) = \frac{q\left(\text{Vehicles/hour}\right)}{V\left(\text{km/hr}\right)}$$





Capacity flow:

V_{af} : Free mean speed

k_j : Maximum density or Jam density (occurs at zero speed)

q_{max} : Maximum flow or capacity flow.

$$q = k.v \qquad v = v_{af}(1-k)$$

$$q = k.v_f(1-k) = v_f(k-k^2)$$

$$\text{For maximum } q,\ \frac{dq}{dk} = 0 \Rightarrow v_{af}(1-2k) = 0 \Rightarrow k = \frac{1}{2}$$

$$k = \frac{1}{2} \Rightarrow k = \frac{k_j}{2}; \qquad v = v_{af}\left(1-\frac{1}{2}\right) = \frac{v_{af}}{2}$$

Maximum flow occurs when the speed is $\frac{V_{af}}{2}$ and density is $\frac{k_j}{2}$

$$q_{max} = \frac{k_j}{2}.\frac{v_{af}}{2} = \frac{k_j.v_{af}}{4}$$

Number of lanes based on Traffic:

Number of lanes required, $N = \dfrac{DDHV}{PHF \times MSF \times F_{HV} . f_p}$

DDHV : Directional Design Hourly volume

PHF: Peak Hour Factor

MSF: Maximum Service Flow rate, vehicles/hour

F_{HV} : Heavy vehicle familiarity adjustment factor $F_{HV} = 1$ for Car

f_p : Road user familiarity adjustment factor $f_p = 1$ for regular commuters

DDHV = AADT ×K×D

AADT : Annual Average Daily Traffic, Vehicles/day

K : Proportion of AADT occurring in peak hour

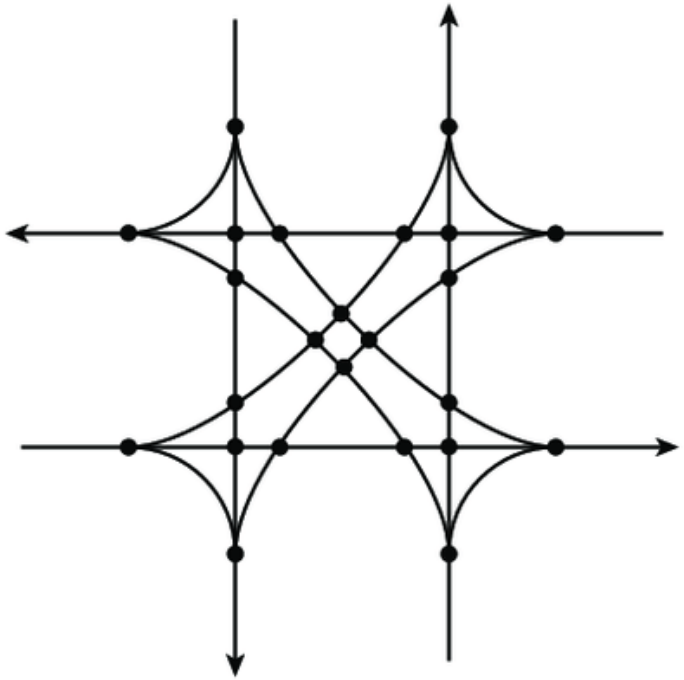
D : Volume Proportion in major direction

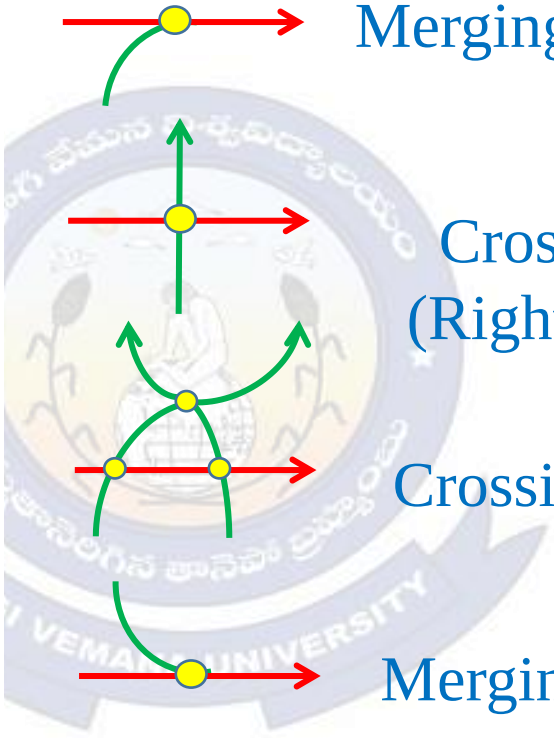
Types of conflicts:

1. Crossing conflicts 2. Merging conflicts 3. Diverging conflicts.

Type of traffic	No. of conflicts			
	Crossing	Merging	Diverging	Total
Two lane two way traffic	16	4	4	24
Two lane with one way traffic on one road	7	4	-	11
Two lane with one way traffic on both roads	4	2	-	6

Two Lane Two way traffic





Merging (Right) = 4

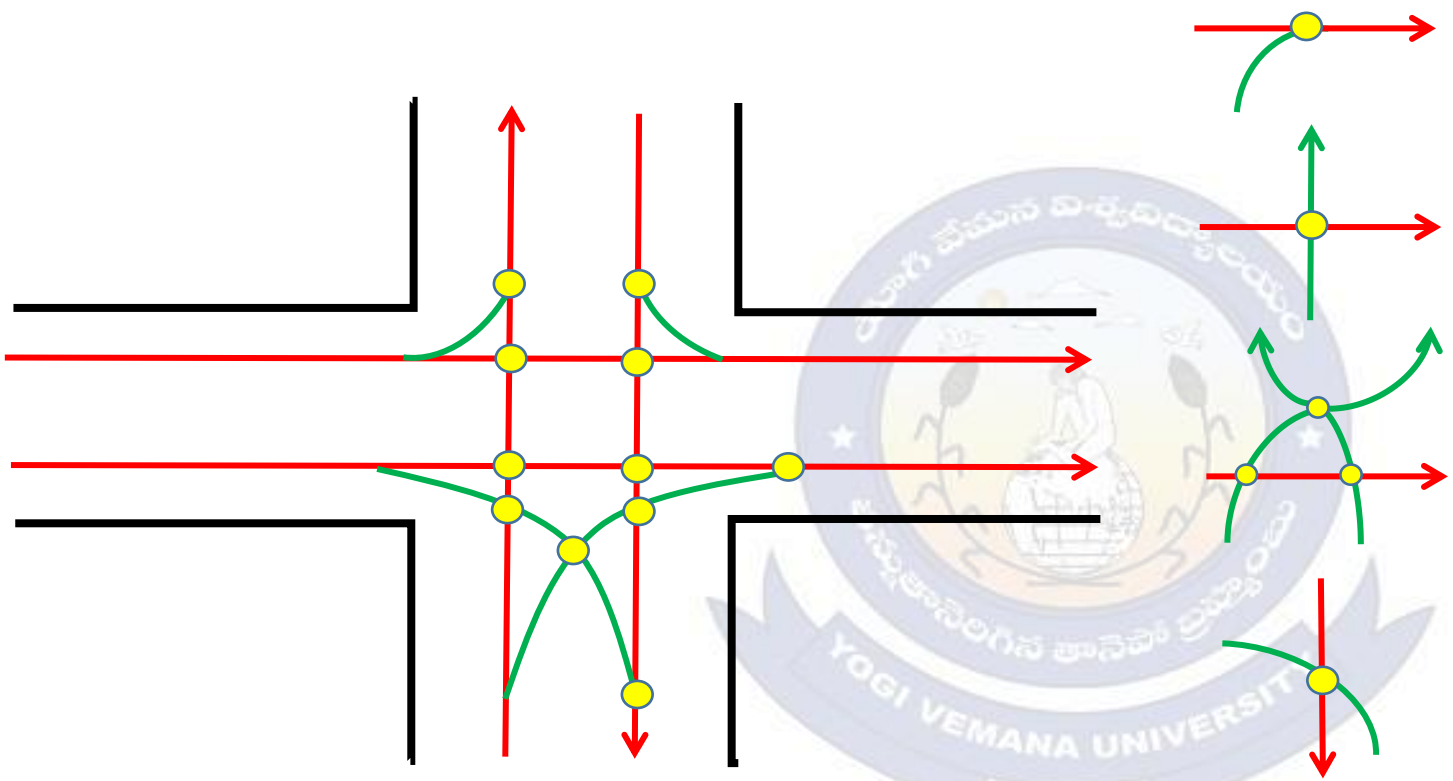
Crossing = 4
(Right angle)

Crossing = 12

Merging (Left) = 4

Total Conflicts = 24

Two Lane with one way traffic on one road



Merging (Right) = 4

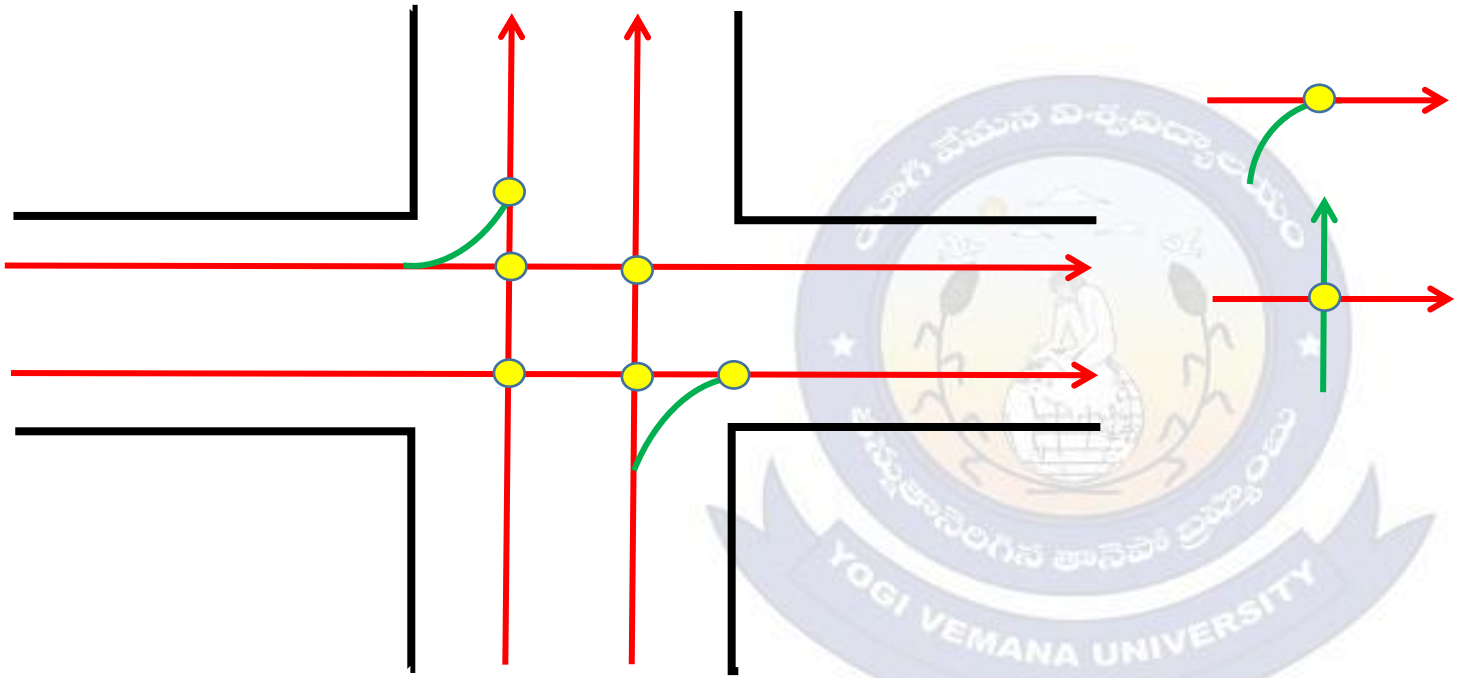
Crossing = 4
(Right angle)

Crossing = 1

Merging (Left) = 2

Total Conflicts = 11

Two Lane with one way traffic on both roads



Merging = 2

Crossing = 4
(Right angle)

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Traffic Control devices:

- located at 0.6 m from kerb.
- located at 2 to 3 m from edge of the carriageway.
- signs should be mounted on sign posts painted alternately with 25 cm black and white bands.

1. Traffic signs:

a. Regulatory signs:

- Regulatory or mandatory signs are meant to inform the road users of certain laws, regulations and prohibitions.

i. Stop signs:

- Stop sign is intended to stop the vehicle on roadway.
- It is octagonal shape and red in colour with a white border.
- may be used in combination with a rectangular definition plate with the word 'STOP'.

ii. **Give-way sign**:

- Give-way sign is used to control the vehicles on a road so as to assign right of way to traffic on other roadways.
- triangular in shape with apex downwards and white in colour with a red border.
- may be used in combination with a definition plate.

iii. **Prohibitory signs**:

- to prohibit certain traffic movements, use of horns or entry of certain vehicle class.
- circular in shape and white in colour with a red border.
- Straight Prohibited, No Entry, One-way, Truck Prohibited, Cycle Prohibited, Right/Left turn Prohibited, Overtaking Prohibited. Horn Prohibited etc.,

iv. **No Parking sign**:

- to prohibit parking of vehicles
- circular in shape with a blue background, a red border and an oblique red border at an angle of 45°.

v. **No Stopping/Standing sign**:

- to prohibit stopping of vehicles.
- circular in shape with blue background, red border and two oblique red bars at 45° and right angles each other.

vi. **Speed limit**:

- to restrict the speed of all or certain class of vehicles on a particular stretch of a road.
- circular in shape having white background, red border and black numerals indicating speed limit.

vii. **Vehicle control signs**:

- similar to speed limit signs with black symbols instead of the numerals.
- width limit, height limit, load limit etc.,

viii. **Restriction Ends sign**:

- indicates the point at which all prohibitions notified by prohibitory signs for moving vehicles cease to apply.
- circular with a white background and a broad diagonal black band at 45°

ix. **Compulsory Direction control signs**:

- indicate by arrows, the vehicles are obilized to follow appropriate directions.
- Circular with a blue background and white direction arrows.
- Turn left, Ahead only, Turn right, Cycle track etc.,

2. **Warning signs or Cautionary signs**:

- used to warn the road users of certain conditions that exist on or adjacent to the roadway.
- equilateral triangle with its apex pointing upwards.
- They have white background, red colour and black symbols.
- located at 120 m in National/State highways.
- Right hand/Left hand curve, Right/Left hair pin bend, Steep Ascent/Descent, Narrow Bridge Road Ahead, Cycle crossing, School zone, Cross road, Men at work, Railway crossing etc.,

Informatory signs:

- Used to guide the road users along routes
- Direction and place identification signs, facility information signs, parking signs, flood gauge and other useful information signs.
- Direction and place identification signs are rectangular with white background, black border and black arrows and letters.

Traffic signals:

- Red light used for stop
- Green light used for Go
- Amber or yellow light allows the clearance time.

Design of isolated fixed time signal:

- The cycle lengths are normally 40 to 60 seconds for two phase signal.
- Longer cycle lengths are in use of complex traffic flow and for more than two phases.

Webster's method:

The optimum signal cycle, $C_o = \dfrac{1.5L + 5}{1 - Y}$

L : Total lost time per cycle, sec

$= 2n + R$

n : Number of phases

R : all red-time

$Y = y_1 + y_2$ $\qquad y_1 = \dfrac{q_1}{S_1}$, $\qquad y_2 = \dfrac{q_2}{S_2}$

Y : Sum of the ratio of actual flow to saturation flow

q_1, q_2 : Actual flow of vehicles passing on road 1 and 2

S_1, S_2 : Saturated flow of vehicles passing on road 1 and 2

$G_1 = \dfrac{y_1}{Y}(C_o - L)$ $\qquad G_2 = \dfrac{y_2}{Y}(C_o - L)$

G_1, G_2 : Green time required for road 1 and 2

The average delay per vehicle on the approach road during a cycle length,

$$d = \frac{\frac{C_o}{2}\left[1-\frac{G}{C_0}\right]^2}{\left[1-\frac{q}{S}\right]}$$

C : Optimum Signal Cycle

G : Green time

q : Actual flow of vehicles passing

S : Saturated flow of vehicles passing

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Effective Green time, $G_e = G + A - L$

G : Green time

A : Amber or Yellow time

L : Total lost time

$L : L_i + L_f$

L_i : Initial lost time

L_f : Final lost time $\quad L_f \leq A$

Amber or Yellow time, $A = \dfrac{S + W + L}{V}$,

S : Safe stopping distance

S : Distance from stop line until vehicle is clear

L : Length of the vehicle

Time required for stopping the approaching vehicles $= \dfrac{S}{V}$

Discharge headway is the headway between successive vehicles negotiating an intersection during the green time of signal operation.

- It is the difference of passage time between the front or rear bumper of successive vehicles over the stop line.

Saturation headway is the difference in the passage time at the intersection stop line between two consecutive vehicles once the queue is moving in a stable manner.

- It is the average headway that can be achieved by a saturated, stable moving queue of vehicles passing through the signal.

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Intersection headway is defined as the difference of passage times between two consecutive vehicles over a stop line or any predetermined reference line in the intersection.

- Time between successive stopped vehicles entering a signalized intersection after the signal turns green.

Effective headway: Composite headway of all bus service at a stop based on bus frequency, the number of buses per hour divided by 60 minutes.

- Number of minutes between buses when all bus headways are combined. For example, if there are two bus routes operating on a segment of roadway each with ten minute headways, the effective headway is five minutes.

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Design method as per IRC:

1. Pedestrian green time required for the major/minor roads is calculated based on walking speed of 1.2 m/sec and initial walking time of 70 sec. These are minimum green time required for the vehicular traffic on the minor/major roads respectively.
2. The green time for the vehicular traffic on the major road is increased in proportion to the traffic on the two approach roads.
3. The cycle time is calculated after allowing amber time of 2 sec each.
4. The minimum green time required for clearing the vehicles arriving during a cycle is determined for each lane of the approach road assuming that the first vehicle will take 6 sec and the subsequent vehicles (PCU) of the queue will be cleared at a rate of 2 sec. The minimum green time required for the vehicular traffic on any of the approach is limited to 16 sec.
5. The optimal signal cycle time is calculated using websters formula. Saturation flow may be assumed as 525 PCU per hour per m width.

6. Lost time per cycle for each phase = (Amber time + inter-green time + time lost for initial delay of first vehicle (4 sec)
7. The signal cycle time and the phases may be revised.