TRAFFIC ENGINEERING
Open Elective

PRESENTED BY
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CELEBRATING 25 YEARS
CMRIT
CMR INSTITUTE OF TECHNOLOGY, BENGALURU.
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SYLLABUS - MODULE 2

Module -2 :

Traffic Surveys- Speed, journey time and delay surveys, Vehicles Volume Survey including non-motorized transports, Methods and interpretation, Origin Destination Survey, Methods and presentation, Parking Survey, Accident analyses-Methods, interpretation and presentation, Statistical applications in traffic studies and traffic forecasting, Level of service-Concept, applications and significance.

CO-PO AND CO-PSO MAPPING

Course Outcomes		Blooms Level	Modules covered	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
CO1	Understand the human factors and vehicular factors in traffic engineering design.	L2, L3	1	2	2	1	-	-	1	-	-	-	-	-	1	-	-	-	-
CO2	Conduct different types of traffic surveys and analysis of collected data using statistical concepts.	L2, L3	2	2	1	-	-	-	1	1	-	-	-	-	1	-	-	-	-
CO3	Use an appropriate traffic flow theory and to comprehend the capacity & signalized intersection analysis.	L4	3, 4	2	2	1	-	-	1	-	-	-	-	-	1	-	-	-	-
CO4	Understand the basic knowledge of Intelligent Transportation System.	L2, L3	4, 5	2	2	1	-	-	1	1	-	-	-	-	1	-	-	-	-

IMPORTANCE OF MODULE 2

Volume count

Speed studies

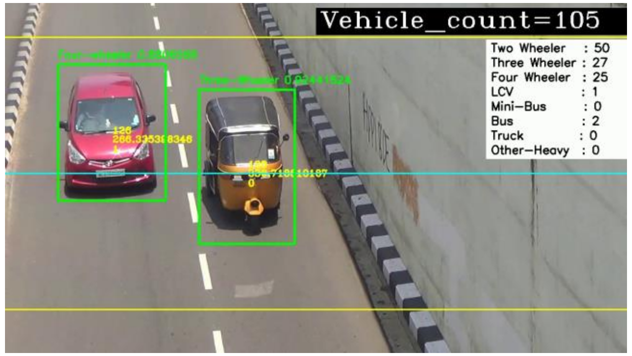
CCTV for traffic survey

Parking survey

Different terms and definitions

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

Traffic volume studies are conducted to collect data on the number of vehicles and/or pedestrians that pass a point on a highway facility during a specified time period.



Different terms and definitions

Traffic flow rate is defined as the number of vehicles that pass by a point in a given time period. This value is usually expressed as an hourly rate.

For an hour let the 15 min count of traffic volume be 1000, 1200, 1100 and 1000 vehicles.

Total volume count = 4300

Flow rates are: 1000/0.25; 1200/0.25; 1100/0.25; 1000/0.25;

Flow rates are: 4000 veh/hr ; 4800 veh/hr; 4400 veh/hr ; 4000 veh/hr

Different terms and definitions

Peak hour factor = Hourly volume/ Peak flow rate

Speed: It is the rate of movement of traffic (KPH)

Spot speed – this is the instantaneous speed of the vehicle at a location.

Here length of stretch considered will be 30 m or 45 m or so.

Running speed

Journey speed

Different terms and definitions

Running speed – is the average speed maintained by the vehicle over a given course while the vehicle is in motion

$$Running\ speed\ = \frac{Length\ of\ course}{Running\ time} = \frac{Length\ of\ course}{Journey\ time\ - Delay}$$

Journey speed – is the effective speed of vehicle of a vehicle between the two points.

$$Journey\ speed\ = \frac{Distance}{Total\ journey\ time\ (including\ delays)}$$

Different terms and definitions

Space mean speed: The space mean speed also averages the spot speed, but spatial weightage is given instead of temporal. Space mean speed for n no of vehicles moving at a speed of v_i can be given by the following equation

Time mean speed: Time mean speed is the average of all vehicles passing a point over a duration of time. It is the simple average of spot speed.

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

Different terms and definitions

Three vehicles are recorded with speed of 40, 60 and 80 kmph. The time to travel are recorded as 1.5 min, 1.0 min and 0.75 min for a length of 1 km. Estimate time mean speed and space mean speed.

$Speeds\ are\ \frac{1\times60}{1.5}, \frac{1\times60}{1}, \frac{1\times60}{0.75}$	$Speeds\ are\ 40, 60\ and\ 80\ kmph$
$Space\ mean\ speed = \frac{3}{\frac{1}{40}+\frac{1}{60}+\frac{1}{80}}$ $= 55.38\ kmph$	$Time\ mean\ speed = \frac{40+60+80}{3}$ $= 60\ \mathrm{kmph}$

Different terms and definitions

Density — Density (k) is defined as the number of vehicles per unit length of the roadway. k is given as

$$k = \frac{q}{v}$$

Where q is the flow rate and v is the speed

A highway segment with a flow rate of 1000 veh/hr and an average travel speed of 50 kmph,

$$k = \frac{1000}{50} = 20 \text{ veh/km}$$

Different terms and definitions

Headway= spacing (m)/Speed(m/s): Time headway or simply headway (h), is the time interval between the passage of the fronts of successive vehicles at a specified point. It is measured in seconds.

H_t = 1/volume

Minimum time head way = 1/ C (where C= capacity or maximum volume)

Space headway: Centre to centre distance between two successive vehicles measured from the same point on each vehicle

S = 1/ density

Unit : Km/vehicles or m/vehicles

Traffic flow parameters

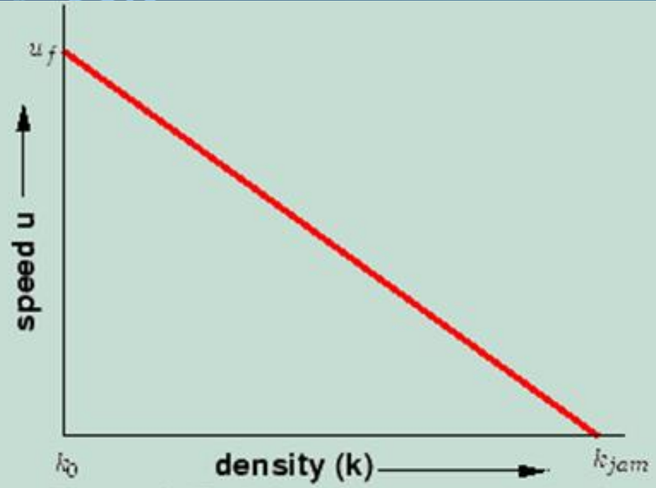


Figure 1: Relation between speed and density

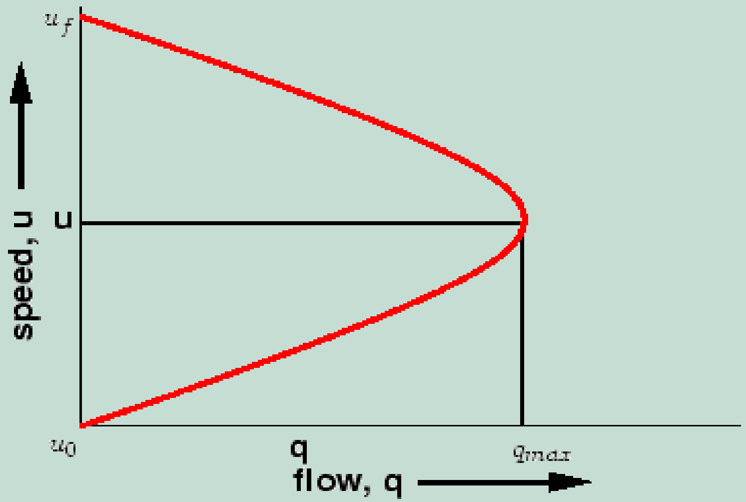


Figure 2: Relation between speed and flow

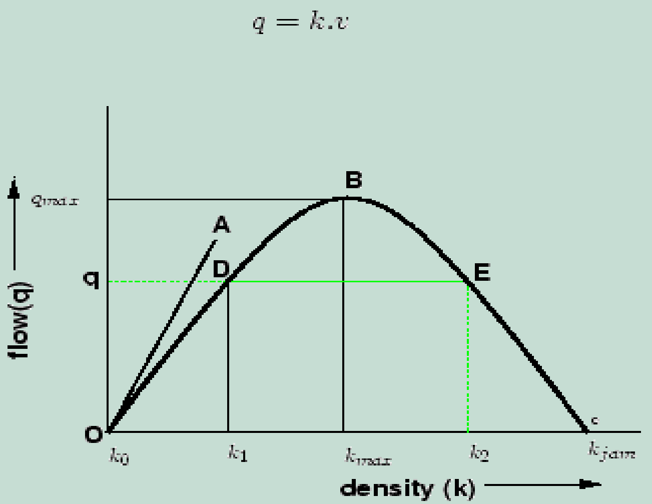
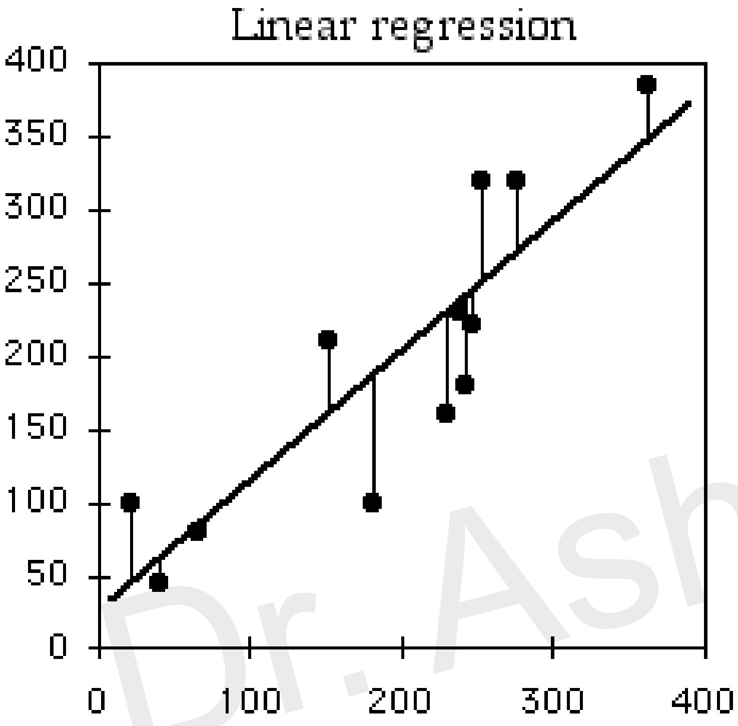


Figure 3: Relation between flow and density

$$y = mx + c$$

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

Linear Regression and Correlation



$$y_i = a + bx_i + \varepsilon \quad or\ \varepsilon = y_i - a - bx_i$$

***Method of least squares*:**

$$R = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} [y_i - a - bx_i]^2$$

$$\frac{\partial R}{\partial a} = 0; \ \frac{\partial R}{\partial b} = 0;$$

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

Linear Regression and Correlation

Method of least squares:

$$R = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} [y_i - a - bx_i]^2$$

$$\frac{\partial R}{\partial a} = 0; \frac{\partial R}{\partial b} = 0;$$

$$\hat{a} = \bar{y} - \hat{b}\bar{x}$$

$$\hat{b} = \frac{\sum x_i . y_i - n\bar{x}.\bar{y}}{\sum x_i^2 - n\bar{x}^2}$$

$$\hat{b} = \frac{\sum(x_i - \bar{x}).(y_i - \bar{y})}{\sum\left(x_i - \bar{x}\right)^2}$$

Problem

Develop a linear relationship from the following speed-density data and determine jam density and free speed.

$$\hat{a} = \bar{y} - \hat{b}\bar{x}$$

Density, VPH, (x)	10	20	30	40	50	60	70	80	90	100
Speed, KPH, (y)	60	50	45	40	35	30	20	15	10	5

$$\hat{b} = \frac{\sum x_i . y_i - n\bar{x}.\bar{y}}{\sum x_i^2 - n\bar{x}^2}$$

$$\hat{b} = \frac{\sum (x_i - \bar{x}).(y_i - \bar{y})}{\sum \left(x_i - \bar{x}\right)^2}$$

Problem

Develop a linear relationship from the following speed-density data and determine jam density and free speed.

Density, VPH, (x)	10	20	30	40	50	60	70	80	90	100	550
Speed, KPH, (y)	60	50	45	40	35	30	20	15	10	5	310
$x_i y_i$	600	1000	1350	1600	1750	1800	1400	1200	900	500	12100
x_i^2	100	400	900	1600	2500	3600	4900	6400	8100	10000	38500

Problem

Develop a linear relationship from the following speed-density data and determine jam density and free speed.

$$\hat{b} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{\sum x_i^2 - n\bar{x}^2} = \frac{12100 - 10 \times 55 \times 31}{38500 - 10 \times 55 \times 55} = \frac{-4950}{8250} = -0.6$$

$$\hat{a} = \bar{\bar{y}} - \hat{b}\bar{x} = 31 + 0.6 \times 55 = 64$$

So, the equation is v =64 - 0.6k

Traffic capacity

Basic Capacity **is the maximum number of passenger cars that can pass a given point on a lane or roadway during one hour under the most ideal roadway and traffic conditions which can possibly be attained. Thus, basic capacity is the *theoretical capacity*.**

Possible capacity **is the maximum number of passenger cars that can pass a given point on a lane or roadway during one hour under the prevailing roadway and traffic conditions. Value of possible capacity varied from zero to basic capacity.**

Traffic capacity

Practical capacity **is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour, without traffic density being so great as to cause unreasonable delay, hazard or restriction to the driver's freedom to manoeuvre under the prevailing roadway and traffic conditions.**

Theoretical capacity of a single lane,

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

Where, C is the capacity of a single lane, veh/hr

V is the speed in kmph

S is the average centre to centre spacing of vehicles, m

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Traffic capacity

Estimate the theoretical capacity of a lane, with one way traffic flow at a stream speed of 50 kmph. Assume average speed gap between the vehicles to follow a relationship S_g = 0.278Vt m with a reaction time of 0.75 seconds. Assume the average length of the vehicle travelling at 6 m and hence evaluate capacity for a two lane system.

Theoretical capacity of a single lane, $C = \frac{1000V}{S}$

Space Headway = 0.278 × 50 × 0.75 + 6

= 16.425 m

$$C = \frac{1000 \times 50}{16.425}$$

C = 3044 veh/hr/lane

For two lanes = 6088 veh/hr

Spot Speed study - Uses

Speed limits

Accident

Capacity

Geometric design

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Spot Speed study Uses

- Helps in deciding design speed and other geometric elements of the road such as curves, horizontal and vertical alignment
- For regulation and control of traffic operations
  e.g. signal design and locations of sign board
- For analyzing the causes of accidents
- Identify relation between speed and accident
- Before and after road improvement schemes
- Determining congestion problems and capacity of roads

Journey Speed and delays - Uses

Economic analysis

Congestion

Traffic control devices

Improvement measures

Journey Speed and delays - Uses

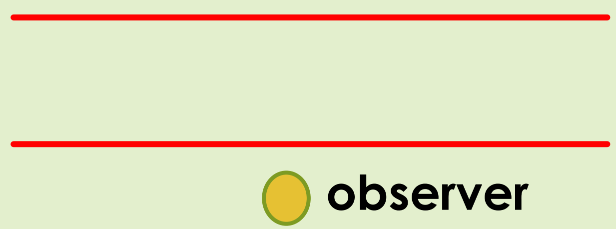
- Necessary for economic analysis
- To evaluate congestion, capacity and level of service
- Essential for trip assignment
- This is important for assessing improvement measures
- Delay studies provide data for the design and installation of traffic control devices

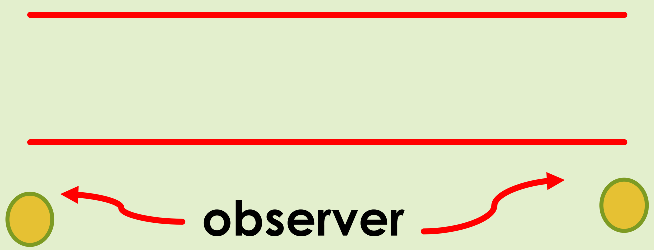
Methods of spot speed measurement

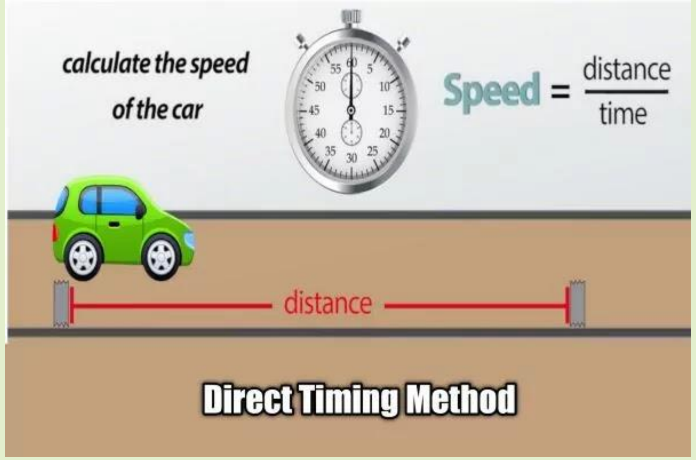
Long base methods	Short base methods
➢ Direct timing procedure ➢ Enoscope ➢ Pressure contact tubes	➢ Radar speed meter ➢ Photographic method/video camera method

Spot speed measurement – Long base methods

Direct timing procedure

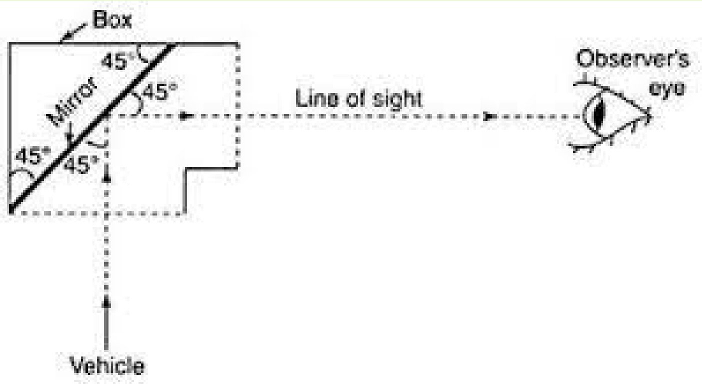


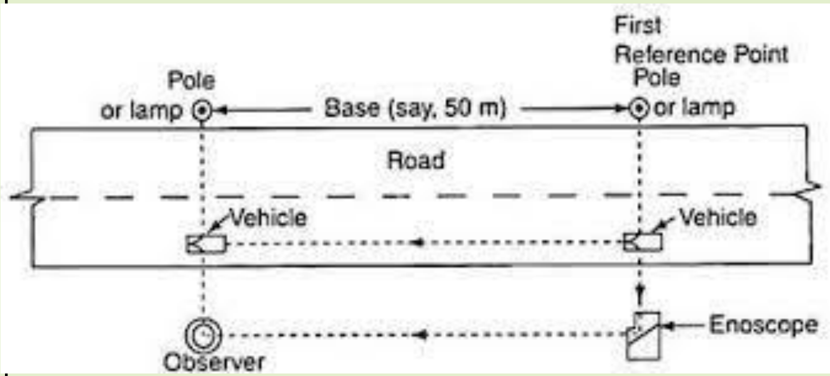


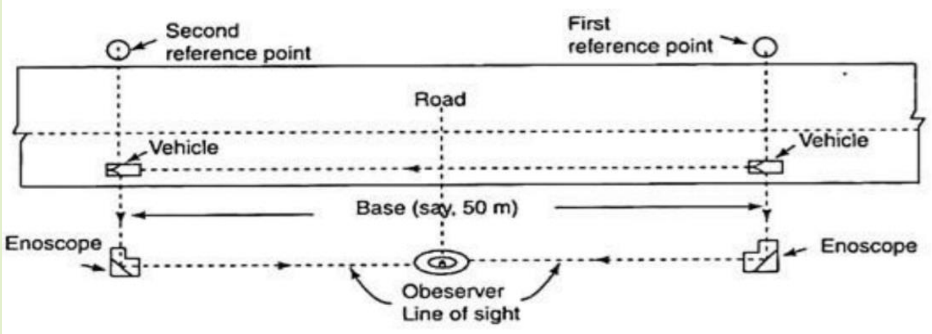


Spot speed measurement – Long base methods

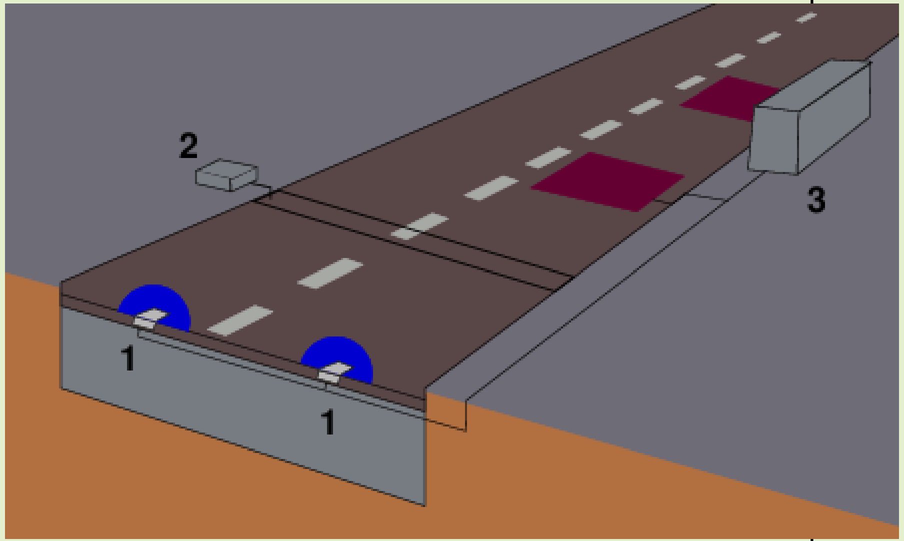
Enoscope



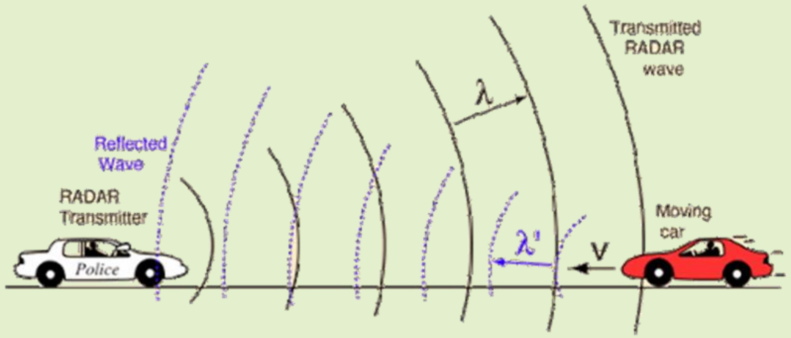




Spot speed measurement – Long base methods

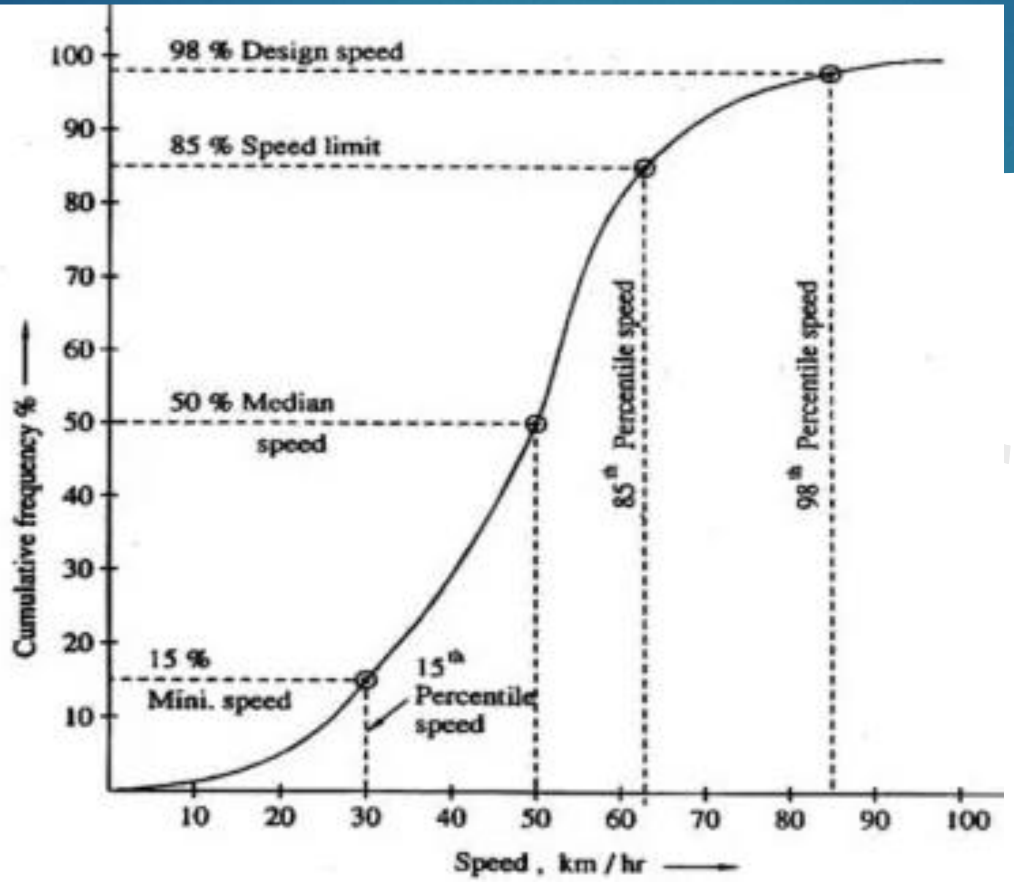
Pressure contact tubes/inductive loops		
		

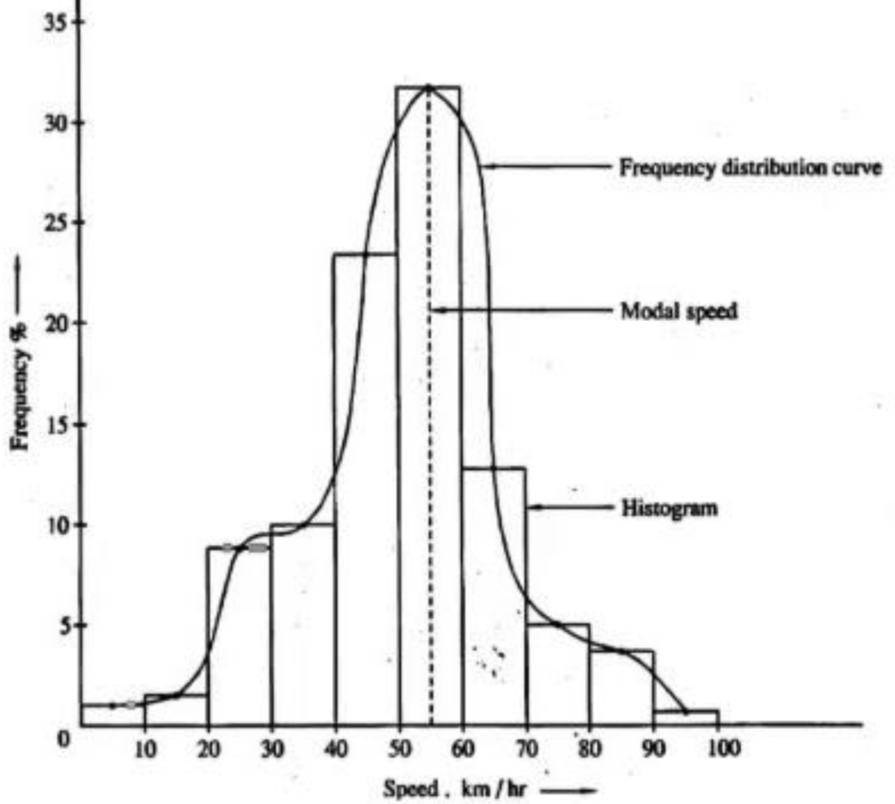
Spot speed measurement – Short base methods

Radar speed meter	Photographic method/video camera method
 	

Presentation of spot speed data

- Histogram And Frequency Distribution Curve
- Cumulative Frequency Curve





Problem

Spot speed studies were carried out at a certain stretch of a highway and the consolidated data collected are given below:

Speed range, kmph	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
Number of vehicles observed	12	18	68	89	204	255	119	43	33	9

Determine:

(i) Upper and lower values of speed limits for regulation of mixed traffic flow

(ii) Design speed for checking geometric design

(iii) Most preferred speed at which maximum proportion of vehicles travel

Problem

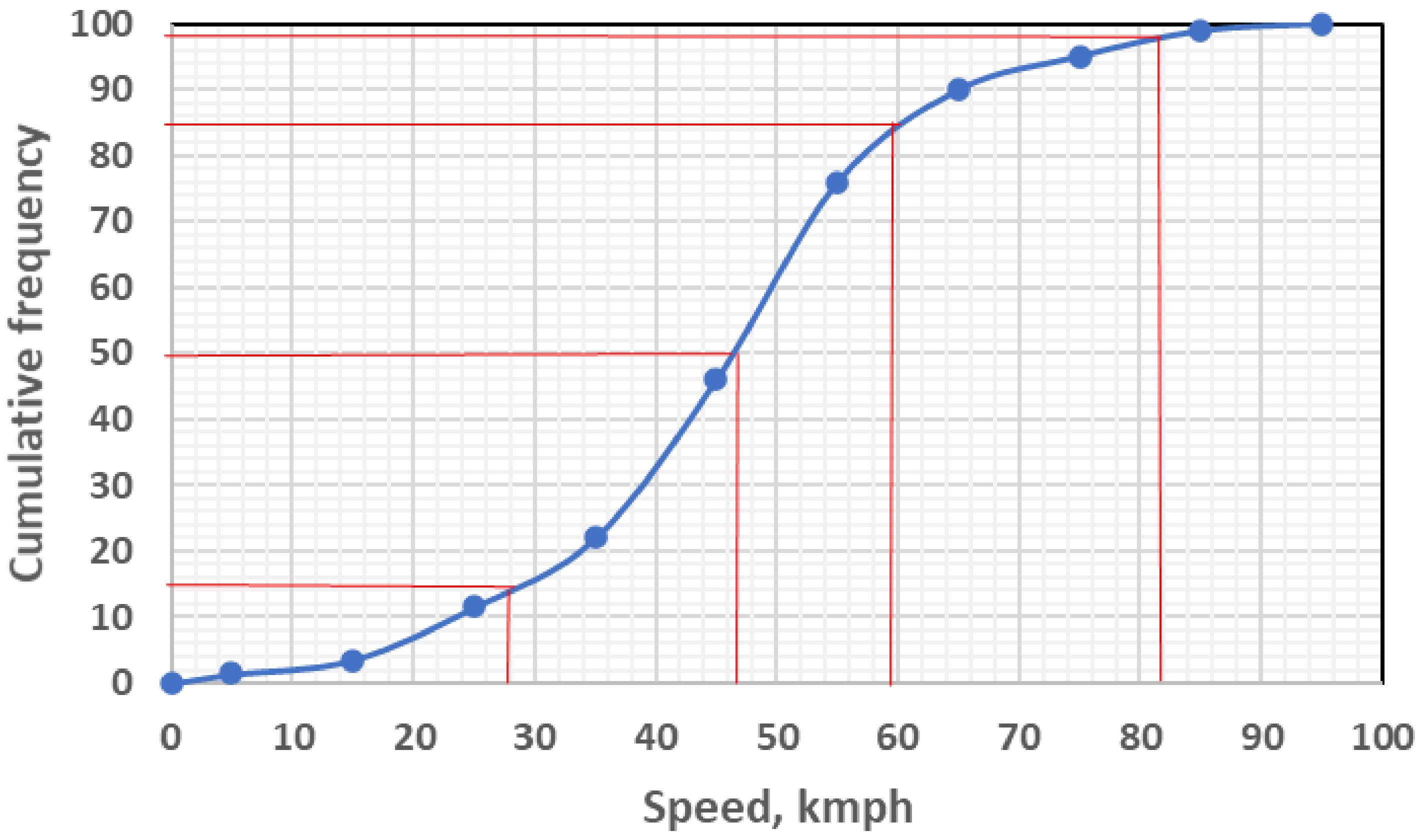
Speed range, kmph	Number of vehicles observed	Mid speed	Cumulative number of vehicles	Cumulative frequency, %
0 - 10	12	5	12	1.41
10 - 20	18	15	30	3.53
20 - 30	68	25	98	11.53
30 - 40	89	35	187	22.00
40 - 50	204	45	391	46.00
50 - 60	255	55	646	76.00
60 - 70	119	65	765	90.00
70 - 80	43	75	808	95.06
80 - 90	33	85	841	98.94
90 - 100	9	95	850	100.00

Problem

Determine:

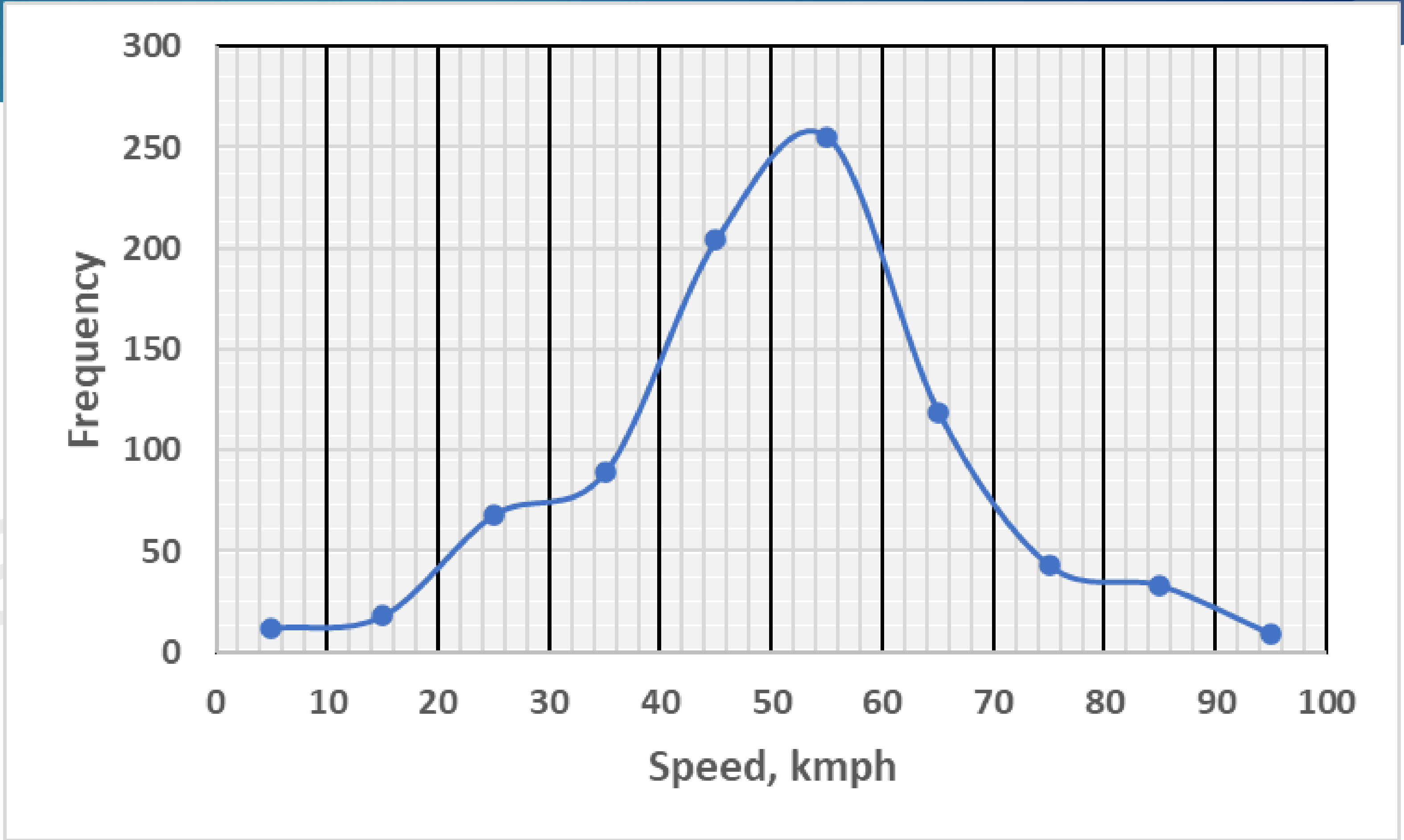
(i) Upper and lower values of speed limits for regulation of mixed traffic flow – 28 kmph and 59 kmph

(ii) Design speed for checking geometric design – 82 kmph



Problem

(iii) Most preferred speed at which maximum proportion of vehicles travel – 54 kmph

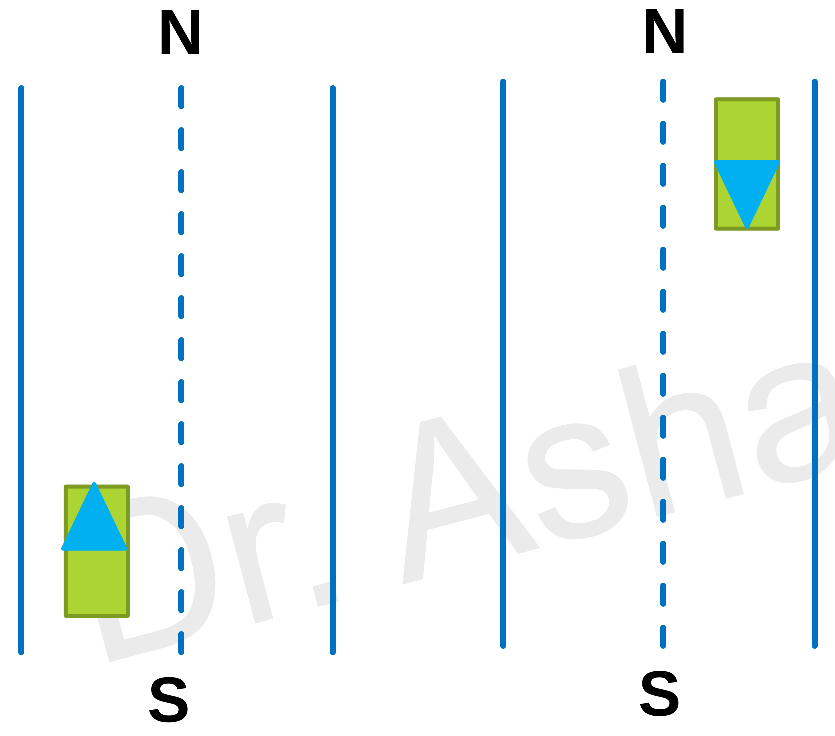


Methods of conducting speed and delay studies

- **Floating car method or riding check method**
- **License plate or vehicle number method**
- **Interview technique**
- **Elevated observations**
- **Photographic technique**

Methods of conducting speed and delay studies

- Floating car method or riding check method



4 observers:

- Time, location and cause of delays
- Number of vehicles overtaking the vehicle
- Number of vehicles overtaken by the vehicle
- Number of vehicles travelling in opposite direction

Methods of conducting speed and delay studies

Floating car method or riding check method

q – flow of vehicles in one direction of the stream

n_a – average no of vehicles counted in the direction of stream q, when the test vehicle travels in the opposite direction or against the stream

n_y - average no of vehicles overtaking the test vehicle minus the number of vehicles overtaken when the test vehicle is in the direction of the stream q

t_w - average journey time, when the test vehicle is traveling with the stream q

t_a - average journey time, when the test vehicle is running against the stream q

$$Average\ journey\ time, \bar{t} = t_w - \frac{n_y}{q}$$

$$q = \frac{n_a + n_y}{t_a + t_w}$$

Methods of conducting speed and delay studies

License plate or vehicle number method

Methods of conducting speed and delay studies

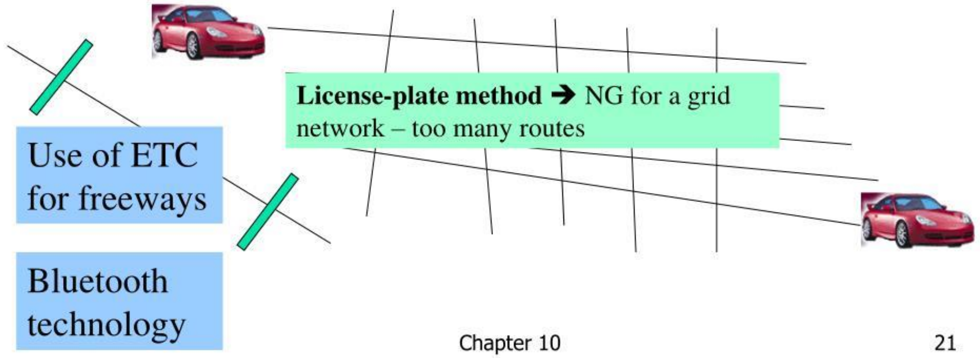
Interview technique

Elevated observations and Photographic technique

- Can be used for short stretches and signals
- Evaluate the effectiveness of control devices

Methods not requiring a test vehicle:

License-plate observation	Each observer located at strategic points record last 3 or 4 digits of license plates. Need to synchronize the observer's watch.
Interviews	Ask the drivers!



Chapter 10 21

Problem

The following tables give the particulars collected for a section of road 0.7 km long during the course of a moving observer study:

Journey: North Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
1	1.01	0.04	11	0	5	1	0
2	0.92	0.10	13	0	0	2	1
3	0.77	0.08	19	2	11	1	1
4	0.03	0.14	14	2	4	1	0
5	0.84	0.08	2	0	11	0	1
6	1.06	0.13	19	1	7	2	1

Problem

Journey: South Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
1	1.00	0.05	10	0	2	1	1
2	0.87	0.07	2	0	3	1	0
3	1.20	0.11	23	1	6	2	1
4	1.18	0.12	7	0	1	2	0
5	1.06	0.09	8	0	1	1	1
6	1.02	0.10	11	0	8	2	0

Calculate the flow in PCU/hr in both directions of traffic assuming an equivalency factor of 1 per car, 3 for bus and 2 for trucks. Calculate the journey speed and running speed.

Methods of conducting speed and delay studies

Floating car method or riding check method

q – flow of vehicles in one direction of the stream

n_a – average no of vehicles counted in the direction of stream q, when the test vehicle travels in the opposite direction or against the stream

n_y - average no of vehicles overtaking the test vehicle minus the number of vehicles overtaken when the test vehicle is in the direction of the stream q

t_w - average journey time, when the test vehicle is traveling with the stream q

t_a - average journey time, when the test vehicle is running against the stream q

$$Average\ journey\ time, \bar{t} = t_w - \frac{n_y}{q}$$

$$q = \frac{n_a + n_y}{t_a + t_w}$$

Problem

Journey: North Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
1	1.01	0.04	11	0	5	1	0
2	0.92	0.10	13	0	0	2	1
3	0.77	0.08	19	2	11	1	1
4	0.03	0.14	14	2	4	1	0
5	0.84	0.08	2	0	11	0	1
6	1.06	0.13	19	1	7	2	1

Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
Total	4.63	0.57	78	5	38	7	4
Avg	0.77	0.10	28.17 (28)			1.17	0.67

Problem

Journey: South Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
1	1.00	0.05	10	0	2	1	1
2	0.87	0.07	2	0	3	1	0
3	1.20	0.11	23	1	6	2	1
4	1.18	0.12	7	0	1	2	0
5	1.06	0.09	8	0	1	1	1
6	1.02	0.10	11	0	8	2	0

Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
Total	6.33	0.54	61	1	21	9	3
Avg	1.06	0.09	17.67			1.5	0.5

Problem

North Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction (N-S)			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
Avg	0.77	0.10	28.17 (28)			1.17	0.67
South Bound							
Trip No	Journey time, min	Stopped time, min	Vehicles met with in the opposite direction (S – N)			Vehicles in the same direction	
			Car	Bus	Truck	Overtaking vehicles	Overtaken vehicles
Avg	1.06	0.09	17.67 (18)			1.5	0.5

$$\bar{t} = t_w - \frac{n_y}{q}$$

$$q = \frac{n_a + n_y}{t_a + t_w}$$

$$q_N = \frac{18 + (1.17 - 0.67)}{1.06 + 0.77} = 10.11\ PCU's/hr$$

$$q_S = \frac{28 + (1.5 - 0.5)}{1.06 + 0.77} = 15.85\ PCU's/hr$$

$$\bar{t}_N = 0.77 - \frac{(1.17 - 0.67)}{10.11} = 0.72\ min$$

$$\bar{t}_S = 1.06 - \frac{(1.5 - 0.5)}{15.85} = 0.997\ min$$

Problem

$$\bar{t}_N = 0.77 - \frac{(1.17 - 0.67)}{10.11} = 0.72\ min$$

$$\bar{t}_S = 1.06 - \frac{(1.5 - 0.5)}{15.85} = 0.997\ min$$

$$Mean\ journey\ speed\ (north) = \frac{0.7}{0.72/60} = 58.3\ kmph$$

$$Mean\ journey\ speed\ (south) = \frac{0.7}{0.997/60} = 42.13\ kmph$$

$$Mean\ running\ speed\ (north) = \frac{0.7}{(0.72 - 0.1)/60} = 67.74\ kmph$$

$$Mean\ running\ speed\ (south) = \frac{0.7}{(0.997 - 0.09)/60} = 46.31\ kmph$$

Traffic volume study - Uses

Pavement design

Congestion

Traffic control devices

Improvement measures

Traffic volume study - Uses

- Helps in understanding the efficiency of a traffic system
- Helps in estimating the Level of Service of a system
- Estimate whether the traffic is above or below the capacity
- Helps in estimating congestion of roads
- Indicator of improvement of transport facilities
- Helps to draw up schemes for improvement
- Helps in traffic forecasting
- Essential data for pavement design
- Implementing traffic control and regulating measures
- For evaluating financial viability of toll roads
- Number of commuters and vehicle occupancy is important in estimating monetary value/man-hour

Traffic volume study - Uses

- **Average annual flow: expressed as vehicles/year**
- **AADT – Annual Average Daily Traffic is defined as 1/365 of the total annual flow.**
- **ADT - If the flow is measured for a few days, the average flow taken is known as Average Daily Traffic**

Methods of traffic volume studies – Purpose and use

Short term counts	Counts for a full day	Continuous for a full week	Continuous counts
➢ To determine the peak hour traffic ➢ Used to determine saturation flow at signalised intersections	➢ To determine hourly fluctuation of traffic ➢ Used in intersection counts	➢ To determine the hourly and daily fluctuation of flow ➢ Used for traffic census of non-urban highways	➢ Determine the fluctuation of daily, weekly, seasonally and yearly traffic flow ➢ Determine the annual rate of growth of traffic

Methods of traffic volume studies – Purpose and use

- Manual methods
- Combination of manual and mechanical methods
- Automatic devices
- Moving observer method
- Photographic method

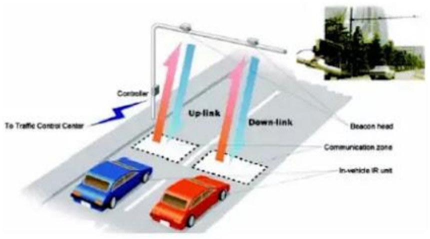
Methods of traffic volume studies – Automatic devices

- Pneumatic tube
- Electric contact
- Coaxial cable
- Photoelectric
- Radar
- Infra red and ultrasonic
- Magnetic
- Videographic

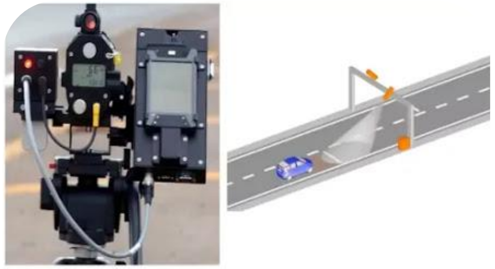
Infrared Devices

Coaxial Cable

Photo electric Devices



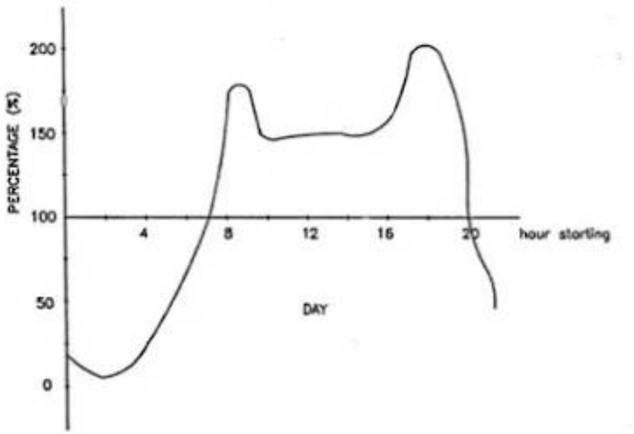
Magnetic Counters



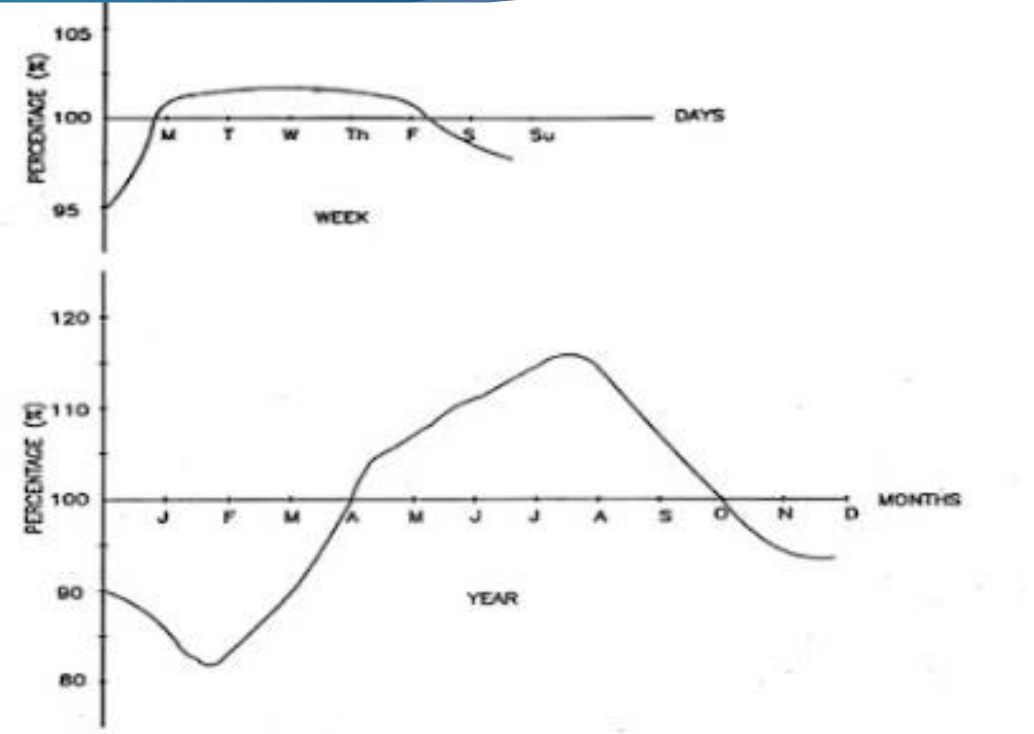
Radar Devices

Presentation of traffic volume data

- AADT or ADT
- Trend charts
- Variation charts
- Traffic flow maps
- Volume flow diagram
- 30th highest hourly volume



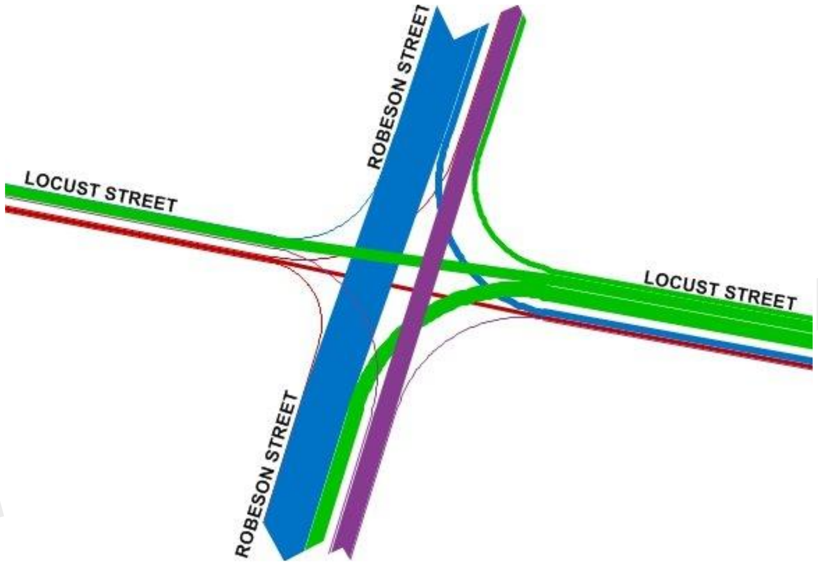
Traffic Pattern throughout day



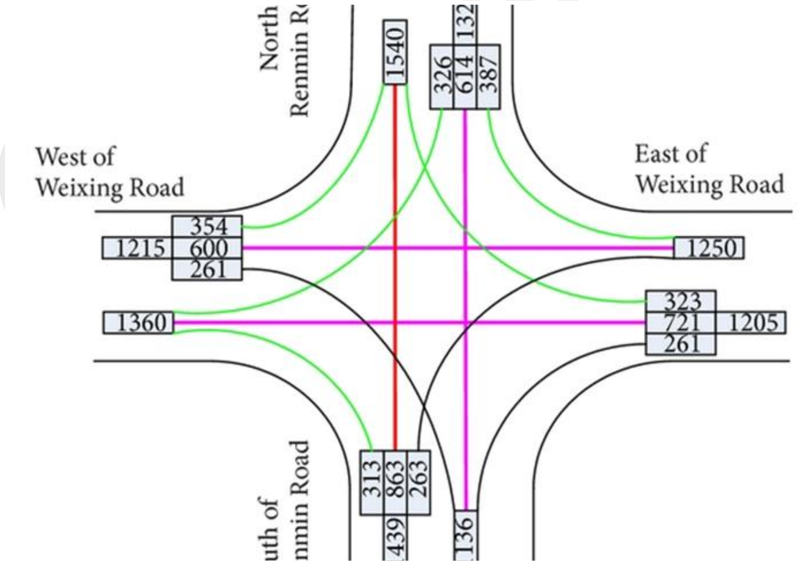
Typical traffic flow patterns throughout the day, week and year

Presentation of traffic volume data

- AADT or ADT
- Trend charts
- Variation charts
- Traffic flow maps
- Volume flow diagram
- 30th highest hourly volume



Traffic flow maps

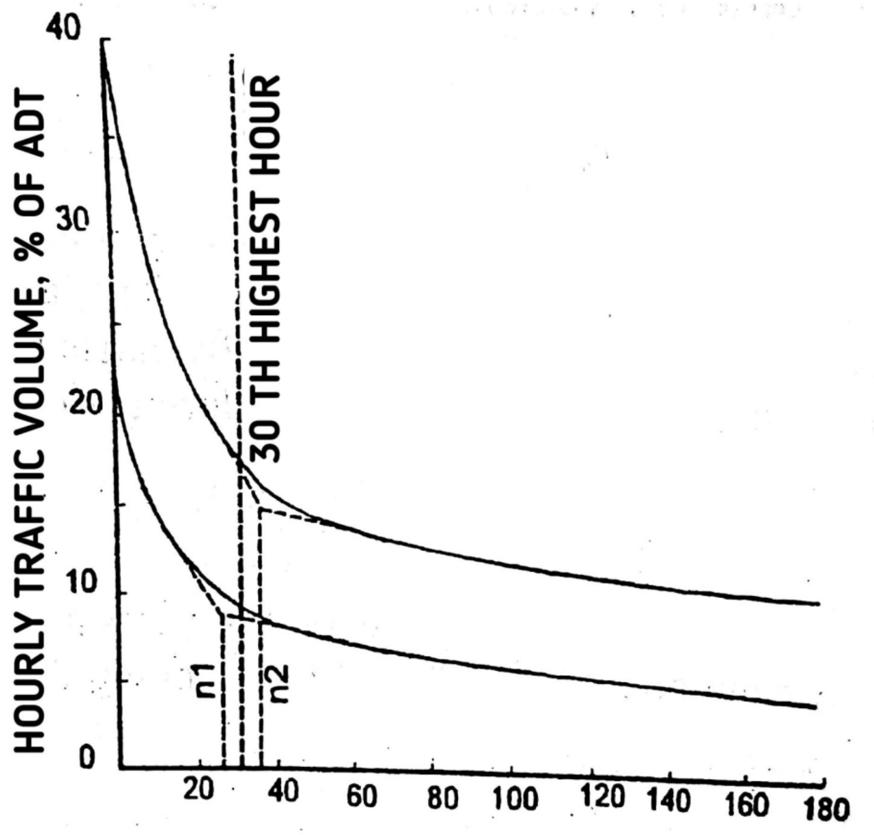


Traffic flow diagrams

Presentation of traffic volume data

- AADT or ADT
- Trend charts
- Variation charts
- Traffic flow maps
- Volume flow diagram
- 30th highest hourly volume

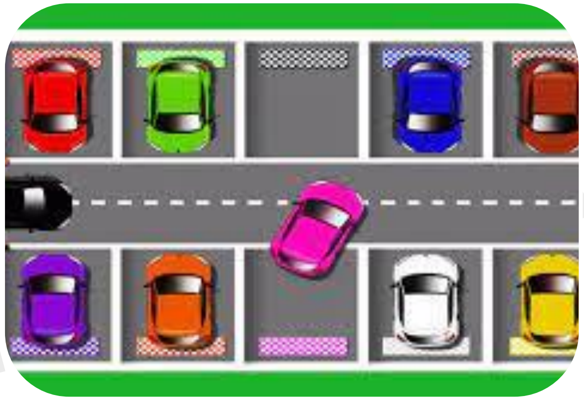
30th highest hourly volume – it is that hourly volume which is exceeded only 29 times in a year and all other hourly volumes are less than this volume



Origin – Destination study - Uses

Origin and destination

Bypass roads



Adequacy of parking

Adequacy of highway system

Origin – Destination study - Uses

- Origin is the place where the trip begins and destination is the place where the trip ends

- To determine the amount of bypassable traffic that enters a town and thus establish the need of a bypass road
- To develop trip generation and trip distribution models in transport planning process
- To determine the extent to which the present highway system is adequate and plan new facilities
- To assess the adequacy of parking facilities and to plan in future

O-D survey

Data collected in O-D survey

- How many trips are made
- Landuse of zones and its destination
- Household characteristics of the trip making family
- Trip purpose and mode of travel

Methods of conducting O-D studies

- Home interview survey
- Road side interview survey
- Post card questionnaire survey
- License plate or registration number plate survey
- Tags on vehicles

Study area

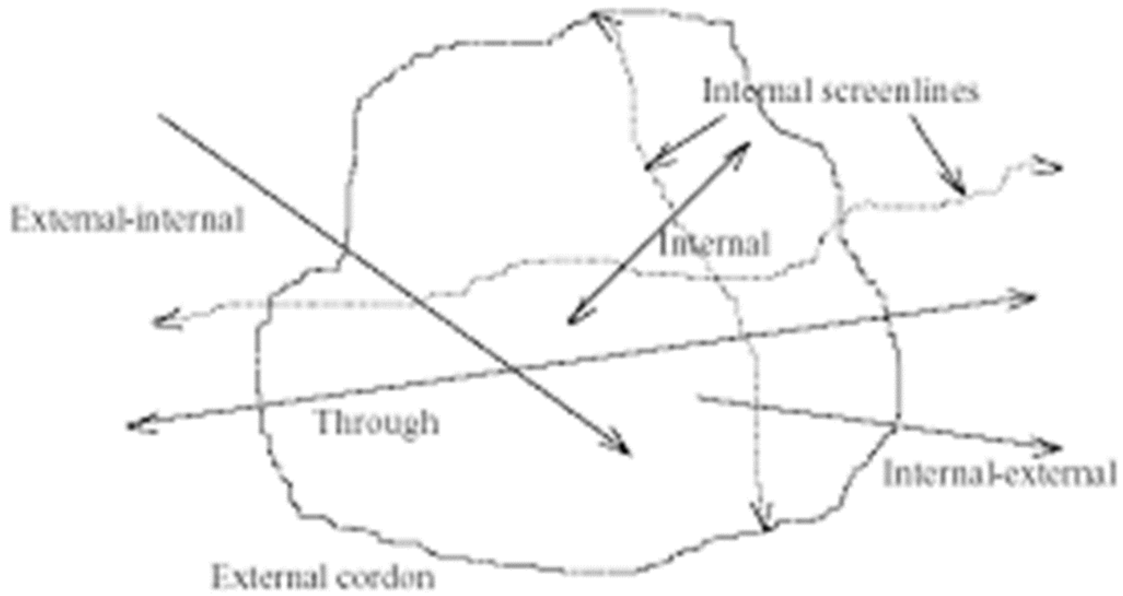
- Existing travel pattern
- Existing land use
- Existing transport facilities

- National level planning
- Regional level planning
- Urban level planning

Cordon Line. The imaginary line representing the boundary of study area is termed as Cordon Line and the survey done inside the area covered by cordon line to study travel pattern to large extent is known as Cordon Line Survey.

Selection of cordon line

- Should include all built up areas and those areas that are likely to be built up during the period of study
- External cordon line should include all areas of systematic daily life of people oriented towards the city centre
- Should be compatible with previous studies
- The cordon ines should be uniform and continuous so that movement cross it only once.



Zoning

- Zoning is the way the governments control the physical development of land and the kinds of uses to which each individual property may be put.
- Zoning laws typically specify the areas in which residential, industrial, recreational or commercial activities may take place.
- Zones should reflect average characteristics of individual households
- Zones within study area are called as internal zones and those outside are called as external zones.
- Zones can be further divided into sub-zones based on land use.

Division of area into zones

- Landuse is the most important factor viz., residential, industrial, commercial, recreational.
- Zones should have homogenous land use to reflect the associated trip- making behaviour.
- Anticipated changes in land use should be considered when sub-dividing the area into zones
- Subdivision should closely follow that adopted by other bodies for data collection.
- Zones should not be too large
- Zones should have regular geometrics such that its centroid can be determined accurately
- Znes should be compatible with screen lines and cordon lines
- Sectors should represent the catchment of trips
- Zone boundaries should preferably be water sheds of trip making
- Natural boundaries such as canals, rivers etc form convenient zone boundaries

O-D survey methods

Methods of conducting O-D studies

- Home interview survey
- Road side interview survey
- Post card questionnaire survey
- License plate or registration number plate survey
- Tags on vehicles

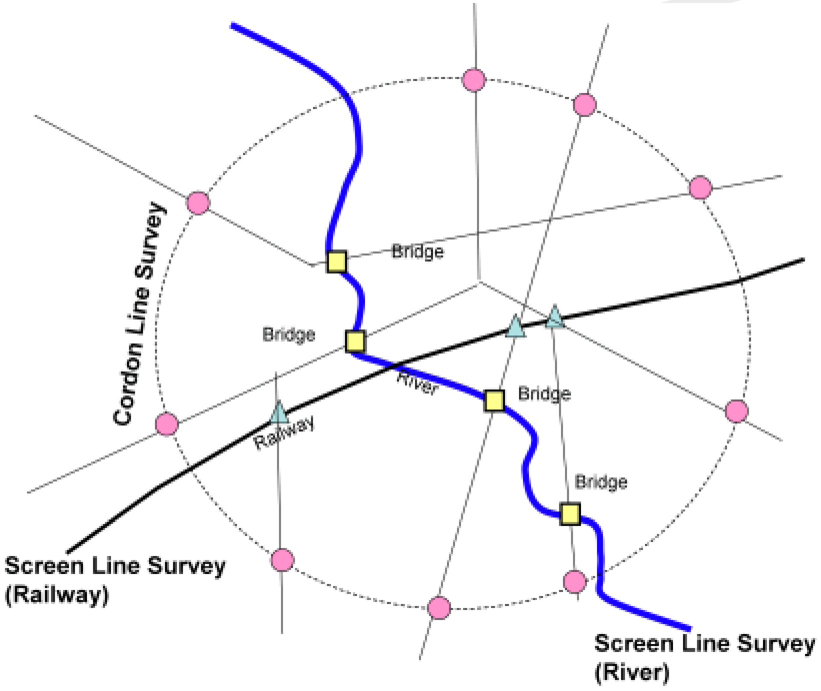
Home interview Survey:

- Household information
- Journey data

O-D survey methods

Methods of conducting O-D studies

- Home interview survey
- Road side interview survey
- Post card questionnaire survey
- License plate or registration number plate survey
- Tags on vehicles



Presentation of O-D Data

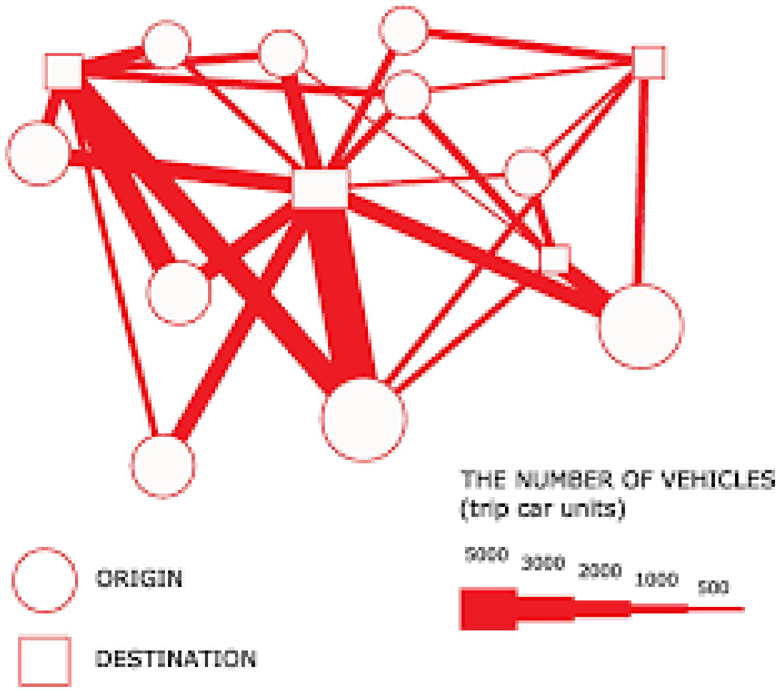
- O-D table
- Desire lines
- Pie charts
- Contour lines

OD Zones	2	1	4	7	8	9	3	Total
2	-	505	572	111	875	111	17	2200
1	505	-	260	50	398	50	8	1271
4	572	260	-	57	451	57	9	1405
7	111	50	57	-	87	11	2	219
8	875	398	451	87	-	87	13	1911
9	111	50	57	11	87	-	2	219
3	17	8	9	2	13	2	-	51
Total	2200	1271	1405	219	1911	219	51	9810

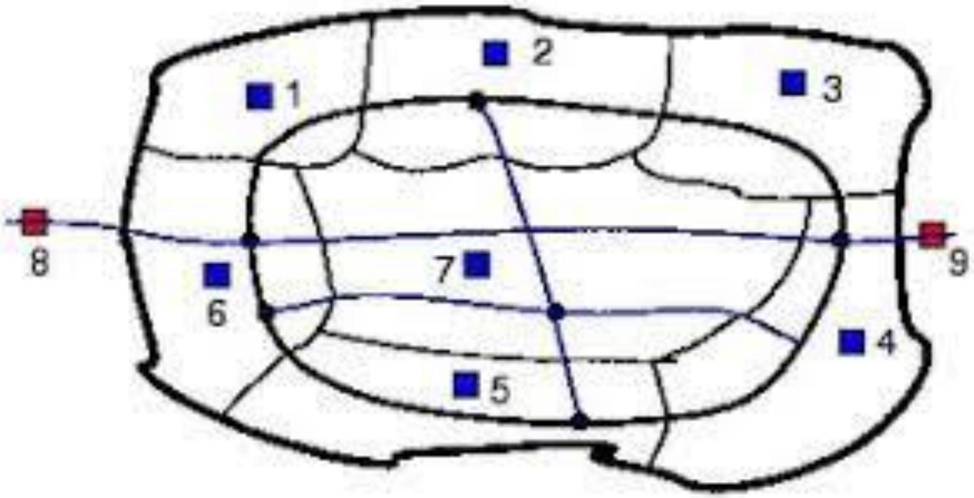
O-D table

Presentation of O-D Data

- O-D table
- Desire lines
- Contour lines
- Pie charts



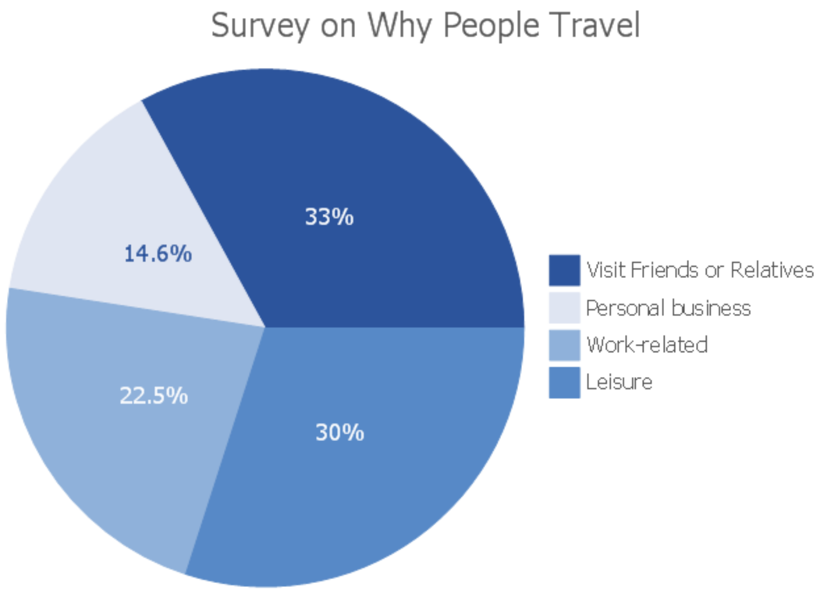
Desire lines

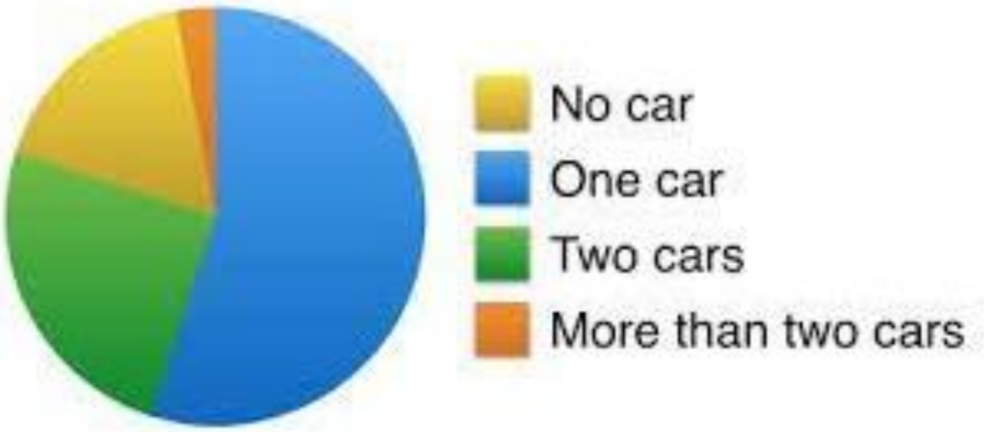


Contour lines

Presentation of O-D Data

- O-D table
- Desire lines
- Contour lines
- Pie charts

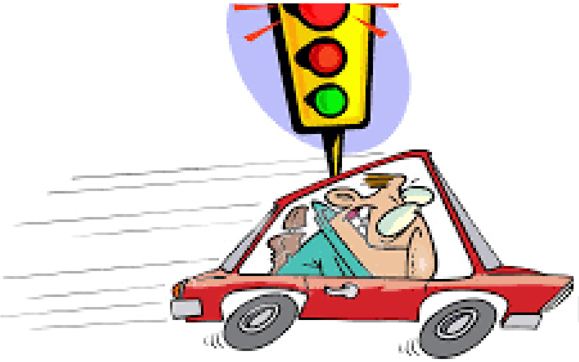




Pie charts

Accident study- Uses

Causes of accidents



Before and after improvement

Financial loss

Evaluate and re-evaluate

Accident studies - Objectives

- To study causes of accidents and to suggest corrective measures
- To evaluate existing designs
- To support proposed designs
- To carry out before and after studies and to demonstrate improvement in the problem
- To compute financial loss
- To give economic justification for the improvement suggested by the traffic engineer

Causes of road accidents

Road user

Vehicular characteristics

Road and its condition

Weather

Causes of road accidents

Improper road design

Due to animals on road

Accidents due to passengers

Due to pedestrians

Steps involved - Accident studies and records

- Collection of accident data
- Preparation of reports
- Location file and diagrams
- Application of the above for suggesting preventive measures

- Date, time and persons involved in accidents, classification of accident like fatal, serious, minor etc
- Location
- Details of vehicles involved
- Nature of accident
- Road and traffic conditions
- Primary causes of accidents
- Accident costs

- Legal action, especially in accidents, property damage etc

Accident records

- **Location files**
- **Spot maps**
- **Condition diagram**
- **Collision diagram**

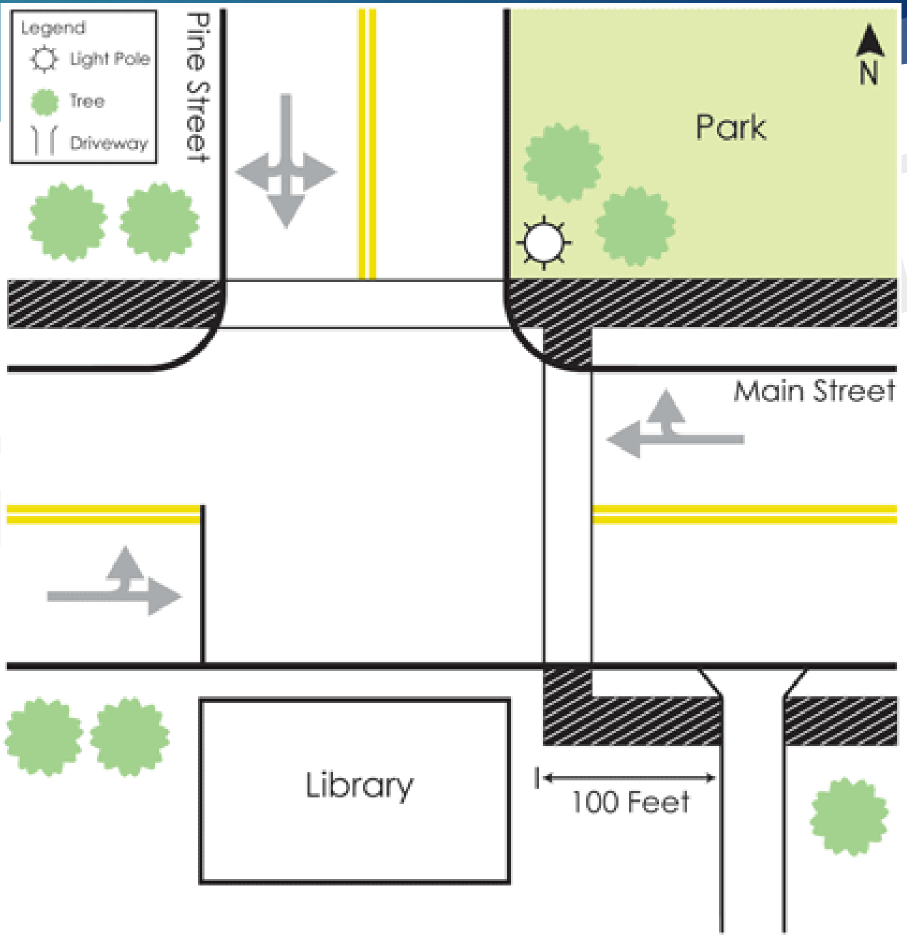
- **Spot maps**

indicate severity of accident

Type of accident	Fatal	Non-fatal
Motor – vehicle pedestrian	◉	◉
Other motor vehicle traffic	●	○

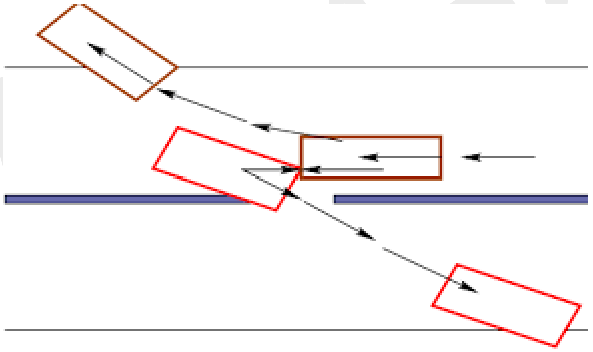
Accident records

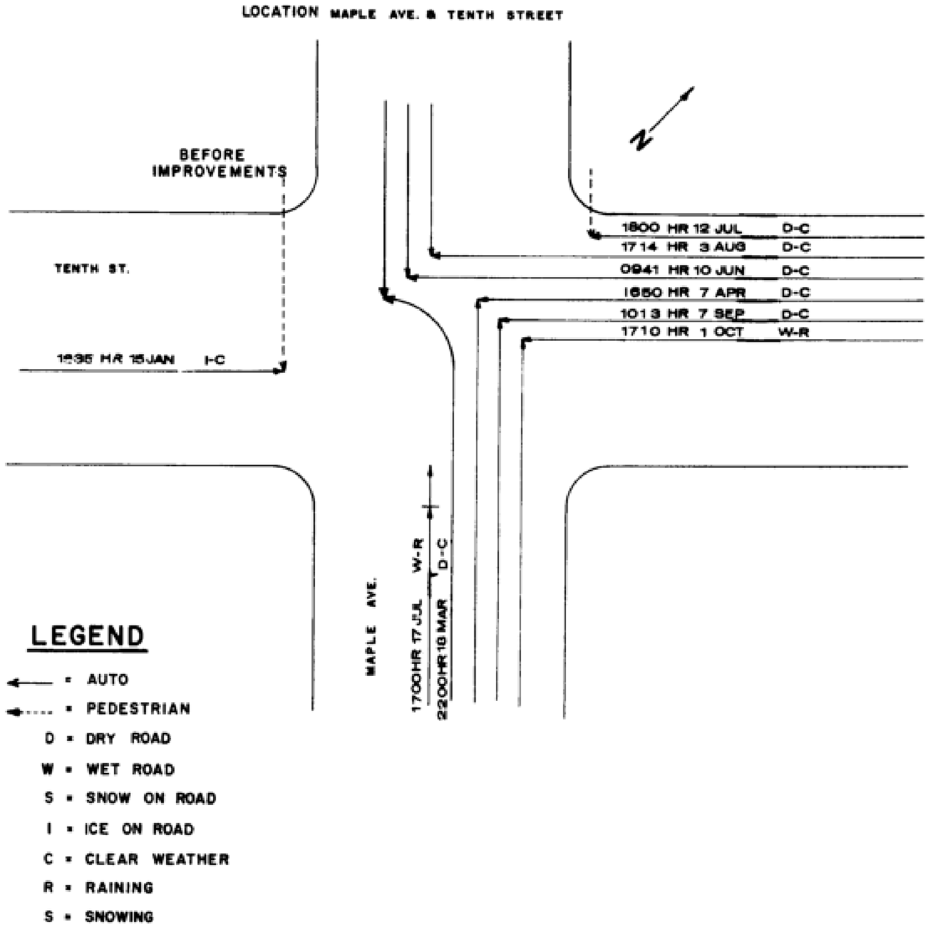
A condition diagram is a scale drawing which provides an accurate picture of the physical conditions present at the location under study. Condition diagrams may indicate view obstructions are contributory causes of accidents.



Accident records

Collision diagrams are used to display and identify similar accident patterns. They provide information on the type and number of accidents; including conditions such as time of day, day of week, climatic conditions, pavement conditions, and other information critical to determining the causes of safety problems.





Collision Diagram

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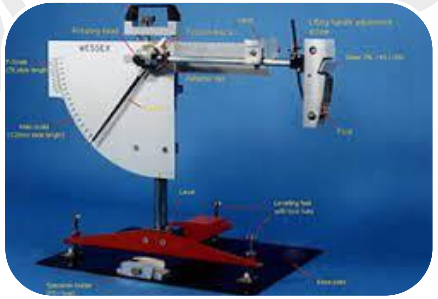
Stages in Accident analysis

- Accident investigations
- Analysis of individual accidents
- Statistical analysis of accidents

Accident investigations

- Recording general observations
- Driver tests
- Skid resistance of pavement surface
- Vehicle tests
- Probable cause of accident
- Cost analysis



Stages in Accident analysis

- Accident investigations
- Analysis of individual accidents
- Statistical analysis of accidents

Statistical analysis of accidents

- Number of vehicle
- Population
- Speed
- Probability study
- Reliability studies

Analysis of individual accidents

- Moving vehicle collides with a parked vehicle
- Two vehicles approaching from different directions collide at an intersection
- Head on collision of vehicles
- Moving vehicle collide with stationary vehicle

After collision

During collision – momentum is equated

Before collision

Problem

A vehicle of weight 2 t skids through a distance equal to 40 m before colliding with another parked vehicle of weight 1 t. After collision both the vehicles skid through a distance equal to 12 m before stopping. Compute the initial speed of the moving vehicle. Assume coefficient of friction is 0.5.

Before collision

Initial velocity of A va1 =?

Final velocity of A is va2 = ?

S = 40 m

$$va2^2 = va1^2 - 2aS$$

$$16.28^2 = va1^2 - 2 \times 9.81 \times 0.5 \times 40$$

va1 = 25.64 m/s

At collision

Initial velocity of A is va2 =?

Initial velocity of B is vb1 = 0

Final velocity of A and B is v1

Equating momentum

$$2 \times va2 + 1 \times 0 = 3 \times v1$$

va2 = 16.28 m/s

After collision

Initial velocity of A and B is v1

Final velocity of A and B is 0

S = 12 m

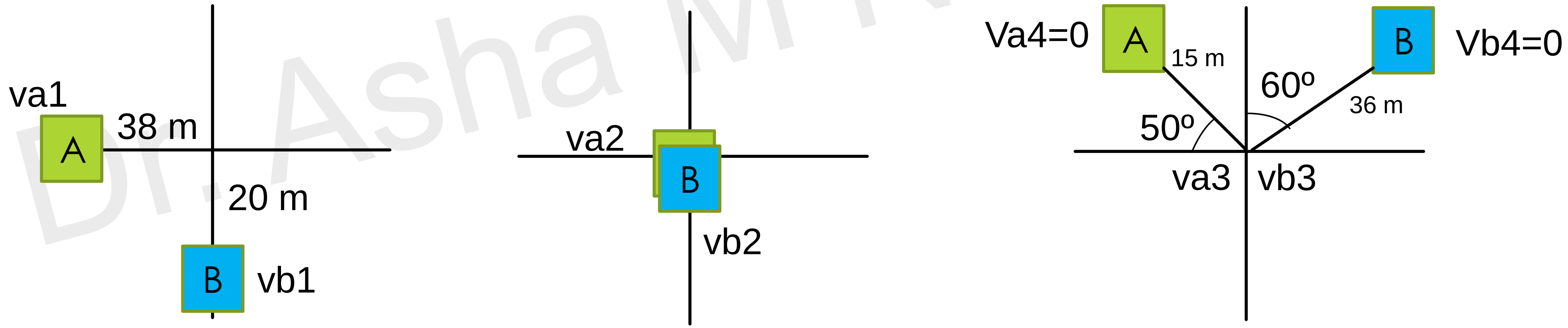
$$v2^2 = v1^2 - 2aS$$

$$0 = v1^2 - 2 \times 9.81 \times 0.5 \times 12$$

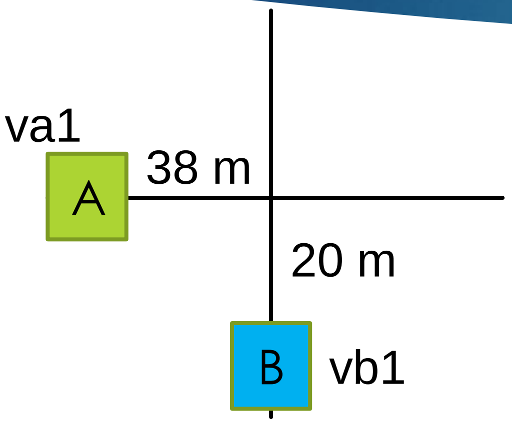
v1 = 10.85 m/s

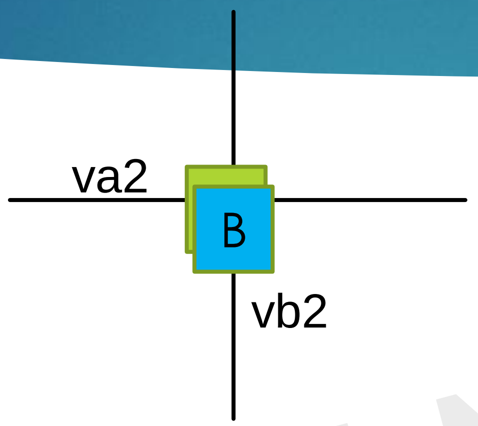
Problem

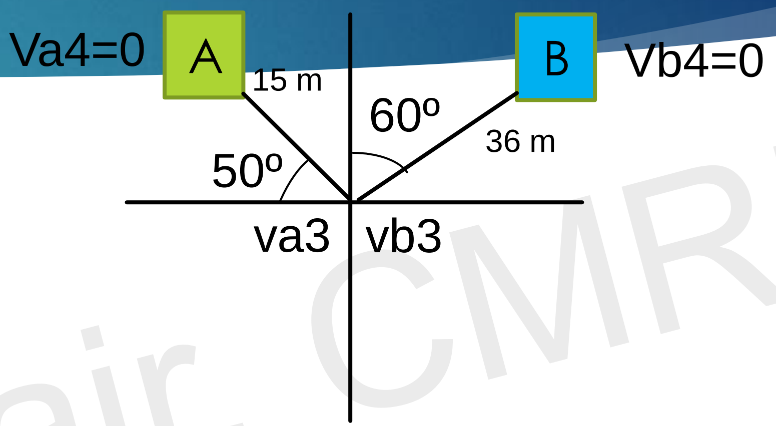
Two vehicles A and B approaching at right angles, A from West and B from South collides with each other. After the collision, vehicle A skids in a direction of 50° North of West and vehicle B, 60° East of North. The initial skid resistance of the vehicles are 38 m and 20 m before collision. The skid resistances after collision are 15 m and 36 m respectively. If the weights of vehicles B and A are 6.0 and 4.0 tonnes, calculate original speeds of the vehicles. The average skid resistance of the pavement is found to be 0.55.



Problem







After collision for A

Initial velocity va3 =?

Final velocity va4 = 0

Sa = 15 m

$$v2^2 = v1^2 - 2aS$$

$$0 = v3^2 - 2 \times 9.81 \times 0.55 \times 15$$

va3 = 12.72 m/s

After collision for B

Initial velocity vb3 =?

Final velocity vb4 = 0

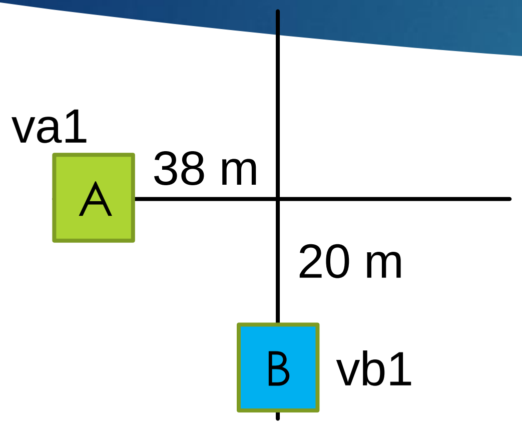
Sa = 36 m

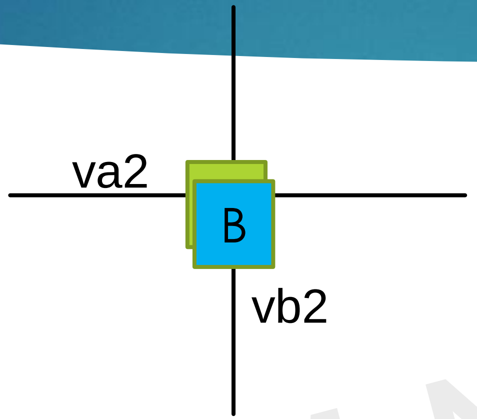
$$v2^2 = v1^2 - 2aS$$

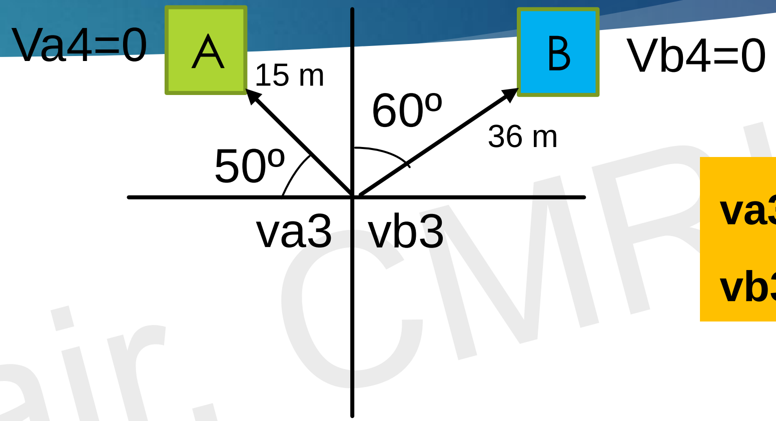
$$0 = vb3^2 - 2 \times 9.81 \times 0.55 \times 36$$

vb3 = 19.71 m/s

Problem







va3 = 12.72 m/s

vb3 = 19.71 m/s

At collision,

Momentum in X direction

$$4 \times va2 = -4 \times va3Cos50 + 6vb3sin\,60$$

Va2 = 17.43 m/s

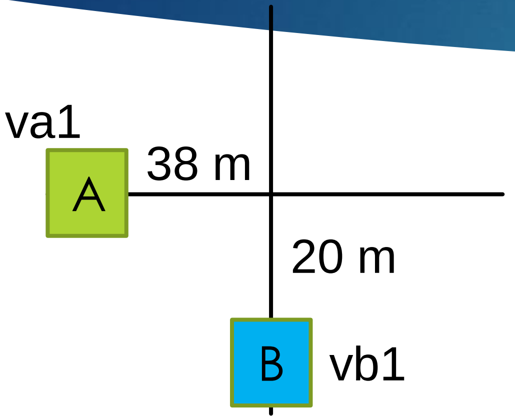
At collision,

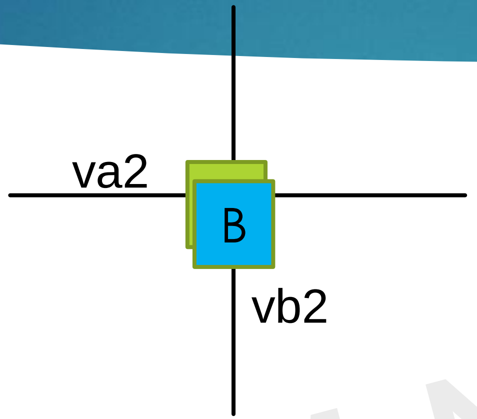
Momentum in Y direction

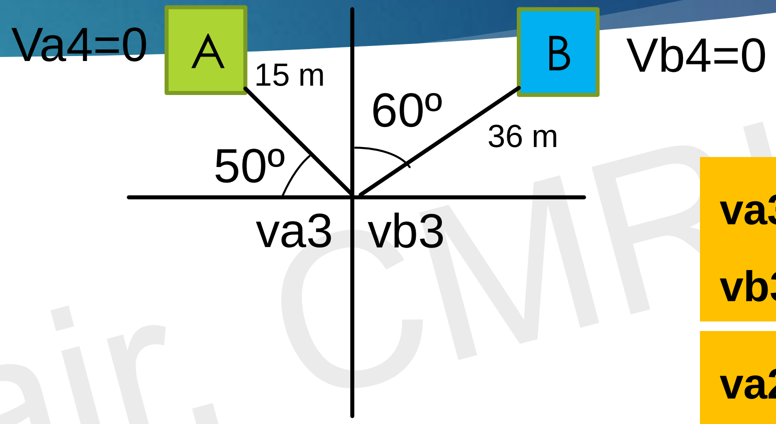
$$6 \times vb2 = 4 \times va3 \times Sin50 + 6 \times vb3 \times Cos\,60$$

Vb2 = 16.36 m/s

Problem







va3 = 12.72 m/s

vb3 = 19.71 m/s

va2 = 17.43 m/s

vb2 = 16.36 m/s

Before collision,

$$va2^2 = va1^2 - 2 \times 9.81 \times 0.55 \times 38$$

Va1 = 26.72 m/s

At collision,

$$vb2^2 = vb1^2 - 2 \times 9.81 \times 0.55 \times 20$$

Vb1 = 21.98 m/s

Methods for reducing accidents

3E's

- Engineering measures
- Enforcement measures
- Education measures

Road design

Preventive maintenance of vehicles

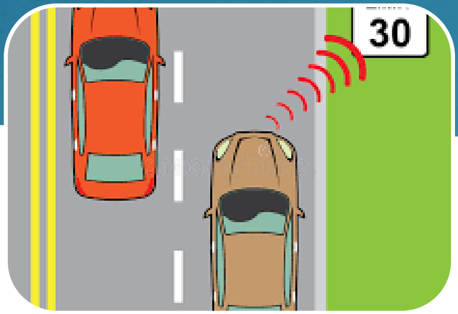
Before and after studies

Road lighting

Engineering measures

Methods for reducing accidents

- Engineering measures
- Enforcement measures
- Education measures



Speed control

Preventive maintenance of vehicles

Rules and regulations

Special precautions for CVs

Reaction time of driver – medical check

Training and supervision

Enforcement measures

Methods for reducing accidents

- Engineering measures
- Enforcement measures
- Education measures

Education measures

Passenger car unit

It is a vehicle unit used for expressing highway capacity. One car is considered as a single unit, cycle, motorcycle is considered as half car unit. Bus, truck causes a lot of inconvenience because of its large size and is considered equivalent to 3 cars or 3 PCU.

PCU values are different for mid block sections and signalized intersections

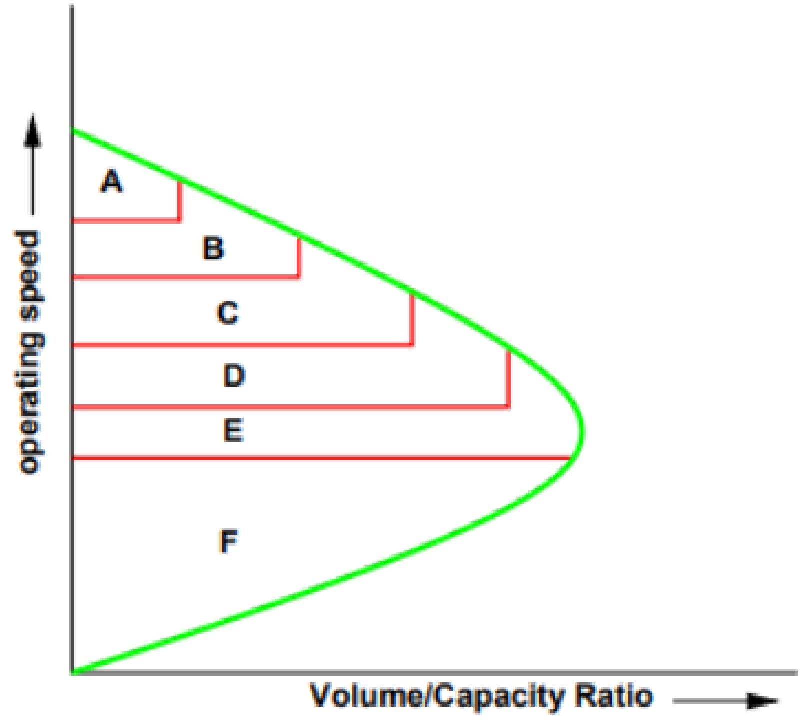
Type of Vehicle	PCU
▪ Car, taxi, pick up	1.0
▪ Cycle, motor cycle	0.5
▪ Bus, truck,	3.0
▪ Horse drawn cart	4.0
▪ Bullock cart	6.0
▪ Bullock cart (Large)	8.0
▪ Cycle rickshaw	1.5

Factors affecting Passenger car unit

- Vehicle characteristics such as dimensions, power, speed, acceleration and braking characteristics
- Transverse or longitudinal gaps and clearances between vehicles which is dependent upon speed, driver charctersistics and vehicle classes
- Traffic stream characteristics such as composition of different vehicle classes, mean speed and speed distribution of mixed traffic stream, volume to capacity ratio etc.
- Roadway characteristics such as road geometrics includes gradient, curve etc., rural or urban road, presence of intersections and the types of intersections.
- Regulation and control of traffic such as speed limit, one-way traffic, presence of different traffic control devices etc.
- Environmental and climatic conditions

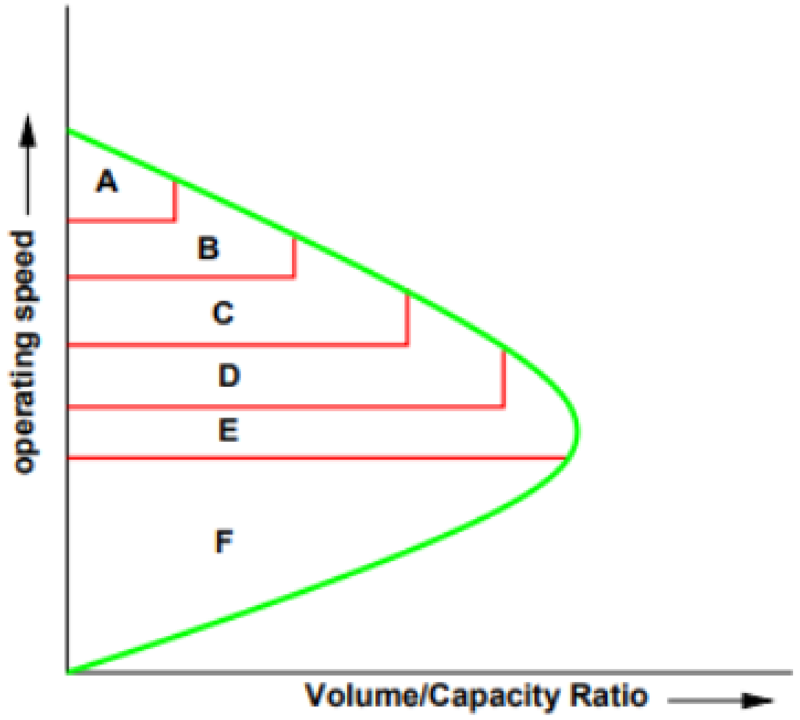
Level of Service

- This is defined as a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.
- LOS are designated using letter A to F
- LOS A represents best operating conditions and LOS F is the worst
- Each LOS represents a range of operating conditions and the driver's perception of those conditions.
- Safety is not included in the measures to establish LOS
- Six LOS are defined for each type of facility



Level of Service

Performance measures	Operational measures
➢ Travel speed ➢ Traffic density ➢ Delays at signalized intersections ➢ Walking speed for pedestrians	➢ Dependent upon type of facility. ➢ Also called as Measure of Effectiveness (MOE) for each facility type ➢ Typically three parameters are used under this and they are speed and travel time, density, and delay



Statistical Applications in Traffic Engineering

Probability of occurrence of A = Ratio of Number of experiments in which A occurs to Total number of experiments

Simple laws of probability:

1. Probability of an event will be between 0 and 1
2. For an event with two outcomes, If the probability of an outcome is p, the probability of non-occurrence of the outcome is 1-p
3. If an event A is a composite event which is a collection of simple events e1, e2, e3 .. en, then the probability of composite event A is P(A) = P(e1)+ P(e2)+ P(e3)+……+ P(en)

Statistical Applications in Traffic Engineering

Mean and Standard deviation

$$Mean = \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i}$$

$$Standard\ Deviation = s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

$$Standard\ Deviation = s = \sqrt{\frac{\sum_{i=1}^{m}(x_i - \bar{x})^2 . f_i}{\sum_{i=1}^{m} f_i - 1}}$$

Variance = s^2

Statistical Applications in Traffic Engineering

For the following speed range find mean, standard deviation and variance of the following data:

Mid point in speed range, kmph	Frequency, f
32.45	1
37.45	3
42.45	6
47.45	9
52.45	12
57.45	10
62.45	5
67.45	1
72.45	1

Statistical Applications in Traffic Engineering

x_i	f_i	$x_i f_i$	$x_i - \overline{x}$	$(x_i - \overline{x})^2$	$(x_i - \overline{x})^2 . f_i$
32.45	1	32.45	-19.27	371.37	371.37
37.45	3	112.35	-14.27	203.66	610.97
42.45	6	254.70	-9.27	85.95	515.69
47.45	9	427.05	-4.27	18.24	164.16
52.45	12	629.40	0.73	0.53	6.38
57.45	10	574.50	5.73	32.82	328.23
62.45	5	312.25	10.73	115.12	575.58
67.45	1	67.45	15.73	247.41	247.41
72.45	1	72.45	20.73	429.70	429.70
		48	2482.60		3249.48

Mean and Standard deviation

$$Mean = \frac{2482.60}{48} = 51.72$$

$$Standard\ Deviation = s = \sqrt{\frac{3249.48}{47}}$$

$$s = 8.31$$

Variance = 69.14

Binomial and Poisson distribution

Binomial distribution:

Each trial has only two outcomes

Population from which samples are drawn is infinite

Probability of occurrence of an event is a constant

$$P(r) = \frac{n!}{r!\,(n-r)!} \times p^r . q^{n-r}$$

Probability of occurrence is r times in n trials

p is the probability of occurrence of an event

q is the probability of non - occurrence of an event

Poisson distribution:

If n becomes very large, np is a constant

$$P(r) = \frac{(np)^r e^{-(np)}}{r!} = \frac{m^r e^{-m}}{r!}$$

Where m is the mean

Poisson distribution is valid if

(i) n is sufficiently large, n>>> 50

(ii) p is small, p<<<0.1

For vehicles arriving per second, m = λt

Where λ is the arrival rate per second

Binomial and Poisson distribution

On a motorway, the number of vehicles arriving from one direction in successive 10 seconds intervals was counted and recorded in Table. Find out the mean rate of arrival with the help of Poisson distribution and compare the observed frequency with the theoretical frequency. Does the data suggest that the arrival pattern can be considered as random?

Vehicles arriving in 10 s intervals	0	1	2	3	4	5	6	7 or more
Frequency	11	28	30	18	8	4	1	0

Binomial and Poisson distribution

Vehicles arriving in 10 s intervals	Frequency	Total number of vehicles
0	11	0
1	28	28
2	30	60
3	18	54
4	8	32
5	4	20
6	1	6
7	0	0
	100	200

P(r)	Theoretical number of vehicles
0.14	13.53
0.27	27.07
0.27	27.07
0.18	18.04
0.09	9.02
0.04	3.61
0.01	1.20
0.00	0.34

$$P(r) = \frac{(np)^r e^{-(np)}}{r!} = \frac{m^r e^{-m}}{r!}$$

$$Mean = \bar{x} = \frac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i} = \frac{200}{100} = 2$$

It is noted that observed frequency is matching with theoretical frequency. Hence Poisson distribution can be used to study vehicle arrival

Binomial and Poisson distribution

The data below shows the occupancy of parking spaces in a parking lot consists of 50 spaces. The count was taken as 15 minute intervals during the 4hours duration between 11 am and 3 pm on 6 week days. Find by inspection whether the number of vacant spaces during any count follows a Poisson distribution.

Occupancy of parking spaces	50	49	48	47	46	45	44	43	42	41	40 and less
Frequency	6	15	21	20	15	10	5	2	1	1	0

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Binomial and Poisson distribution

Occupancy of parking spaces	Frequency	Vacant spaces	number of vacant spaces
50	6	0	0
49	15	1	15
48	21	2	42
47	20	3	60
46	15	4	60
45	10	5	50
44	5	6	30
43	2	7	14
42	1	8	8
41	1	9	9
40 and less	0	10 and more	0
	96		288
	Mean	288/96	3

P(r)	Theoretical number of vehicles	Frequency
0.0498	4.78	6
0.1494	14.34	15
0.2240	21.51	21
0.2240	21.51	20
0.1680	16.13	15
0.1008	9.68	10
0.0504	4.84	5
0.0216	2.07	2
0.0081	0.78	1
0.0027	0.26	1

$$P(r) = \frac{(np)^r e^{-(np)}}{r!} = \frac{m^r e^{-m}}{r!}$$

It is observed that given frequency is matching with theoretical frequency. Hence Poisson distribution can be used to study vehicle arrival

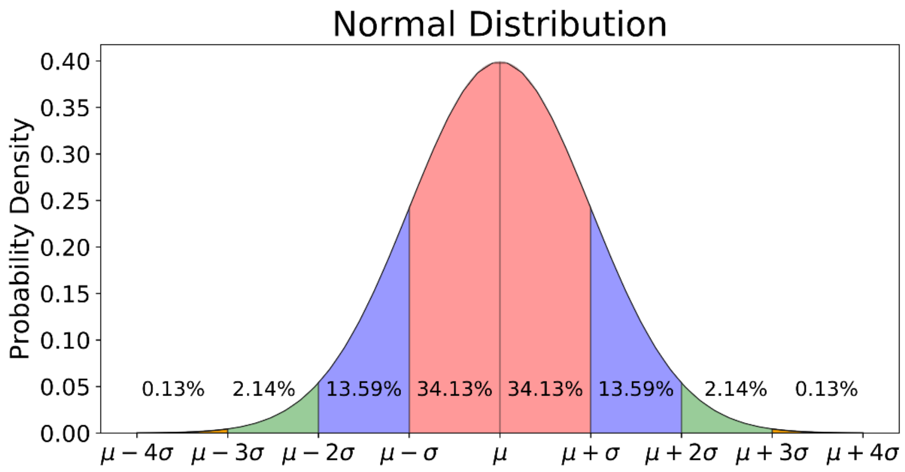
Normal distribution

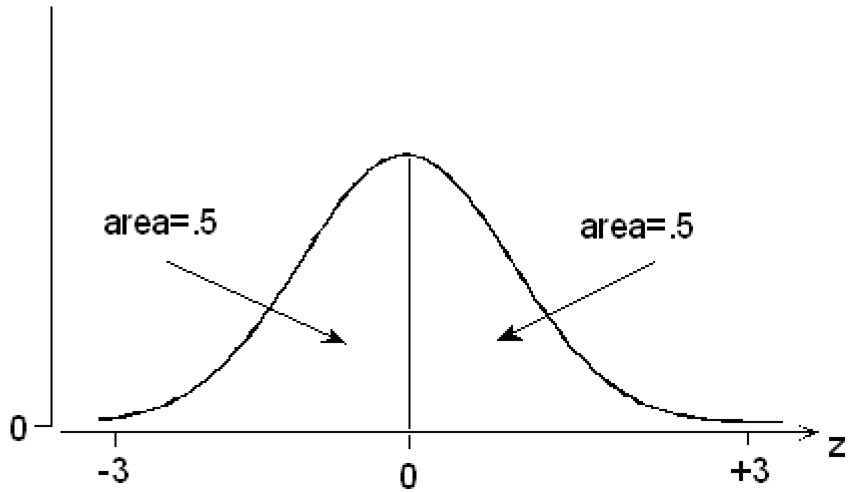
The normal density function is given as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \times e^{-\frac{1}{2}\times\left(\frac{x-\mu}{\sigma}\right)^2}$$

$$-\infty < x < +\infty$$

Curve is symmetrical with respect to μ





We can standardise the curve by using standard normal variate,

$$z = \left(\frac{x-\mu}{\sigma}\right)$$

If μ = 0 and σ = 1

$$f(z) = \frac{1}{\sqrt{2\pi}} \times e^{-\frac{1}{2}\times(z)^2}$$

$$-\infty < x < +\infty$$

Normal distribution

The spot speeds at a particular location are normally distributed with a mean speed of 51.7 kmph and a standard deviation of 8.3 kmph. What is the probability that

(a) Speeds exceed 65 kmph

(b) And the speeds lie between 40 kmph and 7

$$z = \left(\frac{x-\mu}{\sigma}\right)$$

$$z = \left(\frac{65-51.7}{8.3}\right)$$

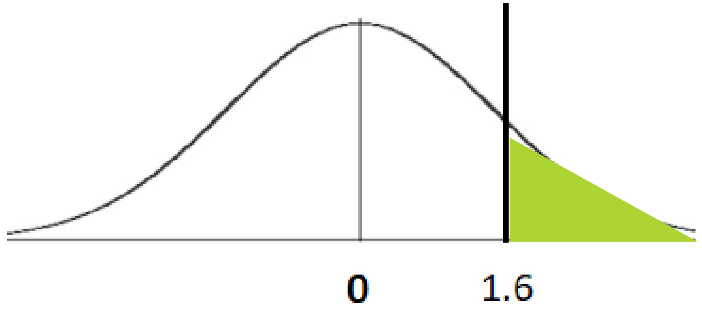
z =1.6

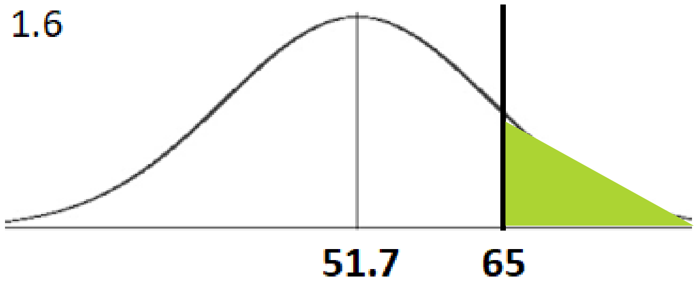
For z =1.6

ϕ(z) = 0.9452

P(z >1.6) = 1- 0.9452

= 5.48%





Standard normal variate,

$$z = \left(\frac{x-\mu}{\sigma}\right)$$

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Normal distribution

The spot speeds at a particular location are normally distributed with a speed of 51.7 kmph and a standard deviation of 8.3 kmph. What is the probability that

(a) Speeds exceed 65 kmph

(b) And the speeds lie between 40 kmph and 70 kmph

(c) What is the 85 percentile speed?

Standard normal variate,

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If μ = 0 and σ = 1

$$f(z) = \frac{1}{\sqrt{2\pi}} \times e^{-\frac{1}{2}\times(z)^2}$$

$$-\infty < x < +\infty$$

$$z = \left(\frac{x-\mu}{\sigma}\right)$$

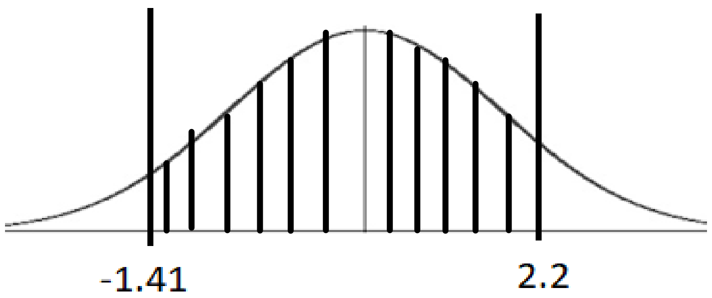
$$z_1 = \left(\frac{40-51.7}{8.3}\right) = -1.41$$

$$z_2 = \left(\frac{70-51.7}{8.3}\right) = 2.2$$

For ϕ (1.41) = 0.9207

For ϕ (2.2) = 0.9861

Shaded area = (0.9861 – 0.5) + (0.9207 -0.5) = 0.9068



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$$-\infty < x < +\infty$$

$$z = \left(\frac{x-\mu}{\sigma}\right)$$

For ϕ (z) = 0.85

z = 1.35

$$1.035 = \left(\frac{x-51.7}{8.3}\right)$$

$$1.035 = \left(\frac{x-51.7}{8.3}\right)$$

x = 60.29 kmph

Sampling theory and significance testing

Types of samples
- Random samples
- Stratified samples
- Systematic samples
- Sequential samples etc

Population

Mean - μ

Standard deviation - σ

Sample Mean = $\bar{x}$

Standard error of mean is s or $\sigma_{\bar{x}}$

This will also follow a normal distribution such that

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

If σ is not known, then s which is the standard deviation of the sample can be used

The normal density function is given as

$$f(x) = \frac{1}{\sigma_{\bar{x}}\sqrt{2\pi}} \times e^{-\frac{1}{2}\times\left(\frac{x-\mu}{\sigma_{\bar{x}}}\right)^2}$$

$-\infty < x < +\infty$

Curve is symmetrical with respect to μ

If x possess a normal distribution with mean μ and standard deviation σ , then the sample mean $\bar{x}$ based on a random sample of size n drawn from an infinite population will also possess a normal distribution with mean μ and standard deviation $\sigma/\sqrt{n}$

Sampling theory and significance testing

The spot speeds at a particular location on a highway are known to be normally distributed with a mean of 80 kmph and a standard deviation of 15 kmph. What is the probability that if a sample of 100 vehicles are tested that the mean speed observed will exceed 75 kmph.

Sample

Mean = 80 kmph

$$\sigma_{\bar{x}} = \frac{15}{\sqrt{100}} = 1.5$$

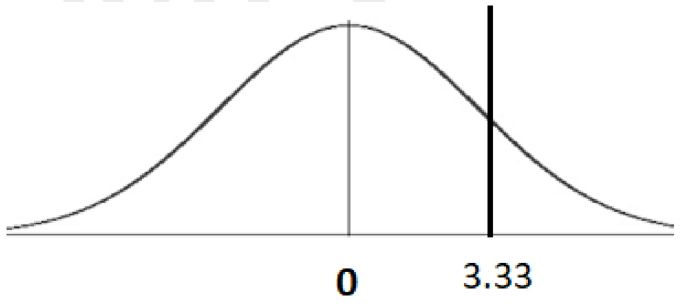
$$z = \frac{x - \mu}{\sigma_{\bar{x}}}$$

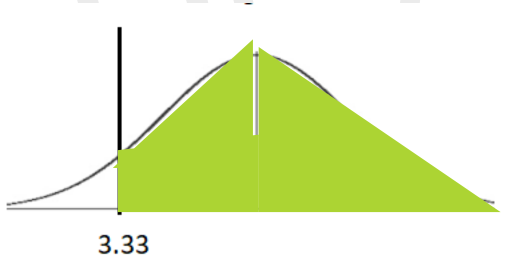
$$z = \frac{75 - 80}{1.5}$$

$$z = -3.33$$

For ϕ (3.33) = 0.999562

P (speed >75 kmph) = 99.96 %





Sampling theory and significance testing

A series of 363 observations of spot speeds was taken and the data has a mean and standard deviation os 39.7 kmph and 6.8 kmph respectively. Give a 95 % confidence interval for the population mean speed.

Sample

Mean = 39.7 kmph

$$\sigma_{\overline{x}} = \frac{6.8}{\sqrt{363}} = 0.36$$

Confidence interval of 95 %, 2.5% confidence interval on either side of bell curve

$$\emptyset(z) = 0.975$$

z = 1.96

$$z = \frac{x - \mu}{\sigma_{\overline{x}}}$$

$$1.96 = \frac{x \pm 39.7}{0.36}$$

$$x = 38.99 \text{ to } 40.41 \text{ kmph}$$

Sampling theory and significance testing

In connection with a survey for determining the spot speed at a given location of a highway, it is desired to obtain the average speed within 2kmph within a probability of 0.95. Previous studies have indicated that the standard deviation of the speeds is 8 kmph. What size of sample should be selected?

Confidence interval of 95 %, 2.5% confidence interval on either side of bell curve

$$\emptyset(z) = 0.95$$

z = 1.96

$$1.96 = \frac{x \pm \mu}{\sigma_{\overline{x}}} = \frac{2}{\sigma_{\overline{x}}}$$

$$\sigma_{\overline{x}} = \frac{2}{1.96} = \frac{8}{\sqrt{n}}$$

n = 61.5 or say 60 observations

Significance testing

Significance testing is testing of hypothesis.

It assumes distribution of a variable

There are two hypothesis:

- **Null hypothesis (H_0) – no effect/ no difference**
- **Alternate hypothesis (H_1) – effect is there**

	H_0 true	**H_1 true**
Accept H_0	Probability = 1- α	Probability = β
Accept H_1	Probability = α	Probability =1- β

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Significance testing

The spot speeds at a particular location on an expressway are known to be normally distributed with a mean of 80 kmph. A new radar speedometer was bought by Traffic Department and a set of 100 observations of speed was taken. The mean speed observed was 77.3 kmph and the standard deviation was 15 kmph. Is there any evidence to prove that

(i) The new speedometer might have been faulty

(ii) The new speedometer is showing speeds lesser than actual.

$$\sigma_{\bar{x}} = \frac{15}{\sqrt{100}} = 1.5$$

$$1.96 = \frac{x - 80}{1.5}$$

$\mu = 80$ kmph

$\bar{x} = 77.3\ kmph$

s = 15

n = 100

$\emptyset(z) = 0.975$

z = 1.96

(i) Null hypothesis: Speedometer is not faulty;

$H_0 : \mu = 80$ kmph

(ii) Alternate hypothesis: Speedometer is faulty;

$H_1 : \mu \neq 80$ kmph

x = 77.06 to 82.94

Since observed speed is within the range, speedometer

Accept null hypothesis, no significant difference

Significance testing

(i) The new speedometer is showing speeds lesser than actual.

$\mu = 80 \text{ kmph}$

$\bar{x} = 77.3\ kmph$

s = 15

n = 100

(i) Null hypothesis: Speedometer is not faulty;

$H_0 : \mu = 80 \text{ kmph}$

(ii) Alternate hypothesis: Speedometer is faulty;

$H_1 : \mu < 80 \text{ kmph}$

Single tailed test – let area of critical region be 5 %

$\emptyset(z) = 0.95$

$z = 1.645$

$$1.645 = \frac{x \pm 80}{1.5}$$

x = 77.53 to 82.4675

Lower limit only needs to be considered.

Reject null hypothesis since the given mean falls in the critical region.

Traffic forecasting

Factors influencing traffic forecast

1. **Population Growth/Migration**
2. **Land Use Changes**
3. **National/Regional Economy**
4. **Vehicle Operating Costs**
5. **Capacity Restraints**
6. **Induced Traffic due to new road facilities nearby**
7. **Vehicle ownership levels**
8. **Availability of alternative transport modes**

Traffic forecasting

Data for traffic prediction

Time series data consist of data that are collected, recorded, or observed over successive increments of time.

Cross-sectional data are observations collected at a single point in time.

Panel data are cross-sectional measurements that are repeated over time, such as yearly passengers carried for a sample of airlines.

Traffic forecast - Models

Linear trend

$$Y_t = \beta_0 + \beta_1 t + \varepsilon$$

Exponential Trend

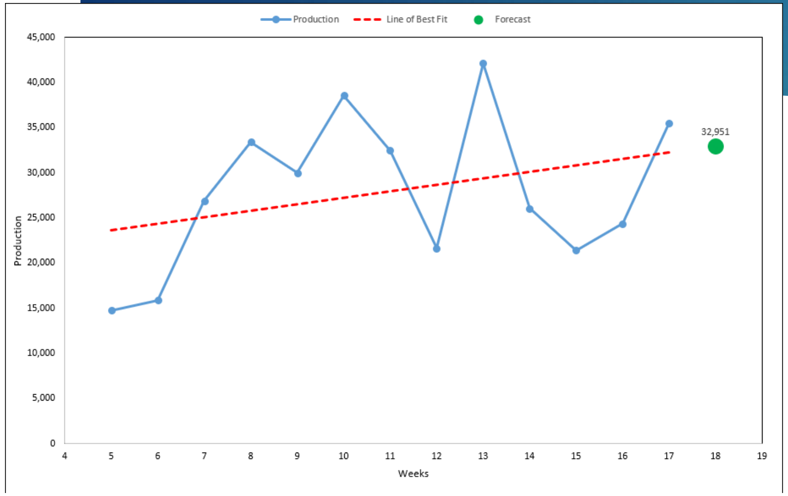
$$Y = a(1+b)^T \quad \text{or} \quad \ln(Y) = \ln(a) + T \times \ln(1+b)$$

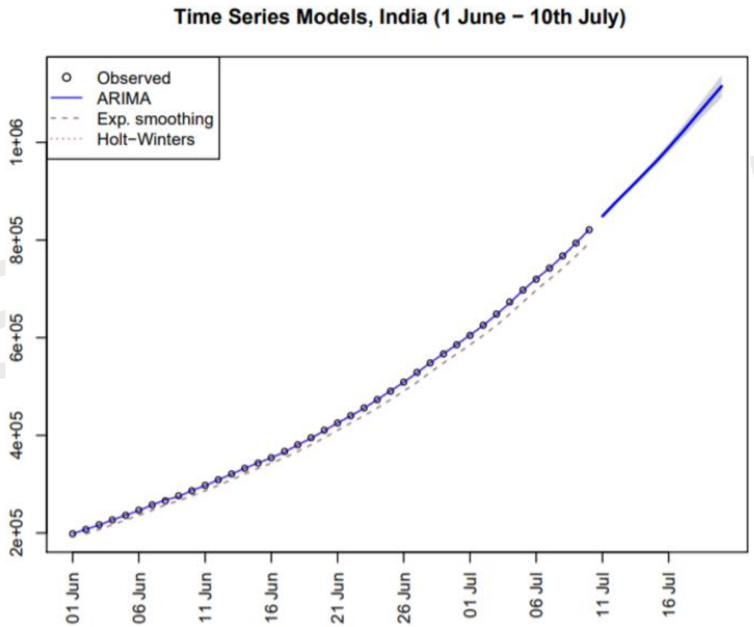
Polynomial Trend Analysis

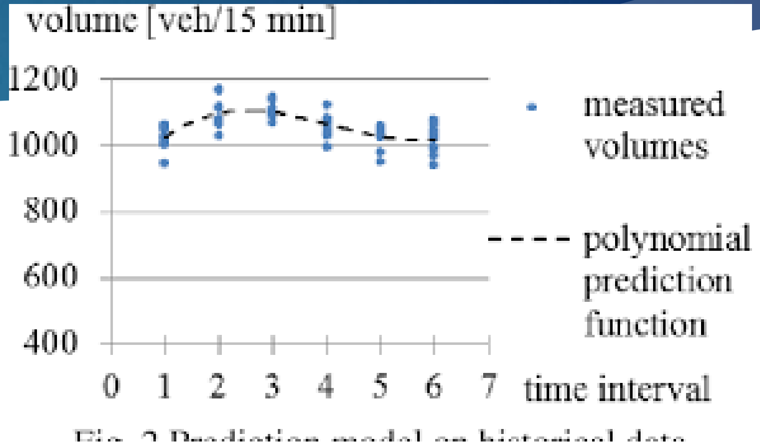
$$Y = a + bT + cT^2$$

Forecasts based on Past Trends and Extrapolation *– this can be done based on experience.*

Traffic forecasting







THANK YOU FOR YOUR PATIENCE!!!!

Open for Questions !!!

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