DESIGN OF INTERSECTION

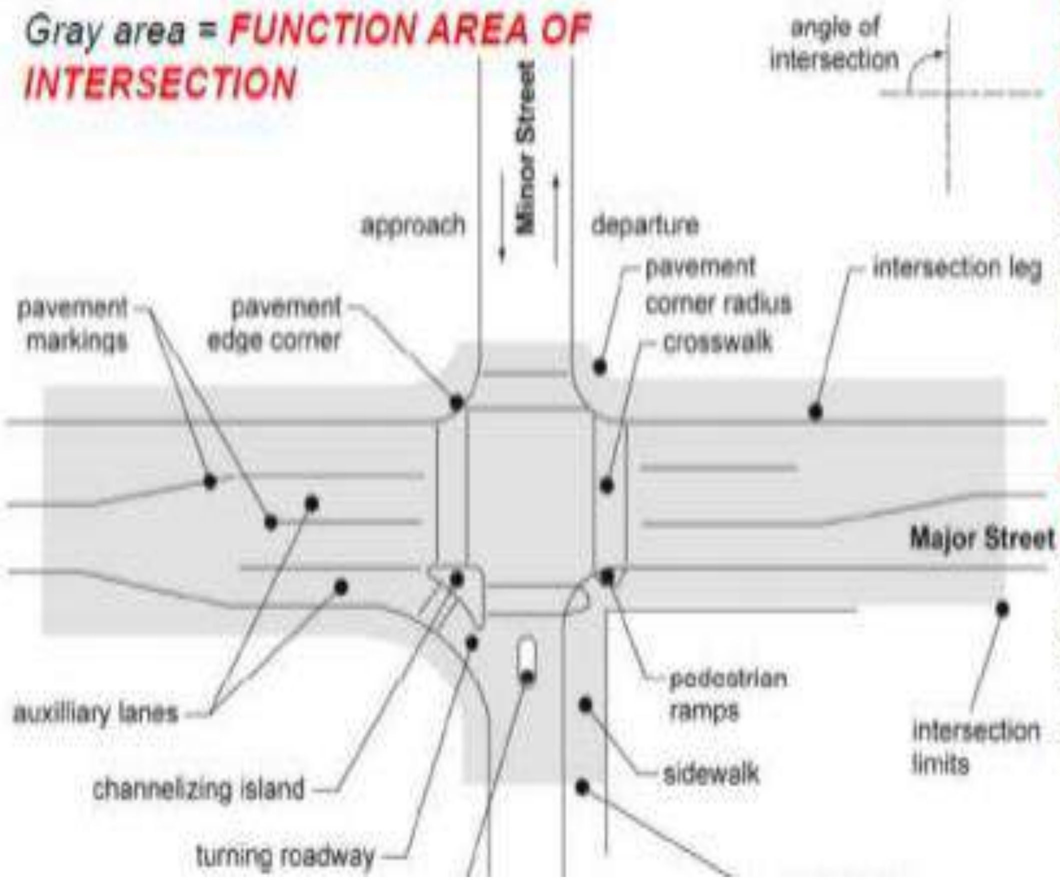
INTERSECTION

- An intersection is defined as the general area where two or more highways join or cross
- This area is designated for the vehicles to turn to different directions to reach their desired destinations.
- This is because vehicles moving in different direction want to occupy same space at the same time.

INTERSECTIONS

Definitions and key elements

Intersection Terminology



Sidewalks, crosswalks and pedestrian curb cut ramps *are considered to* be within the intersection.

The ***pavement edge corner is the curve*** connecting the edges of pavement of the intersecting streets.

Elements of intersection

- Each roadway extending from the intersection is referred to as a leg.
- The intersection of two roadways has usually four legs (or three if there one of the roadway is ended).
- The leg used by traffic approaching the intersection is the approach leg, and that used by traffic leaving is the departure leg.

- The major street is typically the intersecting street with greater traffic volume, larger cross-section, and higher functional class.
- The minor street is the intersecting street likely to have less traffic volume, smaller cross-section and lower functional classification than the major street.

- Channelization is the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings (regulation of traffic).

The following principles should be followed for a good design of intersection

- The number of intersection should be kept minimum
- The geometric layout should be so selected that hazardous movement by drivers are eliminated
- The design should permit the driver to find distinguish quickly either from the lay out or from traffic signs the path he should follow and the actions of merging and diverging
- The layout should follow the natural vehicle path . It must be smooth avoid abrupt and sharp corners

- The number of conflicts point should be minimised by separating some of the many cuttings, merging or diverging movement
- Vehicles that are forced to wait in order to cross a traffic should be provided with adequate space at the junction

Types of intersection

- There are two main types of intersection of roads.
- Grade – separated intersections or interchanges.
- At – grade intersections.

Grade separated

- An intersection were where roads cross at different level
- It is a bridge that eliminates crossing conflicts at intersections by vertical separation of roadways in space.
- Route transfer at grade separations is accommodated by interchange facilities consisting of ramps.
- The interchange configurations are designed in such a way to accommodate economically the traffic requirements of flow, operation on the crossing facilities, physical requirements of the topography, adjoining land use, type of controls, right-of-way and direction of movements.

At grade intersection

- At-grade intersections in which all the exchanges between the roads take place on the same plane.
- These are of two types
- Standard at-grade intersections
- Round about at-grade intersections.

Choice of intersection

- The choice between an at grade and grade separated junctions at a particular sites depends upon various factors such as traffic, economy, safety, aesthetic, delay etc.
- Grade separated junctions are generally are more expensive initially and are justified in certain situations

- On high type facilities such as expressways, freeways and motor ways
- Certain at grade intersection which have reached the maximum capacity
- At certain locations which have a proven record of bad accidents history when functioning as at grade junction
- At junctions where the traffic volume is heavy and delays and loss caused justify economically

- At certain specific topographical situations where it is logical to provide grade separated rather than at grade

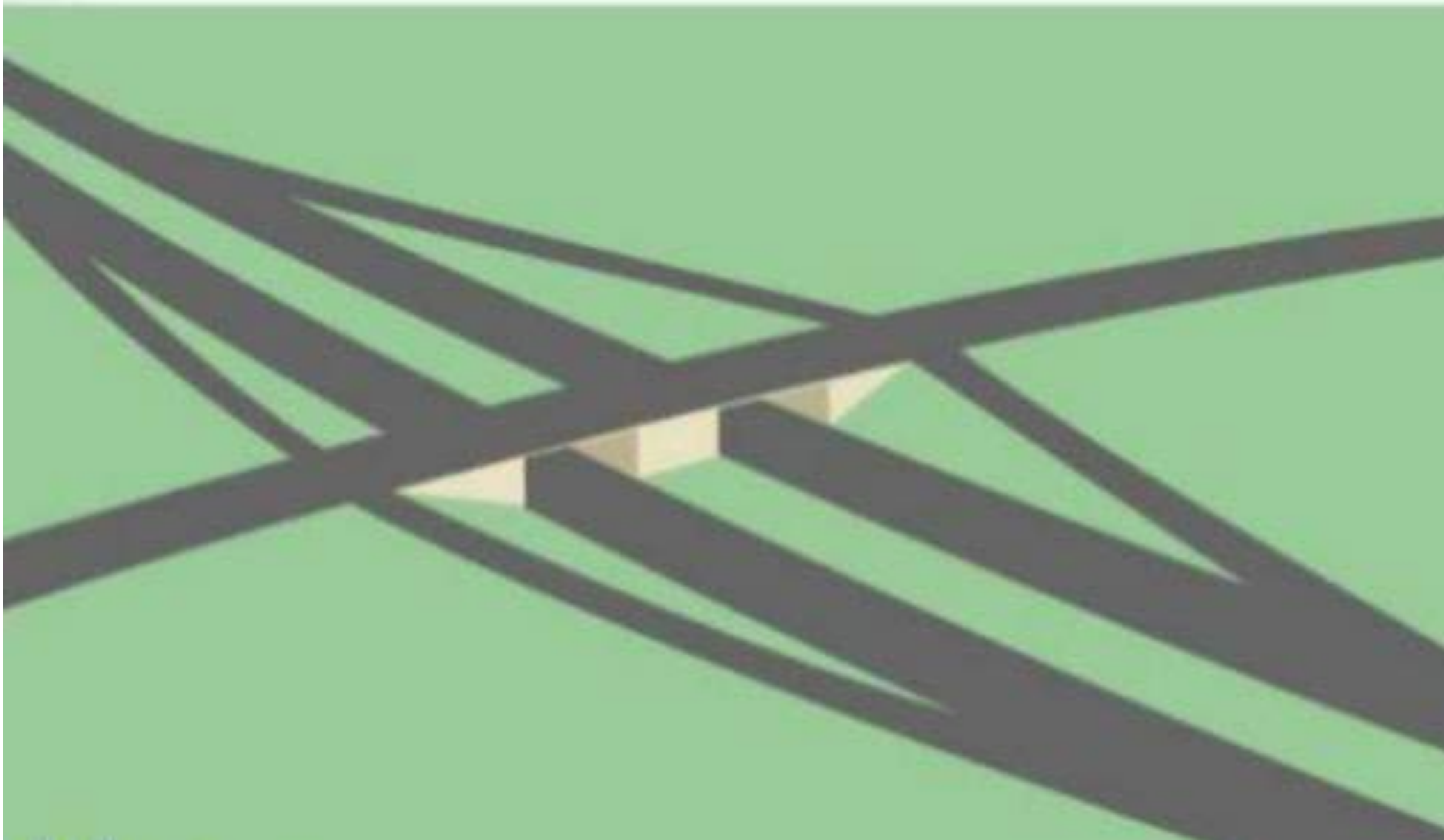
Types of grade separated intersection

- Underpass
- ⍰ Overpass
- ⍰ Trumpet Interchange
- ⍰ Diamond Interchange
- ⍰ Cloverleaf Interchange
- ⍰ Partial cloverleaf Interchange
- ⍰ Directional Interchange
- ⍰ Bridged Rotary

underpass

Overpass

Diamond interchange



Cloverleaf interchange

Partial cloverleaf interchange

GRADE SEPARATED INTERSECTION

GRADE SEPERATED INTERSECTION

- ✓ Highest form of intersection treatment.
- ✓ Much superior to intersection at grade from the point of view of traffic safety and efficient operation.
- ✓ Highway grade separation is achieved by means of vertical level.
- ✓ The grade separation may be either by bridge or under pass.
- ✓ Transform of rout at grade separation is provided by interchange facilities consisting of ramp.

Ramps classified in to:

a. **Direct interchange ramp** involves diverging to right side and merging from the right.
b. **Semi-direct interchange ramp** allows diverging to left but merging from right side.
c. **Indirect interchange ramp** allows a simple diverging to left and merging from left side.

ADVANTAGES OF GRADE SEPARATION

- ✓ Maximum facility given to the crossing traffic.
- ✓ There is increased safety for turning traffic and by indirect interchange ramp right turn movement is made safe.
- ✓ Overall increase in comfort and convenience to motorists and saving travel time and vehicle operation cost.
- ✓ Capacity of grade operated intersection can pratical ly approach that of two cross roads.
- ✓ Grade separation is an essential part of controlled access highway like expressway and freeway.
- ✓ It is possible to adopt grade separation for all likely angles and layout of intersecting roads.
- ✓ Stage construction of additional ramp are possible after grade separation structure b/n main roads are constructed.

DISADVANTAGES OF GRADE SEPERATION

- ✓ It is costly to provide complete grade separation and interchange facilities.
- ✓ Where there is limited right of way like build up or urban areas or where topography is not favourable, construction of grade separation is costly, difficult and undesirable.
- ✓ In flat or plain terrain , grade separation may introduce undesirable crests and sags in the vertical alignment.

GRADE SEPARATION STRUCTURES

- ✓ Bridge structure used to separate the grades of 2 intersecting highway may be T-beam bridge,rigid frame type and prestressed concrete bridges.
- ✓ There should be vertical clearance of atleast 4.3m.
- ✓ Type of bridge structure should be selected depending on design ,construction and other consideration like site condition etc.
- ✓ Grade separated intersection are classified as *over-pass* and *under –pass*.

Over-pass

- ✓ Major highway is taken above by rising its profile above the general grond level by embankment and an overbridge across another highway

Advantage

- ✓ Drainage problem may be reduced
- ✓ Cost of bridge structure is less.
- ✓ Future expansion or lateral expansion or construction of separate bridge structure is possible.

Disadvantages

- ✓ In rolling terrain ,vertical profile will also have rolling grade line.
- ✓ By constructing high embankment and by providing steep gradient will result in increased grade resistance
- ✓ Restriction to sight distance

Under pass

- ✓ If the highway is taken by depressing it below the ground level to cross another road by means of an under-bridge ,it is known as under-pass.

Advantages

- ✓ There is a warning to traffic in advance due to the presence of under pass
- ✓ When the major highway is taken below , it is advantageous to the turning traffic.
- ✓ It may be of advantage when main highway is taken along the existing grade

Disadvantage

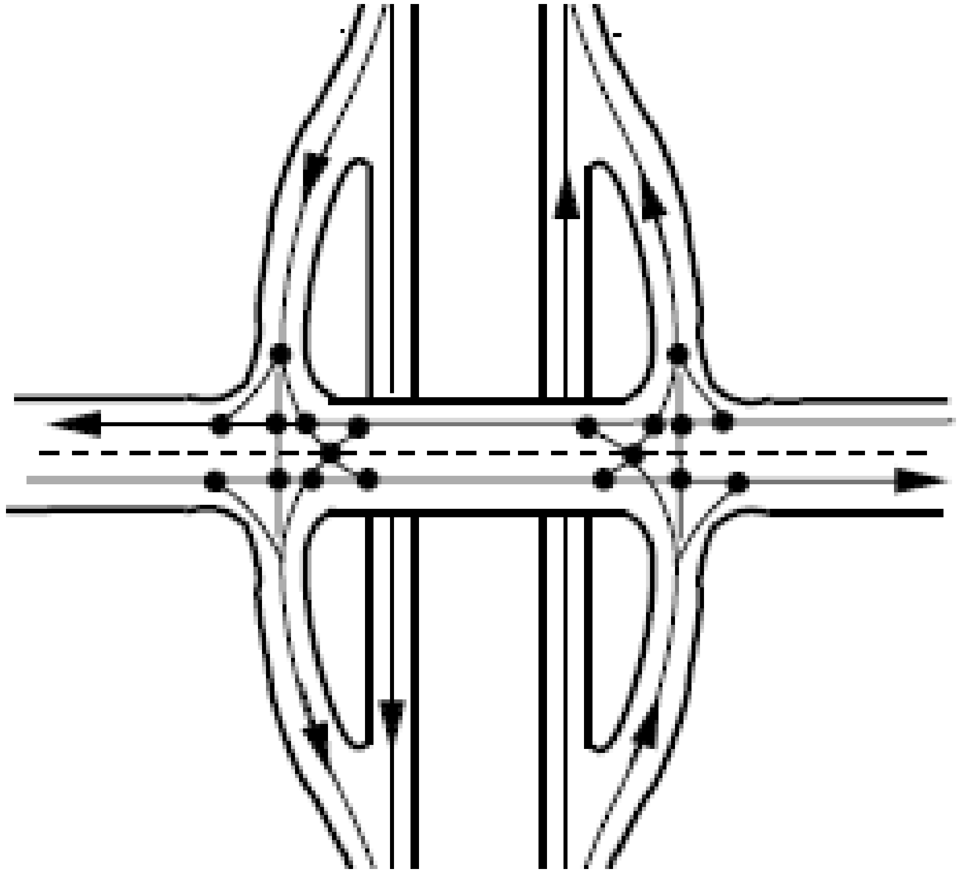
- ✓ Drainage problem
- ✓ The over head structure may resist the vertical sight
- ✓ No possibility of stage construction for bridge structure

INTER CHANGE

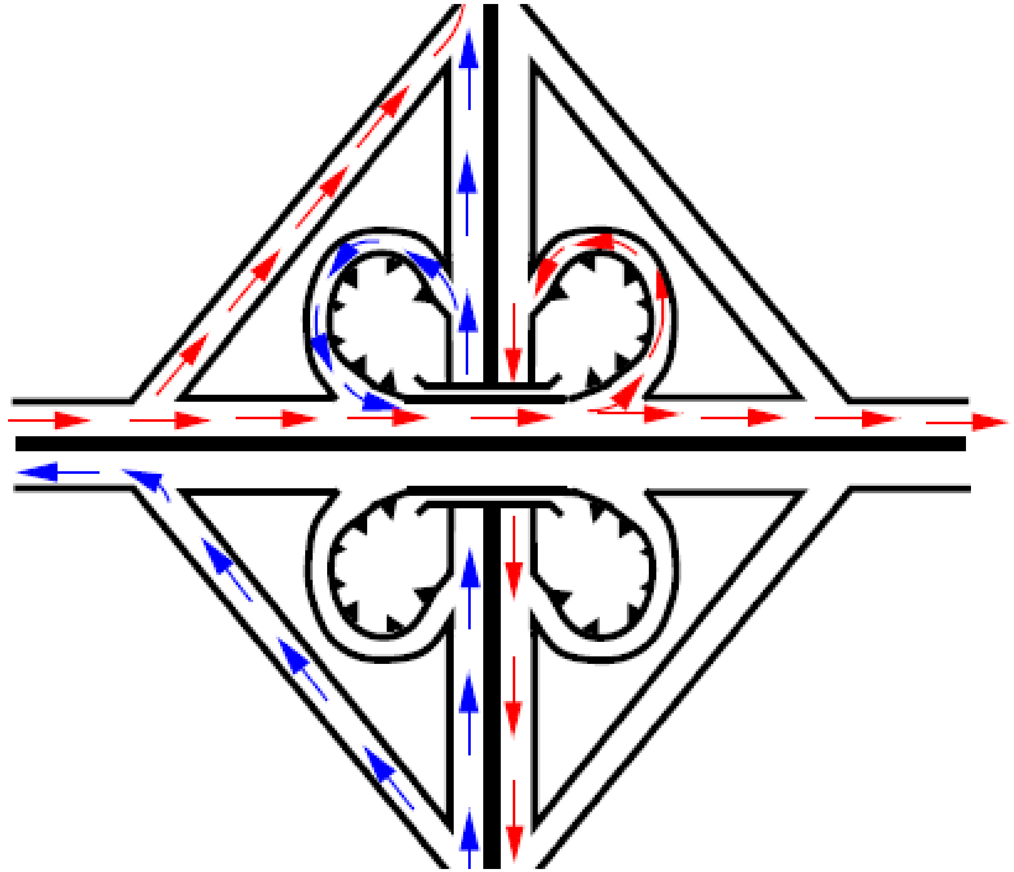
Grade separated intersection with complete interchange facilities is essential to develop a highway with full control of access.

Some types of interchanges are

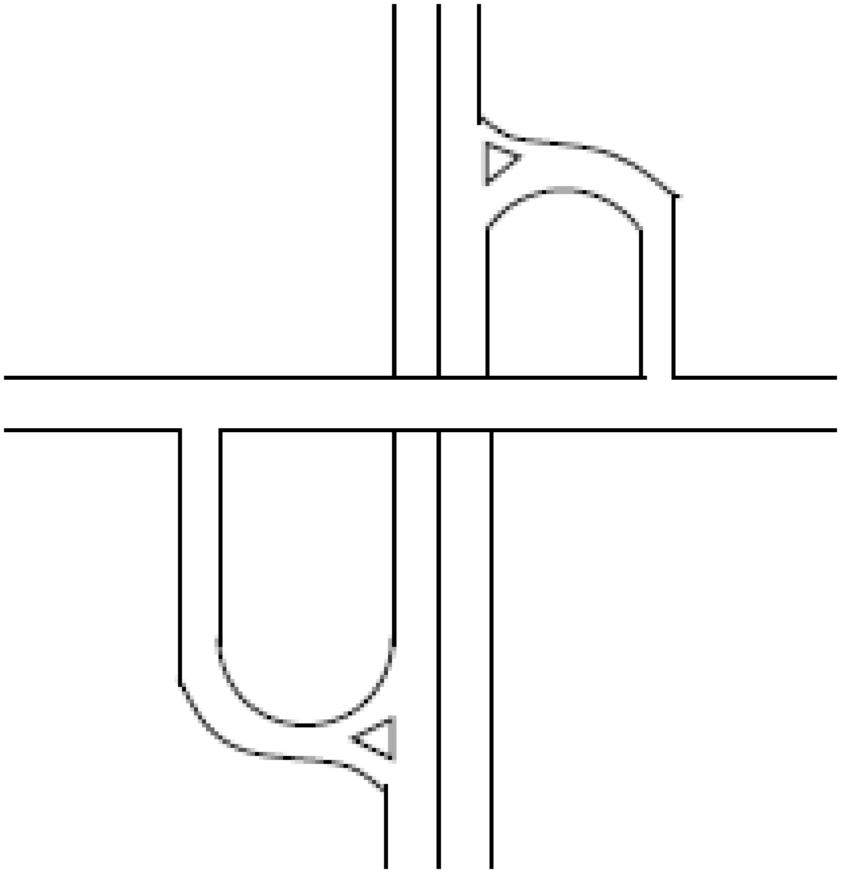
1. Diamond
2. Rotary interchange
3. Partial clover leaf
4. Full clover leaf



DIAMON



CLOVER LEAF INTERCHANGE



PARTIAL CLOVER INTERCHANGE

INTER SECTION AT GRADE

All road intersections which meet at about the same level allowing traffic manoeuvres like merging, diverging, crossing, and weaving are called intersections at grade.

Requirements are,

- Area of conflict should be small
- Relative speed and angle of approach of vehicle should be small
- Adequate visibility
- Sudden change should be avoided
- Geometric features should be provided
- Proper sign should be provided
- Good lighting
- If no. Of pedestrians and cyclists are large, Separate provisions should be made for safe passage

Examples foe channelized and unchannellized intersection

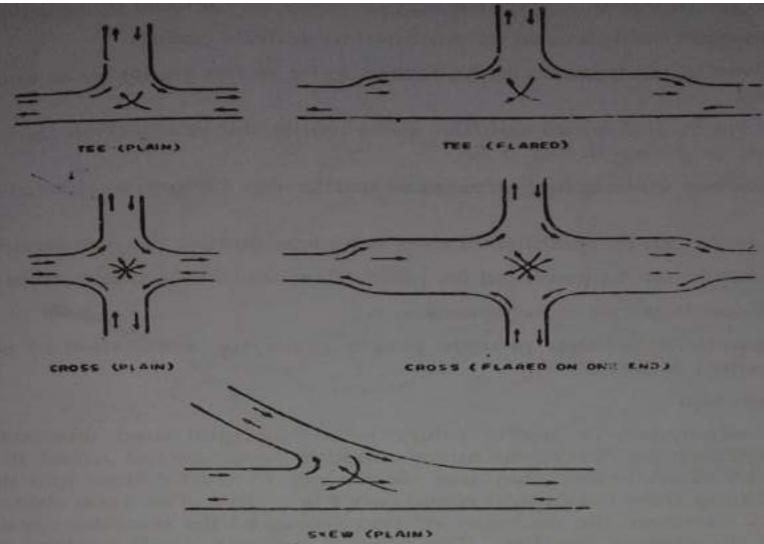


Fig. 5.34 Unchannelized Intersections

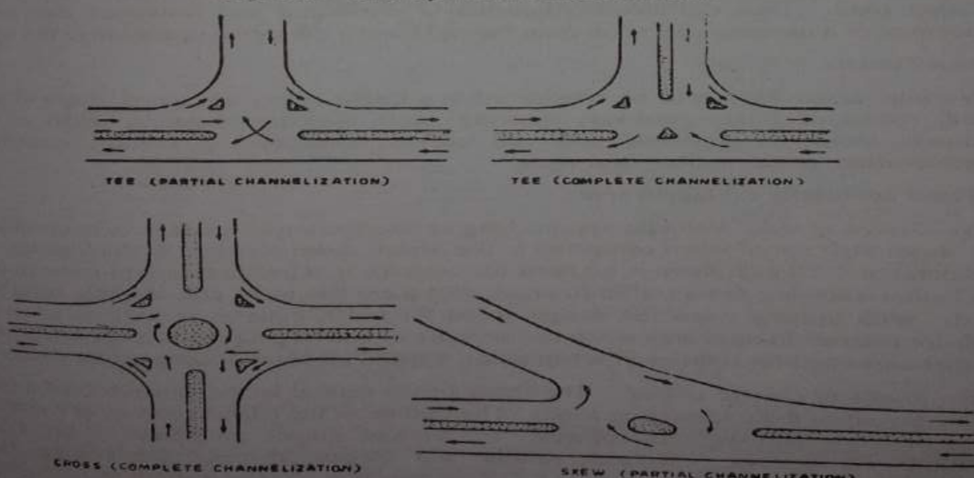


Fig. 5.35 Channelized Intersections

Various forms of intersections

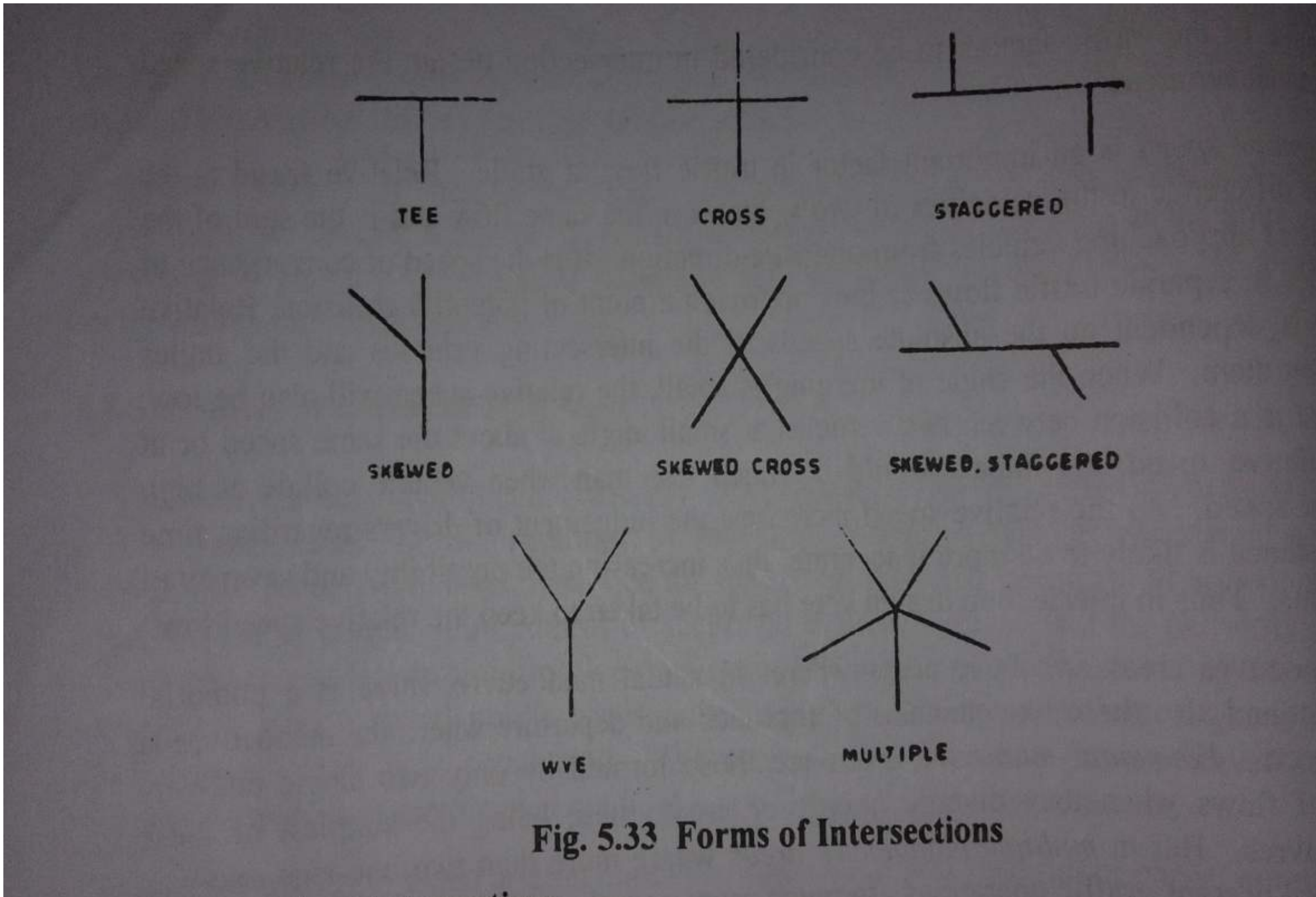


Fig. 5.33 Forms of Intersections

Intersections may be Classified into two

- Unchannelized intersections
- Channelized intersection

UNCHANNNELIZED INTERSECTION (all paved)

The intersection area is paved and there is no restriction to vehicles to use of any part of intersection area.

hence the unchannelized intersection are the

- Lowest class of intersection
- Easiest in design
- Most complex in traffic operation
- Resulting maximum conflict area
- When no additional pavement width for turning movement – called plain intersection

- when pavement is widened at intersection – called flared intersection
- In fig arrows indicate – path of traffic flow, turning, crossing and through movements

CHANNELIZED INTERSECTIONS

- ❖ Achieved by – introducing islands into intersectional area
- ❖ Reducing the total conflict area available in the unchannelized intersection
- ❖ To accommodate the channelizing islands- radius of the entrance, exit curves and area are suitably designed
- ❖ islands helps- channelized turning traffic, to control their speed and angle of approach to decrease the conflict area
- ❖Thes intersections are may be partial or complete with divisional and directional islands and medians
- ❖ here better control of traffic on the traffic entering and leaving

Advantages of channelized intersection

- Vehicles can be confined to definite paths
- Cause minimum disruption
- Angle between intersecting streams of traffic may be kept as desired in favourable way
- Speed control can be established
- Points of conflicts can be separated
- Provide proper place for installation of signs and traffic control devices

Advantages of channelized intersection

- Vehicles can be confined to definite paths
- Angle of merging streams can be forced to be flat Cause minimum disruption
- Angle between intersecting streams of traffic may be kept as desired in favourable way
- Speed control can be established
- Points of conflicts can be separated
- Provide proper place for installation of signs and traffic control devices
- Both major and minor conflict area within the intersection considerably decreased

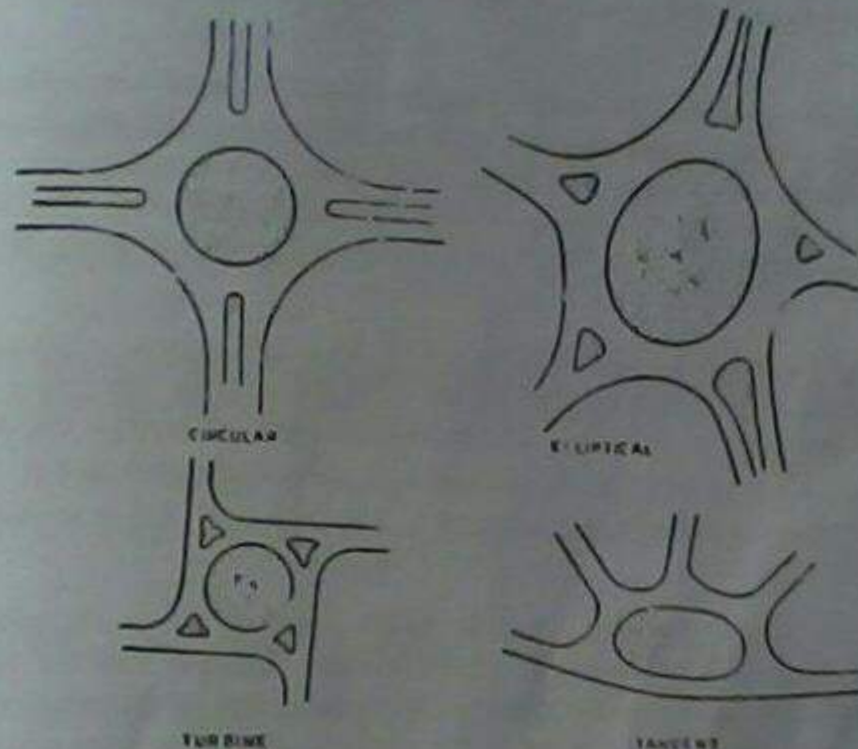


Fig. 5.37 Shapes of Rotary Islands

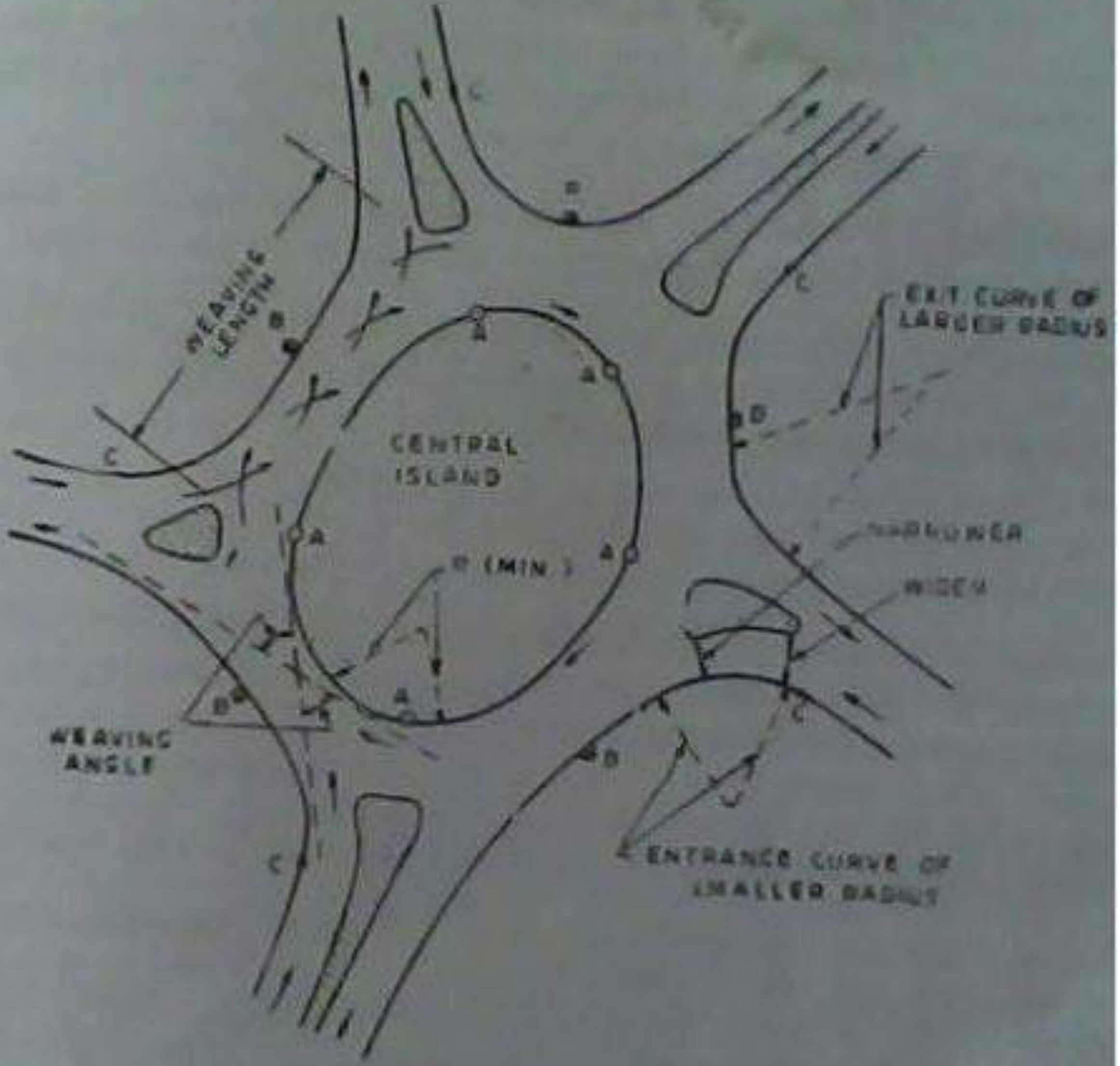


Fig. 5.36 Rotary Intersection

ROTARY INTERSECTION

- Enlarged road intersection.
- All the converging vehicles are forced to move round a large central island in one direction.
- direction- clock wise direction
- Objective:
  - eliminate the stopping of vehicle
  - Reduce area of conflict.
- Crossing of vehicle is avoided by
  - vehicles merge into the stream
  - Then to diverge out to the desired radiating road
- Crossing conflict is eliminated.

Design factors of Rotary

1. Speed

- Vehicles have to slow down their speed than design speed , even if in the NH design speed is considered.
- No need of dead stop
- Speed at rotary in India:
  a. 40kmph in rural area.
  b. 30kmph in urban area and other cases.

2. Shape of central island

- Depends on the number and the layout of the intersecting roads
- Different shapes adopted are
  1. Circular
  2. Elliptical
  3. Turbine
  4. Tangent
- Circular shape: When 2 equally imp roads cross at roughly right angle.

- Island may be elongated
  - To accommodate in the layout 4 or more intersecting roads
  - To allow for the greater traffic flow along the direction of elongation
- Too much elongation and tangent shape : not desirable bcz there will be tendency for the traffic to move much faster.
- Turbine shape:
  - reduction the vehicle speed at the entering of the rotary and enables speeding up of the vehicles going out
  - the headlight glare is a limitation of the design at night.

3. Radius of rotary roadway

- One way rotary road round the island has different radii at different points depending on the shape of the island
- Adequate super elevation cannot be provided and hence it is safer to neglect the super elevation and to take friction only into consideration and hence the radius of curvation

$$R= V*V/(127*f)$$

- f= 0.43 and design speed: 20-35m for 40kmph
- f=0.47 and design speed:15-25m for 30kmph
- Factor of safety :1.5
- Recommended min radii of central island: 1.33 times the radius of entry curves.

4.Weaving angle and weaving distance

- Weaving angle: angle b\w the path of a vehicle entering the rotary and that of another vehicle leaving the rotary in adjacent road.
- weaving length: length of rotary roadway
- For smooth flow of traffic, weaving angle should not less than 15degree as the dia of central island required is too large.
- For any design speed, the freedom of movement on a rotary depends on the size of weaving area.
- Weaving length:at least (4 X width of the weaving section)
- Recommended value:
  - Weaving length: 45 to 90m for 40kmph
  - Weaving length: 30 to 60m for 30kmph

5. Width of carriageway at entry and exit

- It is governed by amount of traffic entering and leaving the rotary.
- Minimum width of carriageway at entrance and exit : 5m
- Entry width (e1) may inc.ed to 6.5,7 & 8 when width of approaching road is 7,10.5 & 14 and radius at entry is 25 to 35m.

6. Width of rotary roadway

- All the traffic go round the one way roadway aleast for a short distance.
- Outer kerb line follow the entrance and exit-sides of roads.
- Actual width of roadway varies section to section.
- Effective width of rotary roadway: minimum width of the roadway b/w edge of the central island and adjoining kerb.
- It determines the capacity of rotary.
- Width of the non-weaving section (e2)=widest single entry
- e2< the width of the weaving section(W).
- W of the rotary : one traffic wider than the mean width of entry and non-weaving section i.e.

$$W = \frac{(e1+e2)}{2} + 3.5$$

7.Entrance and exit curves

- Curve traced by the inner rear wheel determines the radius and shapes of the kerb to be set.
- Radius of entrance curve= minimum recommended radius of central island.
- Radius at entry curve= 20 to 35m for 40kmph

  =15 to 25m for 30kmph
- Easy for bus to take right angle turn at curve in design speed.
- Exit curve should have larger dia as the speed inc.ed in radiating roads.
- Reasonable radius of exit curves is one and a half to 2 times radius of entry.
- Extra widening at entry and entrance curve is provided.
- Pavement width at entrance curve > than at exit curve as the radius of former is less than the later.

8.Capacity of the rotary:

Practical capacity depends on the minimum capacity of the individual weaving section.

Practical capacity $Q_p = \dfrac{280W(1+e/w)(1-p/3)}{(1+W/L)}$

Where, Qp = practical capacity of the weaving section of a rotary in pcu per hour.

W = width of weaving section(6to 18m)

e = avg width of entry e1& width of non-weaving s/c e2 for the range e/W = 0.4 to 1.0

L = length of the weaving s/c btw the ends of channelizing islands in metre for the range of W/L= 0.12 t 0.4.

p = proportion of weaving traffic given by

$$p = \frac{b+c}{a+b+c+d} \quad \text{in the range 0.4 to 1.0}$$

a = left turning traffic moving along left extreme lane.

d= right turning traffic moving along right extreme lane.

b= crossing traffic turning towards rgt while entering the rotary.

c= crossing traffic turning towards left while leaving the rotary.

The IRC has recommended the following PCU(Passenger car unit) values for finding the capacity of the rotary :

Cars, light commercial vehicles and three-wheelers = 1.0

Buses and heavy commercial vehicles = 2.8

Motor cycles ,scooters = 0.75

Pedal cycles = 0.50

Animal drawn vehicles = 4 to 6

9.Channelizing islands:

- Provided at the entrance & exit of the rotary to prevent undesirable weaving,& turning & to reduce area of conflict.
- Helps vehicles to reduce speed to the design speed.
- Serve as convenient place for erecting traffic signs & as a pedestrian refuge.
- Shape & size governed by:

  1.Radius of the rotary

  2. Radii of the entrance & exit curves

  3.Angles & layout of the radial road &rotary.
- Generally provided with kerbs 15 t0 21cm high.

10. Camber & Superelevation:

- Vehicle passing along rotary traverses a reverse curve while changing from one-path of roadway to the exit of the radial road.
- Cross slope should be min at the point of change in direction.
- Inward slope of camber serves as superelevation, though design of the curve made assuming no superelevation.
- Outer slope helps vehicles turning left towards the exit curve to the radiating road.

11. Sight distance, grade:

- Sight distance should be large as possible.
- Should not be less than safe stopping distance for the design speed.
- min sight distance= 45-30m for design speed of 40-30kmph resp.
- locate rotary on level ground or with slope not exceeding 1 in 50 with the hzl.

12. Lighting :

- Min lighting-one each on the edge of island facing each radiating road.
- Additional lights when the central island is larger than 60m dia.
- If pedestrians are more, then lighting is provided at the entrance curve.

13. **Traffic Signs**:

- Should be installed at all approaching roads .
- Red reflector is placed at 1m abv road level on the nose of each directional island & on the kerb of the central island.
- Vertical balck&white strips of width 25-30cm painted on kerb of central island & channelizing islands improve visibility.

14. Provision for cyclists and pedestrians:

- As far as possible pedestrians & cyclists should be isolated from the general traffic utilizing the rotary.
- If the cyclists are less than 50per hour they may be permitted to mix up with the other traffic.
- If they are more, a separate cycle track is provided.
- If a large no of pedestrians, separate foot path with guard rails should be provided around the rotary.
- Provision of crossing facilities to pedestrian by subway or over bridge is possible solution for pedestrian crossing in rotary.

DESIGN OF INTERSECTION

Design factors of Rotary

1. Speed
    a. 40kmph in rural area.
    b. 30kmph in urban area and other cases.

2. Shape of central island

Different shapes adopted are

1. Circular
2. Elliptical
3. Turbine
4. Tangent

3. Radius of rotary roadway

Radius at entry

- 20-35m for 40kmph
- f=0.47 and design speed:15-25m for 30kmph

Radius at exit=1.5 to 2 timesradius at entry curve

Radius at entry curve=1.33xradius at entry

weaving length

- weaving length: length of rotary roadway
- Weaving length:at least (4 X width of the weaving section)
- Recommended value:
  - Weaving length: 45 to 90m for 40kmph
  - Weaving length: 30 to 60m for 30kmph

.Width of carriageway at entry and exit

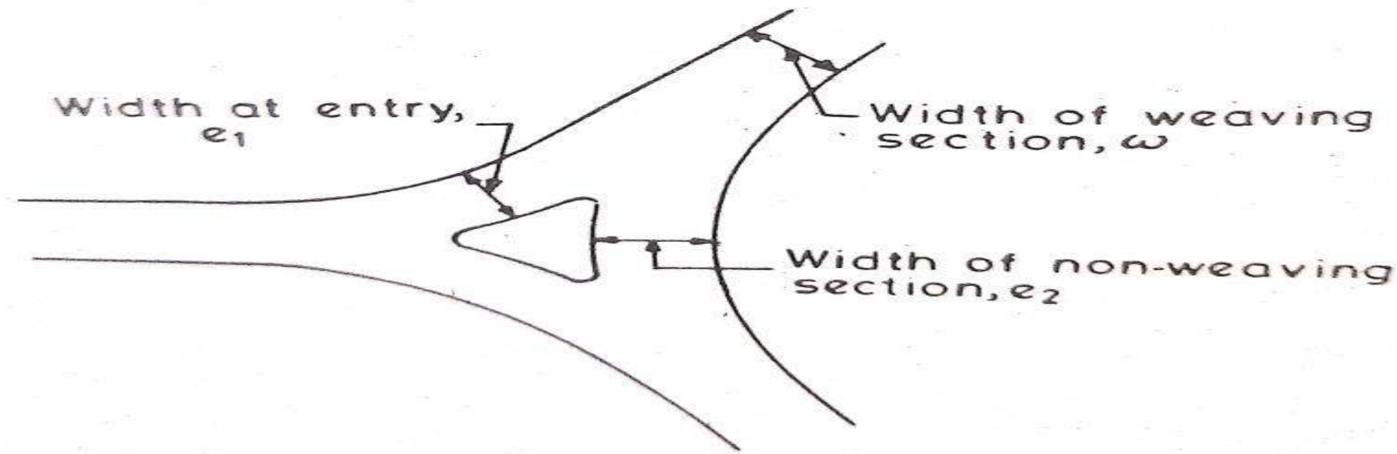
Table 11·[illegible]

Width of Carriageway at Entrance and Exit

(*Source* : Ref. 26)

Carriageway width of approach road	*Radius at entry (m)*	*Width of carriageway at entry and exit (m)*
7 m (2 lanes)	25–35	6·5
10·5 m (3 lanes)		7·0
14 m (4 lanes)		8·0
21 m (6 lanes)		13·0
7 m (2 lanes)	15–25	7·0
10·5 m (3 lanes)		7·5
14 m (4 lanes)		10·0
21 m (6 lanes)		15·0

Width of rotary roadway



$$W = \frac{(e1+e2)}{2} + 3.5$$

$$e = \frac{(e1+e2)}{2}$$

$$W = \frac{(e1+e2)}{2} + 3.5$$

$$e = \frac{(e1+e2)}{2}$$

11·10·16·7·8. Entry and exit angles

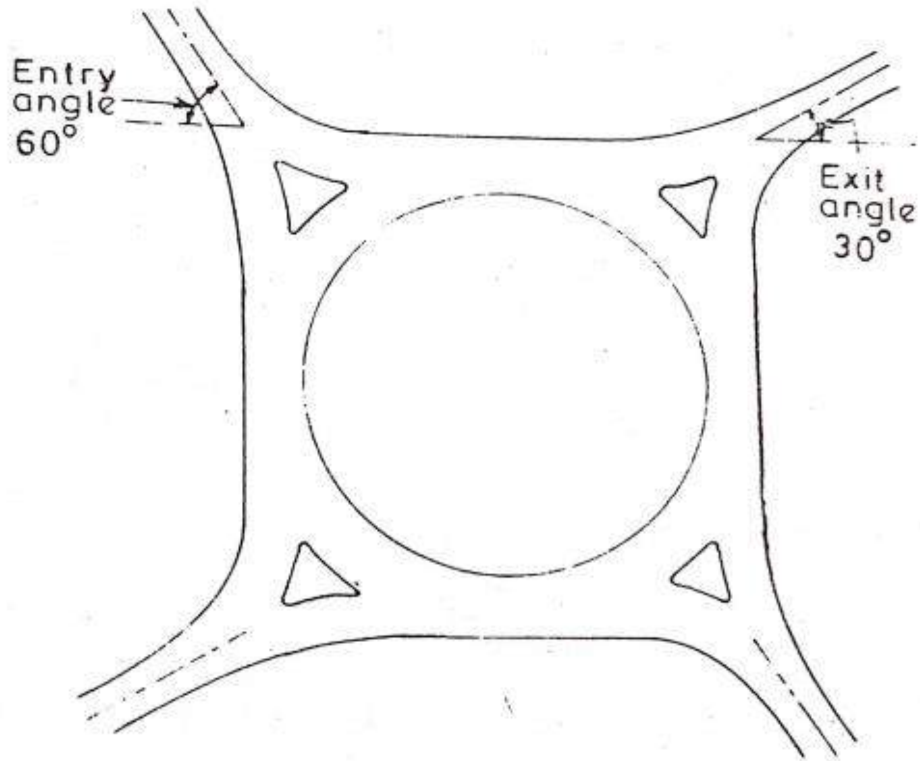


Fig. 11·65. An ideal layout with 60° entry angle and 30° exit angle

8.Capacity of the rotary:

Practical capacity $Q_p = \frac{280W(1+e/w)(1-p/3)}{(1+W/L)}$

Where, Qp = practical capacity of the weaving section of a rotary in pcu per hour.

W = width of weaving section(6to 18m)

$W = \frac{(e1+e2)}{2} + 3.5$

$e = \frac{(e1+e2)}{2}$

L = length of the weaving s/c btw the ends of channelizing islands in metre for the range of W/L=0.12 t 0.4.

p = proportion of weaving traffic given by

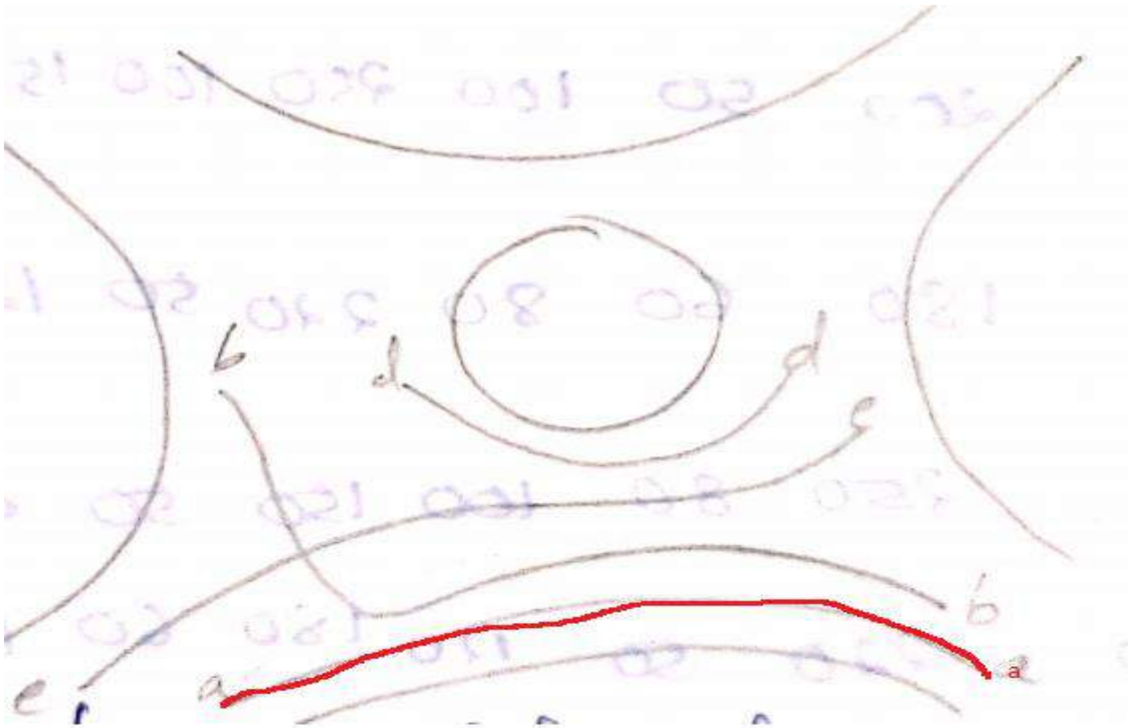
$$p = \frac{b+c}{a+b+c+d} \quad \text{in the range 0.4 to 1.0}$$

a = left turning traffic moving along left extreme lane.

d= right turning traffic moving along right extreme lane.

b= crossing traffic turning towards rgt while entering the rotary.

c= crossing traffic turning towards left while leaving the rotary.



$$p = \frac{b+c}{a+b+c+d}$$ in the range 0.4 to 1.0

The IRC has recommended the following PCU(Passenger car unit) values for finding the capacity of the rotary :

Cars, light commercial vehicles and three-wheelers = 1.0

Buses and heavy commercial vehicles = 2.8

Motor cycles ,scooters = 0.75

Pedal cycles = 0.50

Animal drawn vehicles = 4 to 6

Problem 11·1. *Traffic flow in an urban sections at the intersection of two highways in the design year are given below :*

	Left turning			Straight ahead			Right turning		
Approach	Cars	Commercial	Scooters	Cars	Commercial	Scooters	Cars	Commerical	Scooters
N	200	50	100	250	100	150	150	50	80
E	180	60	80	220	50	120	200	40	120
S	250	80	100	150	50	90	160	70	90
W	220	50	120	180	60	100	250	60	100

The highways at present intersect at right angles and have a carriageway width of 15 m. Design a rotary intersection making suitable assumptions.

- Assume design speed =30kmph (urban area)
- Assume a circular central island
- Assume radius of entry =20 m
- Assume radius of exit =2x radius of entry =2x20=40m
- Radius of central island =1.33xradius of entry =1.33x20=28 m
- Weaving length =30m
- Width of carriageway at entry and exit =10m
  - $e = \frac{(e1+e2)}{2} = 10$ m   e1=10 m & e2=10 m

- Width of weaving section, $W = \frac{(e1+e2)}{2} + 3.5 = 13.5m$

$$\frac{weaving\ length}{weaving\ width} = \frac{4}{1}$$

$$l : w = 4 : 1$$

$$\frac{l}{w} = \frac{30}{13.5} = 2.2 < 4$$

$$l = 4 \times w = 4 \times 13.5 = \underline{\underline{54\ m}}$$

Approach	Left turning			Straight ahead			Right turning		
	Cars	Commercial	Scooters	Cars	Commercial	Scooters	Cars	Commerical	Scooters
N	200	50	100	250	100	150	150	50	80
E	180	60	80	220	50	120	200	40	120
S	250	80	100	150	50	90	160	70	90
W	220	50	120	180	60	100	250	60	100

	Vehicle type	*PCU*
1.	Cars and light commercial vehicles, including 3-wheelers	1·0
2.	Buses and medium heavy commercial vehicles	2·8
3.	Motorcycles and scooters	0·75
4.	Pedal cycles	0·5
5.	Animal drawn vehicles	4 to 6

Approach	Left Turning	Straight ahead	Right Turn
N	$200 \times 1 + 50 \times 2.8 + 100 \times 0.75 = 415$	642.5 ≈ 643	350
E	408	450	402
S	540	357.5 ≈ 358	423.5 ≈ 424
W	450	423	403

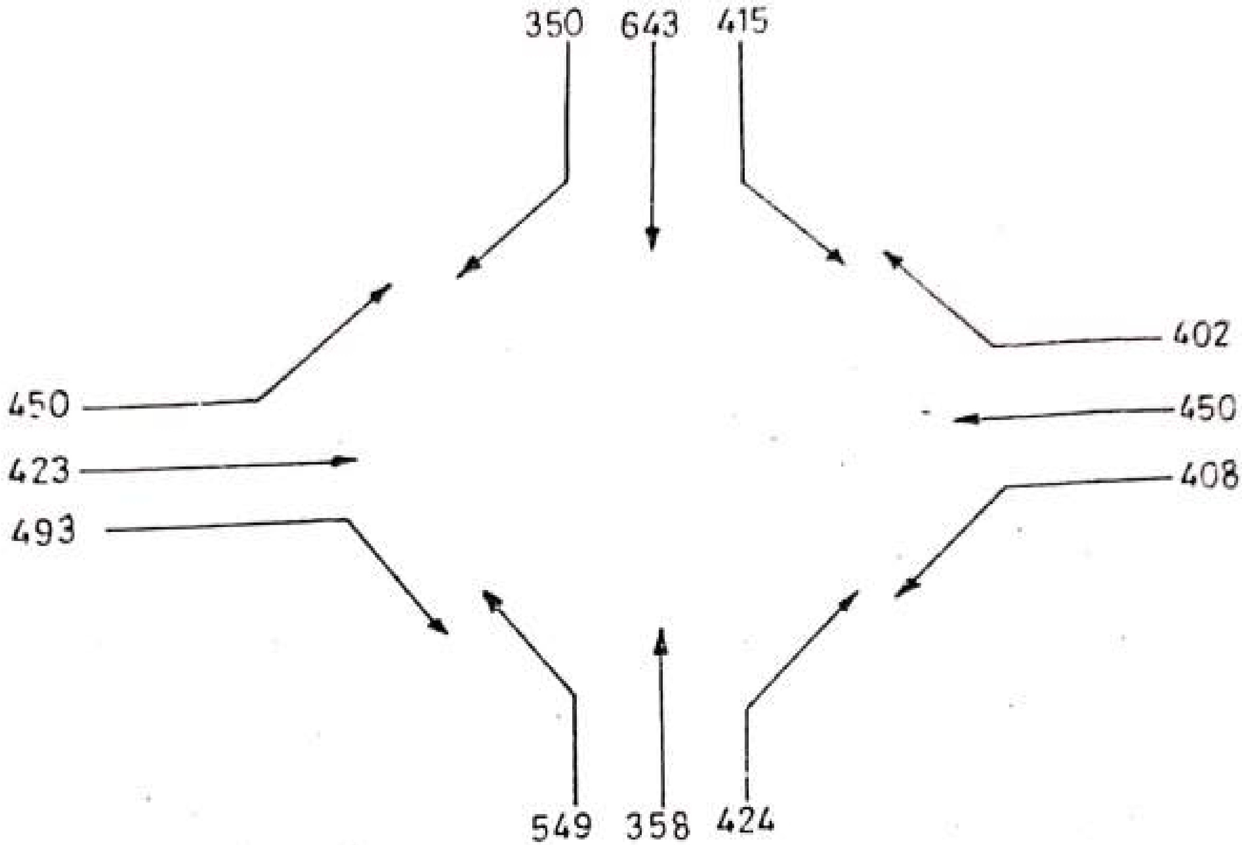
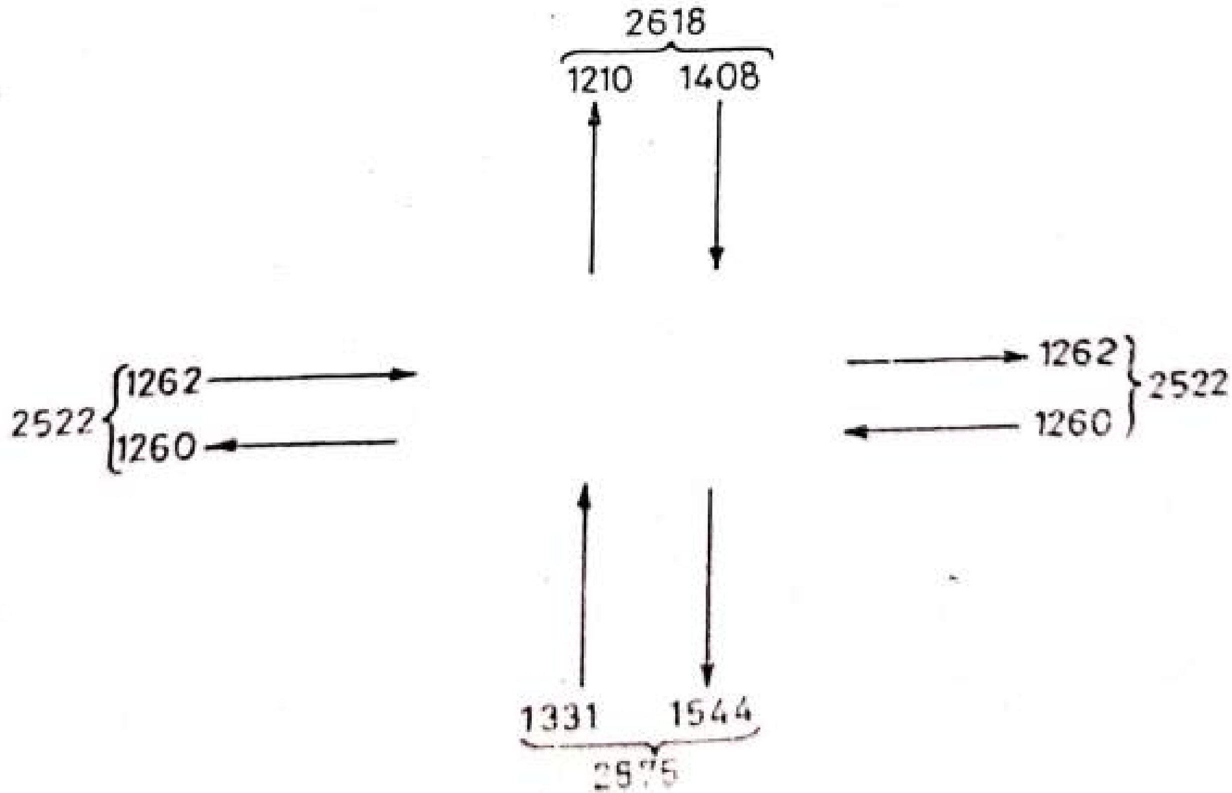
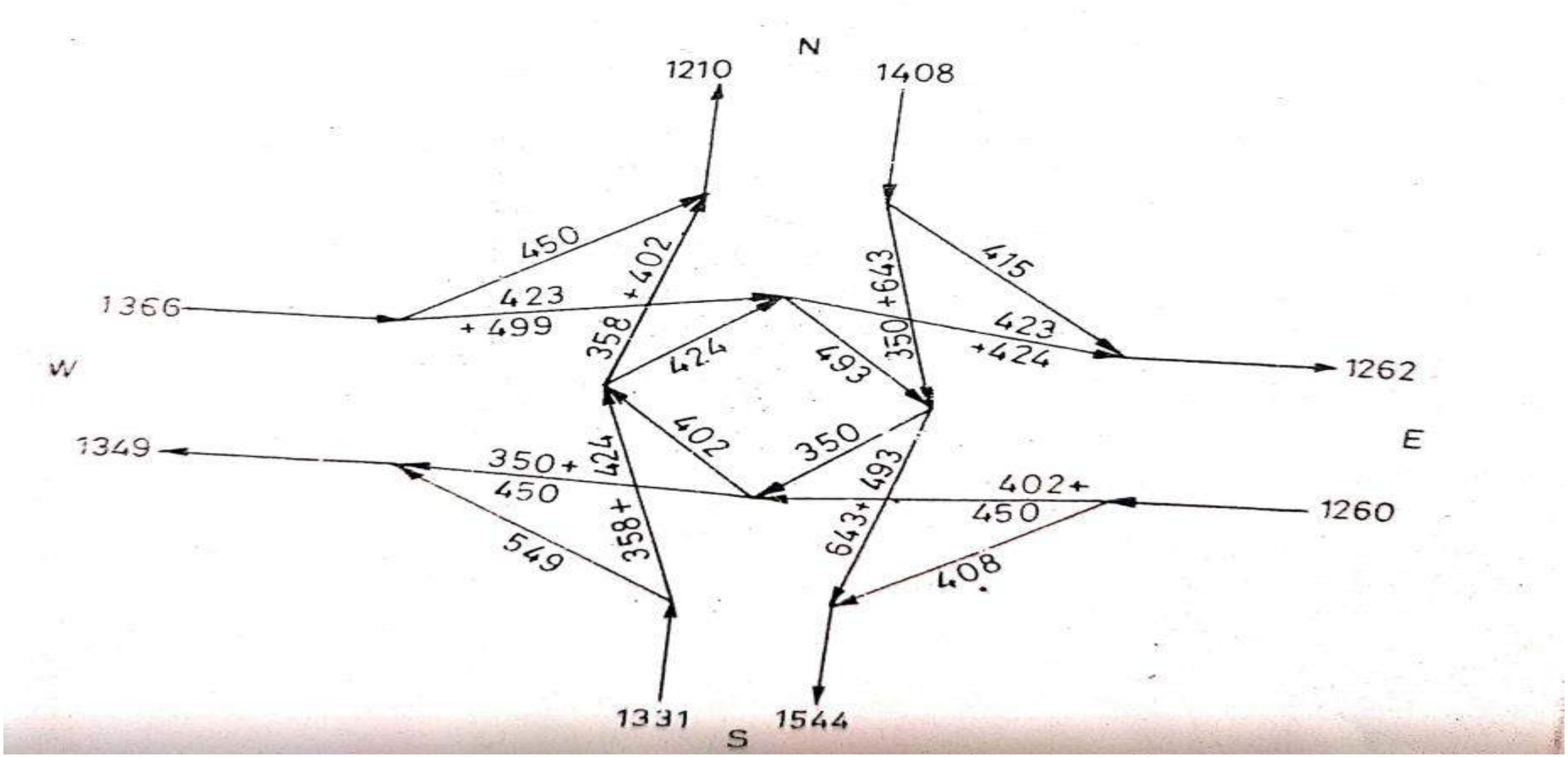


Fig. 11·68


2618
1210
1408
2522
1262
1260
1262
2522
1260
1331
1544

The traffic is assigned to the network in Fig. 11·70.



- Weaving traffic in each direction
- N-E=643+350+423+424=1840
- E-S=643+493+450+402=1988
- S-W=1331+54981582
- W-N=358+402+423+493=1672

DESIGN OF INTERSECTION

Design factors of Rotary

1. Speed
    a. 40kmph in rural area.
    b. 30kmph in urban area and other cases.

2. Shape of central island

Different shapes adopted are

1. Circular
2. Elliptical
3. Turbine
4. Tangent

3. Radius of rotary roadway

Radius at entry

- 20-35m for 40kmph
- f=0.47 and design speed:15-25m for 30kmph

Radius at exit=1.5 to 2 timesradius at entry curve

Radius at entry curve=1.33xradius at entry

weaving length

- weaving length: length of rotary roadway
- Weaving length:at least (4 X width of the weaving section)
- Recommended value:
  - Weaving length: 45 to 90m for 40kmph
  - Weaving length: 30 to 60m for 30kmph

.Width of carriageway at entry and exit

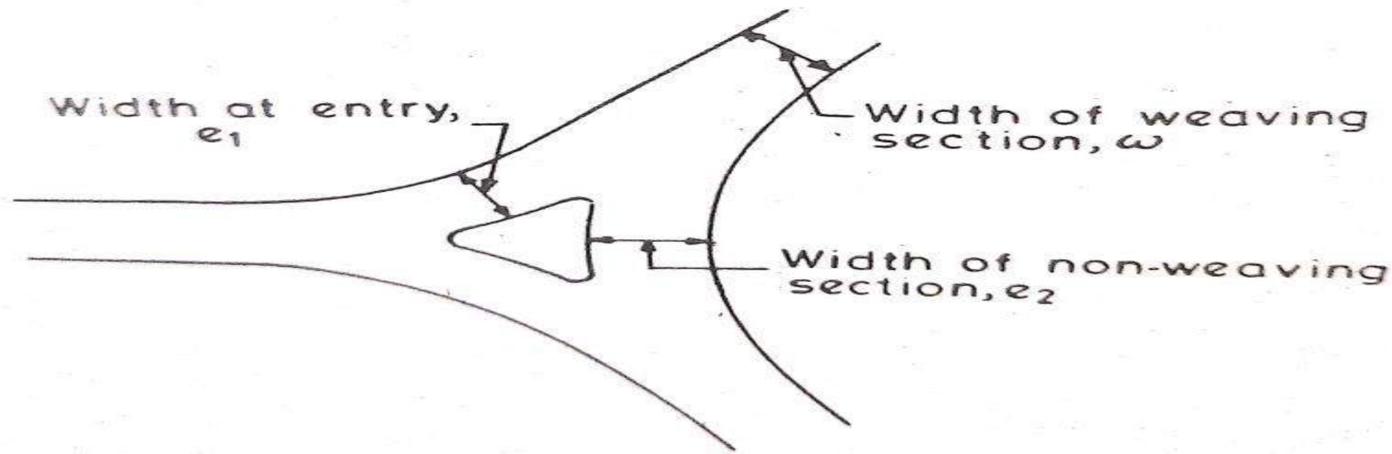
Table 11·34

Width of Carriageway at Entrance and Exit

(*Source* : Ref. 26)

Carriageway width of approach road	*Radius at entry (m)*	*Width of carriageway at entry and exit (m)*
7 m (2 lanes)	25–35	6·5
10·5 m (3 lanes)		7·0
14 m (4 lanes)		8·0
21 m (6 lanes)		13·0
7 m (2 lanes)	15–25	7·0
10·5 m (3 lanes)		7·5
14 m (4 lanes)		10·0
21 m (6 lanes)		15·0

Width of rotary roadway



$$W = \frac{(e1+e2)}{2} + 3.5$$

$$W = \frac{(e1+e2)}{2} + 3.5$$

$$e = \frac{(e1+e2)}{2}$$

$$e = \frac{(e1+e2)}{2}$$

11·10·16·7·8. Entry and exit angles

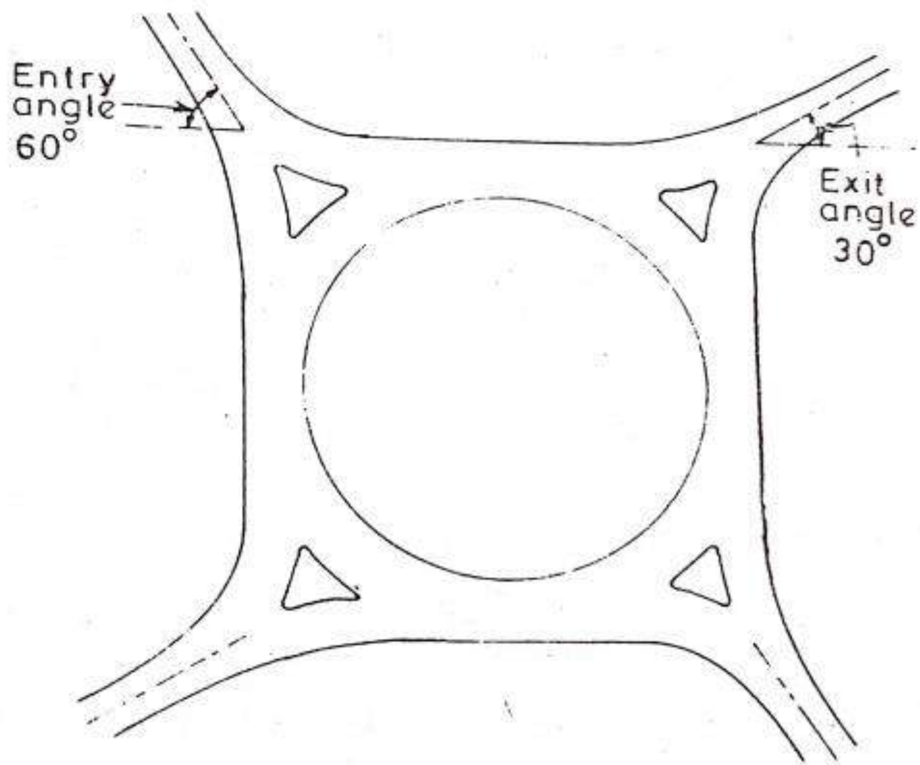


Fig. 11·65. An ideal layout with 60° entry angle and 30° exit angle

8.Capacity of the rotary:

Practical capacity $Q_p = \frac{280W(1+e/w)(1-p/3)}{(1+W/L)}$

Where, Qp = practical capacity of the weaving section of a rotary in pcu per hour.

W = width of weaving section(6to 18m)

$$W = \frac{(e1+e2)}{2} + 3.5$$

$$e = \frac{(e1+e2)}{2}$$

L = length of the weaving s/c btw the ends of channelizing islands in metre for the range of W/L=0.12 t 0.4.

p = proportion of weaving traffic given by

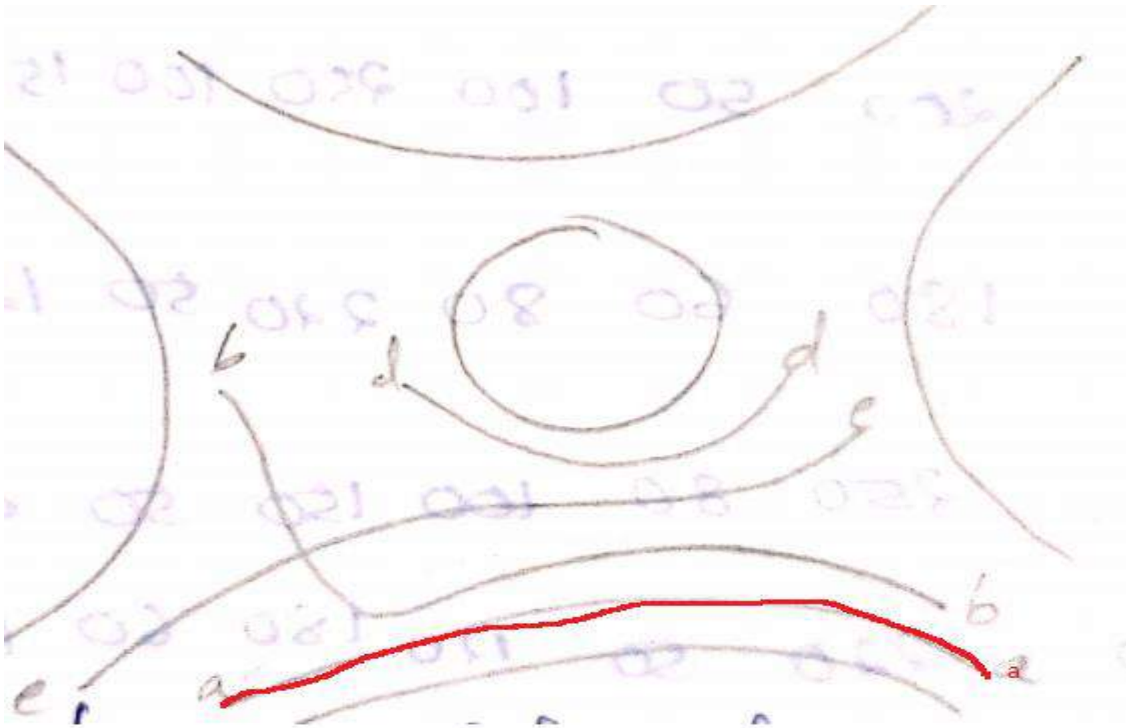
$$p = \frac{b+c}{a+b+c+d} \quad \text{in the range 0.4 to 1.0}$$

a = left turning traffic moving along left extreme lane.

d= right turning traffic moving along right extreme lane.

b= crossing traffic turning towards rgt while entering the rotary.

c= crossing traffic turning towards left while leaving the rotary.



$$p = \frac{b+c}{a+b+c+d} \quad \text{in the range 0.4 to 1.0}$$

The IRC has recommended the following PCU(Passenger car unit) values for finding the capacity of the rotary :

Cars, light commercial vehicles and three-wheelers = 1.0

Buses and heavy commercial vehicles = 2.8

Motor cycles ,scooters = 0.75

Pedal cycles = 0.50

Animal drawn vehicles = 4 to 6

Problem 11·1. *Traffic flow in an urban sections at the intersection of two highways in the design year are given below :*

Approach	Left turning			Straight ahead			Right turning		
	Cars	Commercial	Scooters	Cars	Commercial	Scooters	Cars	Comerical	Scooters
N	200	50	100	250	100	150	150	50	80
E	180	60	80	220	50	120	200	40	120
S	250	80	100	150	50	90	160	70	90
W	220	50	120	180	60	100	250	60	100

The highways at present intersect at right angles and have a carriageway width of 15 m. Design a rotary intersection making suitable assumptions.

- Assume design speed =30kmph (urban area)
- Assume a circular central island
- Assume radius of entry =20 m
- Assume radius of exit =2x radius of entry =2x20=40m
- Radius of central island =1.33xradius of entry =1.33x20=28 m
- Weaving length =30m
- Width of carriageway at entry and exit =10m
  - $e = \frac{e_1 + e_2}{2} = 10$ m $e_1 = 10$ m & $e_2 = 10$ m

- Width of weaving section ,W $= \frac{(e1+e2)}{2} + 3.5 = 13.5m$

$$\frac{weaving\ length}{weaving\ width} = \frac{4}{1}$$

$$l : w = 4 : 1$$

$$\frac{l}{w} = \frac{30}{13.5} = 2.2 < 4$$

$$l = 4 \times w = 4 \times 13.5 = 54\ m$$

Approach	Left turning			Straight ahead			Right turning		
	Cars	Commercial	Scooters	Cars	Commercial	Scooters	Cars	Commerical	Scooters
N	200	50	100	250	100	150	150	50	80
E	180	60	80	220	50	120	200	40	120
S	250	80	100	150	50	90	160	70	90
W	220	50	120	180	60	100	250	60	100

Vehicle type	PCU
1. Cars and light commercial vehicles, including 3-wheelers	1·0
2. Buses and medium heavy commercial vehicles	2·8
3. Motorcycles and scooters	0·75
4. Pedal cycles	0·5
5. Animal drawn vehicles	4 to 6

Approach	Left Turning	Straight ahead	Right Turning
N	$200 \times 1 + 50 \times 2.8 + 100 \times 0.75 = \underline{\underline{415}}$	642.5 ≈ 643	350
E	408	450	402
S	540	357.5 ≈ 358	423.5 ≈ 424
W.	450	423	403

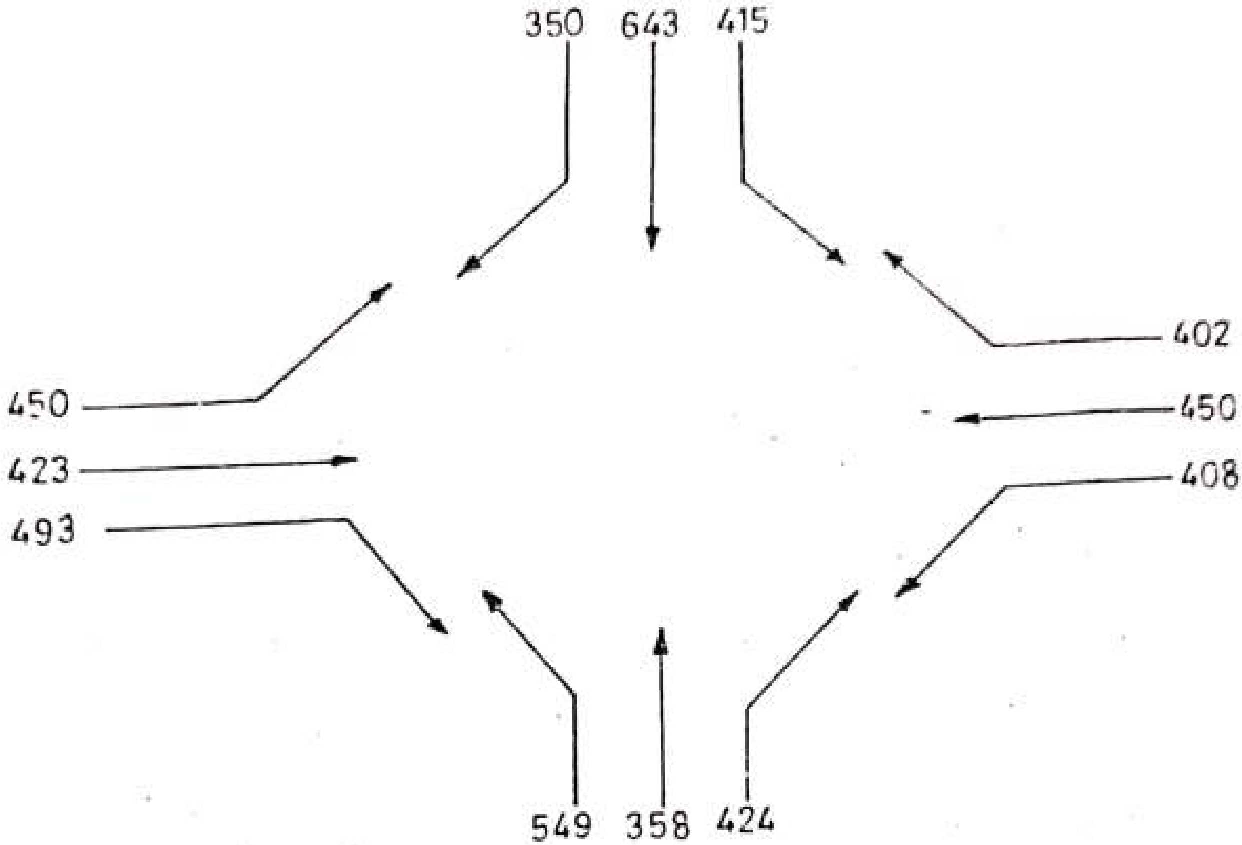
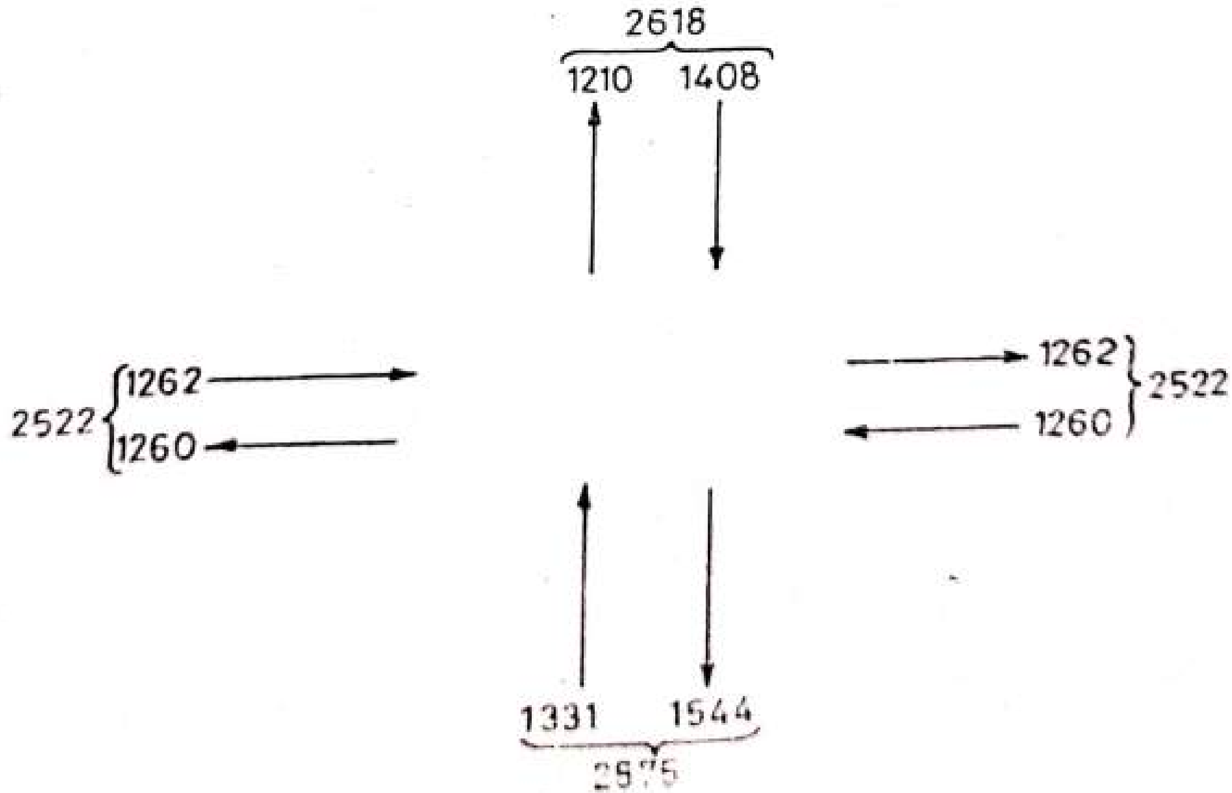
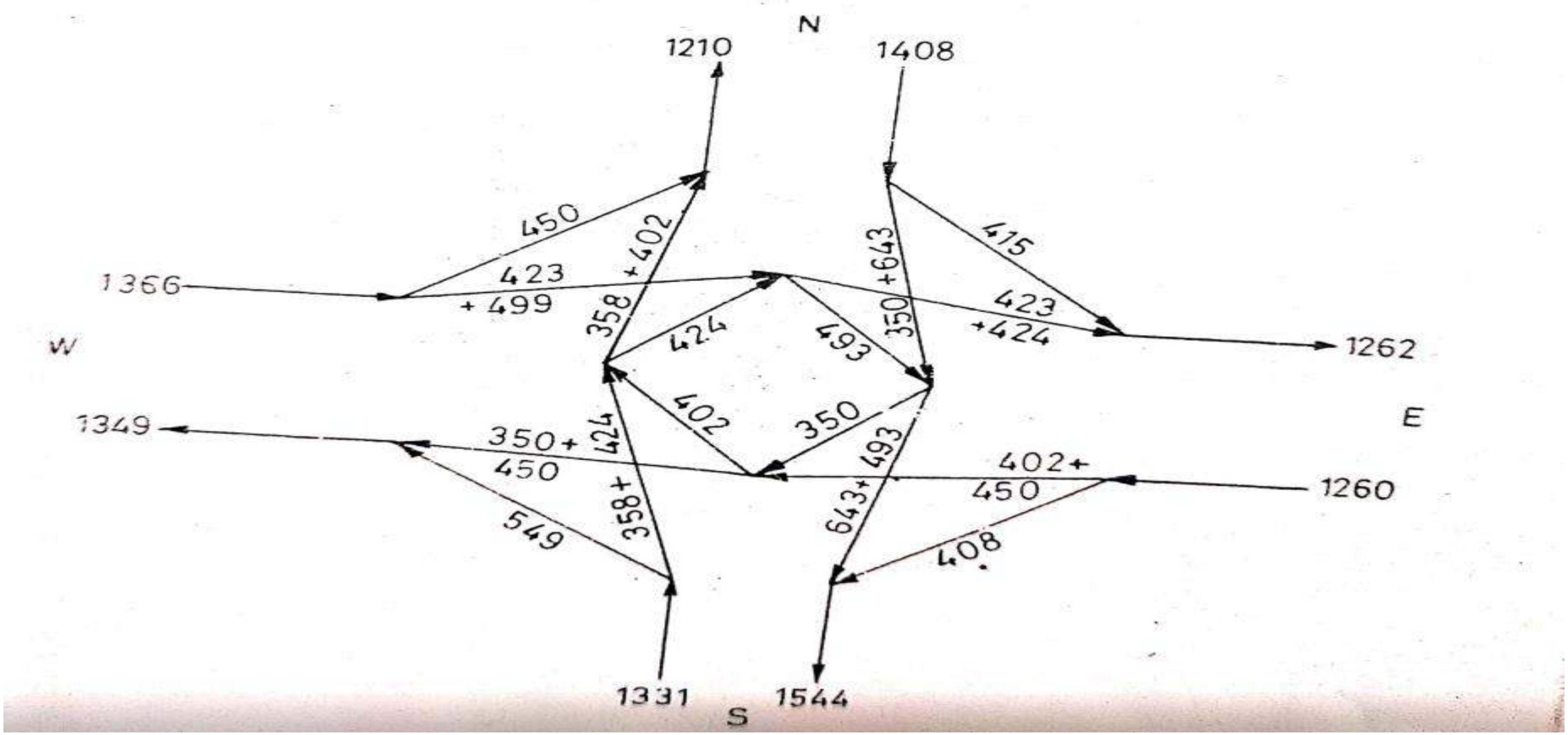


Fig. 11·68


2618
1210
1408
1262
1260
2522
1262
1260
2522
1331
1544

The traffic is assigned to the network in Fig. 11·70.



- Weaving traffic in each direction
- N-E=643+350+423+424=1840
- E-S=643+493+450+402=1988
- S-W=1331+54981582
- W-N=358+402+423+493=1672

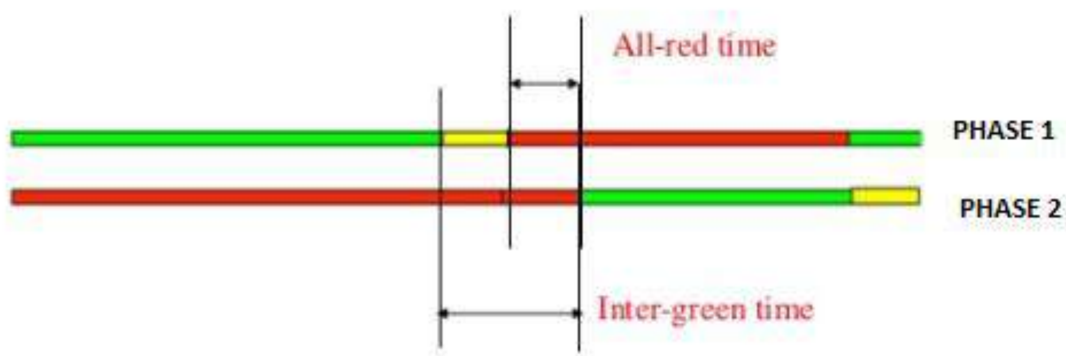
TRAFFIC SIGNAL DESIGN-WEBSTER'S METHOD

Terminology

- Cycle: One complete sequence of the operation of traffic signals.
- Cycle Time/ Cycle length : The time taken to complete one cycle or it is the period of time required for one complete sequence of signal indication.
- Phase of signal: Part of cycle allocated to any combination of traffic movement receiving right of way simultaneously.
- Interval: The path of signal cycle during which signal indications don't change
- Offset: It is the time lag in seconds between the beginning of green phase at intersection and green phase at next intersection
- Intergreen period: The time between end of right of way for a phase and the start of the right of way for the next phase.

Terminology

- All red interval: Time during which the indication is red for all the approaches.
- Lost time: Time not effectively used for vehicle movement



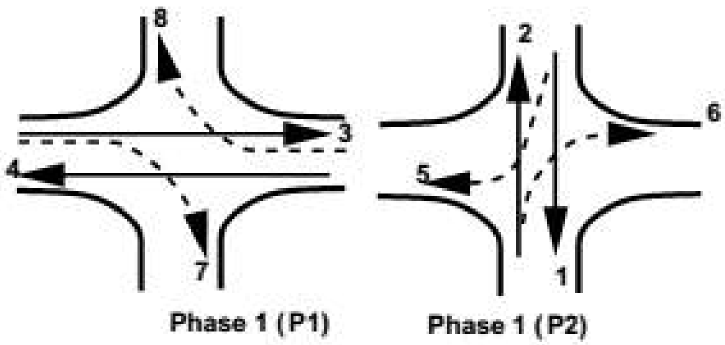


Figure 41:2: Two phase signal

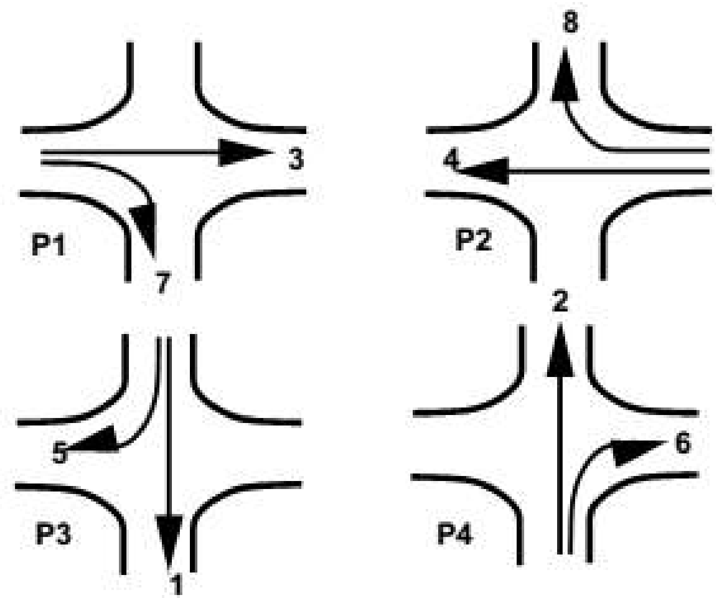


Figure 41:3: One way of providing four phase signals

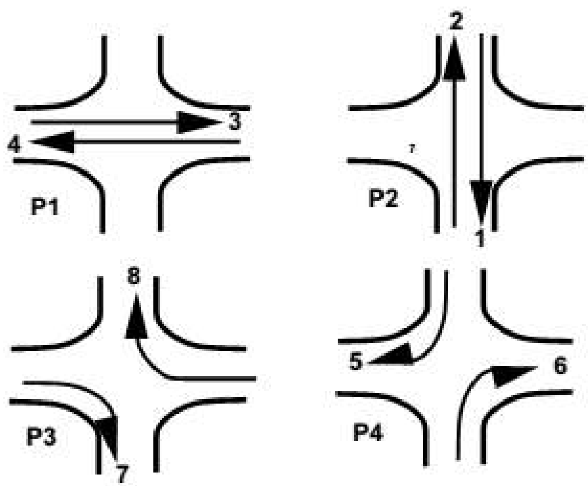


Figure 41:4: Second possible way of providing a four phase signal

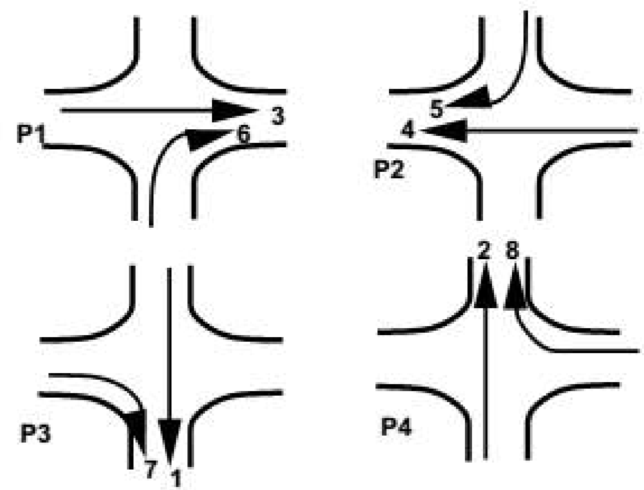


Figure 41:5: Third possible way of providing a four-phase signal

Design of isolated fixed time signal

- Objectives of signalised intersection design
  - To provide sufficient intersection capacity
  - To minimise overall delay
- General principles of 2-phase signal design
  - $R_1 = G_2 + A_2$
  - Red- amber or initial-amber may be provided to end of red phase
  - Clearance time or clearance-amber just after green phase
  - Go time or green time is decided based on approach volume

Signal design methods

- Trial cycle method
- Approximate method based on pedestrian crossing requirement
- Webster's method
- Design as per IRC guidelines

Webster's method of traffic signal design

- Analytical approach of determining the optimum cycle time, C_o corresponding to minimum total delay to all the vehicles at the approach roads of the intersection.
- The field work consist of determining
  - Normal flow, q during design hour
  - Saturation flow, S,

    Saturation flow rate is the number of vehicles that can be moved in one lane in one hour assuming the signal to be green always. If not given, take as 160 PCU per 0.3 m width of road or

    $S=525w$ PCU/hr; w- width of approach, m

Webster's method of traffic signal design contd…

- Design steps:
  - Find ratios $y = \frac{q}{S}$ for given approach roads.
  - Find $Y = y_1 + y_2$
  - Find total lost time per cycle in sec, $L = nl + R$

  n- no of phases; R- All-red time

  l=initial delay/lost time per phase ; if not given take as 2 sec;

  then $L = 2n + R$

Webster's method of traffic signal design contd…

- Cycle length, Co = $\dfrac{1.5L + 5}{1 - Y}$
- Green time for each phase is obtained by:

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

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

Problem 1

- Two roads A and B meet at right-angles. The normal flow and saturated flow on road A are 750PCU/hr and 3600 PCU/hr respectively. On road B normal flow is 550 PCU/hr and saturated flow is 2700PCU/hr. The all red time is 10sec. Design a two-phase isolated traffic signal for the intersection and sketch the phase diagram. **(KTU DEC 2019, 10 marks)**

Solution

ya= 750/3600 =0.208, yb= 550/2700 = 0.204

Y=ya+yb = 0.412

n = 2; R = 10 sec

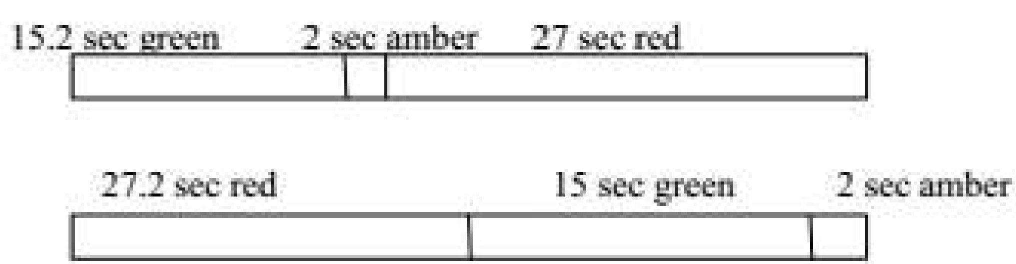
L=2n+R=14sec

Co = (1.5L+5)/(1-Y) =44.2 sec

GA=(ya/Y)x(Co-L) =15.2sec

GB =(yb/Y)x(Co-L) =14.95sec say15sec

Phase Diagram



Problem 2

- The average normal flow of traffic on cross roads A and B during design period are 400 and 250 PCU per hour respectively. The saturation flow values on these roads are estimated as 1850 and 1400 PCU per hour respectively. The all red time required for pedestrian crossing is 16 seconds. Design a two-phase traffic signal by Webster's method. **(KTU MAY 2019, 10 marks)**

Solution

$ya = qa/sa = 0.216$; $yb = qb/sb = 0.178$

$Y = ya + yb = 0.395$

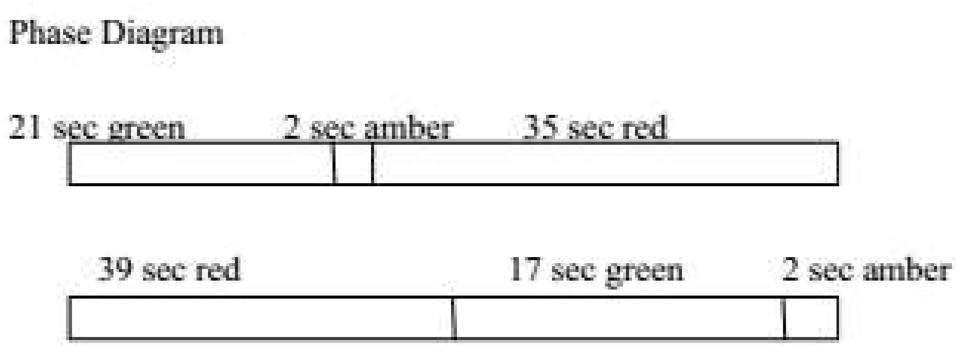
$n = 2; R = 16$ sec

$L = 2n + R = 20$ sec

$Co = (1.5L+5)/(1 - Y) = 58$ sec

$Ga = ya(Co-L)/Y = 21$ sec

$Gb = yb(Co-L)/Y = 17$ sec



Problem 3

- A fixed time 2-phase signal is to be provided at an intersection having four arms. The design hour traffic and saturation flow are

	North	South	East	West
Design hour flow (pcu/hr)	800	400	750	600
Saturation flow (pcu/hr)	2400	2000	3000	3000

Time lost per phase due to starting delay is 2 sec and all red period is 4 sec. Design two phase traffic signal using Webster's method. Draw the phase diagram also. **(KTU APRIL 2018, 12 marks)**

Solution

	North	South	East	West
q	800	400	750	600
s	2400	2000	3000	3000
y=q/s	0.33	0.20	0.25	0.20
y_{max}	0.33		0.25	

Y=0.33+0.25 = 0.58

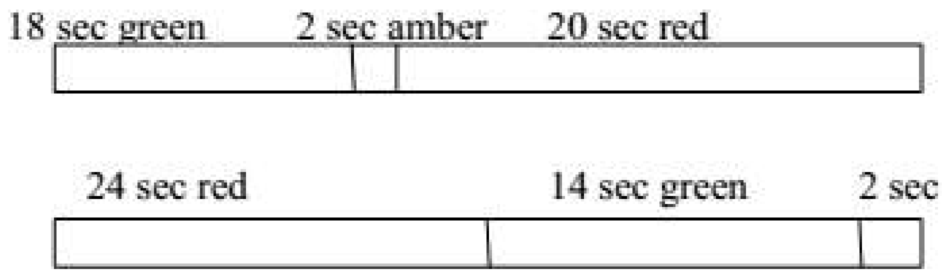
Lost time, L = nl + R = 2*2 + 4 = 8 sec

Optimum cycle length, Co = $\frac{1.5L+5}{1-Y}$ = { (1.5*8+5)/(1-0.58)}= 40 sec

$$G_{NS} = \frac{Y_{NS}(C_0 - L)}{Y} = \frac{0.33 * (40 - 8)}{0.58} = 18\ sec$$

$$G_{EW} = \frac{Y_{EW}(C_0 - L)}{Y} = \frac{0.25 * (40 - 8)}{0.58} = 14\ sec$$

Phase Diagram



TRAFFIC SIGNALS

OBJECTS OF TRAFFIC SIGNALS

- **At intersections where there are a large number of crossing and right-turn traffic, there possibility of several accidents as there cannot be orderly movements.**
- On cross roads with two-lane two-way traffic, there are 16 crossing conflicts as illustrated in Fig. 5.20.
- **The problem of such conflicts at the intersections gains more significance** as **the traffic volume increases.**
- **In such situations the earlier practice has been to control the traffic with the help of traffic police who stops the vehicles on one of the roads alternately and allows the traffic stream of the other road to cross or take right turn.**
- **Thus the crossing streams of traffic flow are separated by 'time-segregation'.**
- **In bigger cities, a large number of police personnel are required simultaneously to control the traffic during peak hours at most of the junctions with heavy traffic flow.**
- **Therefore traffic signals are made use of to perform this function of traffic control at road intersections.**
- **Traffic signals are automatic traffic control devices which could alternately direct the traffic to stop and proceed at intersections using red and green traffic light signals as per the pre-determined time settings.**
- **The main requirements of traffic signal are to:**

  (i) Draw attention of the road users

  (ii) Enable them to understand the meaning of the light signal

  (iii) Provide sufficient time to respond and

  (iv) Ensure minimum waste of time.

ADVANTAGES OF TRAFFIC SIGNALS

(Properly designed traffic signals at intersections **)**

- **Provide orderly movement of traffic** at the intersection.
- **The quality of traffic flow is improved** by forming compact platoons of vehicles, **provided all the vehicles move at approximately the same speed.**
- **Reduction in accidents** due to crossing conflict, notably the right angled collisions.
- **Traffic handling capacity is highest** among the different types of intersections at-grade.
- **Provide a chance to traffic of minor road to cross the continuous traffic flow of the main road at reasonable intervals of time.**
- **Pedestrians can cross the roads safely at the signalized intersection.**
- **When the signal system is properly co-ordinate, there is a reasonable speed along the major road traffic.**
- **Automatic traffic signal may work out to be more economical when compared to manual control.**

DISADVANTAGES OF TRAFFIC SIGNALS

- **The rear-end collisions may increase.**
- **Improper design and location of signals may lead to violations of the control system.**
- **Failure of the signal due to electric power failure or any other defect may cause confusion to the road users.**
- **The variation in vehicle arrivals on the approach roads may cause increase in waiting time on one of the roads and unused green signal time on other road, when fixed time traffic signals are used.**
- **Excessive delay of vehicle may be caused particularly during off-peak hours**.
- **Drivers may be induced to use less adequate and less safe routes to avoid delays at signals.**

DEFINITION OF TERMS USED IN TRAFFIC SIGNAL DESIGN

- **The period of time required for one complete sequence of signal indications** is called '**signal cycle'.**
- **The part of the signal cycle time that is allocated to stop the traffic** or to allow traffic **movement** is called '**signal phase'**
- **The duration of 'stop' phase** is the **red phase** and
- **The duration of 'go' phase** is the **green phase.**
- **Any of the division of the signal cycle during which signal indications do not change** is called the '**interval'.**
- **The engineer has to design the signal with the sequence and duration of individual phases to serve all approaching traffic at a desired 'level of service'.**
- **The level of service is measured by the vehicle delay, the queue length or the number of vehicle backed up and the probability of a vehicle entering the intersection during the first green phase after arrival.**

- **The capacity of a signalized intersection depends on physical factors of the roads such as roadway width, number of lanes, geometric design features of intersection and also the green and red phases of the traffic signal.**
- **The capacity is also affected by operational and control factors such as number of turning movement, number and size of commercial vehicles, pedestrian traffic signal characteristics and abutting land use.**

TYPES OF TRAFFIC SIGNALS

The signals are classified into the following types:

Traffic control signals

Pedestrian signal

Special traffic signal

THE TRAFFIC CONTROL SIGNAL

- **The traffic control signals have three coloured lights which glow facing each direction of traffic flow namely, red, amber and green.**
- **The red light is meant for 'stop',**
- **The green light** for **'go'** and
- **The amber or yellow light allows** the '**clearance time' for the vehicles which enter the intersection area by the end of green time** to clear off the intersection, before the change-over to red signal light.
- A typical traffic signal head is shown in Fig. 5.27.
- **Additional signals showing green lights for separate movements of turning traffic movements may also be provided, where necessary.**

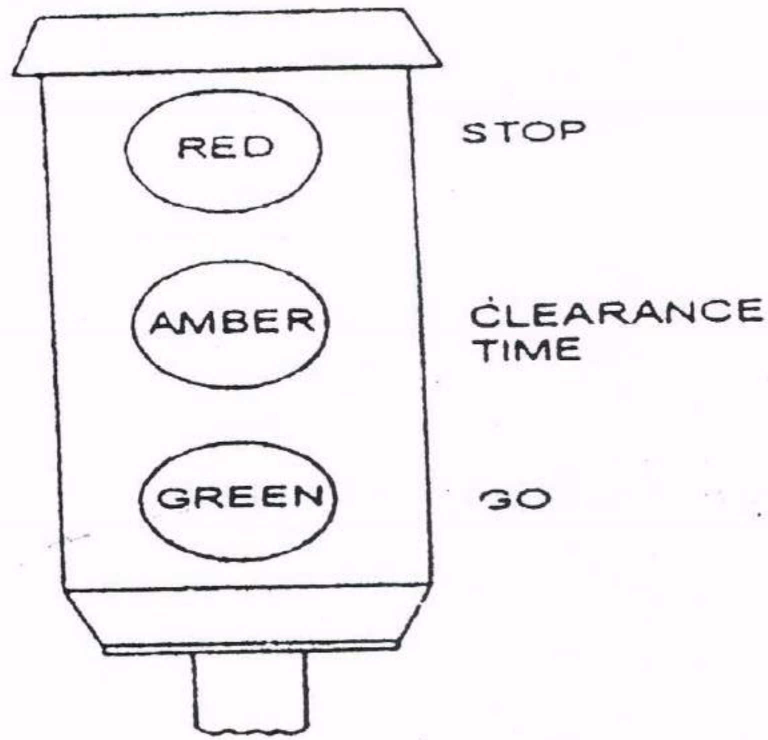


Fig. 5.27 Traffic signal head

PEDESTRIAN SIGNALS

- **Pedestrian signals may be installed at the intersections controlled by traffic signals to enable the pedestrians to safely cross the specified roads;**
- **In such cases, the pedestrian signals and their timings are interlinked to operate along with the traffic control signal.**
- **At certain locations of mid-block stretches of urban roads with high demand for pedestrian crossing, separate pedestrian signals may be installed along with appropriate warning and informatory signs.**

SPECIAL TRAFFIC SIGNALS

- **Special traffic signals such as '<u>flashing beacons</u>' may be installed at certain locations in order to warn the traffic of certain situations.**
- **At flashing red signals, the drivers of vehicles shall stop before entering the nearest cross walk at an intersection or at a stop line.**
- **Flashing yellow signals are cautionary signals meant to signify that drivers may proceed with caution.**

TRAFFIC CONTROL SIGNALS

Different types of traffic signals are in use in India namely,

(i) Manually operated signals

(ii) Fixed time automatic signals and

(iii) Automatic traffic-actuated signals.

I) MANUALLY OPERATED SIGNALS

- **Each of manually signals is operated** from a **salient point at or near the intersection by a traffic police constable;**
- **The signal phases may be varied depending on the traffic demand at that point of time.**

(II) FIXED TIME AUTOMATIC SIGNALS

- **The fixed time automatic traffic signal keeps repeating** the **same set of signal phases and the signal cycle time that has been set in the signal controller.**
- **This type of traffic signal may function satisfactorily at locations** where **there is no significant variation in traffic flow on different approach roads.**
- **U.S.A. fixed time signals are far more numerous than vehicle-actuated types.**
- **The timing of each phase of the cycle is predetermined** based on **the traffic studies** and
- **they are the simplest and cheapest type of automatic traffic signals which are electrically operated.**
- **The main drawback is that when the traffic flow on one road may be almost nil and traffic on the cross road may be quite heavy, yet the traffic in the heavy stream will have to keep waiting at red phase.**

(III) AUTOMATIC TRAFFIC- ACTUATED SIGNALS.

- **Traffic actuated signals are those in which** the **timings of the phase and cycle are changed according to traffic demand.**
- **Vehicle actuated signals, in which** the **green periods vary and are related to the actual demands made by traffic.**
- **This is made possible by installing detectors on all the traffic.**
- **Vehicle-actuated signals are very popular in U.K.**

(a) SEMI-ACTUATED TRAFFIC SIGNALS

- **In semi-actuated traffic signals** the **normal green phase of an approach may be extended up to a certain period of time for allowing a few more vehicles approaching closely**, **to clear off the intersection with the help of detectors installed at the approaches**.
- **Semi-vehicle-actuated signals, in which the right of way normally rests with the main road and detectors are located only on the side roads.**

(b) FULLY ACTUATED TRAFFIC SIGNAL

- **In fully actuated traffic movements on the basis of demand and pre-determined programming.**
- **But these are very costly** to **be installed at all intersections.**

(c) MODERN FIXED TIME EQUIPMENTS

- **Modern fixed time equipments are built** for **operation with different settings at certain periods of the day, to cover different conditions.**
- **This is achieved** by **providing time switches**

TYPE		ADVANTAGES		DISADVANTAGES	
	Fixed time	(i)	Simple in construction.	(i)	Inflexible and hence may cause avoidable delay.
		(ii)	Relatively inexpensive	(ii)	Require careful setting
		(iii)	Most successfully used in linked systems requiring a fixed cycle length for a given pattern and speed of progression		
	Vehicle-actuated.	(i)	They are flexible and are able to adjust to changing traffic conditions automatically	(i)	Require costly equipment such as detectors and sophisticated controllers
	Semi-vehicle-actuated	(ii)	Delay is held to minimum and maximum capacity is achieved. Useful for junction of a side street having low traffic volume with a main street having heavy flow	(ii)	Cannot provide signal co-ordination. They are believed to cause high accident rates at times of light traffic.

CO-ORDINATED CONTROL OF SIGNALS

Co-ordinated signal system

- **Co-ordinated signal system on a road net-work of an area** is a **very complex problem.**
- **Area traffic control system with co-ordinated signal network is to be implemented with the help of advanced technology.**

Need for co-ordinated control

- **Need for co-ordinated control of signals arises on a main traffic route when it is desirable to reduce delays and avoid main traffic from having to stop at every junction**.
- **When a signal indicates a stop aspect at a junction, a queue of vehicles is formed behind the stop line.**
- **When the signal changes to green, the vehicles start moving in a platoon.**
- **If this platoon is made to meet a green aspect at the next junction no delay is caused to the vehicles.**
- **This principle of linking adjacent signals so as to secure maximum benefits to the flow of traffic is called co-ordinated control of signals.**
- **The co-ordination of signals is bought for with the following objectives in view:**

(i) To pass the maximum amount of traffic without enforced halts.

(ii) To have minimum overall delay to traffic streams, both in the main and side roads.

(iii) To prevent the queue of vehicles at one intersection from extending and reaching the next intersection.

V	Traffic Safety: causes of road accidents – collection of accident data – influence of road, the vehicle .the driver, the weather and other factors on road accident – preventive measures	7	20

Road Accidents

- Types
- Causes
- Preventive Measures

Accidents

- Nearly 60,000 people are killed in road accidents every year.
- Accidents cause damage, loss of property, injury or even death.
- Accidents can’t be prevented totally but can be minimized by proper management of traffic.

Necessity of Accidents Study

- To study the causes and put remedial measures
- To check existing designs and suggest proposed designs
- To carry out surveys for putting causes and remedies
- To calculate financial and manpower loss and justify the proposal

Classification of Accidents

I. Collision Accidents:

- Collision with pedestrians
- Collision with other moving vehicles
- Collision with fixed objects

II. Non-Collision Accidents:

- Running off the roadway
- Over-turning
- Any other non-collision.

Causes of Accidents

- Road Users
- Vehicles
- Road pavement
- Environmental factors

Elements Causing Accidents

- Drivers
- Pedestrians
- Moment of Surprise
- Passenger
- Vehicle Defects
- Bad Road Condition
- Defective Road Design
- Weather
- Animals
- Lack of Proper Lighting
- Other Causes

Preventive Measures

- Engineering Measures
- Enforcement of Laws and Regulations
- Public Education of Traffic Laws

Engineering Measures

- Road Design- Proper Design of Pavement and traffic factors
- Road Lighting- Proper Illumination during night
- Maintenance of Defective Roads- regular or periodic checking of road for maintenance
- Maintenance of Defective Vehicles- Checking Brakes, Chassis, and other parts

Enforcement of Traffic Rules

- Speed Control- Use of instruments like tachometers, speed guns, etc., surprise checking, imposing fine, etc.
- Traffic Control- Application of signals, signs, markings, etc., Deploying Traffic Police.
- Training and Supervision- While giving Driving license, drivers should be trained strictly. The trained driver should be tested periodically.

Enforcement of Traffic Rules

- Observance of Law and Regulations- Traffic Laws enforcement teams should be sent to different locations to see if public is following traffic rules properly or not.
- Medical Check up- Alcohol or intoxicating consumption should be checked regularly. Public carrier drivers should be checked for vision and reaction time.
- Education to public- Traffic Education should be provided to public.

18·4. Collection of Accident Data

18·4·1. The usefulness of an accurate and comprehensive system of collection and recording accident data cannot be over-emphasized. Such data serve to identify the basic causes of accidents and to suggest means for overcoming the deficiencies that lead to such accidents. The data have a number of uses (Ref. 5), enumerated below :

(*a*) **Engineering uses.** 1. In determining the adequacy, size, shape and legibility of traffic signs.

2. In determining the justification for traffic control devices, such as traffic signals.

3. In determining and planning pedestrian safety features such as underpasses, overbridges, pedestrian barriers, refuge islands, pedestrian signals and street lighting.

4. In determining speed zoning and speed control.

5. In planning traffic regulation measures such as prohibition of on-street parking, one-way streets and prohibited turnings.

6. In designing safe and efficient street lighting.

7. In designing or redesigning intersection.

8. In designing and providing channelizing islands, central verges and refuge islands.

9. In planning safety measures for traffic during construction.

10. In identifying specific deficiencies in the maintenance procedures and specifications.

11. In improving the horizontal and vertical alignment.

12. In providing adequate sight distances.

13. In determining suitable width for pavement, shoulders and bridges.

14. In understanding the deficiency of the pavement surfaces and devising ways and means of improving them.

15. In determining any deficiencies in super-elevation and camber and rectifying them.

16. In planning safety measures and guard rails.

(*b*) **Enforcement uses.** 1. In planning deployment of personnel for various duties such as manual control and street patrolling depending upon accident frequency at different locations and during different hours of the day.

2. In directing enforcement effort.

3. In controlling pedestrian behaviour.

4. In the safe and efficient operation of traffic control devices.

5. In enforcing curb parking regulations.

6. In planning and enforcing vehicle inspection measures.

7. In planning and enforcing cycle inspection measures.

8. In aiding prosecution of offenders in courts.

(*c*) **Administrative and policy issues.** 1. In initiating and administering Traffic Safety programmes.

2. In evaluating the success of Traffic Safety Programmes.

3. In determining the accident costs.

4. In identifying the need to amend the legislative measures in force and to take appropriate action to amend them.

(*d*) **Educational uses.** 1. In planning and organizing school safety educational Programmes.

2. In planning and organizing driver safety educational programmes.

(*e*) **Uses for the Motor Vehicle Administrator.** 1. In reviewing the procedures for licensing drivers.

2. In reviewing the procedures for registration and licensing of

3. In reviewing the vehicle inspections requirement.

18·4·2. Requirements of accident records

(*i*) If accident records are to be of use, they should be accurate and comprehensive, instead of being vague and misleading.

(*ii*) Accidents must be reported on a standard form so that uniform procedure is followed.

(*iii*) The terms describing the accidents must be accurately defined.

(*iv*) For facility of being analysed by a computor, the data should be coded properly.

Road accidents

- ***Road accident***
- An accident which occurred or originated on a road open to public traffic resulting in either injury or loss of life or damage to property in which at least one moving vehicle was involved

Accident studies and report

- Collection of data
- Accident report
- Accident record

Collection of accident data

- It is the first step in the accident study
- The details to be collected are

1.General(date,time, person, particular, classification of accident)

2. Location

3.Details of the vehicle involved

4. Nature of accident

5. Road and traffic condition

- 6.primary causes of accident
- 7. accident costs

- **Accident report**
- **Accident records**

Location files

Spot maps

Condition diagram

Collision diagram

Uses of collection od data

Causes of road accidents

- Vehicle
- Driver
- Road
- Road users other than motorist
- Environmental and Weather factors

Road user other than motorist

- Pedestrians
- cyclist

Pedestrian safety

- **Trends in pedestrian accident pattern**
- 1.age
- 2. sex
- 3.social condition
- 4.Driving experience
- 5.Familiarity with locality
- 6. the drunken pedestrian

The road and its influence on the pedestrian accidents

- Geometric features of the road
- Design of intersection
- Road lighting and vehicle lighting
- Pedestrian footway

Measures to increase pedestrian safety measures

Environmental and other factors

Weather factors

Rain

Snow or ice

fog

Steps to be taken for Preventing Road Accidents

1. Most important method to bring down accidents is strict enforcement of speed limits. 90 % of accidents can be avoided by strict enforcement of speed limits.

2. Heavy Penalty should be imposed on ALL those who cross speed limits. If this is strictly implemented, nobody will dare to go at high speed.

3. Existing speed limits should be brought down further.

4. Heavy penalty should be imposed for those who cause accidents.

5. Tamper proof speed controllers should be made mandatory for all heavy vehicles. New heavy vehicles should have built in tamper proof speed controllers.

6. Two wheeler manufacturers should be asked to design two wheelers with a designed maximum possible speed of (say) 50/60 kmph. This limit may be decided based on the conditions of each country.

7. New gadgets are to be developed for collision prevention and should be fitted on all vehicle.Research organizations should be asked to develop such gadgets on a war footing. For example, gadgets can be developed to automatically slow down the vehicle, if safe distance commensurate with the speed of the vehicle in front is not maintained. Gadgets can be developed for warning the driver, if the driver sleeps.

8. Diving tests for issue of Driving license is to be made more stringent and foolproof.

9. Lower age limit for two wheeler and Heavy Vehicle license should be raised to 21.

10. Helmet should be made compulsory by law in all countries, OR impose a lower speed limit for those who do not use helmet. Issue of Helmet should be made mandatory with the sale of each two wheeler.

11. Helmet should be made compulsory for back seat riders also.

12. Ensure that all Helmet users are fixing the Chinstrap of Helmet. Otherwise it will not help during an accident.

13. Ensure that ONLY good quality Helmets that meet standard specifications are available in the market

14. Existing traffic rules should be strictly enforced.

15. Law should be modified such that the person who makes the accident has to bear (say) 0 to 10 % of the insurance claims, depending on severity of negligence. Also the compensations should be made very huge, making accidents unaffordable so that everyone will be very vigilant.

16. All those who do not maintain the safe distance for the speed should be punished.

17. Safety awareness should begin from childhood, as it is difficult to impart awareness to a grown up a human. If safety awareness is imparted at childhood, safety will be a habit

18. Video and Computer games that simulate Motor Racing should be banned by Government OR discouraged by parents as it will develop racing habit in children.

19. All sorts of Motor sports, especially racing should be banned by government. Telecast of Motor Sports and Racing also should be banned.

20. Racing, over speed / highly risky riding, driving by Heroes should not be filmed in cinemas and TV serials. Children are likely to imitate the same. Statutory warning will no help. Government should censor such scenes.

21. Advertisements by automobile companies which include scenes of dangerous and risky riding or driving should be banned. Youngsters are likely to imitate the same . Statutory warnings will not help. Such ads will result in irreparable character formation regarding riding and driving in kids and children. Such children may make accidents in future.

20. Children below a certain age should not be permitted to do cycling in busy roads and in roads where heavy vehicles are plying.

23. Refreshment parlors should be made available at every 50 / 100 k.m. on all highways and important roads. Truck, Heavy vehicle drivers should be forced to refresh by having a face wash or by having a cup of tea or coffee.

24. The practice of keeping the traffic signals in standby mode during nights and on holidays is to be reviewed and discontinued.

25. Advertisement boards and other items that may obstruct visibility at junctions, curvatures and other parts of the roads should be removed immediately.

26 Ensure that the money recovered as Road Tax is fully utilised for the construction and maintenance of roads.

27. Time Punching of Private buses practiced in some regions should be discontinued as it is forcing the drivers to go at high speed, after traffic blocks

28. Newspaper, Television and other media should be effectively used for Public Safety

29 Major accidents and accident prone areas should be analysed scientifically.

30 Speed should be restricted at accident prone areas.

31.More stringent traffic rules should be enacted.

32.License of those who are involved in accidents should be suspended immediately, at least until they prove that they are not guilty.

35.Health of vehicles should be strictly enforced.

36.Eyes of old aged driving license holders should be checked at regular intervals.

37.License of drunkard drivers and riders should be cancelled immediately

38Judicial Commissions should be setup to monitor steps taken to control road accidents andto monitor the accident rates on a weekly basis.

39One way traffic should be implemented in all roads as far as possible. Roads should be widened wherever required. Curvatures should be minimised. Medians should be constructed in roads with two way traffic.

40.Footpaths and medians should be made mandatory for all important roads and for all new roads.

41. Zebra crossings should be provided for pedestrians for safe road crossings at appropriate places.

42.Signals for road crossings should be provided at important and busy places where a large number of people have to cross the road everyday.

42.Signals for road crossings should be provided at important and busy places where a large number of people have to cross the road everyday.

43. Roads should be properly marked. Sign posts should be provided wherever required.

Humps should be provided at all important places, accident prone areas. Humps should be made mandatory for all sub roads where it enters a main road.

44Construction, size and shape of the Humps should be scientific. All the Contractors of the Public Works and other departments should be provided with the details of scientific Hump construction.

45.Humps should be clearly marked, to avoid accidents. Methods of permanent nature should be followed in Hump marking. For example white marble pieces / white colour / fluorescent pigment can be used.

46. Provision of small pilot humps few meters before humps can also be considered to ensure that humps are not left unnoticed.

47.Obstructions on road sides caused by unauthorised construction and road side sales should be

Eliminated completely

48.Visibility should be increased near curvatures. Sometimes, even cutting of grass to increase

visibility can help save many lives

50. Road Safety Day / Road Safety Week should be observed in all Schools, every year. Competitions on Road Safety Tips, Slogans, Essays, Paintings etc. should be conducted for students of various classes.

51.School Buses should be painted with Bright Yellow color.

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51.School Buses should be painted with Bright Yellow color.

52.Let 'Road Safety' be a mandatory topic for School Projects for all classes, every year.

53.A small pool of water or a hanging branch of tree on roadsides can cause accidents as such obstructions will make the pedestrians and drivers to take sudden LATERAL movement and result in accidents. Hence any obstruction on road sides which can cause a LATERAL movement should be rectified immediately.

54. Black color should not be permitted for Cycles. Default color for Cycles should be changed to Yellow.

55. Automobile and cycle manufacturers should be asked to stop producing black and dark vehicles. Yellow or other bright colored vehicles should be produced instead.

56. Front and Back of Lorries and Trucks should be painted with bright Yellow color to increase visibility. This will help to prevent collisions while Lorries and Trucks are parked on roadside without parking lights switched on.

57.Reflectors should be fixed on Front and Back of Trucks and Lorries.

58.Accident statistics should be periodically reviewed to understand the effect of actions taken. Corrective steps should be taken based on these reviews.

59. Attention distracting Hoardings, banners, posters, advertisements etc should be banned near roads and highways.

60. Default color of Helmets should be changed to Yellow to reduce accidents by increased visibility. Black and dark colors should not be permitted.

61. All automobile manufacturers should be asked to strengthen safety standards of vehicles by improved design. It is to be noted here that in the series of collisions of 200 plus vehicles at Dubai in 2008, only few people were killed. This is because of the high safety standards.

62.Parking near curvatures should be strictly prohibited.
63.Road crossing near curvatures should be made punishable.

All models of vehicles should be issued a international safety rating number (say from 1 to100) based on their safety features, design, build, colour etc. Vehicle manufacturers will compete to improve the safety to get top ranking. This will ultimately result in saving of many lives. Customers can easily select the safest vehicle based on safety number.

65. Day light like lighting should be provided in main roads, so that high beam can be avoided and a lot of accidents caused by high beam of vehicles coming from opposite direction can be avoided. 66.Drunkard driving should be firmly dealt with.
67.Anti drowsy warning gadgets should be made mandatory during night travel.
68Street dogs should be eliminated completely.
69Low cost tamper proof electronic devices to record the speed of the vehicle should be
developed and should be fitted on all heavy vehicles. The devices should be examined in case of accidents – a miniature version of black box of aero plane.
70. Video cameras should be installed at regular intervals on highways by Police and should be centrally monitored.

VI	Traffic Flow: theory of traffic flow – scope – definition and basic diagrams of traffic flow- basic concepts of light hill – Whitham's theory – Introduction to Car 'following theory and queuing'	**7**	**20**

TRAFFIC FLOW THEORY-INTRODUCTION

=> Mathematical study of the movement of vehicles over road network.

Speed, flow and density are the basic parameters of traffic flow.

Scope:

- Traffic engineer can get knowledge of vehicular traffic,
  - leading to improved techniques
  - for control, regulation and management of traffic

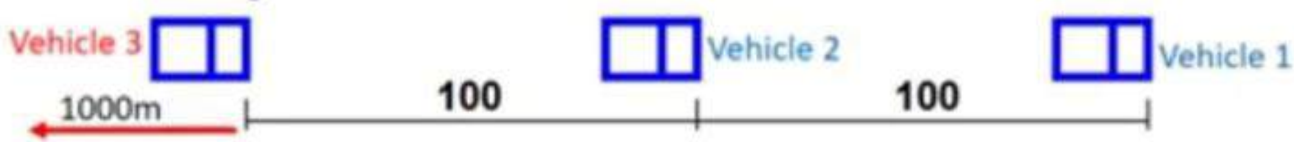
Scope contd.

- It includes relation between speed, flow and concentration(density).
- Approaches to frame relationship includes car following theory, hydro dynamic analogy etc.
- Different measures of speed are used in traffic flow analysis like spot speed, time mean speed, space mean speed etc.
- Knowledge of probability and statistics are needed for the study of congestion, delay, queuing, headway, gap between vehicles etc.

Basic definitions

- Speed(v):
  - Rate of movement of vehicular traffic (km/h)
- Flow (q):
  - No. of vehicles passing a specified point (veh/hr)
- Density (k):
  - No. of vehicles present in a specified length of road at an instant (veh/km in one lane)

$k = \frac{1000}{s}$, where 's' is space headway,



eg. $k = \frac{1000}{100}$ =10 vehicles in **1000m** =10 veh/**km**

Basic definitions contd.

- Space headway(s):
  - Distance between fronts of successive vehicles (m)
- Time headway (h):
  - Time interval between passage of fronts of successive vehicles at a specified point (sec)
- Time mean speed(V_t):
  - Average of speed measurements **at one point in road over a period of time.**
- Space mean speed/ harmonic mean speed(V_s):
  - Average of speed measurements **at an instant of time over space.**

Eg. to understand V_t and V_s

Qn. The speeds of 25 cars are given. 10 cars are noted to travel at 35 km/h, 8 cars at 40 km/h, 2 cars at 50 km/h, 5 cars at 45 km/h. Assume that each cars are travelling at constant speed, find V_t and V_s.

- $v_t = \frac{\sum_{i=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i} = \frac{(10*35)+(8*40)+(2*50)+(5*45)}{25}$ =39.8 km/h
- $v_s = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n} \frac{q_i}{v_i}} = \frac{25}{\left(\frac{10}{35}\right)+\left(\frac{8}{40}\right)+\left(\frac{2}{50}\right)+\left(\frac{5}{45}\right)}$ = 39.26 km/h
- q_i is the number of vehicles having speed v_i, and n is the number of such speed categories

Eg. to understand V_t and V_s

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

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

$$v_s = \frac{n}{\Sigma \frac{1}{v_i}} = \frac{5}{\frac{1}{50}+\frac{1}{40}+\frac{1}{60}+\frac{1}{54}+\frac{1}{45}} = \frac{5}{0.12} = 48.82$$

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

ie, Time mean speed is space mean speed plus standard deviation of the spot speed divided by the space mean speed.

Relationship between variables

- Relation between **fundamental parameters of traffic flow:**
- Space mean speed, flow and density are related by the following equation: $v_s = \frac{q}{k}$ or **q=kv.**
- As $k = \frac{1000}{s}$, $V_s = \frac{q \, x \, s}{1000}$, where 's' is space headway
- Space and time headway relation: $S = \frac{h \, x \, V_S \, x \, 1000}{3600}$

Diagrams of traffic flow

- **The relation between**
  - **Density and flow,**
  - **Flow and speed,**
  - **Density and speed,**
- **can be represented with the help of 3 curves.**
- They are connected to get fundamental diagram of traffic flow.

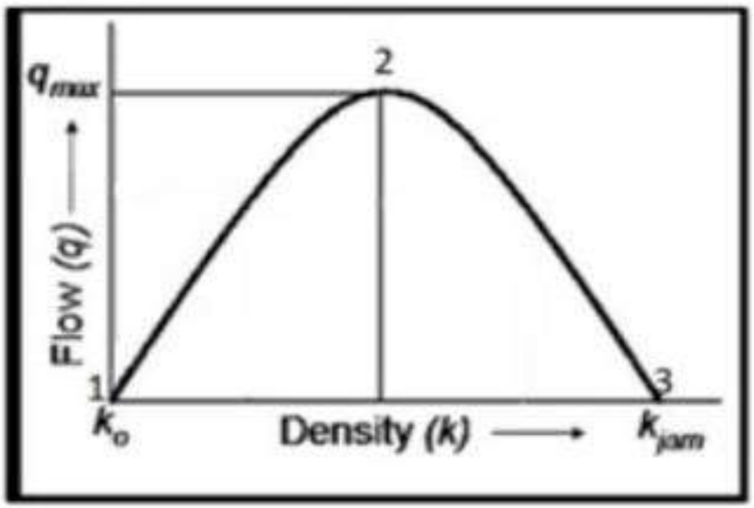
Jamming Concentration

- **Note:**
- Theoretical maximum 'k' = k_j =jamming concentration (vehicles are closely packed)

- Consider one lane of a 1 km road section with only 5m long cars. If cars are closely packed one behind the other, then 's' also =5m. And $k_j = \frac{1000m}{5m}$ =200veh/km/lane.

1.Density(k)-Flow(q) curve

The relation between the density of vehicles (x axis) and the corresponding flow (y axis) on a given stretch of road.

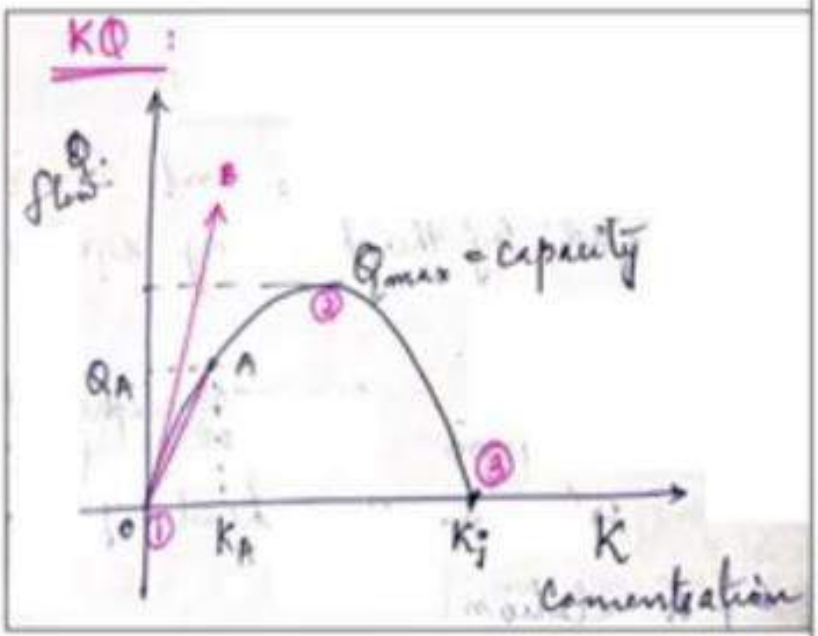


k-q curve

1. When 'k' is zero, flow will also be zero, since there is no vehicles on the road.
2. When number of vehicles gradually increases, 'k' & 'q' also increases.

   The max 'q' that can be accommodated in a road is capacity of road.
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.** Flow will be zero as vehicles can't move.

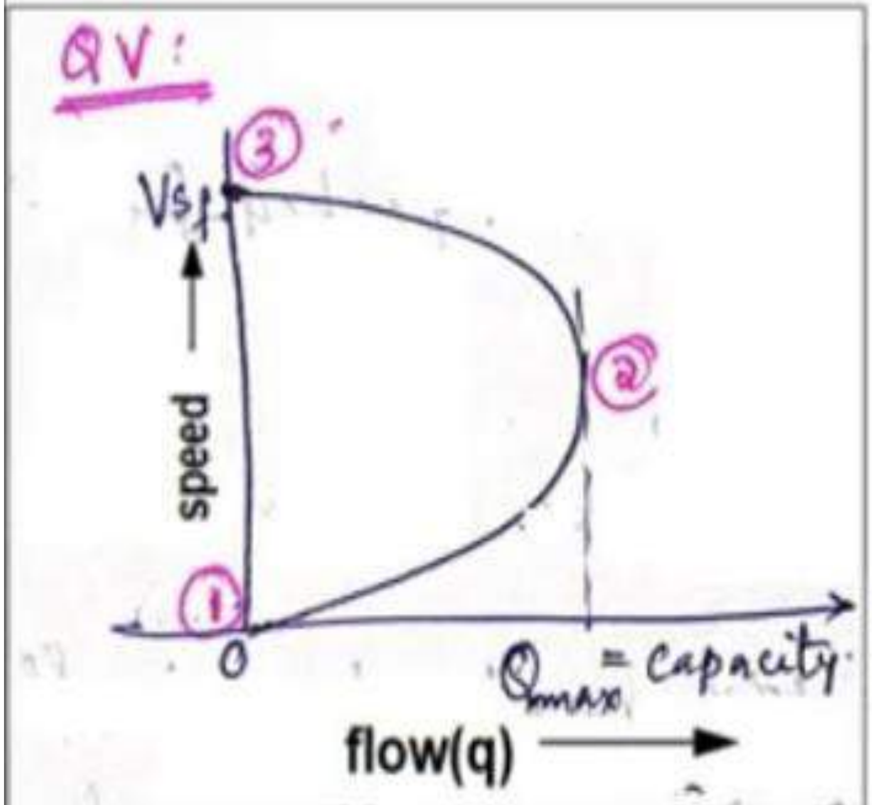
Density(or concentration)-flow curve contd.



k-q curve

- Slope of line joining 'O' & point 'A' is
  - **the space mean speed for the traffic condition with k_A and q_A**
  - ie, $V_A = \frac{q_A}{k_A}$.
  - Same for any point on curve.
- **OB – Mean free speed V_{sf}**
  - ie, the speed which can be adopted by a driver when there are no other interferences.

2.Flow(q)-Speed(v) curve



q-v curve

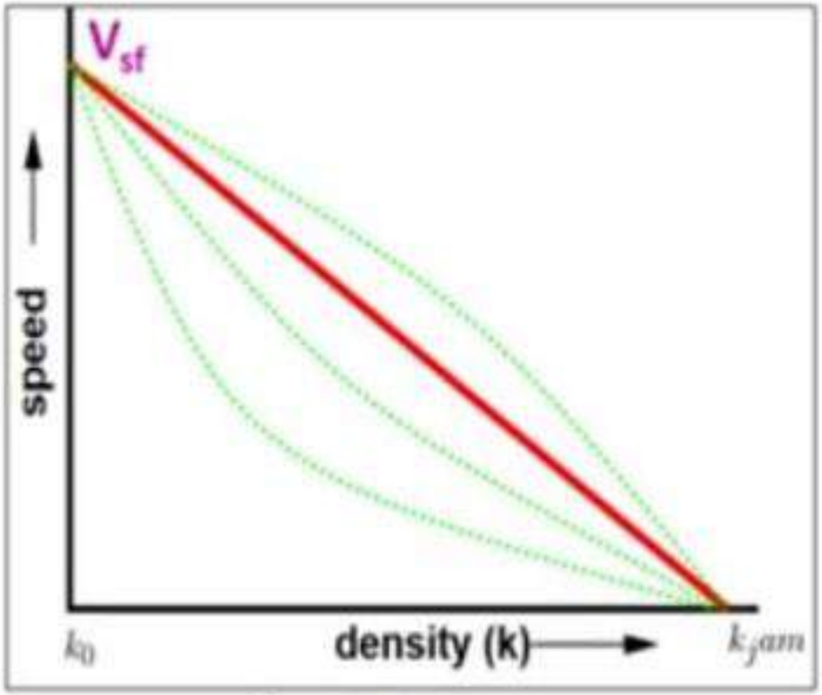
3. when flow is zero, any single vehicle entering to that road will be in free flow condition.

Hence speed= **Mean free speed V_{sf}**

2. Volume of vehicles increased from zero and **flow reached maximum.** ie, capacity of road.

1. there are too many vehicles so that they cannot move. **So flow and speed = 0**

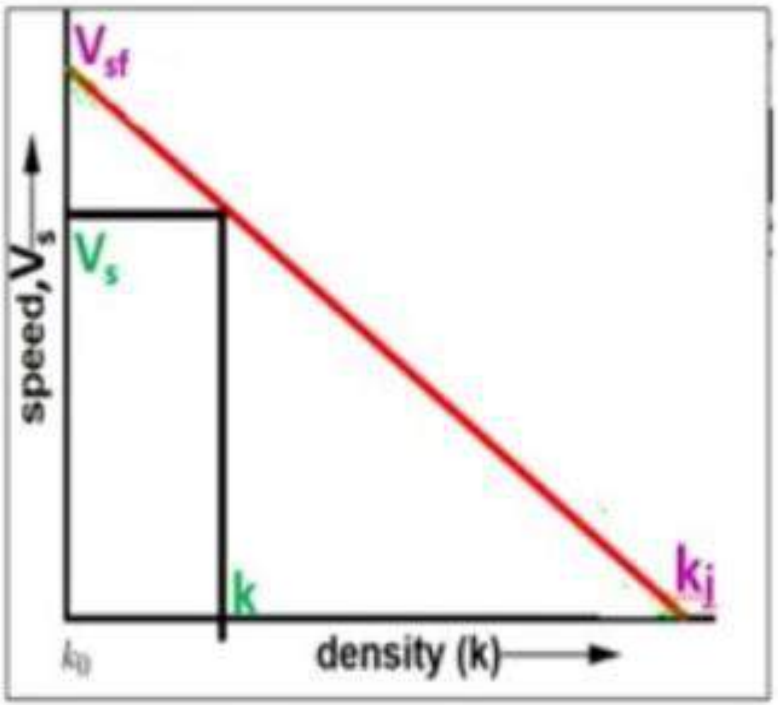
3.Density(k)-speed(v) curve



k-v curve

- The exact shape depends on the actual condition of traffic. It may take parabolic shape also.
- When k»0, free flow condition, LOS A,
  - **So, $V_s = V_{sf}$**
- When k= k_j , no movement of vehicles
  - So V_s = 0

Linear relationship between variables by Greensheild



k-v curve

- From **k-v linear curve:**

$$V_s = V_{sf} - \left(\frac{V_{sf}}{k_j}\right) \times k \longrightarrow \underline{1}$$

- $V_s = V_{sf} - \left(\frac{V_{sf}}{k_j}\right) x\ k$ ⟶ 1

- Put the basic equation $v_s = \frac{q}{k}$ in equation 1 to write it in terms of 'q'.
  - ie, $q = V_{sf}\ x\ k - \left(\frac{V_{sf}}{k_j}\right) x\ k\ x\ k$ ⟶ 2

- Illy, Put the equation $k = \frac{q}{V_s}$ in equation 1 and rearrange it to write as:

$$q = V_s\ x\ k_j - \left(\frac{V_s^2 x\ k_j}{V_{sf}}\right) \longrightarrow 3$$

Linear relationship contd.

- Differentiating equation 2 wrt. 'k' and equating to zero
- 'k' at q_{max} can be obtained
- ie,

$$Q = V_{sf}\, k - \frac{V_{sf}}{k_j} \times k^2 \rightarrow (2)$$

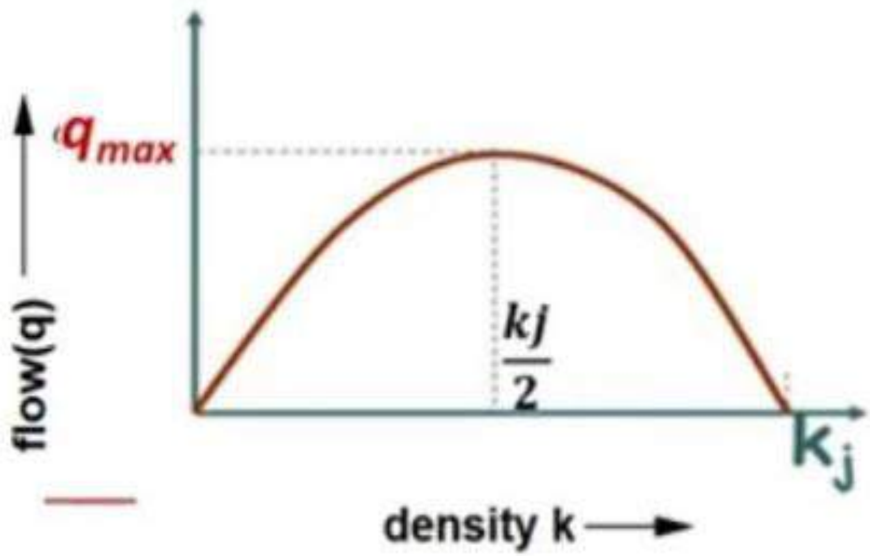
$$\frac{dQ}{dk} = V_{sf} - \frac{V_{sf}}{k_j} \times 2k = 0$$

$$\Rightarrow V_{sf} = \frac{V_{sf} \times 2k}{k_j}$$

$$\Rightarrow \boxed{k_{max} = \frac{kj}{2}}$$

Graph showing 'k' at q_{max}

- $k_{max} = \frac{kj}{2}$



Linear relationship contd.

- Differentiating 3 wrt. V_s and equating to zero
- V_s at q_{max} can be obtained
- ie, $Q = V_s . k_j - \frac{V_s^2 . k_j}{V_{sf}}$ → 3

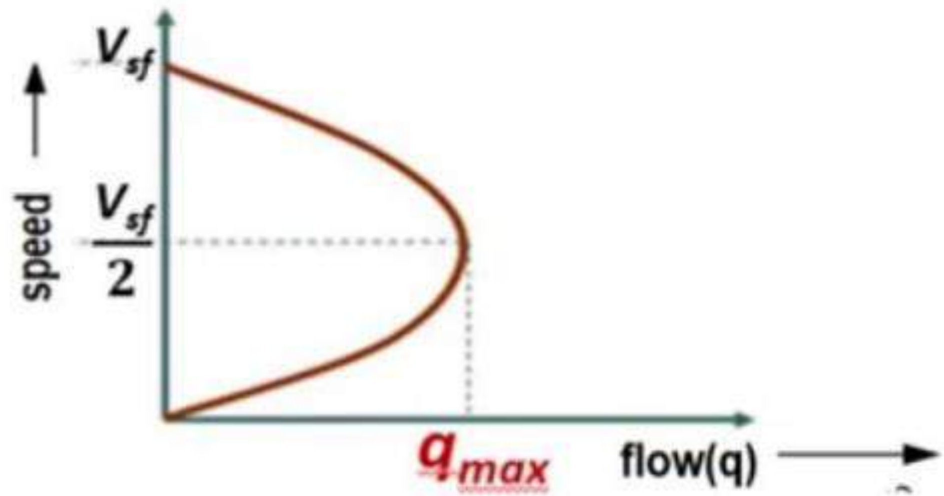
$$\frac{dQ}{dV_s} = k_j - \frac{k_j}{V_{sf}} \times 2V_s = 0$$

$$\Rightarrow k_j = \frac{k_j}{V_{sf}} \times 2V_s$$

$$\Rightarrow \boxed{V_{s\,max} = \frac{V_{sf}}{2}}$$

Graph showing V_s at q_{max}

- $V_{s\,max} = \frac{V_{sf}}{2}$

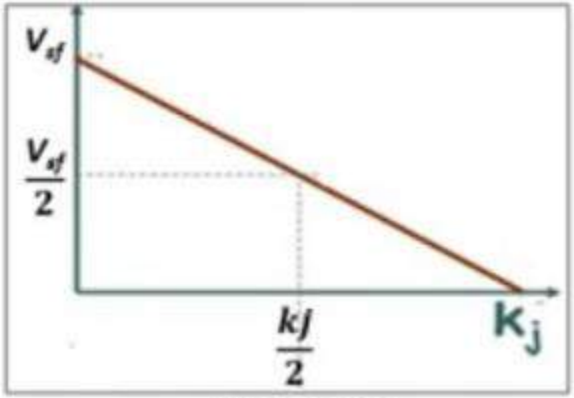


Linear relationship contd.

- Thus at q_{max}, we got $k_{max} = \frac{kj}{2}$ and $V_{s\,max} = \frac{V_{sf}}{2}$
- Put k_{max} and $V_{s\,max}$ in basic equation **q=kv**
- $q_{max} = k_{max} \times V_{s\,max}$

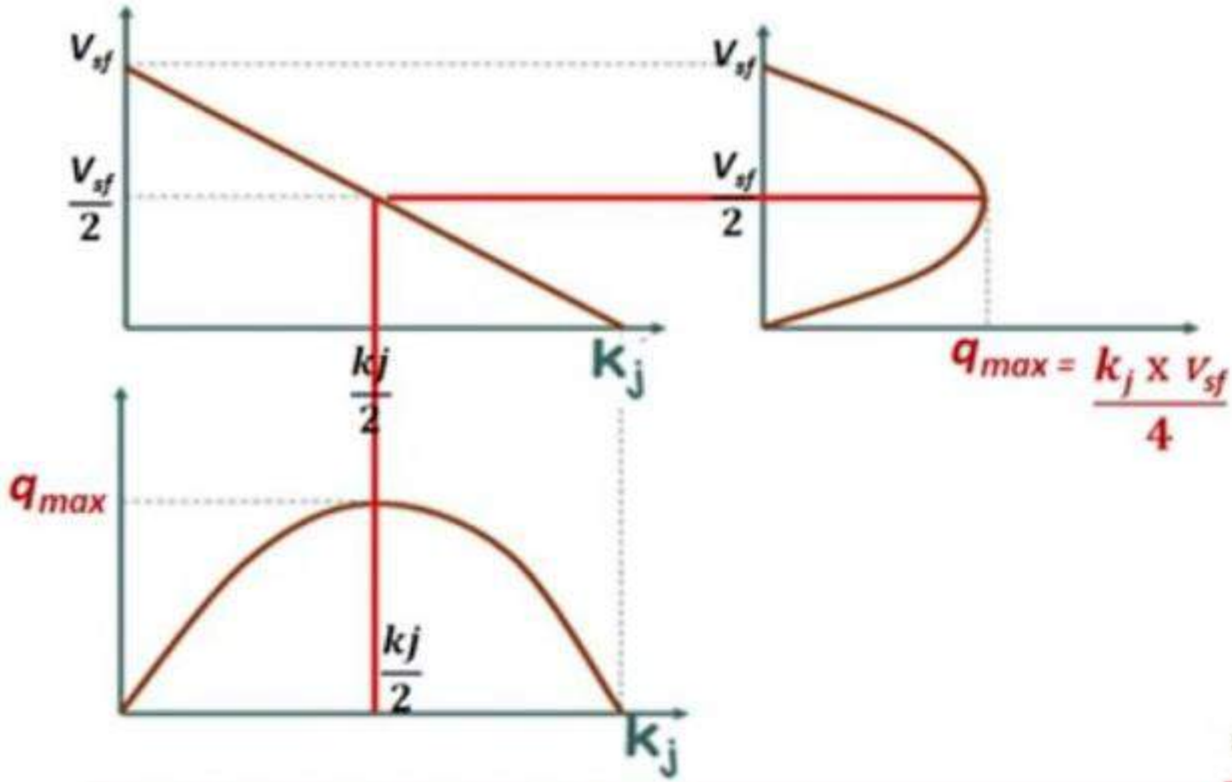
$$= \frac{kj}{2} \times \frac{V_{sf}}{2}$$

$$= \frac{kj \text{ X } V_{sf}}{4}$$



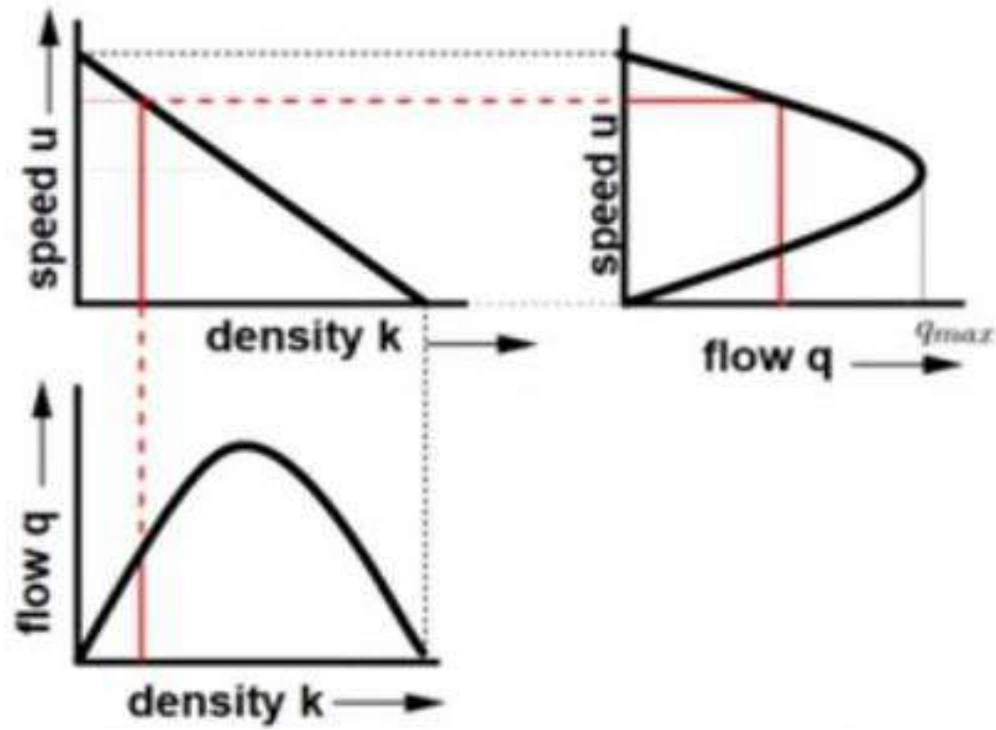
K-v curve

Speed-flow-density Relationship
Greenshield's linear model



Fundamental diagram of traffic flow

- The combined diagram showing relationship between speed- flow, speed-density, and flow-density are called the fundamental diagrams of traffic flow.



Lighthill and Whitham's Theory

23·1. One of the attempts to understand traffic flow has been to draw an analogy between the flow of fluids and the flow of traffic. Lighthill and Whitham (Ref. 1) have contributed to this topic by their theory which is is based on kinematic waves. The limitation of the theory is that it is based on the 'continuous flow' approach in fluid dynamics and it thus represents the limiting behaviour of a stochastic process for a large 'population', which in this case is the total number of vehicles. Therefore, it is applicable to large-scale problems only, and principally to the distribution of traffic on long, crowded roads.

Lighthill and Whitham's Theory

23·2. The assumptions in the derivation of the equations of the theory are :

(*i*) The equation of continuity, *i.e.*, law of the conservation of vehicles, holds good. Thus :

$$\text{Inflow} = \text{outflow} \pm \text{storage}$$

(*ii*) At any point on the road, the flow Q is a function of the concentration K.

Lighthill and Whitham's Theory

23·3. Consider a length of road *AB* with a stationary observer *O* at the mid-point, Fig. 23·1.

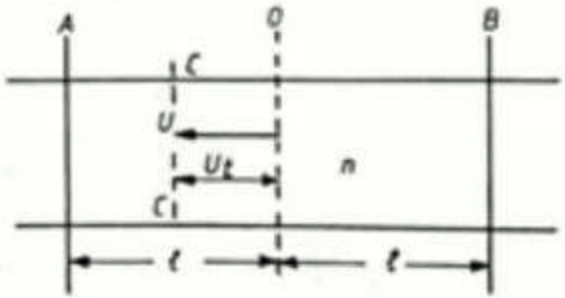
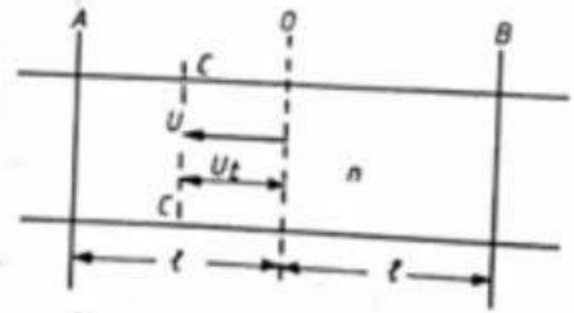


Fig. 23·1.

There are *n* number of vehicles in the length *OB* when the observer starts counting the number passing him. The count stops at the expiry of time *t* when all the *n* vehicles have passed the observer.

Lighthill and Whitham's Theory

At the same instant when the stationary observer starts counting, a moving observer starts at O and travels with the stream at speed U, which is less than $\bar{v}_s$, the space-mean speed of the stream, and counts the vehicles passing him. The count stops at the expiry of time t when all the n vehicles have passed O. The moving observer has travelled a distance OC in time t given by $OC = U.t$. His count will be less than the count of the stationary observer by the number of vehicles in the length OC.



Number counted by the moving observer

$$= \text{Number in length } l - \text{Number in length } OC$$

$$= Q \cdot t - \frac{U \cdot t \cdot n}{l}; \text{ but } \frac{n}{l} = K$$

$$= Q \cdot t - K \cdot U \cdot t$$

Flow relative to the moving observer

$$= Q - K \cdot U.$$

Suppose two moving observers are travelling at speed U at time t apart.

Suppose the flow and concentration change with time, the changes being relatively small ; but the observers have been told to adjust their speeds U so that the vehicles which pass them minus the vehicles which they pass is, on the average, the same for each. That is :

$Q - K \cdot U$ is the same for each.

For observers 1 and 2,

$$Q_1 - K_1 U = Q_2 - K_2 U$$

$$\therefore \qquad U = \frac{Q_1 - Q_2}{K_1 - K_2} \qquad \text{...(23·1)}$$

In the above equation, Q_1 and Q_2 are the flows and K_1 and K_2 the concentration observed by the observers at time t apart.

Calling the changes in flow and concentration as ΔQ and ΔK respectively,

$$U = \frac{\Delta Q}{\Delta K} \qquad \text{...(23·2)}$$

Car-following Theory

24·1. Principles

In the car-following theory approach the vehicle-driver system is visualised as one, where the driver of a following vehicle responds to the stimuli caused by the motion of the vehicle in front. The driver adjusts his speed, acceleration and spacing between the vehicle in front and his own to suit the motion of the vehicle in front. In this process, a certain time lag between receiving the stimulus and reacting to it is inevitable and has to be considered. This interesting theory has been built and enriched by the study of many researchers in the last 30 years (Ref. 1, 2, 3, 4). It may be noted that the theory applies to single lane dense traffic with no overtakings.

24·2. Derivation of Equations

In psychological terms, the car-following theory may be expressed in the form of the equation :

$$\text{Response} = \text{Sensitivity} \times \text{Stimulus} \qquad ...(24\cdot1)$$

Response is taken as the acceleration of the following vehicle, since this is the quantity directly under the control of that driver. The stimulus could be taken as the relative speed between the following vehicle and that ahead. The stimulus can also depend upon the spacing between the two vehicles.

Mathematically, the stimulus-response equation can be put in the following form :

$$\ddot{x}_{(n+1)}(t+T) = \lambda\left[\left(\dot{x}_n t\right) - \dot{x}_{(n+1)}(t)\right] \qquad ...(24\cdot2)$$

where
$\ddot{x}$ = acceleration
$\dot{x}$ = speed
x = position on the road
t = time
T = time lag of response to stimulus (usually 1 to 2·2 seconds) (Ref. 4)
λ = a proportionality coefficient.

In the above equation, the subscript (n) refers to the nth vehicle, $(n + 1)$ to the $(n + 1)$th vehicle, the subscript (t) refers to the position at time t and the subscript $(t + T)$ refers to the position at time $t + T$.

The value of the sensitivity, λ, in Eq. (24·2) is intended to take care of the driver's awareness of the stimuli from the vehicle ahead and the intensity of his reaction to it. It is unlikely that λ is a constant and, in fact, it may be given a number of values such as :

(*i*) $\lambda = c$, a constant

(*ii*) $\lambda = a$, a constant where $s \le s_c$, s being the spacing, defined as

$s = x_n - x_{n+1}$, and s_c is the critical spacing

and $\lambda = b$, a constant, where $s \ge s_c$

(*iii*) $\lambda = c/s$, c being a constant

(*iv*) $\lambda = \dfrac{\dot{x}_{(n+1)}}{s^2}$

(*v*) $\lambda = c/s^2$, c being a constant.

The values (*iii*) to (*v*) above can be included in a general expression of the form :

$$\lambda = \frac{c\dot{x}^m_{(n+1)}(t+T)}{\left[x_n(t) - x_{(n+1)}(t)\right]^l}$$

where l and m are constants and take different values to obtain the three cases.

Two characteristics of traffic flow are important and need consideration : stability and the steady state of flow. Stability is important because of its application to accident studies, but unfortunately these stability criteria are difficult to establish except for the easiest case of $\lambda = C$. For this simple case, the car-following law may be expressed as follows :

$$\dot{x}_{(n+1)}(t+T) = C\left[\dot{x}_{(n)}(t) - \dot{x}_{(n+1)}(t)\right] \qquad ...(24\cdot3)$$

In the steady state, let each car be moving with a speed of a, so that we may write $x = u$, and since we are in a steady state condition we may drop T, the timelag of response. This implies that the stability conditions which involve T have been satisfied.

Eq. (24·3) can be then written as :

$$\frac{du(n+1)}{dt} = C\left[u(n) - u(n+1)\right] \qquad ...(24\cdot4)$$

Now, since $x_{(n)} - x_{(n+1)} = S_{(n+1)}$

$$= \frac{1}{K_{(n+1)}} \quad ...(24\cdot5)$$

where K is the concentration.

$$u_{(n)} - u_{(n+1)} = \frac{ds_{(n+1)}}{dt}$$

$$= -\frac{1}{K^2_{(n+1)}} \frac{dK_{(n+1)}}{dt} \quad ...(24\cdot6)$$

Omitting subscripts, and combining Eqs. (24·4) and (24·5)

$$\frac{du}{dt} = \frac{C}{K^2} \frac{dK}{dt} \quad ...(24\cdot7)$$

Integrating Eq. (24·7)

$$u = \frac{C}{K} + A \quad ...(24\cdot8)$$

However, if it is assumed that all changes of concentration are governed by this equation and that when the concentration is K_j (jamming concentration), the flow and, therefore, the velocity is zero, we can evaluate A by using the boundary conditions, $u = 0$ at $K = K_j$, giving $A = -C/K_j$.

Thus, $$u = C\left[\frac{1}{K} - \frac{1}{K_j}\right] \quad ...(24\cdot9)$$

Also, in the steady state,

$$Q = uK$$

and hence, $$Q = C\left(1 - \frac{K}{K_j}\right) \quad ...(24\cdot10)$$

Eq. (24·10) is the flow-concentration relationship.

and hence,

$$Q = C\left(1 - \frac{K}{K_j}\right) \qquad \text{...(24·10)}$$

Eq. (24·10) is the flow-concentration relationship.

Now consider the case of reciprocal spacing, when

$$\lambda = \frac{C}{x_{(n)} - x_{(n+1)}}$$

or

$$\lambda = \frac{C}{s}$$

The car-following Eq. (24·2) now becomes :

$$\ddot{x}_{(n+1)}(t+T) = \frac{C\left[\dot{x}_{(n)}(t) - x_{(n+1)}(t)\right]}{x_{(n)}(t) - x_{(n+1)}(t)} \qquad \text{...(24·11)}$$

In the steady state, Eq. (24·11) can be written as :

$$\frac{du(n+1)}{dt} = \frac{C\left[u_{(n)} - u_{(n+1)}\right]}{x_{(n)} - x_{(n+1)}} \qquad \text{...(24·12)}$$

From Eq. (24·5), we have

$$u_{(n)} - u_{(n+1)} = -\frac{1}{K^2}\,\frac{dK_{(n+1)}}{dt}$$

and from Eq. (24·6), we have

$$x_{(n)} - x_{(n+1)} = \frac{1}{K_{(n+1)}}$$

Substituting these in Eq. (24·12), we have

$$\frac{du}{dt} = -\frac{C}{K}\,\frac{dK}{dt} \qquad \text{...(24·13)}$$

Integrating, and using boundary conditions,

$u = 0$ at $K = K_j$, we get

$$u = C \log \frac{K_j}{K} \qquad \text{...(24·14)}$$

In the steady state,

$Q = u\,K$, and hence

$$Q = CK \log_e \frac{K_j}{K} \qquad \text{...(24·15)}$$

Eq. (24·15) is the same as Eq. (23·19), which was derived from different conditions.

It may be noted that Eqs. (24·10) and (24·15) are not valid near $K = 0$ and hence they apply only to dense traffic.

... the 'follow-the leader'

QUEUEING THEORY

Type1: Single Server Infinine no.of Customers.

Type2: MultiServer Infinite no.of Customers

Type3: Single Server Finite No.of Customers

Type4: Multi Server Finite no.of Customers.

Type I: Single Server Infinite no. of Customers

1) Average no. of customers in the System,

$$L_s = \frac{\rho}{1-\rho} \quad \text{where } \rho = \frac{\lambda}{\mu}$$

ρ - Traffic intensity or utilization factor

λ - Mean arrival rate

μ - Mean Service rate per channel.

2) Average no. of customers in the queue

$$L_q = L_s - \rho \quad \text{or} \quad \rho L_s$$

3) Average Waiting time of a customer spends in the system, $W_s = \frac{L_s}{\lambda}$

4) Average waiting time per customer in the queue, $W_q = L_q / \lambda$

5) Average length of the queue / Average no. of customers in the non-empty queue,

$$L_w = \frac{\mu}{\mu - \lambda} = \frac{1}{1 - \rho}$$

6) Probability that the no. of customers in the system exceed k,

$$P(N > k) = \rho^{k+1}$$

7) The probability that a waiting time of a customer in the system exceeds t,

$$P(W_s > t) = e^{-(\mu - \lambda)t}$$

8) Average Waiting time of a customer in the Queue if he has to wait,

$$W_n = \frac{1}{\mu - \lambda}$$

9) The System is idle or probability of having zero customer in the system,

$$P_0 = 1 - \rho$$

10) Probability of having 'n' customers in the system,

$$P_n = (1 - \rho)\rho^n$$

25·5. Assumptions Made in a Simple Queueing Approach as Applied to Traffic Flow

The queueing theory will be developed on the basis of the following assumptions as applicable to traffic flow :

(*i*) The system is in a steady state and has "settled down". This assumption is valid only when the arrival and the service patterns are sustained for indefinitely long periods of time, and not for "peaking situations" or "transient behaviour". This implies that the traffic intensity (ρ), which is defined as

$$\frac{\text{Average rate of arrival } (\lambda)}{\text{Average rate of service } (\mu)}$$ is less than 1. Thus

$$\rho = \frac{\lambda}{\mu} < 1 \qquad \ldots(25\cdot1)$$

(*ii*) The number of customers is "discrete".

(*iii*) The population of potential customers is infinite.

(*iv*) The arrivals are random in nature and Poissonian distribution applies, the mean rate of arrival being λ.

(*v*) There will be no simultaneous arrivals.

(*vi*) There will be a single service channel. Separate modifications of the approach are available for multiple channels.

(*vii*) The queue is single and is of infinite capacity.

(*viii*) The order of service is first in first out.

(*ix*) There is a single follow-on service discipline.

(*x*) The service times vary and follow an exponential distribution, with a mean rate μ.

Problem 25·1. *A toll booth at the entrance to a bridge can handle 120 veh/hour, the time to process a vehicle being exponentially distributed. The flow is 90 veh/hour with a Poissonian arrival pattern. Determine :*

(i) *the average number of vehicles in the system ;*

(ii) *the length of the queue ;*

(iii) *the average time spent by the vehicle in the system ;*

(iv) *the average time spent by the vehicle in the queue.*

Solution. In this problem,

$$\lambda = \frac{90}{3600}$$

$$= \frac{1}{40} \text{ veh/second.}$$

$$\mu = \frac{120}{3600} = \frac{1}{30} \text{ veh/second}$$

$$\rho = \frac{\lambda}{\mu} = \frac{30}{40}$$

$$= \frac{3}{4}$$

Expected number of customers in the system

$$\bar{n} = \frac{\rho}{(1-\rho)} = 3$$

Average length of the queue, which is the number of vehicles the queue

$$\bar{q} = \frac{\rho^2}{1-\rho} = 3 \times \frac{3}{4} = 2{\cdot}25.$$

Average time spent by the vehicle in the system

$$\bar{d} = \frac{1}{\mu(1-\rho)} = \frac{1}{\frac{1}{30} \times \frac{1}{4}}$$

$$= 120 \text{ seconds.}$$

Average time spent by the vehicle in the queue

$$= \bar{w} = \frac{\rho}{\mu(1-\rho)}$$

$$= \frac{3}{4} \times 120$$

$$= 90 \text{ seconds.}$$

Problem 25·2. *The off-peak traffic flow arriving at random at toll booth facility is 90 V.P.H. and the peak flow is 180 V.P.H. The service rate, exponentially distributed, at the booth is 3·5 per minute. What is the average number of customers in the queue for each flow ?*

Solution. Off-peak flow :

$$\lambda = \frac{90}{60} = 1{\cdot}5 \text{ veh/minute}$$

$$\mu = 3{\cdot}5 \text{ veh/minutes}$$

$$\rho = \frac{\lambda}{\mu} = \frac{1{\cdot}5}{3{\cdot}5} = \frac{3}{7}$$

Average number of vehicles in the queue

$$= \bar{q} = \frac{\rho^2}{1-q} = \frac{3}{7} \times \frac{3}{7} \times \frac{7}{4}$$

$$= \frac{9}{28}$$

Peak flow : $\lambda = \frac{180}{60} = 3{\cdot}0 \text{ veh/minute}$

$$\mu = 3{\cdot}5 \text{ veh/minute}$$

$$\rho = \frac{3}{3{\cdot}5} = \frac{6}{7}$$

Average number of vehicles in the queue

$$= \bar{q} = \frac{\rho^2}{1-\rho} = \frac{6}{7} \times \frac{6}{7} \times \frac{7}{1}$$

$$= \frac{36}{7} = 5 \text{ (approx.)}$$

Problem 35·3. *There is a single toll booth in operation at a motorway where motorists are charged before being allowed to cross a bridge. The booth can handle 800 V.P.H. and the service times may be considered exponential. The peak flow is 720 V.P.H., the vehicle arrivals being random. Calculate :*

(i) *the average number of vehicles in the system ;*

(ii) *the average time a vehicle is in the system ;*

(iii) *the average time a vehicle is in the queue ;*

(iv) *the chances of there being more than 4 vehicles in the system ;*

(v) *the percentage of time a toll booth operator is free ;*

(vi) *the probability that there is no vehicle in the system ;*

(vii) *the probability that the number of vehicles in the system is three.*

Solution.

$$\lambda = \frac{720}{3600} = \frac{1}{5} \text{ veh/second.}$$

$$\mu = \frac{800}{3600} = \frac{2}{9} \text{ veh/second.}$$

$$\rho = \frac{\lambda}{\mu} = \frac{1}{5} \times \frac{9}{2} = \frac{9}{10}$$

Average number of vehicles in the system

$$= \bar{n} = \frac{\rho}{(1-\rho)} = \frac{9}{10} \times \frac{10}{1} = 9$$

The average time a vehicle is in the system

$$\bar{d} = \frac{1}{\mu(1-\rho)} = \frac{1}{\frac{2}{9} \times \frac{1}{10}}$$

$$= 45 \text{ seconds.}$$

The average time a vehicle is in the queue

$$\bar{w} = \frac{\rho}{\mu(1-\rho)} = 45 \times \frac{9}{10}$$

$$= 40{\cdot}5 \text{ seconds}$$

Probability of there being more than 4 vehicles in the system

$$= \rho^{n+1} = \left(\frac{9}{10}\right)^{4+1} = \left(\frac{9}{10}\right)^{5} = 0{\cdot}59$$

Percentage of time toll booth operator is free

$$= \frac{800-720}{800} = 10 \text{ per cent.}$$

Probability that there is no vehicle in the system

$$P_0 = (1-\rho) = \frac{1}{10} = 0{\cdot}1$$

Probability that there are three vehicles in the system

$$= P_{(3)} = (1-\rho)\rho^3$$

$$= \left(\frac{9}{10}\right)^3 \frac{1}{10} = \frac{9^3}{10000}.$$

$$= 0{\cdot}0729.$$

Module 1

Traffic Engineering is that phase of engineering which deals with the planning and geometric design of streets, highways and abutting lands and with traffic operation thereon, as their use is related to the safe, convenient and economic transportation of persons & goods.

Traffic Engineering Management is a set of measures available to the traffic engineer to make the most productive and cost-effective use of existing transportation facilities, services and modes.

- Scope

The fundamental approach in traffic management measures is to retain as much as possible existing pattern of streets but to alter the pattern of traffic movement on these, so that the most efficient use is made of the system.

The general aim is to reorient the traffic pattern on the existing streets so that the conflict between vehicles and pedestrians is reduced.

Some of well known traffic management measures are:

- => Restrictions on turning movements
- => One way streets
- => Tidal-flow operations
- => Exclusive Bus-lanes
- => Closing side-streets

The inevitable result in delay, congestion and accident due to improper traffic volume design can be reduced by good traffic management.

The traffic control measures include traffic signals and these constructing bypass, urban expressways etc.

Regulatory measures include restrictions on speed, parking, size of vehicles and so on.

Management of all these mentioned above are included in Traffic management system.

Restrictions of turning movements

- Problem posed by turning traffic

At a junction, the turning traffic includes left turners & right turners. Left turning traffic does not usually obstruct traffic flows through the junctions, but right-turning traffic can cause serious loss of capacity.

Right turning traffic can lock the flow and bring the entire flow to a halt.

One way of dealing with heavy right turning traffic is to incorporate a separate right turning phase in signal scheme or to introduce and early cut-off or late start arrangement. Limitation to this is long signal cycle.

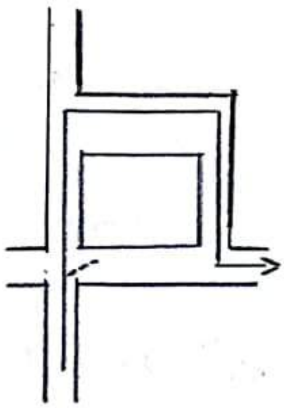
Another solution is to ban turning movements.

- Prohibited right turning movement

Prohibition of right-turning movement can be established only if the existing street system is capable of accomodating an alternative routing. Depending upon the existing layout of the street system, three methods are available:

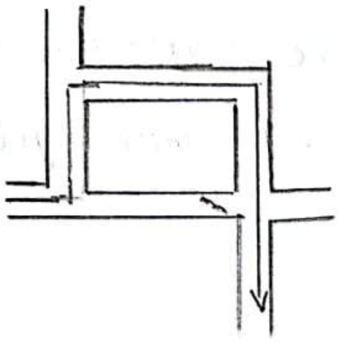
1) T turn
2) G turn
3) Q-turn

Diversion of the right-turning traffic to an alternative intersection farther along the road where there is more capacity for dealing with a right turn (It is often useful for dealing with a difficult right turn from a minor road into a major road.)
The right turn gets shifted to a minor-minor junction.



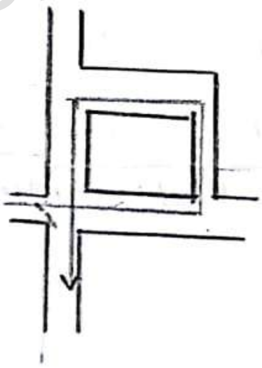
T-turn

Diversion of the right turning traffic to the left before the junction is G turn. It is useful for a right turn from a major road.



G-Turn

(Diversion of right turning traffic beyond the junction is Q turn). Only left turns are involved in it, hence least obstructive.



Q-Turn

- Prohibited left-turning movements

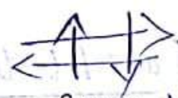
Left turning prohibition may be needed to provide a safe crossing for pedestrians especially when the pedestrians traffic across the minor road is heavy.

One way streets

One way streets are those where traffic movement is permitted in only one direction. One way streets are beneficial to improve traffic flow, increase the capacity and reduce the delays. They afford the most immediate and the least expensive method of alleviating (make less severe) the traffic conditions in a busy area. It is a better method comparing to signal installation, banned turning movements etc.

Advantages

① A reduction in the points of conflict

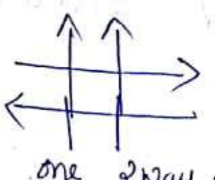


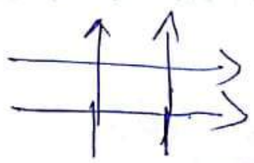
Traffic movements at junctions involve a no: of points of conflict. These generate delay, congestion and accident hazards. Reduction in points of conflict is conductive to better safety and less delay.

For eg: A two way 2 lane street have 16 points of conflict

By providing one 2way street & one one-way street the points of conflict get reduced to 7 points.

If two one way streets are provided the point of conflict reduces to 4.





② **Increased Capacity**

The removal of opposing traffic and the reduction of intersection points of conflict results in a marked increase in capacity of a one way street.

③ **Increased Speed.**

Since the opposing traffic is eliminated drivers can operate at higher speeds. This can be further facilitated by more efficient operation of traffic signal system. Delays are reduced by increasing speed.

④ **Facilitating the operation of a progressive signal system**

The use of one way street operation offers advantages in designing a system of signals for an entire area.

⑤ **Improvement in parking facilities**

A two way street with parking permitted on both sides consumes a good amount of street width. One way operation with permitted parking offers an alternative way.

⑥ **Elimination of dazzle and head on collision**

Elimination of dazzle in one way streets is conductive to greater safety. Ily the elimination of head on collision results in reduction in accident severity.

Disadvantages.

⇒ Although journey times and delays are reduced, the actual distance to be covered by driver increases.

⇒ Difficult for passengers who travel in buses, long distance to walk.

⇒ May be a hazard to residential area due to excessive speed.

⇒ One of the important drawback of a one-way street operation is the prerequisite need for the availability of a street system that can be easily modified to suit the new scheme.

For eg: A gridiron pattern lends itself to change easily than irregular street patterns.

⇒ Emergency vehicles may be blocked by cars in all lanes at intersections waiting for signals to change.

Proper signs should be put up for safe & efficient traffic. 'No entry' signs are needed at all terminal points of one way street.

Sadia (40) -

Tidal flow operations

One of the familiar characteristics of traffic flow in any street leading to the city centre is the imbalance in directional distribution of traffic during the peak hours. For instance, the morning peak results in a heavy preponderance of flow towards the city centre, whereas the evening peak brings in heavier flow away from the city centre. In either case the street space provided for the opposing traffic will be found to be in excess. This phenomenon is commonly termed as "tidal flow".

One method of dealing with this problem is to allot more than half the lanes for one direction during the peak hours. This system is known as "tidal flow operation" or "reverse flow operation".

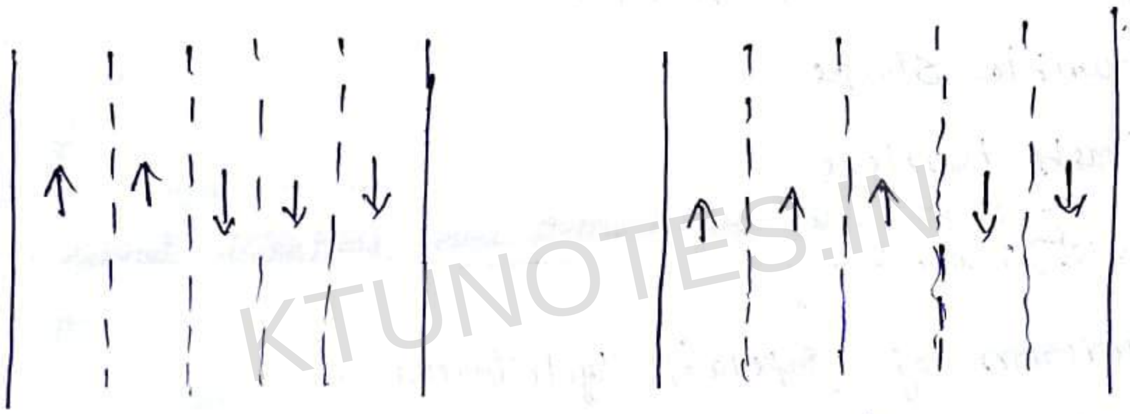
Methods to do it in practice include

(i) The first is to apportion a greater number of lanes in a multilane street to the in-bound traffic during the morning peak and lly a great no: of lanes to the out-bound traffic during the evening peak.

(ii) The second requires the existence of two seperate streets parallel to each other and close to each other, so that the wider of the two can be set apart for the heavier traffic both during the morning & evening Peak.

The two streets will operate as one way streets.

Draw fig.



AM Peak

PM Peak.

Traffic ~~Claiming~~ Calming

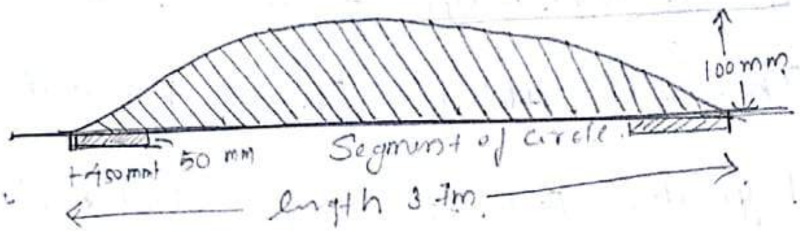
Traffic ~~Claiming~~ Calming is a set of engineering measures to reduce speeds and volume of motor vehicle in local areas, thereby increasing safety.

Some of the measures include:-

a) Speed breakers or humbs.
b) Rumble strips
c) Crash barriers
d) Road narrowing
e) Provision of separate cycle tracks.

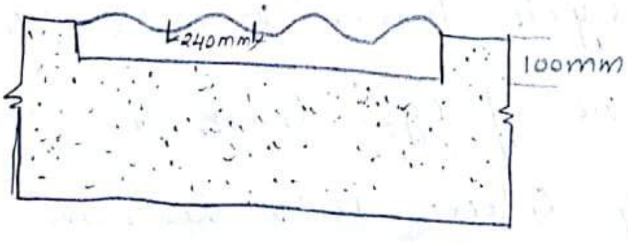
Speed breakers are also known as speed control humps, are commonly used on private access roads and near schools and universities in urban situation. They are to be disfavoured on through roads since they are dangerous to the vehicles. In India the Ministry of Surface Transport & IRC have been opposing the provision of these on the road in an indiscriminate manner. However in above situations, they are used in country.

The speed breakers should be painted with white road paint to make them visible at night. Suitable road signs should be posted to alert driver about humps



Rumble Strips

Speed breakers are sometimes hazardous, inspite of precautions taken in their safe design & construction As a substitute to this rumble strips which are corrugated surfaces producing noise and a physical sensation on the steering are provided. These are inserted by incorporating changes in the pavement texture, either by a rough surface or by artificial corrugations.



Crash barriers also known as traffic barriers keep vehicles within their road way & prevent from colliding with dangerous obstacles such as boulders, sign supports, trees, buildings etc. They are used in highways to reduce head on collisions. They are also add to protect vulnerable areas like school yards, pedestrian zone, fuel tanks from errant vehicles. It is preferable to remove, relocate if needed.

Road narrowing

It is some times necessary to reduce the carriage way width of a road to earmark some space for parking, such as in busy shopping centres. This can be achieved by chicanes. Suitable signing that the carriage way is narrowed is necessary.

Provision of seperate cycle tracks

Segregation of cycle tracks promotes safety. In view of large no. of cyclists on the street of Indian towns & cities, it is desirable that separate cycle tracks be provided wherever feasible.

Few design Critria according to IRC ;

When peak hr cycle traffic is 400 or more on routes with a vehicular traffic of 100-200 veh/hr, Segregation is ~~necessary~~ justified.

It should be provide on both sides of road.

Tracks should be clear with no obstructions such as hedges, ditches tree roots etc.

Exclusive Bus Lanes.

This is a recent innovation in traffic management practicle in some Cities to reserve a lane of Carriage way mainly for bus traffic. It is possible only in situations where the Carriage way is of adequate Width & a lane can be easily spared for the buses. This implies that there should be atleast 3 lanes in each direction. Such an arrangement nearly halves the Journey time. Regularity of the buses can be improved. To be successful, the bus lanes should be created for a good length of the road insted on small bits. Satisfactory signing and marking of the lanes & adequate publicity are also needed.

In some advanced countries, as a further measure of patronage of the buses, traffic signals have been installed with special bus detectors at street intersections. This minimize delays.

The capacity of exclusive bus lanes may be computed by assigning a PCU (passenger car unit) of 1.6 to each bus

For eg: If the road way lane has a capacity of 1500 PCU per ~~day~~ hour, the exclusive bus lane can be deemed to have a capacity of 1940 buses per hour. The width of bus lane should be minimum of 2.8 m & if possible 3.5 m.

For the case of pedestrians "Bus only" streets can also be established

~~18~~, ~~45~~, ~~31~~, ~~7~~, ~~38~~, ~~54~~, (39) ~~26~~, ~~27~~, 53

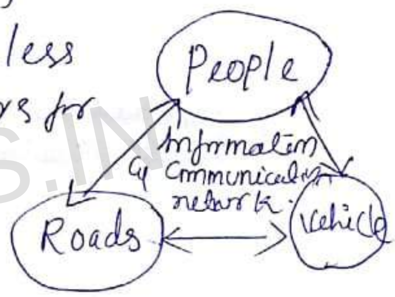
~~28~~, ~~39~~, 20, 21, 11, 2, 22, 1, ~~40~~, 5

Intelligent Transportation Systems (ITS)

Definition

ITS is the integrated application of advanced technologies of electronics, communication, computers, control and sensing in all kinds of transportation system in order to improve safety & efficiency, ~~service~~ of transportation system..

It used the technologies of wireless communication, Radar & acoustic sensors for detecting vehicles in road way.



Objectives

- To improve traffic safety
- To relive traffic congestion.
- To improve transportation efficiency.
- To reduce air pollution
- To increase the energy efficiency.
- To promote the development of related industries

Applications

⇒ Incident detection & management
⇒ Route guidance
⇒ Parking management
⇒ Electronic toll collection, GPS etc.

ITS is classified into 5 systems

1. Advanced Traffic Management system (ATMS)
2. Advanced Traveler Information system (ATIS)
3. Advanced Vehicle Control & Safety Systems (AVCSS)
4. Advanced Public Transportation system (APTS)
5. Commercial Vehicle Operation (CVO)

1. Advanced Traffic Management System (ATMS)

It detects traffic situations, transmits them to control center via communication network & then develop traffic control strategies by combining all kinds of traffic information.

eg: electronic toll collection.
signal control, speed control etc.

2. Advanced Traveler Information System (ATIS)

ATIS with advanced communication technology makes road users access real time information in the car, at home, in the office or outdoors. It includes Changeable message signs, Highway Advisory Radio (HAR), GPS etc.

(3) Advanced Vehicle Control & Safety System (AVCSS)

AVCSS applies advanced technologies in vehicles and roads, and helps drivers control vehicle in order to reduce accidents and improve traffic safety. This mainly includes anti-collision warning & control.

(4) Advanced Public Transportation System (APTS)

APTS applies the technology of ATMS, ATIS & AVCSS in public transportation in order to improve the quality of service & increase efficiency & the no: of people who take public transportation.

It includes Computer scheduling &. E-tickets etc.

(5) Commercial Vehicle operation, CVO

CVO applies the technology of ATMS, ATIS & AVCSS in commercial vehicle operation such as truck, buses, taxies & ambulance in order to improve efficiency & safety. It includes Automatic vehicle [illegible]

Module 2

Traffic Regulations

In order to have safe traffic operations on roads, it is essential to impose adequate traffic regulations & impress the public to get loathoued about these regulations.

The traffic regulations should cover all aspects of control of vehicles, driver and all other road users. The regulations should be rational.

Traffic regulations & laws give legal coverage for strict enforcement. The traffic laws implemented by legislative laws are obligatory on all road users. The different phases of traffic regulations are:

⇒ Driver control - These include driving licenses for light & heavy motor vehicles, driver tests & minimum requirements, financial responsiblity & civil liability.

⇒ Vehicle control - The various regulations and controls on vehicles are vehicle registration, requirements of vehicle, equipment & accessories, maximum dimensions &

weight & fitness and inspection of vehicles.

=> Flow Regulations : Regulations of traffic flow have been laid down such as directions, turning and overtaking etc. Some regulatory signs are speed limit, one way, pedestrian controls etc.

=> General Controls : Some other general regulations and provisions are made to report accidents and recording & disposing traffic violation cases.

Scope of traffic regulations.

=> It covers matters dealing with the control of vehicles, drivers & road users.

=> The control of vehicles deals with the registration weight, size, design, const & maintenance.

=> Driver regulation deal with the licencing & other aspects of operation of vehicles by drivers.

=> Reg of other road users deals with the rules regarding Pedestrians, cyclists & motorcyclists.

=> India, having have a mixed traffic character & this brings in the need to regulate the movement of animal drawn vehicle, cycle rickshaw & hand carts.

Need for regulation of traffic

⇒ The regulation of traffic is necessary so as to achieve safe & efficient movement of traffic & pedestrians. ~~[illegible]~~

⇒ The regulations should evoke respect by the road users and not be disregarded.

⇒ They should be flexible & should keep pace with the changing conditions & times

⇒ They should be reviewed & altered periodically in light of traffic conditions & accident data analysis.

⇒ The design of streets & facilities & the safe operation of traffic are vitally connected with Traffic regulations.

Motor Vehicle Act

The MVA (1988) Provides the basis for regulating vehicles, drivers, other road users & traffic. It contains the following Chapters:-

Chapter I : Preliminary
II : Licensing of drivers of motor vehicle
III : Licensing of conductors of stage carriages
IV: Registration of motor vehicles.
V : Control of Transport vehicles
VI A: Special provision relating to State Transport undertakings
VII : Construction, equipment & maintenance of Motor vehicles

VIII : Control of Traffic
IX : Motor vehicles temporarily leaving or visiting India

X : Liability Without fault in Certain Cases
XI : Insurance of Motor Vehicles against Third Party Risks

Speed Limit

A road speed limit is the limit of speed allowed by law of road vehicles, usually the max speed allowed. These are commonly set by the legislative bodies of national or local governments.

The speed limits should be realistic, so that they are not disregarded by drivers.

It should be reviewed periodically based on accumulated experience & future needs.

=> Volume & Character of traffic
=> Presence of pedestrians
=> features of road

In India traffic is mixed in character.

Urban areas

	Light/Medium vehicle	Heavy vehicle
Major roads of arterial / sub arterial character mostly in open & thinly buildup area.	50	40
Roads with moderate traffic situation in semi build up areas	40	30
Congested roads.	30	20

Regulation of vehicles

It includes the aspects explained below:

- Vehicle Registration.
- Construction & equipment of vehicles
- Size, weight & loads of vehicles.
- Lighting of vehicles
- Inspection of vehicles
- Control of transport vehicles.
- Insurance.

Vehicle registration

=> " Data accumulated provides guidance to administrators, traffic police, traffic engineers on total no: of vehicles in use, the types & use name of owner, licence plate no:.

In case of transport vehicle / private vehicle.	Black on white background.
temp registrations	red on yellow background.
taxies	black on yellow background.

Construction & equipment of vehicles

=> It is essential that the motor vehicles be constructed & equipped in such a manner as to promote safe & efficient traffic

Reg Conn following aspects:

- Width, H, length & overhang of vehicles & trailers.
- dm, width & condition of types of vehic.
- max unladen & laden wt of vehicle & max axle wt.
- Seating arrangements in public vehicle
- breaks & steering gear.
- Safety glass.
- lamps, reflectors.
- Smoke emissions, or/r pollutants.
- noise caused,
- Prohibiting use of horns at special locations.
- Inspection of vehicle.