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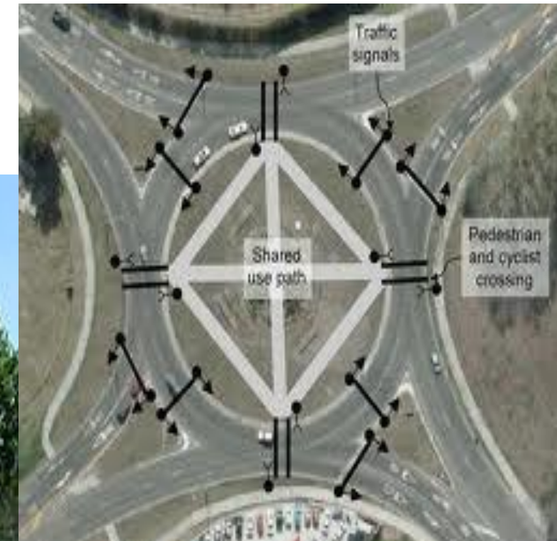
SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Transport Engineering CENG 3201

Chapter 3 Traffic Engineering



Tamru T.

2012 EC (2019/20 GC)
1st Sem

Lecture Overview

- **Traffic engineering studies**
  - Spot speed studies
  - Volume studies
  - Travel time and delay studies
  - Parking studies
- **Fundamental principles of traffic flow**
  - Traffic flow elements
  - Flow-density relationships
  - Fundamental diagram of traffic flow
  - Mathematical relationships describing traffic flow
  - Shockwaves in traffic stream

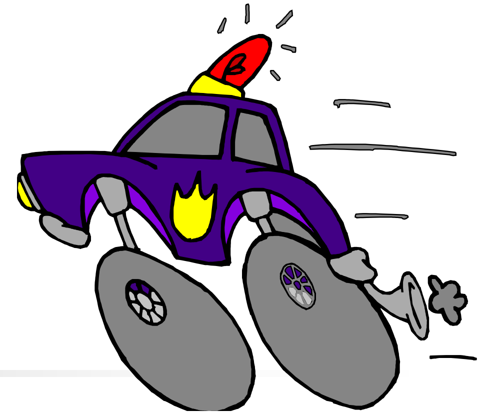
Traffic Engineering Studies

- To reduce the negative impact of highways, it is necessary to adequately collect information that describes the extent of the problems and identifies their locations. Such information is usually collected by organizing and conducting traffic surveys and studies.
  - Spot speed studies
  - Volume studies
  - Travel time and delay studies
  - Parking studies

Traffic Engineering Studies Cont…

- Traffic studies may be grouped into three main categories
  - *Inventories:-* provide a list or graphic display of existing information, such as street widths, parking spaces, transit routes, traffic regulations, and so forth.
  - *Administrative studies:-* use existing engineering records, available in government agencies and departments.
    - Used to prepare an inventory of the relevant data.
  - ***Dynamic studies:-*** collection of data under operational conditions and include studies of speed, traffic volume, travel time and delay, parking, and accidents.

Spot speed studies



- Conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway.
- Uses to:-
  - Establish speed zones
  - Determine whether complaints about speeding are valid
  - Establish passing and no-passing zones
  - Design geometric alignment
  - Analyze accident data
  - Evaluate the effects of physical improvements
  - Determine the effects of speed enforcement programs and speed control measures
  - Determine speed trends

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Spot speed studies Cont…

- Locations for Spot Speed Studies:- Depend on the anticipated use of the results

1. Locations that represent different traffic conditions on a highway or highways are used for *basic data collection*.
2. Mid-blocks of urban highways and straight, level sections of rural highways are sites for *speed trend analyses*.
3. Any location may be used for the solution of a *specific traffic engineering problem*.

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Spot speed studies Cont…

- Definitions of values that are used to describe speed characteristics:
  - Average speed

$$\bar{u} = \frac{\sum f_i u_i}{\sum f_i} \quad or; \bar{u} = \frac{\sum u_i}{N}$$

  - Median speed
  - Modal speed
  - The ith-percentile spot speed
  - Pace
  - Standard deviation of speeds

$$S = \sqrt{\frac{\sum (u_j - \bar{u})^2}{N-1}} \qquad S = \sqrt{\frac{\sum (f_i u_i^2 - (\sum f_i u_i)^2 / \sum f_i}{\sum f_i - 1}}$$

Spot speed studies Cont…

Sample Size for Spot Speed Studies

- The minimum sample size depends on the precision level desired.
- The confidence level is commonly given in terms of the level of significance (α), where α= (100 - confidence level).
- Normal distribution have been used to develop an equation relating the sample size to the number of standard variations corresponding to a particular confidence level, the limits of tolerable error, and the standard deviation.

$$N = \left(\frac{Z\sigma}{d} \right)^2 .$$

Table 4.1

Constant Corresponding to Level of Confidence

Confidence Level (%)	Constant Z
68.3	1.00
86.6	1.50
90.0	1.64
95.0	1.96
95.5	2.00
98.8	2.50
99.0	2.58
99.7	3.00

- Where: N= minimum sample size; Z = number of standard deviations corresponding to the required confidence level 1.96 for 95 percent confidence level; σ = standard deviation (mph); d = limit of acceptable error in the speed estimate (mph)

Example 1

Determine the minimum sample size required for a spot peed study on a rural highway if the confidence level for the study is 95.0 percent and the tolerance 1.0mph Assume a standard deviation of $\pm$ 5.30mph.

Solution

Solve for N:-

$$N = [(1.96 \times 5.3)/1]^2$$

$$=108$$

The sample size should therefore be at least 108

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Spot speed studies Cont…

- Methods for Conducting Spot Speed Studies

1. Those that use road detectors,
2. Those that use Doppler principle meters (radar type), and
3. Those that use the principles of electronics

Road Detectors

- Classified into two general categories: pneumatic road tubes (air impulse) and induction loops (electric resonance circuit).
- Devices can be used to collect data on speeds at the same time as volume data are being collected.
- The advantage of the detector meters is that human errors are considerably reduced.
- The disadvantages are that

  (1) these devices tend to be rather expensive, and

  (2) when pneumatic tubes are used, they are rather conspicuous and may, therefore, affect driver behavior, resulting in a distortion of the speed distribution.

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Road Detectors Cont…

pneumatic road tubes

Road Detectors Cont…

induction loops

Doppler-Principle Meters

- Work on the principle that when a signal is transmitted onto a moving vehicle, the change in frequency between the transmitted signal and the reflected signal is proportional to the speed of the moving vehicle.
- The difference between the frequency of the transmitted signal and that of the reflected signal is measured by the equipment, and then converted to speed in kmph or mph.
- The value of the speed recorded depends on that angle.

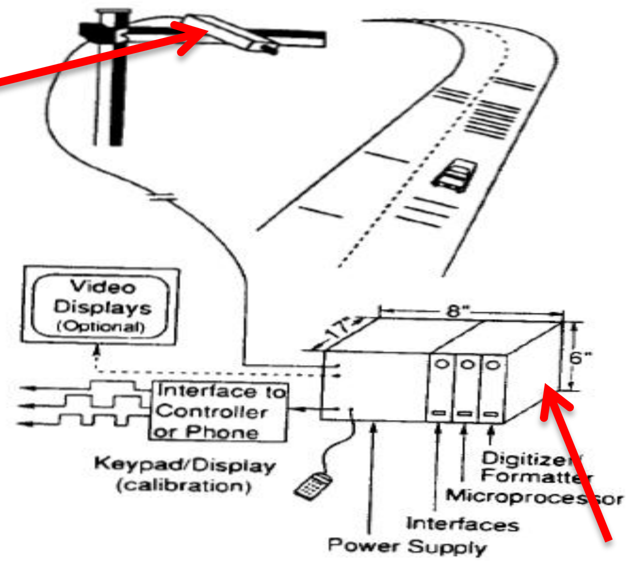
Doppler-Principle Meters Cont…

RADAR/LIDAR Technology

Electronic-Principle Detectors

- The presence of vehicles is detected through electronic means, and information on these vehicles is obtained, from which traffic characteristics such as speed, volume, queues, and headways are computed.
- Not necessary to physically install loops or any other type of detector on the road.
- Electronics is video image processing, sometimes referred to as a machine-vision system.

Electronic-Principle Detectors Cont…



Autoscope Systems

Example 2

For the data shown above determine

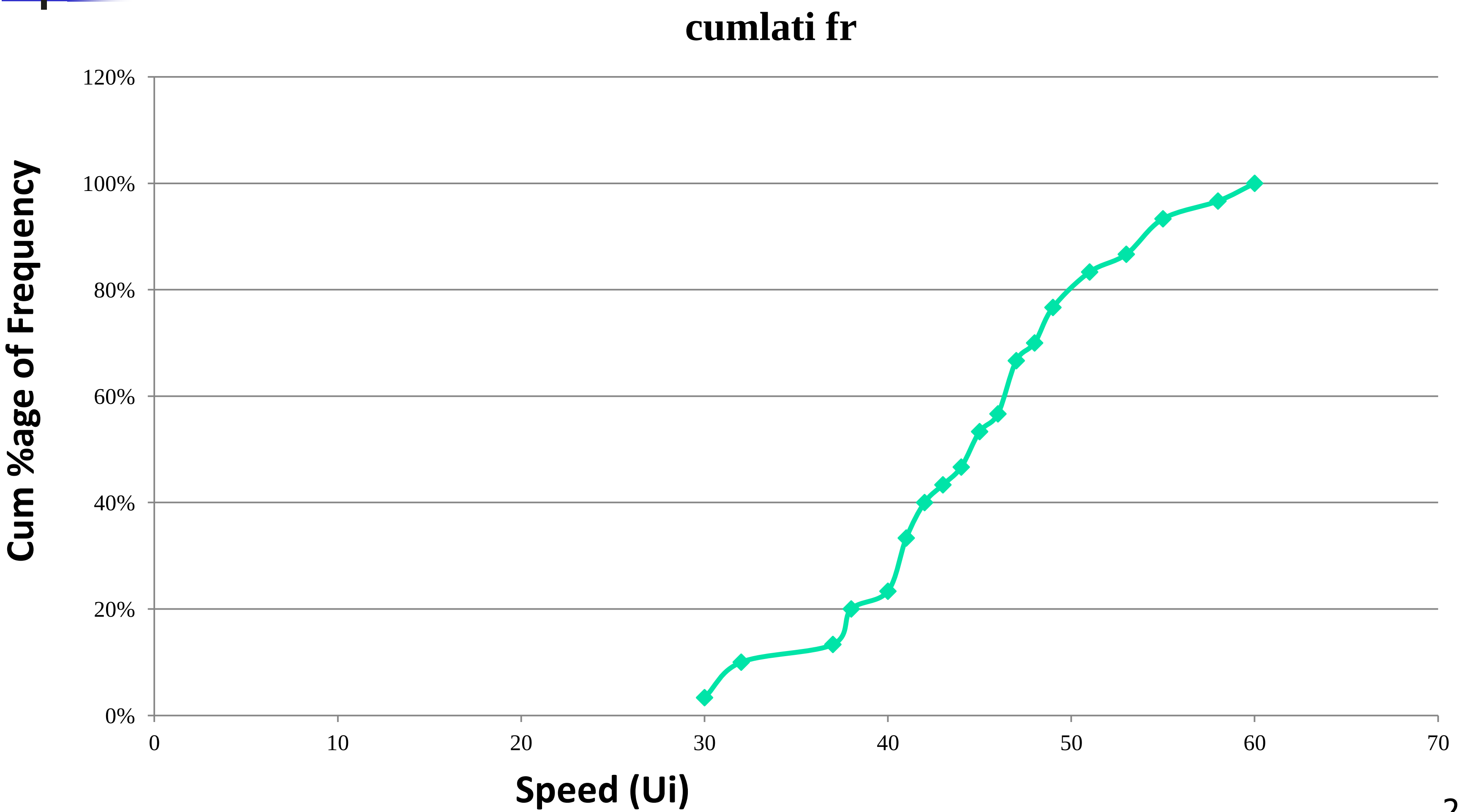
- Arithmetic mean speed
- Standard deviation
- Median speed
- Pace
- Modal speed
- 85th percentile

Car No.	Speed (kmph) ,u_i
1	47
2	49
3	42
4	41
5	45
6	48
7	42
8	51
9	58
10	32
11	32
12	53
13	46
14	30
15	41
16	47
17	38
18	43
19	45
20	55
21	60
22	47
23	49
24	41
25	44
26	51
27	37
28	40
29	55
30	38

Example…

Ui	Frequency	%age of Frequency	Cum %age of Frequency
30	1	3%	3%
32	2	7%	10%
37	1	3%	13%
38	2	7%	20%
40	1	3%	23%
41	3	10%	33%
42	2	7%	40%
43	1	3%	43%
44	1	3%	47%
45	2	7%	53%
46	1	3%	57%
47	3	10%	67%
48	1	3%	70%
49	2	7%	77%
51	2	7%	83%
53	1	3%	87%
55	2	7%	93%
58	1	3%	97%
60	1	3%	100%

Example…


cumlati fr
120%
100%
80%
60%
40%
20%
0%
0
10
20
30
40
50
60
70
Cum %age of Frequency
Speed (Ui)

Class Exercise

For the data shown below determine

- Arithmetic mean speed
- Standard deviation
- Median speed
- Pace
- Modal speed
- 85^{th} percentile

(You can use in class of 2mph)

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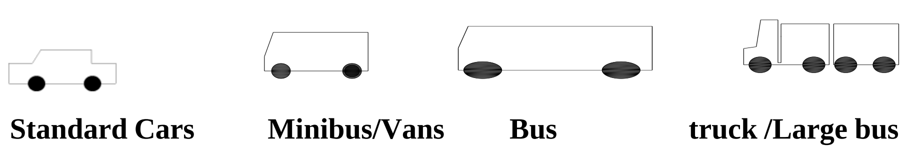
Table 1 DATA COLLECTED FROM THE FIELD (SPOT SPEED)

Car No.	Speed (mph)	Car No.	Speed (mph)	Car No.	Speed (mph)	Car No.	Speed (mph)
1	35.1	24	54.2	47	34.8	70	56.4
2	44	25	52.3	48	52.4	71	48.5
3	45.8	26	57.3	49	39.1	72	45.4
4	44.3	27	46.8	50	37.1	73	48.6
5	36.3	28	57.8	51	65	74	52
6	54	29	36.8	52	49.5	75	49.8
7	42.1	30	55.8	53	52.2	76	63.4
8	50.1	31	43.3	54	48.4	77	60.1
9	51.8	32	55.3	55	42.8	78	48.8
10	50.8	33	39	56	49.5	79	52.1
11	38.3	34	53.7	57	48.6	80	48.7
12	44.6	35	40.8	58	41.2	81	61.8
13	45.2	36	54.5	59	48	82	56.6
14	41.1	37	51.6	60	58	83	48.2
15	55.1	38	51.7	61	49	84	62.1
16	50.2	39	50.3	62	49.8	85	53.3
17	54.3	40	59.8	63	48.3	86	53.4
18	45.4	41	40.3	64	45.9		
19	55.2	42	55.1	65	44.7		
20	45.7	43	45	66	49.5		
21	54.1	44	48.3	67	56		
22	54	45	47.8	68	49.1		
23	46.1	46	47.1	69	49.2		

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.
- The data collected may also be put into subclasses which may include directional movement, occupancy rates, vehicle classification, and pedestrian age.
- Volume characteristics
  - ✓ Average Annual Daily Traffic (AADT)
  - ✓ Average Daily Traffic (ADT)
  - ✓ Peak Hour Volume (PHV)
  - ✓ Vehicle Classification (VC)



  - ✓ Vehicle Miles of Travel (VMT)

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Volume studies Cont…

- Methods of Conducting Volume Counts
  - ***Manual Method***

    Disadvantages of the manual count method are that

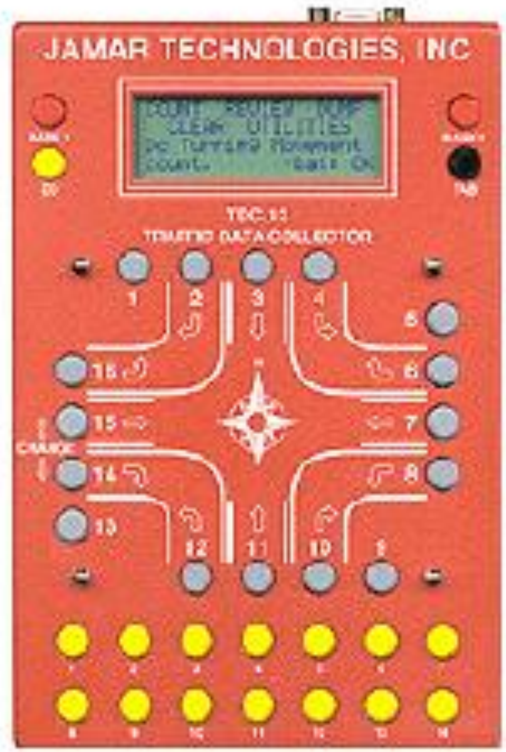
    (1) it is labor-intensive and can therefore be expensive,

    (2) it is subject to the limitations of human factors, and

    (3) it cannot be used for long periods of counting.
  - ***Automatic Method***

  Involves the laying of surface detectors (such as pneumatic road tubes) or subsurface detectors (such as magnetic or electric contact devices) on the road.

Volume studies Cont…



Jamar Technologies

Volume studies Cont…

Types of Volume Counts:- Depends on the anticipated use of the data to be collected.

- *Cordon Counts :-* When information is required on vehicle accumulation within an area, such as the central business district (CBD) of a city, particularly during a specific time, a cordon count is undertaken.
- *Screen Line Counts:-* In screen line counts, the study area is divided into large sections by running imaginary lines known as screen lines, across it. Traffic counts are then taken at each point where a road crosses the screen line.
- *Intersection Counts:-* Intersection counts are taken to determine vehicle classifications, through movements and turning movements at intersections.
- *Pedestrian Volume Counts*

Volume studies Cont…

- Expansion Factors from Continuous Count Stations
  - *Hourly expansion factors (HEFs)*

$$HEF = \frac{total..volume..for..24-hr..period}{volume..for..particular..hour}$$

  - *Daily expansion factors (DEFs)*

$$DEF = \frac{average..total..volume..for..the..week}{average..volume..for..particular..day}$$

  - *Monthly expansion factors (MEFs) are computed as*

$$MEF = \frac{AADT}{ADT..for..particular..month}$$

Example 4

A traffic engineer urgently needs to determine the AADT on a rural primary road that has volume distribution characteristics shown in tables shown below. She collected the data shown below on Friday during the month of February. Determine the AADT of the road.

7:00-8:00a.m	*500*
8:00-9:00a.m	*635*
9:00-10:00a.m	*750*
10:00-11:00a.m	*810*
11:00-12:00p.m	*675*

Table 4.5 Hourly Expansion Factors for a Rural Primary Road

Hour	*Volume*	*HEF*	*Hour*	*Volume*	*HEF*
6:00–7:00 a.m.	294	42.00	6:00–7:00 p.m.	743	16.62
7:00–8:00 a.m.	426	29.00	7:00–8:00 p.m.	706	17.49
8:00–9:00 a.m.	560	22.05	8:00–9:00 p.m.	606	20.38
9:00–10:00 a.m.	657	18.80	9:00–10:00 p.m.	489	25.26
10:00–11:00 a.m.	722	17.10	10:00–11:00 p.m.	396	31.19
11:00–12:00 p.m.	667	18.52	11:00–12:00 a.m.	360	34.31
12:00–1:00 p.m.	660	18.71	12:00–1:00 a.m.	241	51.24
1:00–2:00 p.m.	739	16.71	1:00–2:00 a.m.	150	82.33
2:00–3:00 p.m.	832	14.84	2:00–3:00 a.m.	100	123.50
3:00–4:00 p.m.	836	14.77	3:00–4:00 a.m.	90	137.22
4:00–5:00 p.m.	961	12.85	4:00–5:00 a.m.	86	143.60
5:00–6:00 p.m.	892	13.85	5:00–6:00 a.m.	137	90.14

Total daily volume = 12,350.

Table 4.6 Daily Expansion Factors for a Rural Primary Road

Day of Week	*Volume*	*DEF*
Sunday	7895	9.515
Monday	10,714	7.012
Tuesday	9722	7.727
Wednesday	11,413	6.582
Thursday	10,714	7.012
Friday	13,125	5.724
Saturday	11,539	6.510

Total weekly volume = 75,122.

Table 4.7 Monthly Expansion Factors for a Rural Primary Road

Month	*ADT*	*MEF*
January	1350	1.756
February	1200	1.975
March	1450	1.635
April	1600	1.481
May	1700	1.394
June	2500	0.948
July	4100	0.578
August	4550	0.521
September	3750	0.632
October	2500	0.948
November	2000	1.185
December	1750	1.354

Total yearly volume = 28,450.
Mean average daily volume = 2370.

QUESTIONS?

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Travel time and delay studies

- Determines the amount of time required to travel from one point to another on a given route.
- Information may also be collected on the locations, durations, and causes of delays.
- Applications of Travel Time and Delay Data
  - Determination of the efficiency of a route with respect to its ability to carry traffic
  - Identification of locations with relatively high delays and the causes for those delays
  - Performance of before-and-after studies to evaluate the effectiveness of traffic operation improvements
  - Determination of relative efficiency of a route by developing sufficiency ratings or congestion indices
  - Determination of travel times on specific links for use in trip assignment models
  - Compilation of travel time data that may be used in trend studies to evaluate the changes in efficiency and level of service with time

Travel time and delay studies

- Definition of Terms Related to Time and Delay Studies
  - ***Travel time:-*** is the time taken by a vehicle to traverse a given section of a highway
  - ***Running time:-*** is the time a vehicle is actually in motion while traversing a give section of a highway.
  - ***Delay:-*** is the time lost by a vehicle due to causes beyond the control of the driver.
  - ***Operational delay:-*** is that part of the delay caused by the impedance of other traffic.
  - ***Stopped-time delay :-*** is that part of the delay during which the vehicle is at rest.
  - ***Fixed delay:-*** is that part of the delay caused by control devices such as traffic signals.
  - ***Travel-time delay :-*** is the difference between the actual travel time and the time that will be obtained by assuming that a vehicle traverses the study section at an average speed equal to that for an uncontested traffic flow in the section being studied.

Travel time and delay studies

- Methods for Conducting Travel Time and Delay Studies
  - Those using a test vehicle and
  - Those not requiring a test vehicle.

Those using a test vehicle

- ***Floating-Car Technique.*** In this method, the test car is driven by an observer along the test section so that the test car "floats" with the traffic. This is repeated, and the average time is as the travel time.
  - The minimum number of test runs

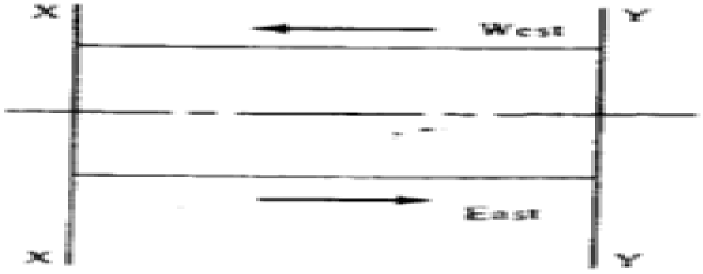
$$N = \left(\frac{t_{\alpha} . \sigma}{d} \right)^2 ---$$

- ***Average-Speed Technique.*** This technique involves driving the test car along the length of the test section at a speed that, in the opinion of the driver, is the average speed of traffic stream.
- Determines the amount of time required to travel from one point to another on a given route.
- Information may also be collected on the locations, durations, and causes of delays.
- Applications of Travel Time and Delay Data

Those using a test vehicle Cont…

- ***Moving-Vehicle Technique.*** In this technique, the observer makes a round trip on a test section like the one shown in below, where it is assumed that the road runs east-west.
  - The time it takes to travel from X-X to Y-Y (T_e), in minutes
  - The time it takes to travel from Y-Y to X-X (T_w), in minutes
  - The number of vehicles traveling west in the opposite lane while the test car is traveling east (N_e)
  - The number of vehicles that overtake the test car while it is traveling from Y-Y to X-X, that is, traveling in the westbound direction (O_w)
  - The number of vehicles that the test car passes while it is traveling from Y-Y to X-X, that is, traveling in the westbound direction (P_w)
  - The volume (V_w) in the westbound direction can then be obtained from the expression

$$V_w = \frac{(N_e + O_w - P_w) * 60}{T_e + T_w}$$



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Those using a test vehicle Cont…

- Similarly, the average travel time Tw in the westbound direction is obtained from

$$\frac{\bar{T}_w}{60} = \frac{T_w}{60} - \frac{O_w - P_w}{V_w}$$

$$\bar{T}_w = T_w - \frac{60*(O_w - P_w)}{V_w}$$

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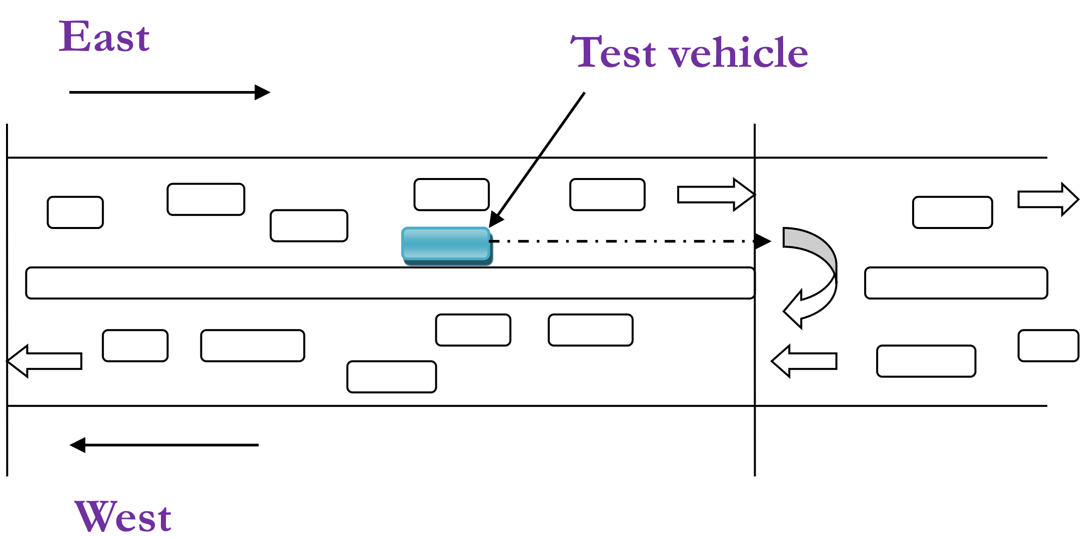
Example 5

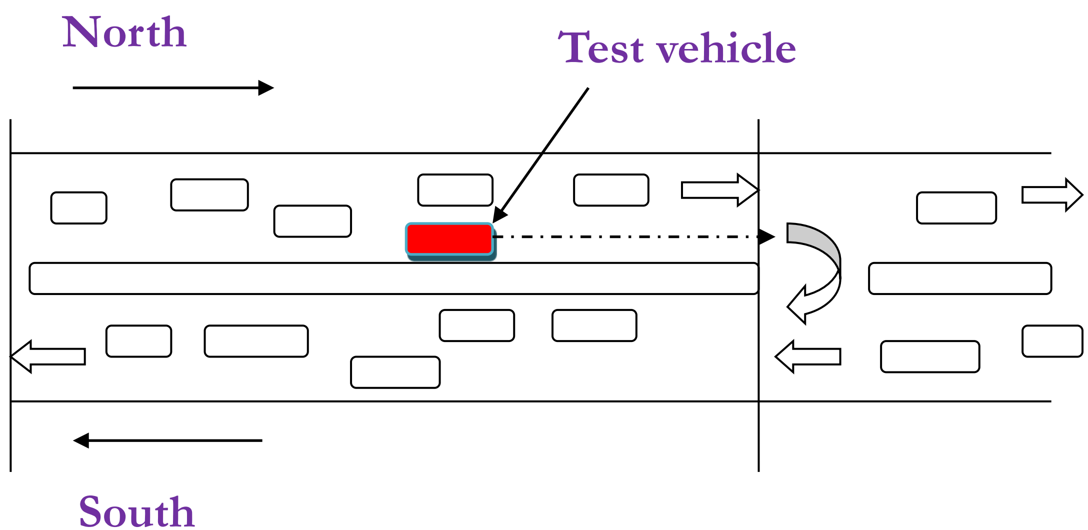
The data below were obtained in travel time study on a section of road using the moving –vehicle technique. Determine the travel time and volume in each direction at this section of the road.



Run direction/ no.	Travel time (Min)	No.Of veh. Traveling in opposite dir.	No.Of veh. That overtook test vehicles	No.Of veh. Overtaken by test vehicles
Eastward				
1	2.75	80	1	1
2	2.55	75	2	1
3	2.85	83	0	3
4	3	78	0	1
5	3.05	81	1	1
6	2.7	79	3	2
7	2.82	82	1	1
8	3.08	78	0	2
Westward				
1	2.95	78	2	0
2	3.15	83	1	1
3	3.2	89	1	1
4	2.83	86	1	0
5	3.3	80	2	1
6	3	79	1	2
7	3.22	82	2	1
8	2.91	81	0	1

Class Exercise

The data below were obtained in travel time study on a section of road using the moving –vehicle technique. Determine the travel time and volume in each direction at this section of the road.



Run direction/ no.	Travel time (Min)	No.Of veh. Traveling in opposite dir.	No.Of veh. That overtook test vehicles	No.Of veh. Overtaken by test vehicles
Northbound				
1	55.1	712	11	7
2	61.7	677	3	4
3	55.3	681	7	10
4	52.4	733	4	5
5	57	660	10	9
6	56.6	685	9	8
7	50.5	704	5	2
8	51.8	698	11	13
9	52.1	710	10	5
10	54.9	695	9	9
Southbound				
1	53	801	9	12
2	58.9	930	13	7
3	54.8	872	8	10
4	61.2	903	9	15
5	57	917	14	10
6	60.1	861	11	13
7	59.7	829	12	11
8	60.4	935	10	10
9	56.3	956	11	5
10	61.2	898	12	9

Methods Not Requiring a Test Vehicle

- *License-Plate Observations*. The license-plate method requires that observers be positioned at the beginning and end of the test section. Each observer records the last three or four digits of the license plate of each car that passes, together with the time at which the car passes.

- *Interviews*. The interviewing method is carried out by obtaining information from people who drive on the study site regarding their travel times, their experience of delays, and so forth.

Parking studies

- *On-Street Parking Facilities:-* These are also known as curb facilities. Parking bays are provided alongside the curb on one or both sides of the street.
- *Off-Street Parking Facilities:-* These facilities may be privately or publicly owned; they include surface lots and garages.

Parking studies Cont…

- **Definitions of Parking Terms**

- ***A space-hour:-*** is a unit of parking that defines the use of a single parking space for a period of 1 hr.
- ***Parking volume:-*** is the total number of vehicles that park in a study area during a specific length of time, usually a day.
- ***Parking accumulation:-*** is the number of parked vehicles in a study area at any specified time. These data can be plotted as a curve of parking accumulation against time, which shows the variation of the parking accumulation during the day.
- ***The parking load:-*** is the area under the accumulation curve between two specific times.
- ***Parking duration :-*** is the length of time a vehicle is parked at a parking bay.
- ***Parking turnover:-*** is the rate of use of a parking space. It is obtained by dividing the parking volume for a specified period by the number of parking spaces.

Parking studies Cont…

On- Street Parking

Parking studies Cont…

Off- Street Parking

Methods Parking studies

- *A Inventory of existing parking facilities*
- *Collection of data on parking sites*
- *Identification of parking generators*
- *Information of parking demand and also information of parking factors such as financial, legal, administrative …*

Analysis of Parking Data

- ***The space-hours of demand for parking are obtained from the expression***

$$D = \sum_{i=1}^{N} (n_i t_i)$$

- Where: D= space vehicle-hours demand for a specific period of time;
  N = number of classes of parking duration ranges;
  t_i = mid parking duration of the i^{th} class;
  n_i= number of vehicles parked for the i^{th} duration range

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Analysis of Parking Data

- ***The space-hours of supply are obtained from the expression***

$$S = f\sum_{i=1}^{N}(t_i)$$

- Where: S = practical number of space-hours of supply for a specific period of time;

  N = number of parking spaces available;

  t_i = total length of time in hours when the i^{th} space can be legally parked on during the specific period;

  f= efficiency factor

Example 6

The owner of a parking garage has observed that 20% of those wishing to park are turned back every day during the open hours of 8 a.m. to 6 p.m. because of lack of parking spaces. An analysis of data collected at the garage indicates that 60% of those who park are commuters, with an average parking duration of 9 hr, and the remaining are shoppers, whose average parking duration is 2 hr.

If 20% of those who cannot park are commuters and the rest are shoppers, and a total of 200 vehicles currently park daily in the garage, determine the number of additional spaces required to meet the excess demand. Assume parking efficiency 0.9

QUESTIONS?

Lecture Overview

- **Fundamental principles of traffic flow**
  - Traffic flow elements
  - Flow-density relationships
  - Fundamental diagram of traffic flow
  - Mathematical relationships describing traffic flow
  - Shockwaves in traffic stream

Fundamental Principles of Traffic Flow

- Traffic flow theory involves the development of mathematical relationships among the primary elements of a traffic stream: flow, density, and speed.
- Help the traffic engineer in planning, designing, and evaluating the effectiveness of implementing traffic engineering measures on a highway system.
- Uses:-
  - To determine adequate lane lengths for storing left-turn vehicles on separate left-turn lanes,
  - The average delay at intersections and freeway ramp merging areas, and
  - changes in the level of freeway performance due to the installation of improved vehicular control devices on ramps
  - Simulation, where mathematical algorithms are used to study the complex interrelationships that exist among the elements of a traffic stream or network and
  - To estimate the effect of changes in traffic flow on factors such as accidents, travel time, air pollution, and gasoline consumption.

Traffic Flow Elements

- Flow (q):- is the equivalent hourly rate at which vehicles pass a point on a highway during a time period less than 1 hr. It can be determined by

$$q = \frac{n * 3600}{T} vph$$

Where: n = the no. of vehicles passing a point in the roadway in T secs
q = the equivalent hourly flow.

- Density (k):- sometimes referred to as concentration, is the number of vehicles traveling over a unit length of highway at an instant in time. The unit length is usually 1 Km or mile thereby making vehicles per km or mile (vpk or m) the unit of density.

Traffic Flow Elements

- Speed (is the distance traveled by a vehicle during a unit of time.)
  - *Time mean speed (u_t)* is the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time.

$$\bar{u}_t = \frac{1}{n}\sum_{i=1}^{n} u_i$$

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Where: n =number of vehicles passing a point on the highway;

u_i = speed of the i^{th} vehicle (m/sec)

Traffic Flow Elements

- Space mean speed (u_s) is the harmonic mean of the speeds of vehicles passing a point in a highway during an interval of time. It is obtained by dividing the total distance traveled by two or more vehicles on a section of highway by the total time required by these vehicles to travel that distance.

$$\bar{u}_s = \frac{n}{\sum_{i=1}^{n}(1/u_i)} = \frac{nL}{\sum_{i=1}^{n} t_i}$$

Where: t_i = the time it takes the ith vehicle to travel across a section of highway (see);

U_i =speed of the i^{th} vehicle (ft/sec); L = length of section of highway (ft)

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Traffic Flow Elements cont..

- The time-space diagram is a graph that describes the relationship between the location of vehicles in a traffic stream and the time as the vehicles progress along the highway.

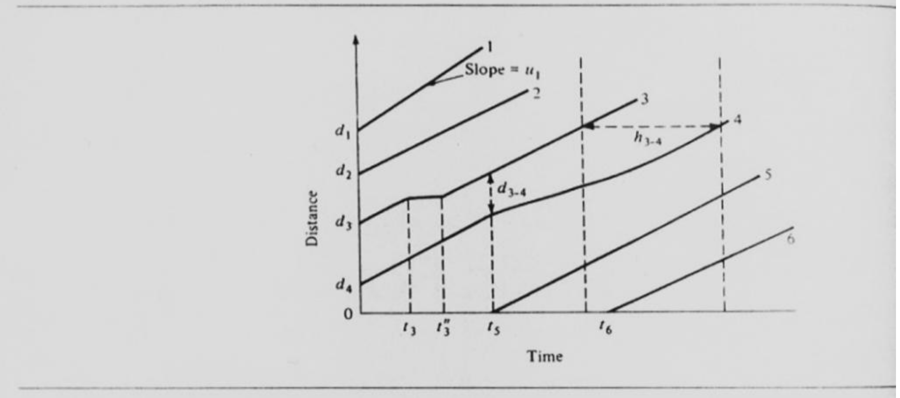
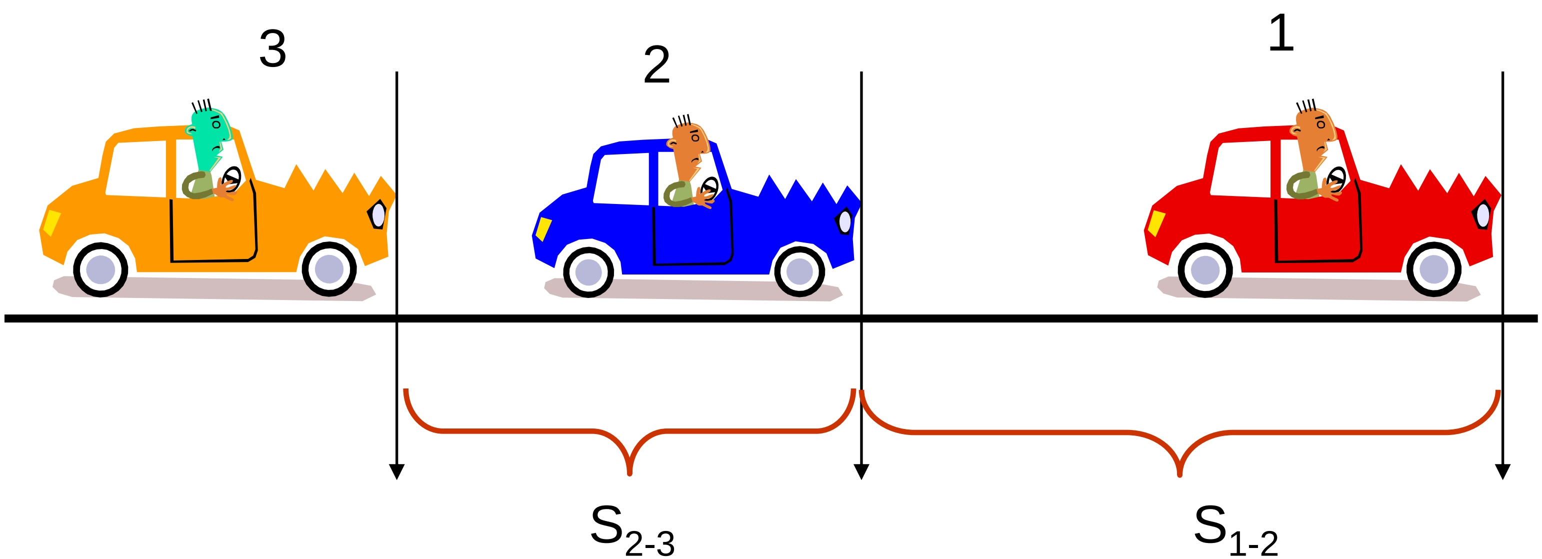


Figure 6.1 ■ Time-Space Diagram

- Time headway (h) is the difference between the time the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives at that same point.
- Space headway (d) is the distance between the front of a vehicle and the front of the following vehicle. It is usually expressed in meter / feet.

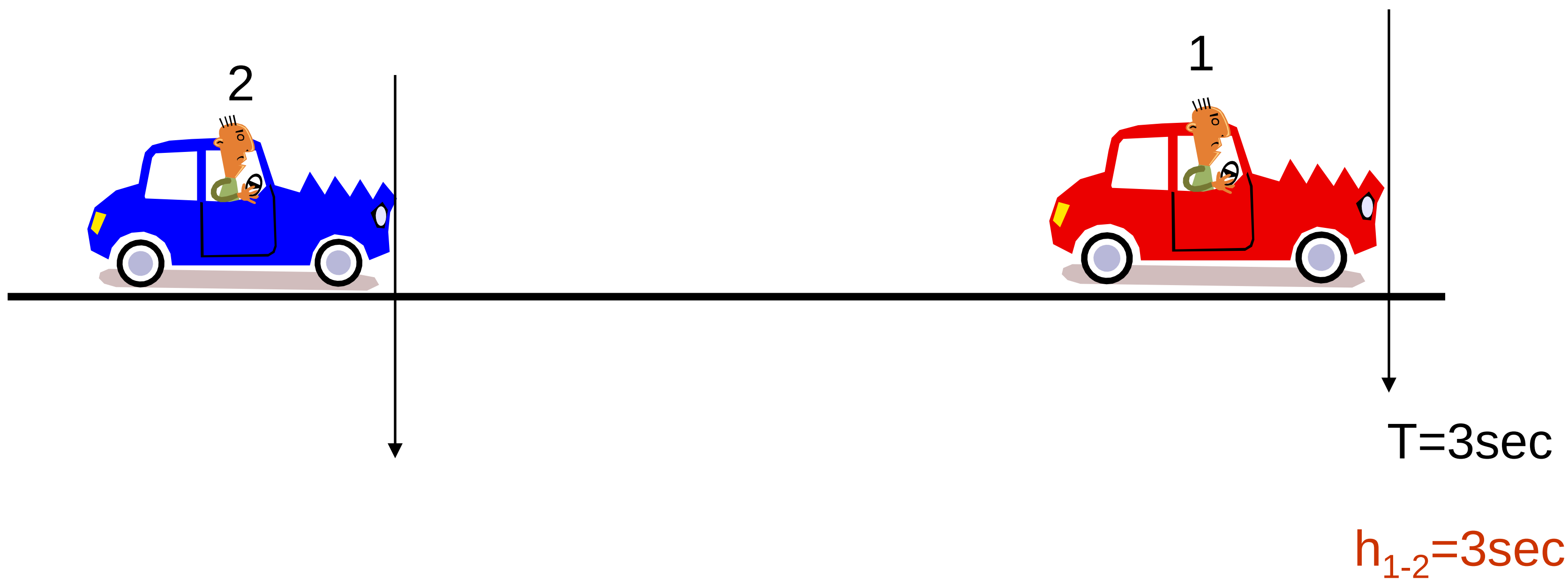
Spacing (s)

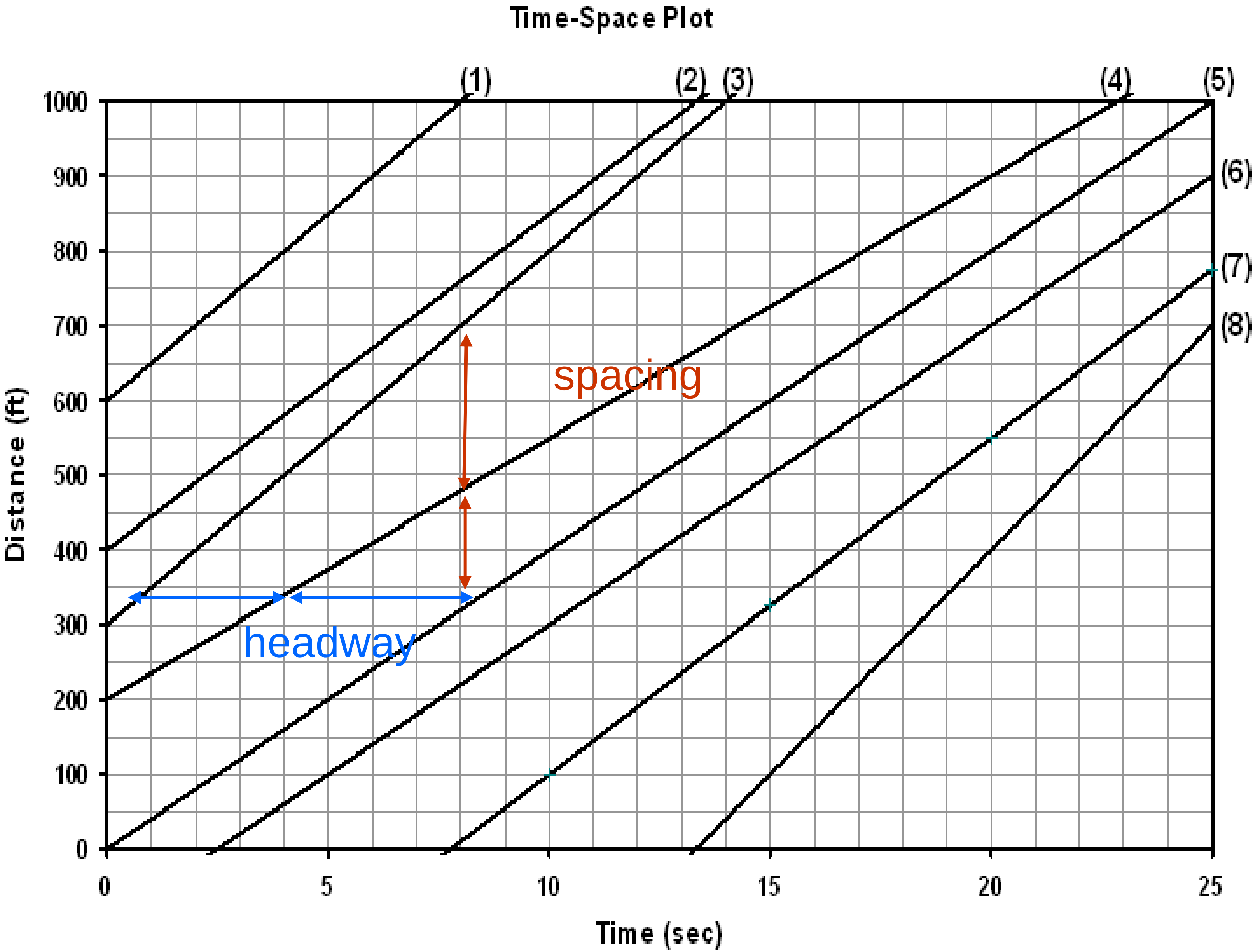
- Front bumper to front bumper distance between successive vehicles



Headway (h)

- Time between successive vehicles passing a fixed point




Time-Space Plot
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
1000
900
800
700
600
500
400
300
200
100
0
Distance (ft)
spacing
headway
0
5
10
15
20
25
Time (sec)

- **Speed (v)** – ft/sec or mph (m/sec or kmph)
- **Flow (q)** – veh/sec or vph
- **Density (k)** – veh/ft or vpm (veh/m or vpkm)
- **Spacing (s)** – ft/veh (m/veh)
- **Headway (h)** – sec/veh
- **Clearance (c)** – ft/veh (m/veh)
- **Gap (g)** – sec/veh

Remember, units are critical!

Fundamental Relationships

- **$q = k \cdot v$ ....Flow**

  $(veh/hr) = (veh/mi) \cdot (mi/hr)$

- **$h = 1 / q$ ....Headway**

  $(sec/veh) = 1 / (veh/hr) \cdot (3600)$

- **$s = 1 / k$ ....Spacing**

  $(ft/veh) = 1 / (veh/mi) \cdot (5280)$

Example 7

i. A volume of 1650 vehicle per hour is observed at intersection approach. Find the peak rate of flow within the hour for the peak hour factor of 0.875.

ii. A traffic stream has an average head way of 2.2 seconds at 80km per hour. Calculate the rate of flow and density.

iii. Determine the PHF for the given volume of traffic in 1hr (15min interval)

- At T_1=900vh at T_2= 1200vh
- At T_3= 1100vh at T_4=1000vh

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Example 8

- A set of 10 vehicles has been observed for 80 sec on a road segment that is 300m. long. The vehicles enter at beginning of segment and leave the end of segment as per the data recording shown below.

Determine:-

a. Draw time space diagram (Time distance plot)

b. Time mean speed

c. Space mean speed

Vehicle Numbers	**Arrival time (t_o) beg. of seg.**	**Departure time (t) end of seg.**
1	0	41
2	2	46
3	3	49
4	5	50
5	10	53
6	13	55
7	15	75
8	20	77
9	25	79
10	35	80

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Flow-density relationships

- Flow = (density) x (space mean speed)

$$q = k * \bar{u}_s$$

- Space mean speed = (flow) x (space headway)

$$\bar{u}_s = q * \bar{d}$$

- Density = (flow) x (travel time for unit distance)

$$k = q * \bar{t}$$

- Average space headway = (space mean speed) x (average time headway)

$$\bar{d} = \bar{u}_s * \bar{h}$$

- Average time headway = (average travel time for unit distance) x (average space headway)

$$\bar{h} = \bar{t} * \bar{d}$$

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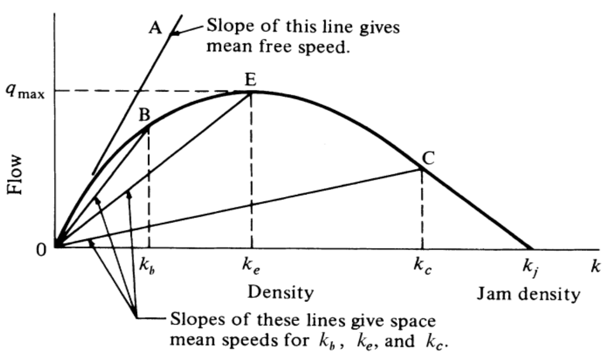
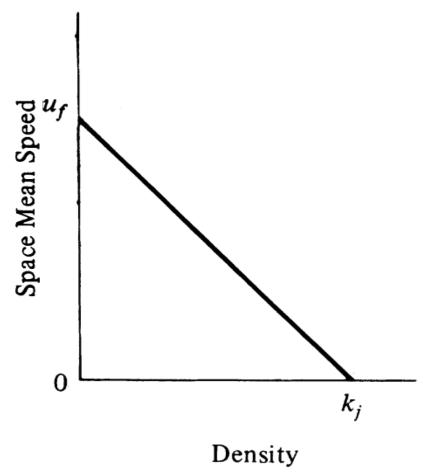
Fundamental diagram of traffic flow

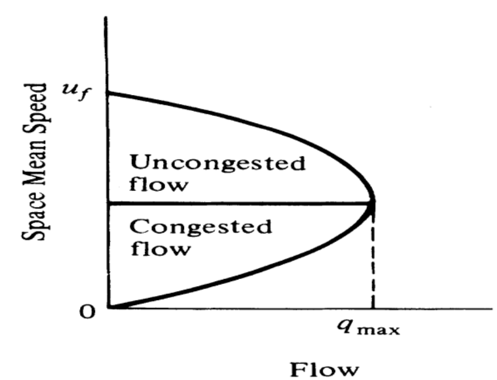
- When the flow is very low, there is little interaction between individual vehicles.
- The absolute maximum speed is obtained as the flow tends to zero, and it is known as the mean free speed (Uf). slopes of lines OB, OC, and OE in Figure (a) represents the space mean speeds at densities kb, kc, and ke, respectively.
- The slope of line OA is the speed as the density tends to zero and little interaction exists between vehicles. The slope of this line is therefore the mean free speed (Uf)



(a) Flow versus density



(b) Space mean speed versus density



(c) Space mean speed versus volume

Mathematical relationships describing traffic flow

- Mathematical relationships describing traffic flow can be classified into
- **The macroscopic approach:-** Considers traffic streams and develops algorithms that relate the flow to the density and space mean speeds.
  - ***Green shields Model.*** Green shields carried out one of the earliest recorded works, in which he studied the relationship between speed and density. He hypothesized that a linear relationship existed between speed and density
  - ***Greenberg Model.*** Use the analogy of fluid flow to develop macroscopic relationships for traffic flow. He hypothesized that a natural logarithmic relationship existed between speed and density.
- **The microscopic approach:-** which is sometimes referred to as the car following theory or the follow-the-leader theory, considers spacing between and speeds of individual vehicles.

Green Shields Model

- He hypothesized that a linear relationship existed between speed and density, which he expressed as $\bar{u}_s = u_f - \frac{u_f}{k_j} * k$
- Since $q = \bar{u}_s k$ there for $\bar{u}_s^{\,2} = u_f.\bar{u}_s - \frac{u_f}{k_j} * q$ $\bar{u}_s$
- Differentiating q with respect to we obtain $2\bar{u}_s = u_f - \frac{u_f}{k_j}\frac{dq}{du_s}$
- For maximum flow, $\frac{dq}{d\bar{u}_s} = 0$ => $k_j = 2\bar{u}_s \frac{k_j}{u_f}$ => $u_{at\max flow} = \frac{u_f}{2}$

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Green Shields Model

$\bar{u}_s = u_f - \frac{u_f}{k_j} * k$, since $q = \bar{u}_s k$ then $q = u_f . k - \frac{u_f}{k_j} * k^2$

- Differentiating q with respect to k,

$$\frac{dq}{dk} = u_f - 2k\frac{u_f}{k_j}$$

- we obtain for maximum q

$$\frac{dq}{dk} = 0 \quad => \quad u_f = 2k\frac{u_f}{k_j} \quad => \quad k_{at\max flow} = \frac{k_j}{2}$$

- The maximum flow can therefore be

$$q_{\max} = \frac{k_j u_f}{4}$$

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Greenberg Model

- Using the fluid-flow analogy was developed by Greenberg in the form $\bar{u}_s = c \ln \frac{k_j}{k}$ $q = ck \ln \frac{k_j}{k}$
- Differentiating q with respect to k, we obtain $\frac{dq}{dk} = c \ln \frac{k_j}{k} - c$
- For maximum flow $\frac{dq}{dk} = 0$ $\ln \frac{k_j}{k} = 1$
- Giving $\ln k_j = 1 + \ln k_o$
- That is, $\ln \frac{k_j}{k_o} = 1$ and Substituting 1 for $\ln \frac{k_j}{k_o}$ gives $u_o = c$
- Thus, the value of **c** is the speed at maximum flow.

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Calibration of Macroscopic Traffic Flow Models

- If a dependent variable y and an independent variable x are related by an estimated regression function, then

$$y = a + bx$$

- The constants a and b could be determined from
- Where: n = number of sets of observations; x_i = i^{th} observation for x; y_i = i^{th} observation for y

$$a = \frac{1}{n}\sum_{i=1}^{n} y_i - \frac{b}{n}\sum_{i=1}^{n} x_i = \bar{y} - b\bar{x} \qquad b = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2}$$

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Calibration of Macroscopic …..

- The coefficient of determination (or square of the estimated correlation coefficient) , which is given by

$$R^2 = \frac{\sum_{i=1}^{n} (Y_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

Where: Yi is the value of the dependent variable as computed from the regression equations.

The closer R^2 is to 1, the better the regression fir

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Example 9

- A study of freeway flow at a particular site has resulted in calibrated speed-density relationship as follow:-

$$U = 57.5(1 - 0.008K)$$

- For this relationship determine

i. The free-way speed

ii. Jam density

iii. The speed-flow relationship (draw the graph)

iv. The flow-density relationship (draw the graph)

v. Capacity

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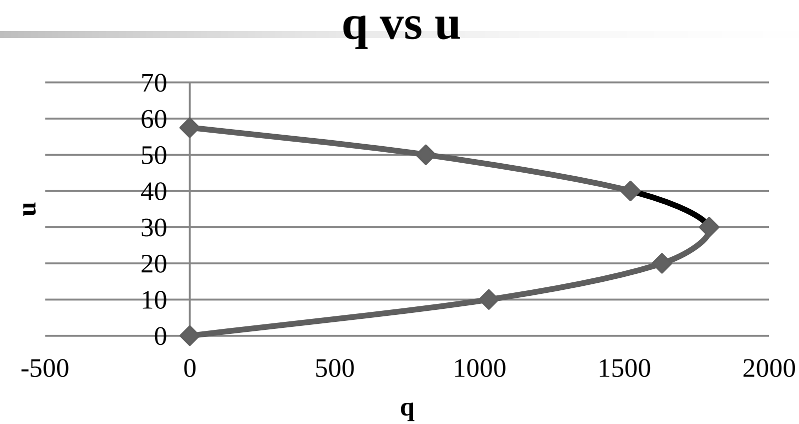
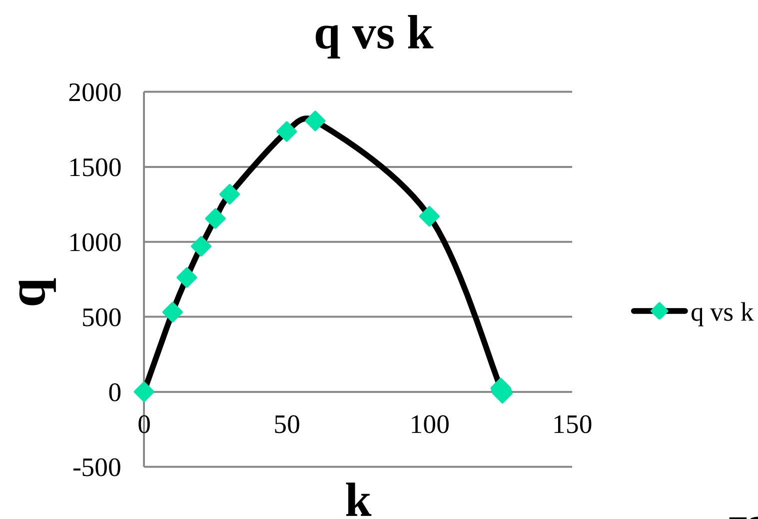
Example 9

u	q
0	0
10	1032.6
20	1630.4
30	1793.4
40	1521.6
50	815
57.5	-0.2875



k	q
0	0
10	531
15	762
20	970
25	1155
30	1317
50	1735
60	1806
100	1170
125	25
125.2	13.5216
125.3	7.7686
125.6	-9.5456



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Exercise

I. Find the equation of the following relationship and which fit is better among the two.

- linear relationship (Y=ax + b)
- logarithmic relationship (Y=aln(x) + b)

II. Transform these formulas to show the model of Green shields and Greenberg and find V_o, V_f, K_o and K_j.

III. Find k = k (u), q = q (u) and q = q (k)

IV. Make a graph of v (k), q (v) & q (k)

Data set`	Speed u(km/hr)	Density K (veh/km)
1	71	13
2	62	22
3	41	45
4	13	96
5	22	75
6	31	58
7	49	33

Introduction to Shock waves in traffic streams.

- The sudden reduction in capacity due to accidents, reduction in the number of lanes, restricted bridge sizes, work zones, a signal turning red, and so forth, creating a situation where the capacity on the highway suddenly changes from C1 to a lower value of C2, with a corresponding change in optimum density from a value of k_o^a to a value of k_o^b
- An observer will see that this point moves upstream as traffic continues to approach the vicinity of the bottleneck, indicating an upstream movement of the point at which flow and density change.

This phenomenon is usually referred to as a shockwave in the traffic stream.

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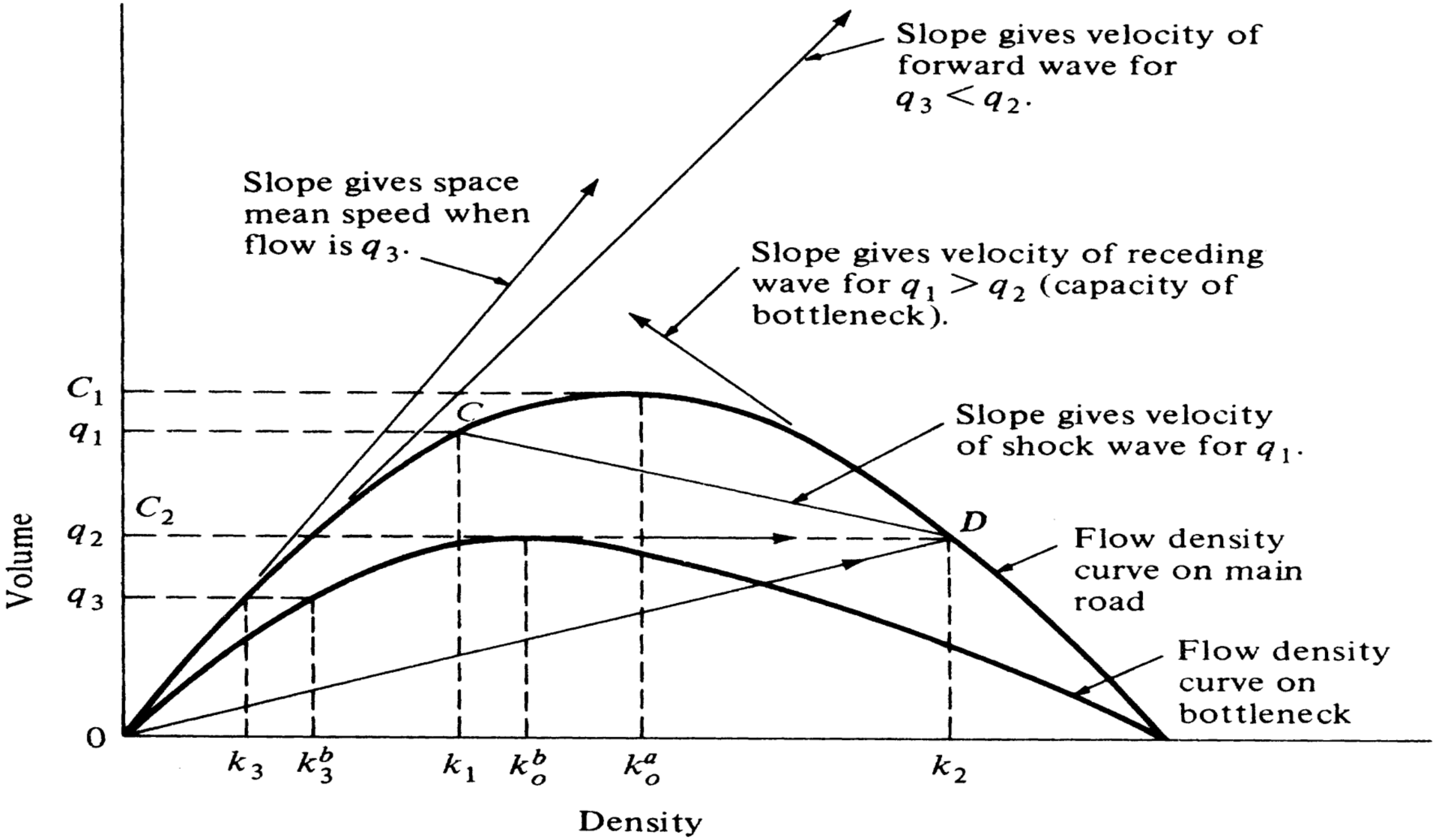
Shock waves cont….



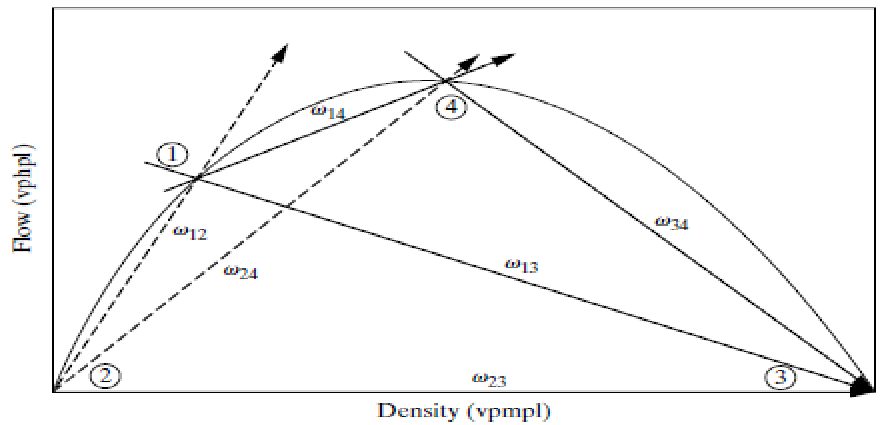
Kinematic and Shock Wave Measurements Related to Flow-Density Curve

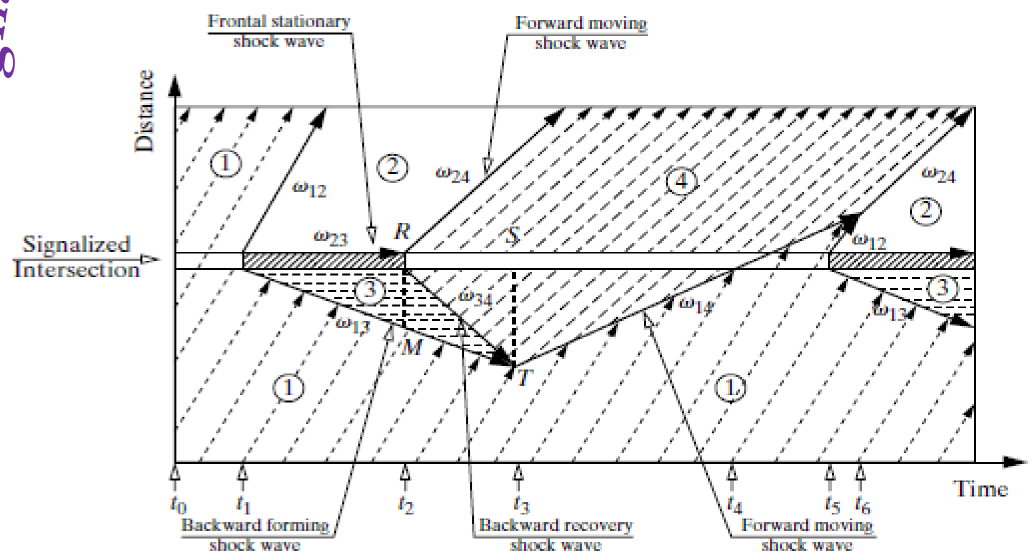
Shock waves cont…

- Types of shock waves
  - Frontal stationary shock wave
  - Backward forming shock waves
  - Backward recovery shock waves
  - Rear stationary and forward recovery shock waves

Shock waves cont….

Shock waves at signalized intersection





The queue length at the signalized intersection during red signal length

r= length of red signal

$$RM = r * \omega_{13}$$

The maximum queue length. (ST)

$$ST = \frac{r\,\omega_{13}\omega_{34}}{\omega_{34} - \omega_{13}}$$

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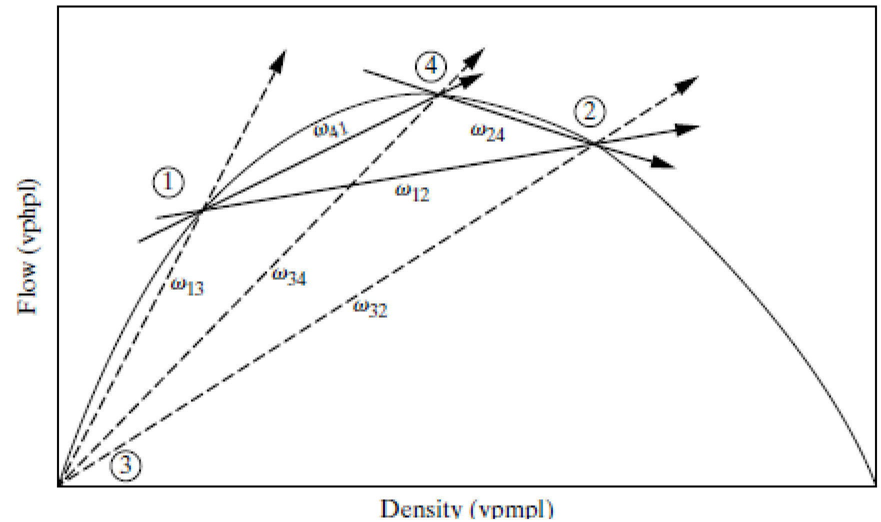
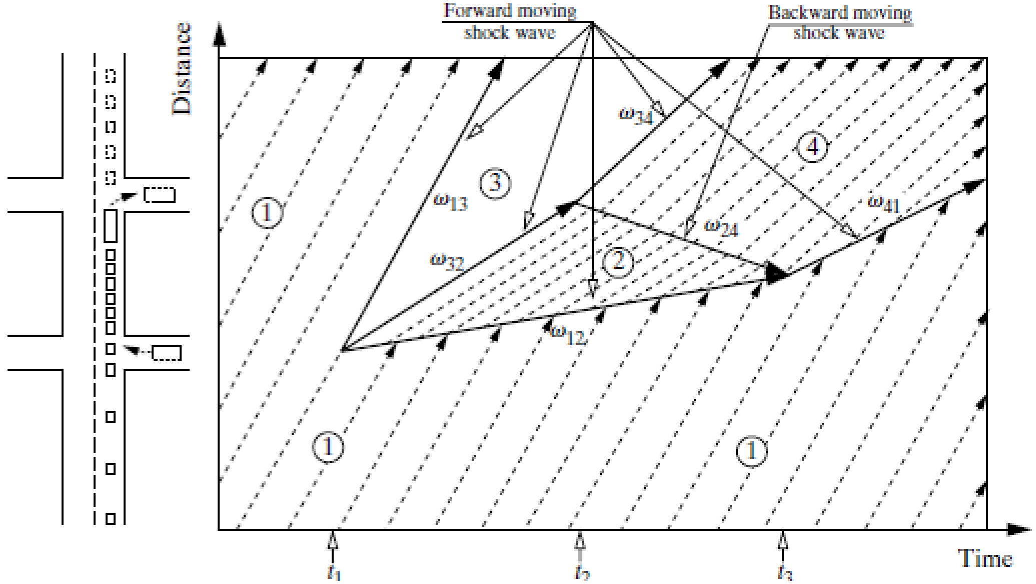
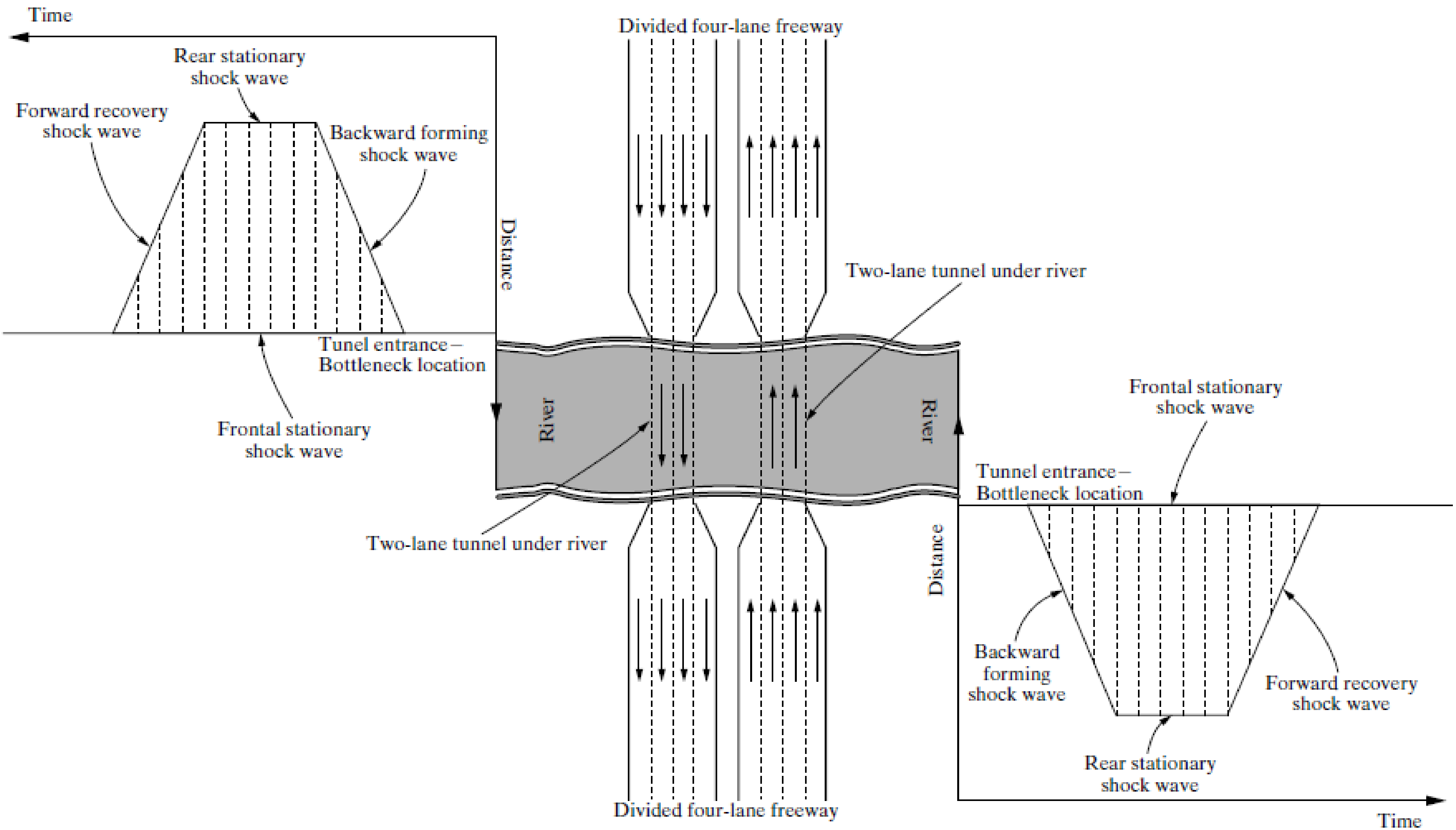
Shock waves cont….

Shock waves created by slow traffic



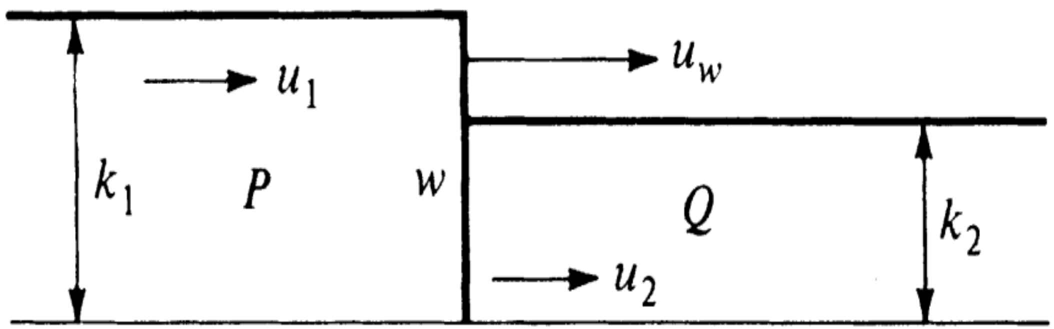


Shock waves cont….



Shock waves due to bottle neck

Shock waves cont….



$$u_w = \frac{q_2 - q_1}{k_2 - k_1} = \omega_{12}$$

Example 10

The traffic situation at some segment of the road section having A volume of 1000veh/hr and the density about 16veh/km. A truck entered at point P which is 1km from an upstream bench mark at a speed of 16km/hr due to decrease speed the the vehicles increase 75veh/km after 10min the truck leave the stream. At a capacity condition flow1400veh/hr and density 44veh/km,

a) Determine the speed of all shock waves.
b) The point that shockwave start dissipating
c) The point that shockwave totally dissipating
d) Max queue length

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Example 11

Consider a case in one leg of a signalized intersection approach in a city, whose traffic stream can be described by Greenshield model, having a density of 55 vh/km/ln , a free flow speed of 80 km/h and the space mean speed of 50km/hr with a stop red signal duration of 60sec.

a) Draw the flow – density (show only the two points) and time- distance diagram of the shock wave.
b) What is the shock wave speed in the two scenarios?
c) How much queue length will be resulted in 60sec of red signal time?

Exercise

The southbound approach of a signalized intersection carries a flow of 1000 veh/h/ln at a velocity of 50 mi/h. The duration of the red signal indication for this approach is 15 sec. If the saturation flow is 2000 veh/h/ln with a density of 75 veh/mil/ln, the jam density is 150 veh/mi/ln, determine the following:

a. The length of the queue at the end of the red phase

b. The maximum queue length

QUESTIONS?