SCHOOL OF CIVIL ENGINEERING & ARCHITECTURE

Civil Engineering Department

Exit Exam Tutorial on Traffic Engineering

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Tutorial Class for Traffic Eng.

Part I: Traffic Engineering studies

- spot speed studies, volume studies, travel time and delay studies parking studies and road traffic safety.

Part II: Fundamental Principles of Traffic flow :

- Traffic flow elements, and flow-density relationships.

Part III: Highway Capacity & Level of service,

- Capacity of highways and intersections.

Part VI: Traffic Operational Flow Analysis

Part V: Traffic-control devices and systems:

- Traffic signs, pavement markings and islands, and traffic signals.

Test Blueprint for BSC in Civil Engineering

Learning Outcome	Learning outcomes								
	Cognitive								
	Remembering	Understanding	Application	Analysis	Evaluation	Creation/Synthesis	Affective	Psychomotor	
CLO1 - Explain Transport system and Project Appraisal	1	1							
CLO2 - Apply Traffic flow theories and models to investigate the effect of traffic congestion			1						
CLO3 - Evaluate the capacity and level of service (LOS) of basic freeway and highway						1			
CLO4 - Design road furniture and traffic signal timing applying Software's			1						
CLO6 - Estimate the current and future travel demand				1					

Part I: Traffic Engineering studies

- **Short Notes on**
  - Spot speed studies
  - Volume studies,
  - Travel time and delay studies
  - Parking studies and road traffic safety.
- **Tutorial Questions on**
  - Traffic Engineering studies

INTRODUCTION

- The availability of highway transport has provided several advantages.
- But it also have problems like accident, parking difficulties, congestion and delay.
- Therefore to reduce the negative impact, it is a must to collect information.
- Traffic studies grouped into three main categories:
  - Inventories:
    - Provide a list of existing information.
    - Such as:street width,parking space,transit routes,traffic regulations…
  - Administrative studies:
    - Use existing engineering records,available in govt agencies.
    - Such as:result of surveys
  - Dynamic studies:
    - Involve the collection of data under operational condition.
    - Such as:Speed,traffic volume,travel time and delay,parking and accidents.

Spot speed studies

- Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at particular location of highway.
- Speed determined from a spot speed study used to:
  - Establish speed zones
  - Determine whether complaints about speeding are valid
  - Establish passing and no-passing zone
  - Design geometric alignment
  - Analyze accident data
  - Evaluate the effect of physical improvement
  - Determine the effect of speed enforcement program and speed control measures.
  - Determine speed trends

Spot speed studies…cont.

- Location for spot speed studies:
- The location for spot speed studies depends on the anticipated use of the result
  - Locations that represent different traffic condition
  - Midblock of urban highways and straight
  - Any location may be used for the solution of a specific traffic engineering problem
- The data should not be biased
  - The drivers be unaware
- Time of day and Duration of spot speed studies:
  - Time of the day:Depends on the purpose of the study
  - Duration of the study: The minimum number of vehicle speeds required for statistical analysis is recorded.

Spot speed studies…cont.

- Definition of some important terms:
- Average speed or Time Mean Speed: is the arithmetic mean of all observed vehicle speed.

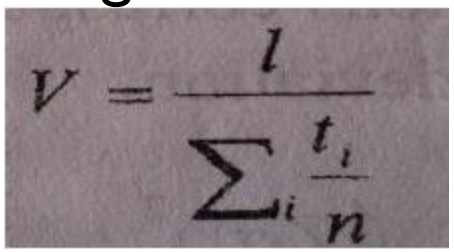
$$\bar{u} = \frac{\sum u_i}{N}$$

  - Where: u= average speed, u_i=speed the i_{th} vehicle, N=number of observation

- Median speed:is the speed at the middle value in series of spot speeds that are arranged in ascending order.
- Modal speed: is the speed value that occurs most frequently in a sample of spot speeds.

Spot speed studies…cont.

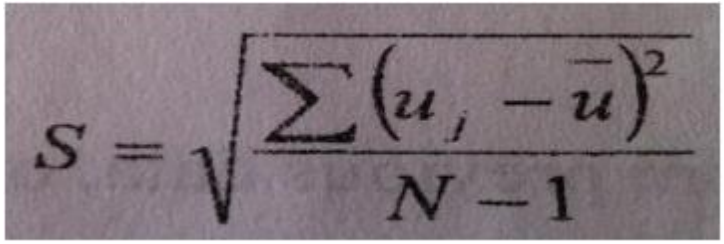
- The ith-percentile spot speed: is the speed value below w/c i percent of the vehicles travel.
- Pace: is the range of speed usually at 10mph interval that has the greatest number of observations.
  - Example: 30-40mph, 40-50mph and 50-60mph; the pace is 40-50mph if the range has highest number.
- Space mean speed: is a measure of the speed of travel over a measured distance rather than at a single location



  - Where: V=the space mean speed, n the number of vehicle, l=length of road length,ti=travel time for i vehicle.

Spot speed studies…cont.

- Standard deviation of speed: is a measure of the spread of individual speed.



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

  - where: S= Standard deviation, u=arithmetic mean, uj=speed for jth observation,N= number of observation

- Sample size for spot speed studies

Spot speed studies…cont.

- Method for conducting Spot speed studies
  - Generally divided into two main categories
    - Manual andAutomatic

- These automatic devices can be grouped into three main categories:
  - Road detectors
  - Doppler-Principle mater
  - Principles of electronics

Spot speed studies…cont.

- Road detectors:
  - Can be pneumatic road tube and induction loop.
  - Used to collect both speed and volume data.
  - Advantage:Reduce human errors
  - Disadvantage: Expansive and When pneumatic tubes used the driver may notice it and results behavioral change
- Doppler-principle Meter:
  - The difference b/n the frequency of the transmitted signal--- and that of the reflected signal…convert speed in mph.(Radar)
  - Advantage:influence on driver is reduced if only it is out of the sight
- Electronic-principle detectors:
  - Use electronic means and the information is used to determine the speed,volume,queues…
  - Example:video image processing (Camera)

Volume studies

- Traffic volume studies are conducted to collect data on the number of vehicles/pedestrians that pass a point on a highway facility during a specified time period.
- Time varies from 15min to as much as year
- The data collected is putted in subclass:
  - Directional movement
  - Occupancy rates
  - Vehicle classification
  - Pedestrian age

Volume studies…cont.

- Average Annual Daily Traffic (AADT)
  - Is the average of 24hr counts collected every day of the year.
  - Estimation of highway user revenues
  - Development of freeway and major arterial street systems
- Average Daily Traffic (ADT)
  - Is the average of 24hr count collected over a number of days greater than one but less than year.
  - Measuring of current demand
  - Evaluation of exiting traffic flow
- Peak Hour Volume (PHV)
  - Is the max no of vehicle that pass a point on a highway during 60min.
  - Design of no of lane,intersection signalization
  - Development of Parking regulation
- Vehicle classification (VC)
  - Recording volume with respect to type of vehicles:
  - Passenger car,two axle trucks,or three axle trucks

Volume studies…cont.

- Method of Conducting Volume Counts

  - Manual Method: Involve one or more person counting
    - Disadvantage: Labor intensive, subjected to human limitation, can't be used for long counting period

  - Automatic Method: Involve the laying surface detectors(pneumatic) or subsurface detectors (electronic contact) on the road.

Volume studies…cont.

- Type of volume Counts:
- Cordon count:
  - When information is required on vehicle accumulation within an area.
  - The area is known as Cordon area
    - Example:Central business districts
  - Intersection of each street crossing the cordon line is counting station
  - Information Used:Parking facility,updating and evaluating traffic operation techniques

Volume studies…cont.

- Screen Line Counts:
  - The study area is divided into large sections by running imaginary lines known as screen lines.
  - The screen lines nay be natural or man made barriers
  - Information used: Detect the variations in traffic volume and traffic flow due to the change in the land use
- Intersection Counts:
  - Are taken to determine through movement and turning movement.
  - Information used: Determining phase length and cycle time and design of channelization at intersection
- ReadingAssignment:Pedestrian and PeriodicVolume count.

Travel time and delay studies

- A travel time study determines the amount of time required to travel from one point to another on a given route
- The data's are used to identify problems then to improve overall flow of traffic on the route.
- Applications:
  - Efficiency of route or ability carry traffic
  - Identification of locations with high delay and causes
  - Performance of before and after the studies
  - Determination of relative efficiency of route
  - In trip assignment models
  - Level of service of the route

Travel time and delay studies…cont.

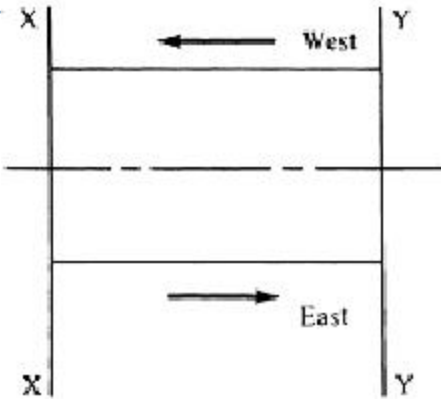
- Definition of terms related to time & delay studies:
  - Travel time is the taken by a vehicles to traverse a given section of a highway
  - Running time is the time a vehicle is actually in motion while traversing a given section of highway
  - Delay is the time lost by a vehicle due to causes beyond the control of the driver.
  - Operational delay is part of delay caused by the impedance of other traffic.(parking or unparking)
  - Stopped-time delay is that part of delay w/c the vehicle is at rest.
  - Fixed delay is part of delay caused by control devices such as traffic signals.
  - Travel-time delay is the difference b/n the actual travel time and the time that will take if the vehicle travel at average speed.

Travel time and delay studies…cont.

- Methods for conductingTravel time and Delay studies
  - Those using a test vehicle
  - Those not required test vehicle
- Method required test vehicle:
- Floating car
  - The test car is driven by observer along the test section so that the test car"floats".
  - The min number of test runs must be determined using T-distribution
- Average speedTechnique
  - 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

Travel time and delay studies…cont.

Moving vehicle Technique



- The observer makes a round trip on a test section.
- The time it takes to travel from X-X toY-Y (Te) in min.
- The time it takes to travel fromY-Y to X-X(Tw) in min
- The number of vehicles traveling west in the opposite lane while the test car is traveling east (Ne)
- 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 (Ow)
- 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 (Pw)

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

Travel time and delay studies…cont.

- Method Not requiring Test vehicle:
- License plate method
  - Observers be positioned at beginning and end of the test section.

- Interviews
  - Is carried out by obtaining information from people who drive on the study site regarding their travel time,delays…

Parking Studies

- Types of parking facilities
  - On street and off street
- On-street parking Facilities:
  - Parking bays are provided alongside the curb on one or both sides of the street.
  - Unrestricted parking: duration of parking is unlimited and parking is free
  - Restricted parking: limited to specific times of the day for the max duration and may be free or not.
- Off-street Parking Facilities:
  - These facilities may be privately or publicly owned.
  - Include surface lots and garages
  - Self or attendant parking

Parking Studies…cont.

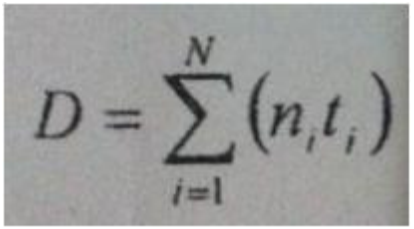
- Definition of Parking Terms:
  - A space-hour: is a unit of parking that defines the use of single parking space for a period of 1hr.
  - Parking volume: is the total number of vehicle that park in a study area during a specific length of time usually a day.
  - Parking accumulation: is the number of parked vehicle in a study area at any specified time.
  - The parking load: is the area under the accumulation curve b/n 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.

Parking Studies…cont.

- Methodbf parking studies
- Parking studies involves:
  - Inventory of existing parking facilities
  - Collection of data parking:accumulation,turnover and duration.
  - Identification of parking generators and
  - Collecting information on parking demand.
- Analysis of parking Data
- Includes summarizing, coding and interpreting the data for decision-making process.
  - Number and duration for vehicles legally parked
  - Number and duration for vehicles illegally parked
  - Space-hours of demand for parking
  - Supply of parking facilities.

Parking Studies…cont.

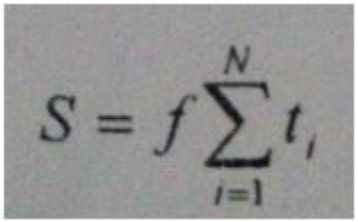
- Space-hours of demand:



- Where:
  - D=space vehicle-hours demand for a specific of time
  - N=number of parking space available
  - ti=mid parking duration of the ith class
  - ni=number of vehicles parked for the ith duration

Parking Studies…cont.

- Space-hour of supply:



- Where:
  - S=practical number of space-hour of supply for a specific period of time
  - N=number of parking space available
  - ti=total length of time in hours when the ith space can be legally parking on during the specific period
  - f=efficiency factor
- Efficiency factor is used a correct for time lost in each turnover.
  - Curb parking:78-96%
  - Surface lots & Garages:75-92%
  - Average:Curb parking:90% and Surface lots:85% and Garages:80%

Tutorial Questions

Q1. Which of the following is not a category of Traffic Studies?

a) Dynamic studies b) Inventories

c) Economic studies d) Administrative studies

Answer: c

Explanation: Traffic Studies is categorized into three main categories- Inventories, Administrative studies, and Dynamic studies.

Tutorial Questions……..cont.

Q2. What is the first stage in traffic engineering studies?

a) Traffic volume studies b) Spot speed studies
c) Speed and delay studies d) Origin and destination studies

Answer: a

Explanation: The first step in traffic engineering studies is traffic volume studies, which are carried out to understand the traffic characteristics.

Tutorial Questions…….cont.

Q3. The number of vehicles crossing a section of road in a unit time at any selected period is called
a) Traffic volume study
b) Traffic flow
c) Traffic origin
d) Traffic destination

- Answer: a
  Explanation: The number of vehicles crossing a section of road in a unit time at any selected period is called Traffic volume study. Its unit is vehicles/hr or vehicles/day.

Tutorial Questions…….cont.

Q4. Which of the following method is more accurate for traffic analysis?

a) Manual count
b) Automatic count
c) Average of manual and automatic
d) Past records

Answer: b

Explanation: The automatic count is more accurate as it is done for 24 hours by machine; it is more reliable than manual counting.

Tutorial Questions…….cont.

Q5. If the traffic volume count on a road is 150 and daily factor is 1.1 and seasonal factor is 1.2 then ADT is
a) 196
b) 197
c) 198
d) 199

- Answer: c
  Explanation: ADT= Traffic volume*D.F*S.F
  =150*1.1*1.2
  =198.

Tutorial Questions…….cont.

Q6.

24-h traffic count at a road section was observed to be 1000 vehicles on a Tuesday in the month of July. If the daily adjustment factor for Tuesday is 1.121 and monthly adjustment factor for July. Is 0.913, the Annual Average Daily traffic (in veh/day, round off to the nearest integer) is

Tutorial Questions…….cont.

Concept:

Annual Average Daily Traffic (AADT): It is the average **24-hour** traffic volume at a given location over a period of 365 days.

It helps in deciding the importance of route and road development. It includes **seasonal variation** also.

It is not feasible to take traffic reading continuously and hence reading is taken periodically and expansion factors are used to convert traffic data into AADT.

1) Hourly Expansion Factor $= \frac{Total\ 24-hr\ volume}{Volume\ for\ particular\ hour}$

2) Daily Expansion Factor $= \frac{Average\ total\ week\ volume}{Average\ voluem\ of\ a\ day}$

3) Monthly expansion factor $= \frac{Average\ annual\ daily\ traffic}{ADT\ of\ a\ month}$

Tutorial Questions…….cont.

Calculation:

Given,

24-hr traffic count = 1000 veh

Daily adjustment factor = 1.121

∴ Average week volume = Daily adjustment factor × 24-hr traffic count

= 1000 × 1.121 = 1121 veh

Monthly adjustment factor = 0.913

∴ AADT = Monthly adjustment factor × Average week volume

= 0.913 × 1121 = 1023.47 = **1024 VPD**

Tutorial Questions…….cont.

Q7. _____ is a part of delay caused by control devices like traffic signal.

a) Operational delay

b) Stopped-time delay

c) Fixed delay

d) Travel time delay

QUESTIONS?

Part II: Fundamental Principles of Traffic flow

- **Short Notes on**
  - Traffic flow elements
  - Flow-density relationships
  - Fundamental diagram of traffic flow
  - Mathematical relationships describing traffic flow
- **Tutorial Questions on**
  - Fundamental principles of traffic flow

Fundamental Principle of Traffic Flow

- Traffic flow theory is a tool that helps
  - The transportation engineers to understand & express the properties of traffic flow
  - To know vehicles interaction with each other & with roadways
- Evaluation of traffic flow helps for
  - Evaluating the capacity of the existing roadways and
  - Designing of new roadways
- Parameters associated with the highway effectiveness:
  - The quantity of traffic
  - The type of vehicles within the traffic stream
  - The distribution of flow over a period of time (usually 24 hours)
  - The average speed of the traffic stream
  - The density of the traffic flow.

Traffic flow theory is a complex matter

- Cooperation between:
  - Vehicle
  - Road
  - Driver
- Every vehicle is controlled by a driver who makes individual choices how to control the vehicle
- The driver is the main reason why traffic flow is such a complex matter

Categories of Traffic Flow

- Uninterrupted flow:Occurs on facilities that have no fixed element such as traffic signal, external traffic stream w/c cause interruption to the flow.
  - Freeways
  - Multilane highways
- Interrupted flow:occurs on transportation facilities that have fixed elements causing periodic interruptions to the flow.Such as traffic signals,stop signs…
  - Signalized streets
  - Unsignalized intersections with stop signs
  - Pedestrian walkway

Traffic Stream Characteristics

Traffic Flow and Water Flow ?

Traffic Stream Parameters

- **Macroscopic**

  describe the traffic stream as a whole.

  Traffic stream may be described macroscopically by these parameters:

  – Volume or rate of flow

  – Speed

  – Density

Traffic Stream Parameters

- **Microscopic**

  describe the behavior of individual vehicles or pairs of vehicles within the traffic stream.

  Traffic stream may be described microscopically by these parameters:

  - The speed of individual vehicles
  - Headway
  - Spacing

Traffic flow Elements

- Functional effectiveness of highway can be measured by its ability to accommodate as much traffic as possible, subjected to safety and environmental constraints.
- Fundamental parameters used to characterize flow of traffic in a roadway are:
  - Flow rate
  - Density
  - Speed

Traffic flow Elements….cont

- Flow (q):
- number of vehicles passing a point in a road/lane in an interval of time (measure of quantity)
  - $q = n/t$
  - Expressed by vehicle/unit time
- Where;
  - The traffic flow,q,a measure of the volume of traffic on a highway,is defined as
  - The number of vehicles,n,passing some given point on the highway
  - The time interval,t,

Traffic flow

- On a ***two-lane road*** we consider:
  - total traffic in both directions
  - directional distribution (e.g 60/40)
- On ***multilane*** roads:
  - each direction is considered individually
- At a ***junction***:
  - traffic volume is defined as the total number of vehicles which <u>enter</u> the junction
  - if the vehicles leaving the junction were included, all the vehicles would have been

Heavy vehides and passenger car units (pcu)

- The proportion of heavy vehicles is calculated as a percentage of the total traffic
- However, automatic classifying systems are usually using vehicle length instead of vehicle weight (it is easier to measure length than weight of moving vehicles)
- Heavy vehicles and passenger cars have very different characteristics
- For evaluation of traffic flow, the traffic volume should be ***converted from vehicles (veh) to passenger car units (pcu)***
- Equivalent factors are used for each vehicle type, for example
  - 1 passenger car = 1.0 pcu
  - 1 motorcycle = 0.5 pcu
  - 1 bus = 2.0 pcu
  - 1 lorry = 2.5 pcu
  - 1 lorry with trailer = 3.0 pcu

Daily Volume Parameters

- *Establish trends over time & used for general planning purposes*
  - ***Average annual daily traffic (AADT)*** - number of vehicles in a year divided by 365
  - ***Average annual weekday traffic (AAWT)*** - number of vehicles on weekdays in a year divided by number of weekdays (260)
  - ***Average daily traffic (ADT)*** - average 24-hr volume over a defined time period less than a year (commonly for each month)
  - ***Average weekday traffic (AWT)*** - the average 24-hr weekday volume over a defined time period less than

Daily Volume Parameters - Example

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

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

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

Hourly Volume Parameters

- For design and operational purposes
- Period of maximum flow during "rush hours"
- ***Peak hour*** - single hour of the day with the highest hourly volume
  - Generally stated as ***directional volume*** (each direction separately)
  - Highways and controls are designed for peak hour for each direction of flow

PEAK-HOUR FACTOR

Peak flow rates and hourly volumes produce the peak-hour factor (PHF), the ratio of total hourly volume to the peak flow rate within the hour, computed by Equation:

$$PHF = \frac{\text{Hourly volume}}{\text{Peak flow rate (within the hour)}}$$

* If 15-min periods are used, the PHF may be computed by Equation

$$PHF = \frac{V}{4 \times V_{15}}$$

Where:

PHF = peak- hour factor

V = hourly volume (v/h) and

V_{15} = volume during the peak 15 min of the peak hour(v/15 min).

Traffic flow Elements…cont.

- Density (k):
- Is defined as the number of vehicles (pedestrians) occupying a given length of a lane or roadway at a particular instant
  - K = n/L
  - Expressed
    - by vehicle/km,vehicle/mile
- Where:
  - the traffic density,k,
  - the number of vehicles,n,
  - occupying a length of roadway..L

Traffic flow Elements…cont.

- Speed (u):
- Is the distance covered by vehicle in unit of time
  - Due to vehicle- vehicle or vehicle – roadway interactions, vehicles will not have similar speed in a given traffic stream
  - Average or mean speed is a significant variable for traffic flow analysis
- Different types of average values of speed are used to characterize a traffic stream.
  - time mean speed
  - space mean speed

Traffic flow Elements…cont.

- Time mean speed
  - This is the arithmetic average of speeds of vehicles observed passing a point on a highway.

$$v_t = \frac{\sum_i v_i}{n}$$

- Space Mean Speed
  - SMS is the average speed of vehicles measured at an instant of time over a specified stretch of road.SMS is the harmonic mean of all speeds.
  - Used in traffic models,but harder to measure.

$$v_s = \frac{L}{\sum_i \frac{t_i}{n}} = \frac{nL}{\sum_i t_i} = \frac{L}{t}$$

Traffic flow Elements…cont.

- The three parameters u,k and q are directly related under stable traffic conditions as follows

$$q \div k = \frac{n}{t} \times \frac{n}{l} = \frac{l}{t} = u$$

$$\Rightarrow q = ku$$ Equation (a)

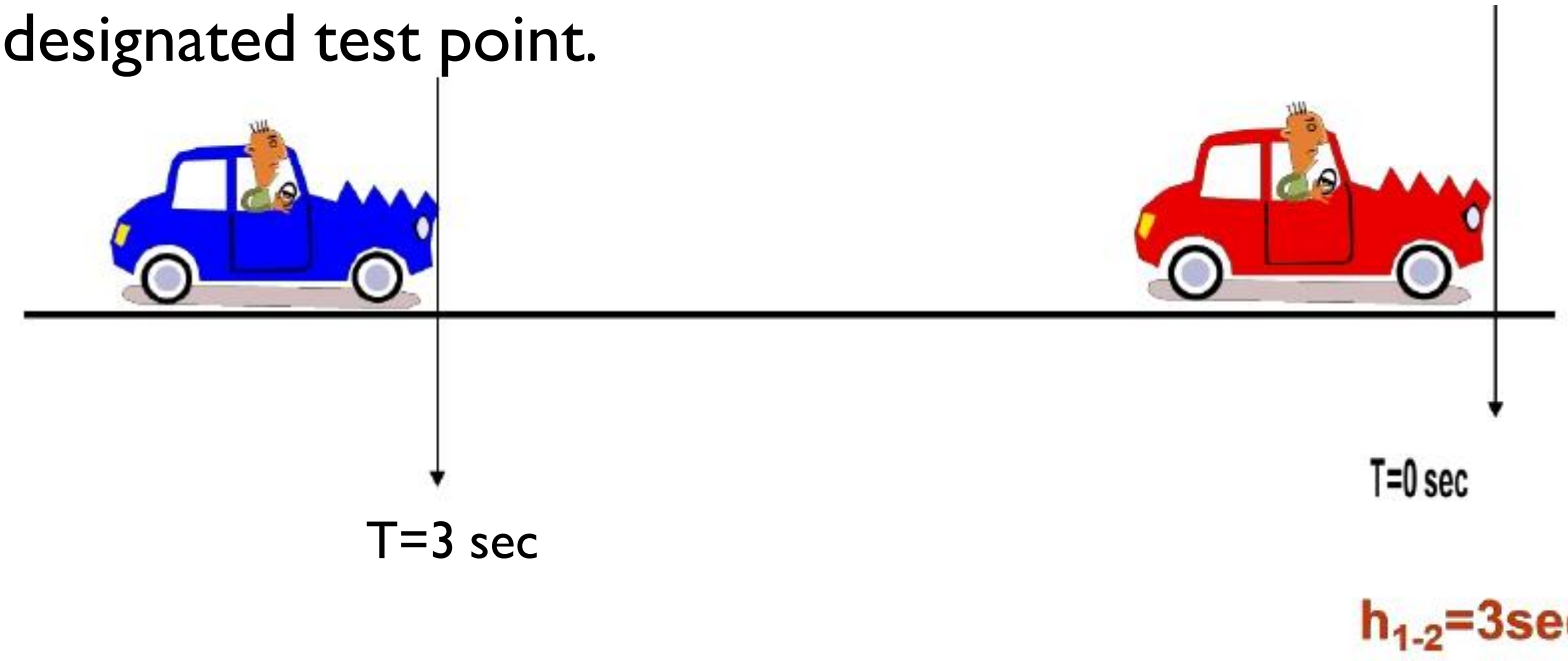
Traffic flow Elements…cont.

- In addition to the above parameters,the following parameters are also important in the study of traffic flow
- Volume - the total number of vehicles that pass over a given point or section of a lane or roadway during a given time interval;
  - volumes may be expressed in terms of annual,daily,hourly,or sub-hourly periods.
- Peak Hour Factor (PHF) –is the ratio of the hourly flow rate (q60) divided by the peak 15 minute rate of flow expressed as an hourly flow (q15)

$$PHF = \frac{q_{60}}{q_{15}}$$

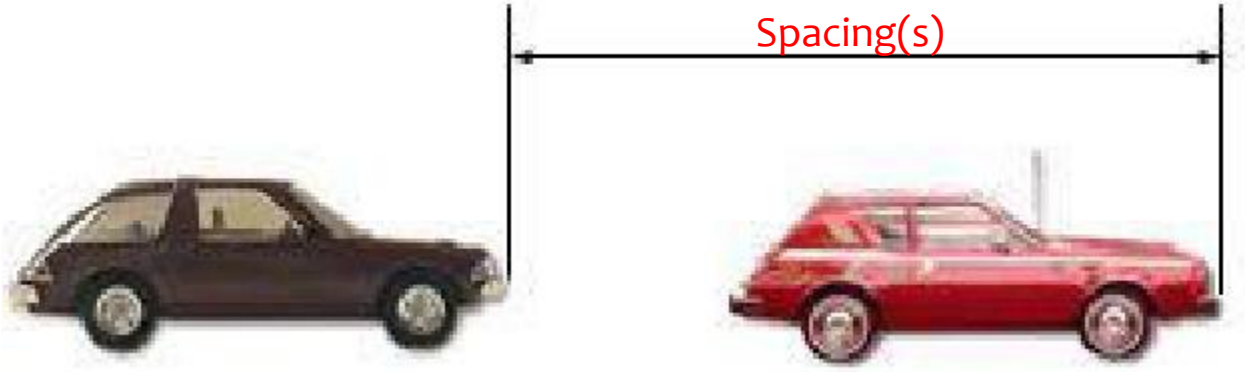
Traffic flow Elements…cont.

- Headway (h) – is the time that elapses between the arrival of the leading vehicle and the following vehicle at a designated test point.



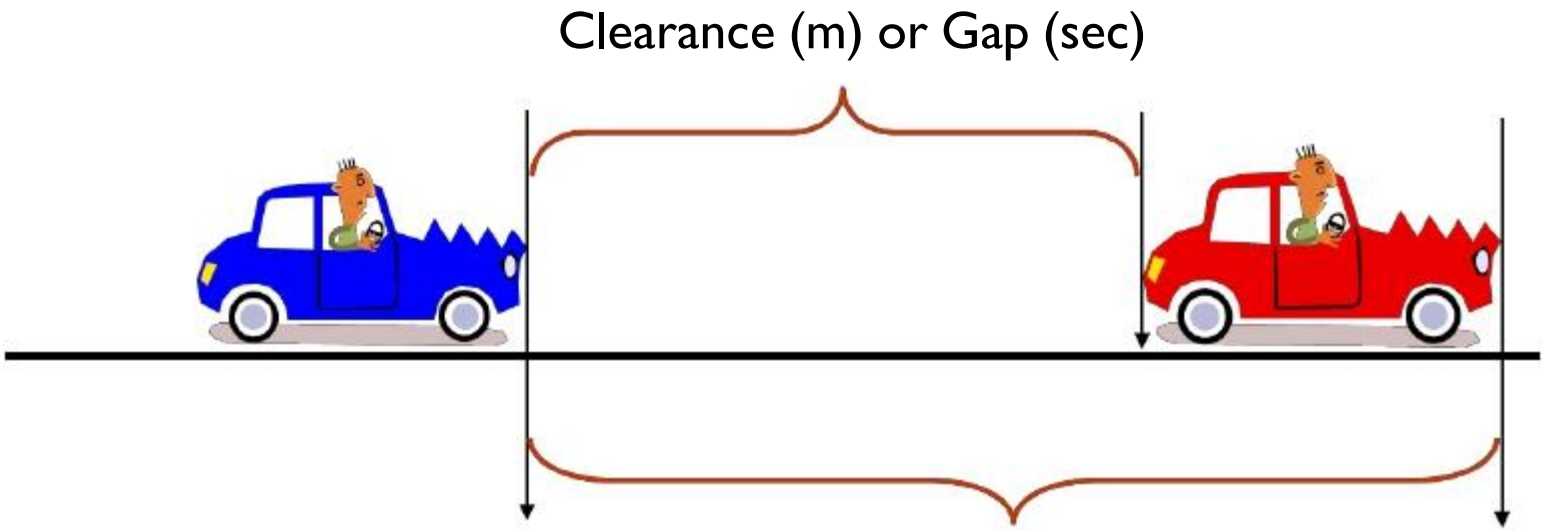
Traffic flow Elements…cont.

- Spacing (s) – is the physical distance between the front bumper of the leading vehicle and the front bumper of the following vehicle

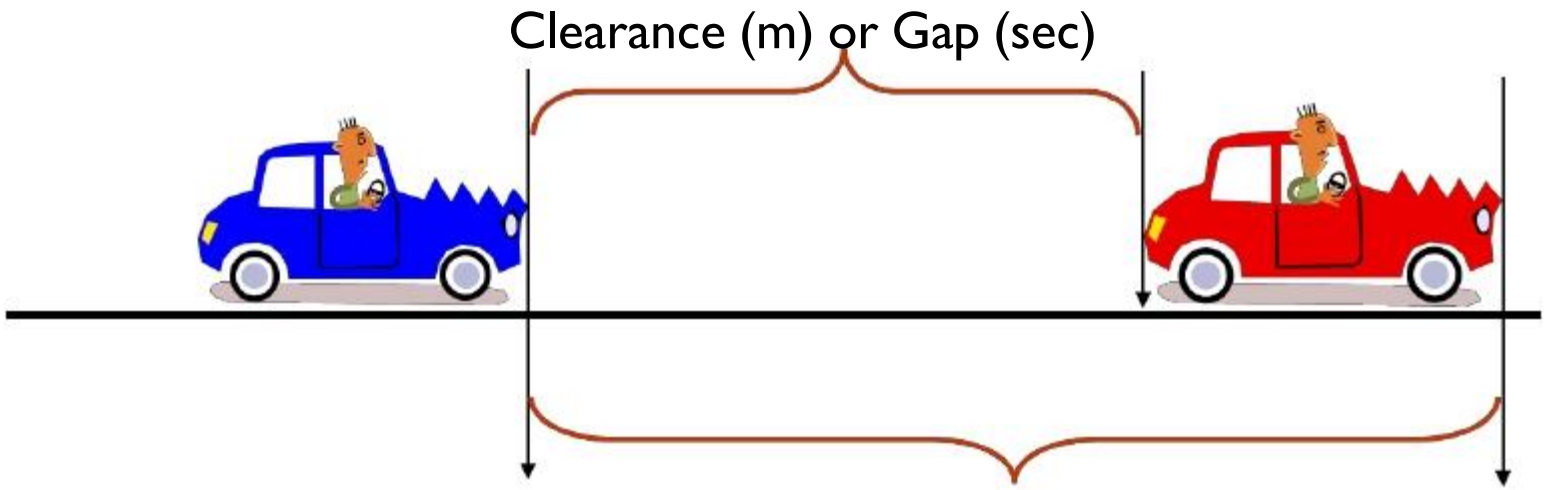


Traffic flow Elements…cont.

- Clearance (c) – is the distance between the rear bumper of the leading vehicle & the front bumper of the following vehicle
  - Is equivalent to the spacing minus the length of the leading vehicle
- Gap(g) – is the measure of the time that elapses between the departure of the first vehicle and the arrival of the second vehicle at the designated test point



Traffic flow Elements…cont.



$$c_{avg} = g_{avg} * v_{avg}$$

$$S_{avg} = h_{avg} * v_{avg}$$

$$g_{avg} = h_{avg} - \frac{L_{avg}}{v_{avg}}$$

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**

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

$$t = \sum_{i=1}^{n} h_i \longrightarrow q = \frac{n}{t} \longrightarrow q = \frac{n}{\sum_{i=1}^{n} h_i}$$

$$q = \frac{1}{\bar{h}}$$

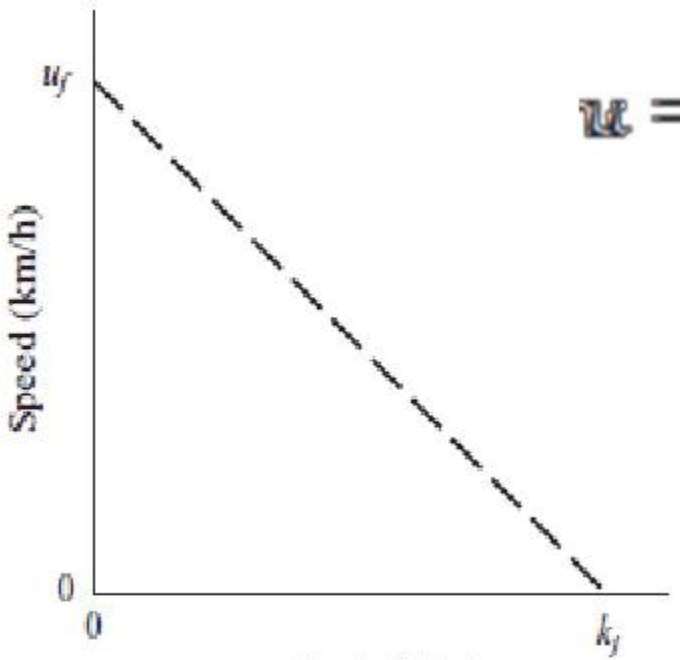
- Where:
  - $\bar{h}$ is the average time headway, $\Sigma h_i/n$, (sec)

Analysis of Speed, Flow and Density Relationship

- Speed- Density Relationship
  - Consider a single car traveling along a highway
  - By definition density will tend to zero
  - The speed at which the car can be driven is determined solely by the geometric design & layout of the road
  - The speed @ which the density is near to zero (0) is defined as Free flow speed (u_f).
  - u_f not hindered by the presence of other vehicles
  - As more vehicles use the section of the highway,density increases & speed decreases from its maximum free flow value
  - If the above condition persists,a point is reached where traffic will be brought to a stop.i.e.,u= 0,with the density at its maximum point as cars are jammed bumper to bumper,termed Jam Density (kj)

Analysis of Speed, Flow and Density Relationship…cont.

- The limiting values are
- When k=0,u=uf & when u=0,k=kj
- Different researchers [Greenshield,Greenberg,& Underwood] had developed different models [linear,logarithmic,& exponential] respectively



$$u = u_f\left(1 - \frac{k}{k_j}\right)$$

Equation (b)

Analysis of Speed, Flow and Density Relationship…cont.

- Flow- Density Relationship
- Combining the relations for u & relations between flow, density,and speed gives

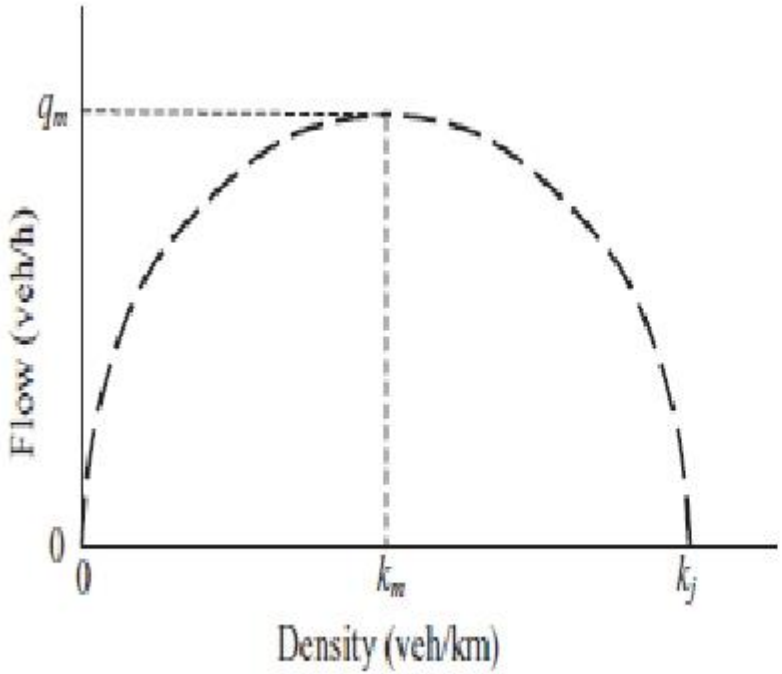


Figure 4.2
Illustration of flow-density relationship.

$$q = uk = u_f\left(1 - \frac{K}{K_j}\right) \times K$$

$$q = u_f\left(k - \frac{k^2}{k_j}\right)$$

Equation (c)

Analysis of Speed, Flow and Density Relationship…cont.

- In order to determine the density at which maximum flow occurs, differentiate eqn (c) w.r.t.k

$$\frac{dq}{dk} = u_f\left(1 - \frac{2k}{k_j}\right) = 0 \longrightarrow k_m = \frac{k_j}{2}$$ Equation (d)

Analysis of Speed, Flow and Density Relationship…cont.

- Speed-Flow Relationship
- Rearranging equ (b) for k and combining it with equ (a) gives

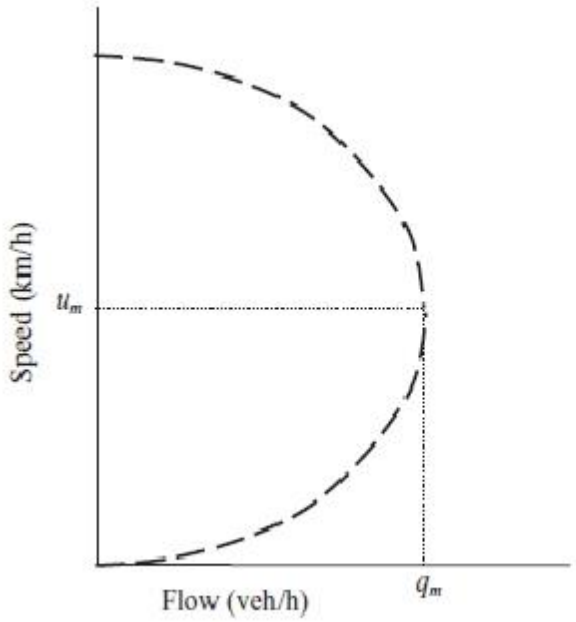


Figure 4.3
Illustration of speed-flow relationship.

$$k = k_j\left(1 - \frac{u}{u_f}\right)$$

$$q = k_j\left(u - \frac{u^2}{u_f}\right)$$

Equation (e)

Analysis of Speed, Flow and Density Relationship…cont.

- In order to determine the speed at maximum flow occurs, differentiate eqn (e) w.r.t.u

$$\frac{dq}{du} = k_j\left(1 - \frac{2u}{u_f}\right) = 0 \longrightarrow u_m = \frac{u_f}{2}$$

Equation (f)

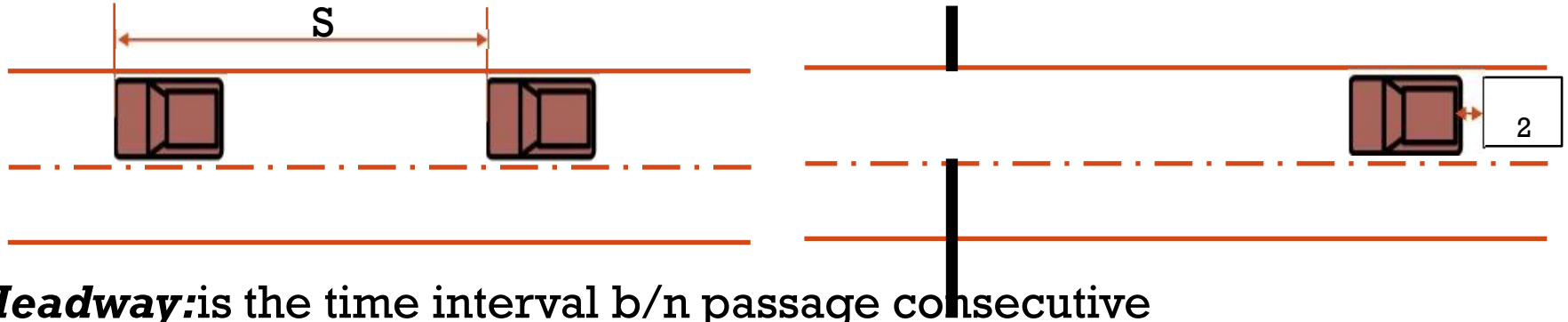
- Combining eqn (d) & eqn (f) gives,

$$q_m = u_m k_m = \frac{u_f}{2}\frac{k_j}{2} = \frac{u_f k_j}{4}$$

SUMMARY

Three basic traffic stream parameter

Parameter	symbol	Typical unit	Reciprocal	symbol	Typical unit
Flow	q	Veh/h	Headway	h	Sec/veh
Speed	v	Km/h	Travel time	T	Sec/km
Density	k	Veh/lane-km	Spacing	S	m/veh



Headway: is the time interval b/n passage consecutive vehicle measured b/n corresponding point. t_1 t_2

Headway (h) = $t_2 - t_1$

Spacing: is distance b/n vehicles moving in the same lane measured b/n corresponding point.

TRAFFIC FLOW THEORY

BASIC SPEED-FLOW-DENSITY RELATIONSHIPS

Low volumes → Highest speeds

High volumes → Low speeds

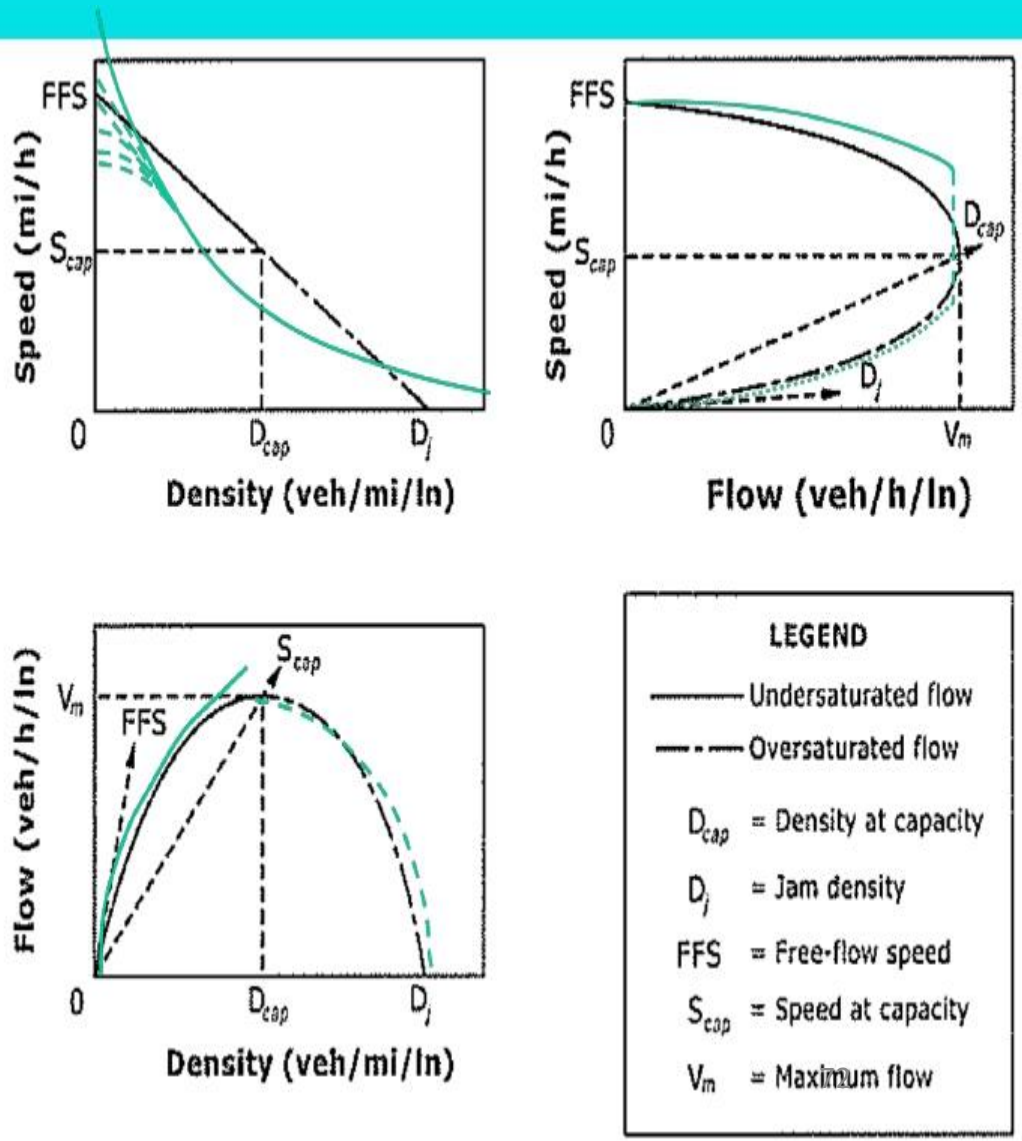
Highest volumes → Medium density

Maximum density → No speed or flow

$$q = ku$$

TRAFFIC FLOW THEORY

BASIC SPEED-FLOW-DENSITY RELATIONSHIPS



TRAFFIC STREAM MODELS

- The Greenshields Model (1935)
  - Assume that under uninterrupted condition speed and density are linearly related

$$u = u_f\left(1 - \frac{k}{k_j}\right) \qquad u_{cap} = \frac{u_f}{2}$$

$$k_{cap} = \frac{k_j}{2}$$

$$q_{cap} = k_{cap}u_{cap} = \frac{k_j u_f}{4}$$

- The Greenberg Model (1959)

$$u = u_c \ln\left(\frac{k}{k_j}\right)$$

- The Underwood Model (1961)

$$u = u_f \exp\left(-\frac{k}{k_c}\right)$$

Where

v_f:free-flow speed

v_c:critical speed

k_j:jam density

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

- 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, $\frac{dq}{d\bar{u}_s} = 0 \Rightarrow k_j = 2\bar{u}_s \frac{k_j}{u_f} \Rightarrow u_{at\,\max\,flow} = \frac{u_f}{2}$

Green Shields Model

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

- 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

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

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

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

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

Tutorial Questions

Q1. Which of the following is not an application of traffic flow theory?

a) to determine adequate lane lengths

b) to study the interrelationships of traffic flow elements

c) to determine PCU

d) to determine the average delay at intersections and freeway ramp merging areas

Answer: c

Explanation: Determination of PCU is not an application of traffic flow theory. Determination of adequate lane lengths, study of the interrelationships of traffic flow elements, and estimation of delay at intersections are some of the applications of traffic flow theory.

Tutorial Questions……..cont.

Q2. The number of vehicles travelling over a unit length of highway at an instant in time is _____

a) flow b) speed

c) density d) acceleration

Answer: c

Explanation: The number of vehicles travelling over a unit length of highway at an instant in time is density. The unit of density is vehicle/m or vehicle/km. It is usually denoted by k.

Tutorial Questions……..cont.

Q3. The harmonic mean of the speeds of vehicles passing a point on a roadway during an interval of time is known as _____

a) Density b) Flow

c) Space mean speed d) Time mean speed

Answer: c

Explanation: Space mean speed is the harmonic mean of the speeds of vehicles passing a point on a roadway during an interval of time. It is the entire distance travelled by the vehicles divided by the total time required by these vehicles to travel that distance. Space mean speed is involved in flow-density relationships.

Tutorial Questions……..cont.

Q4. On a road the free speed was 65 kmph and the space headway at jam density was 6.25 m. What is the maximum flow which could be expected on this road?

A) 2600 vph

B) 1625 vph

C) 1300 vph

D) 406 vph

Tutorial Questions……..cont.

Fundamental Relationships

- **q = k · v** **……..Flow**

  (veh/hr) = (veh/mi) · (mi/hr)

- **h = 1 / q** **……..Headway**

  (sec/veh) = 1 / (veh/hr) · (3600)

- **s = 1 / k** **……..Spacing**

  (ft/veh) = 1 / (veh/mi) · (5280)

$$q_m = u_m k_m = \frac{u_f}{2}\frac{k_j}{2} = \frac{u_f k_j}{4}$$

$$\text{Jam density} = \frac{1000}{\text{space head way (H)}}$$

$$= \frac{1000}{6.25} = 160 \text{ veh/ km}$$

$$\text{Maximum flow} = \frac{\text{jam density} \times \text{free speed}}{4}$$

$$= \frac{160 \times 65}{4} = 2600 \text{ vph} \qquad \text{Choice (A)}$$

Tutorial Questions……..cont.

Q5. Assume a road section of 88m long . Four cars are timed through the section. Their times were: 1 , 1 , 2 , and 1.5 sec respectively. What is the TMS & SMS ?

A) (47.5, 43.63)mph B) (48.5, 44.6)mph

C) (57.5, 63.63)mph D) (37.5, 53.63)mph

Tutorial Questions……..cont.

SOLUTION

$$v_t = \frac{\sum_i v_i}{n} \qquad v_s = \frac{nL}{\sum_i t_i}$$

TMS:

(88/1)+(88/1)+(88/2)+(88/1.5) or individual speeds of 60 mph, 60 mph, 30 mph, and 45 mph

TMS = (60+60+30+40)/4 = 47.5 mph

SMS:

add up the travel times and divide by the number of vehicles. Then divide the length of the section by average time

SMS = (4*88) / (1+1+2+1.5) = 43.63 mph

Tutorial Questions……..cont.

Q6. A volume of 1200 VPH is observed at an intersection approach. Find the peak flow rate within the hour for the 0.80 peak –hour factor.

A) 4800 vph

B) 1500vph

C) 2800 vph

D) 1200 vph

Tutorial Questions……..cont.

$$PHF = \frac{\text{Hourly volume}}{\text{Peak flow rate (within the hour)}}$$

$$PHF = \frac{V}{4 \times V_{15}}$$

Where:
PHF = peak- hour factor
V = hourly volume (v/h) and
V_{15} = volume during the peak 15 min of the peak hour(v/15 min).

Peak flow rate =1,200 v/0.8 = 1,500 v/h
Answer is choice 'A'

Tutorial Questions……..cont.

Q7. On a road the average headway values was Average $\ddot{h}$ = 4.125 sec. What is the flow which could be expected on this road?

A) 873 vph

B) 980 vph

C) 1073 vph

D) 1283 vph

Tutorial Questions……..cont.

Fundamental Relationships

- **q = k · v** **…….Flow**

  (veh/hr) = (veh/mi) · (mi/hr)

- **h = 1 / q** **…….Headway**

  (sec/veh) = 1 / (veh/hr) · (3600)

- **s = 1 / k** **…….Spacing**

  (ft/veh) = 1 / (veh/mi) · (5280)

- **Average ḧ** = 4.125 sec.
- **Flow= 1/ḧ** = 1/ 4.125= 0.242 v/sec=873 v/h.

Tutorial Questions……..cont.

Q8. Data obtained from aerial photography showed six vehicles on a 0.187Km long section of road. Traffic data collected at the same time indicated an average time headway of 4 sec. What is the space mean speed?

A) 28.05km/hr

B) 18.5km/hr

C) 10.73 km/hr

D) 12.83 km/hr

Tutorial Questions……..cont.

Given:

h=4 sec/veh,L= 0.187km,n=6

Density (k):= n/L

= 6/0.187

= 32.08 veh/km

flow (q):= 1/h

= ¼ sec/veh

= 0.25 veh/sec

= 0.25*3600

= 900 veh/hr

Space Mean SpeedVs:= q/k

=900/32.08

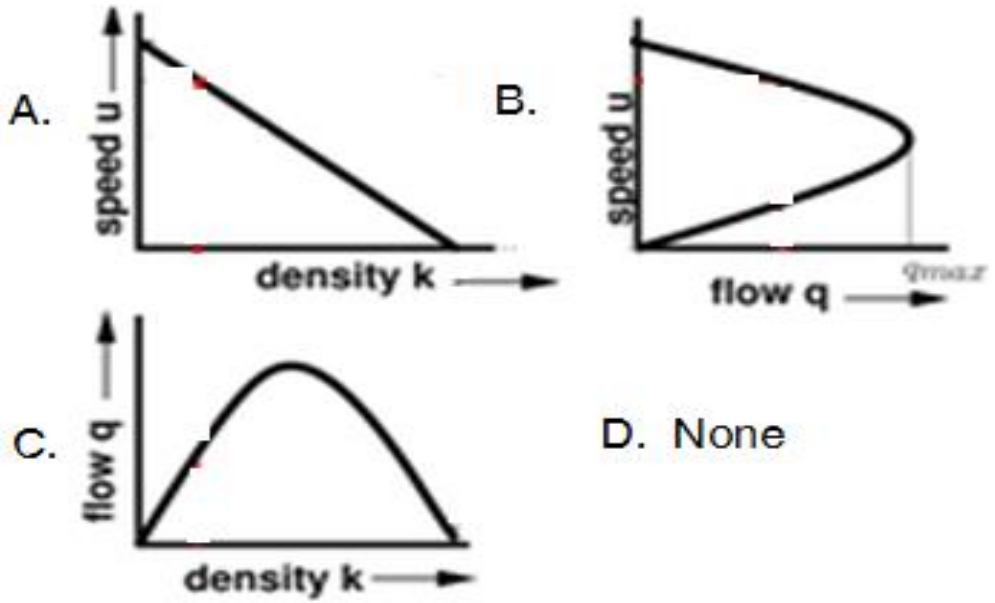
= 28.05km/hr

Answer Choice A

Tutorial Questions……..cont.

Q9. A study of freeway flow at a particular site has resulted in calibrated speed-density relationship as follow: $U = 57.5(1 - 0.008K)$

-Which one of the following graph is the correct flow-density relationship?



Tutorial Questions……..cont.

Free flow speed?

When the density (k) approaches to zero,the space mean speed of vehicle will become a free flow speed (u_f)

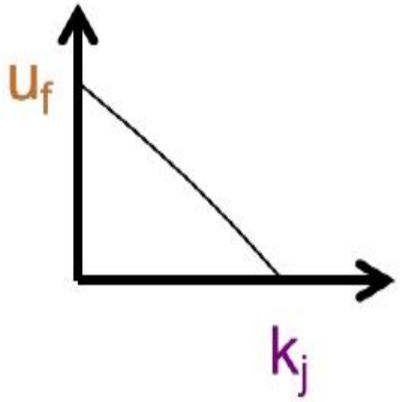
$$v_s = 57.5*(1-0.008\ k)$$

$$= 57.5*(1-0.008\ k)$$

substituting the value of k = 0,

$$u_f = 57.5*(1-0.008*0)$$

$$u_f = \mathbf{57.5\ km/hour}$$



Jam concentration (k_j)?

when the space mean speed $v_s = 0$,the density on the road will become jam

density k_j

$$v_s = 57.5*(1-0.008\ k)$$

$$0 = 57.5*(1-0.008\ k_j)$$

$$1 - 0.008k_j = 0$$

$$k_j = \mathbf{125\ veh/km}$$

Tutorial Questions……..cont.

Relationships *q*-*u*?

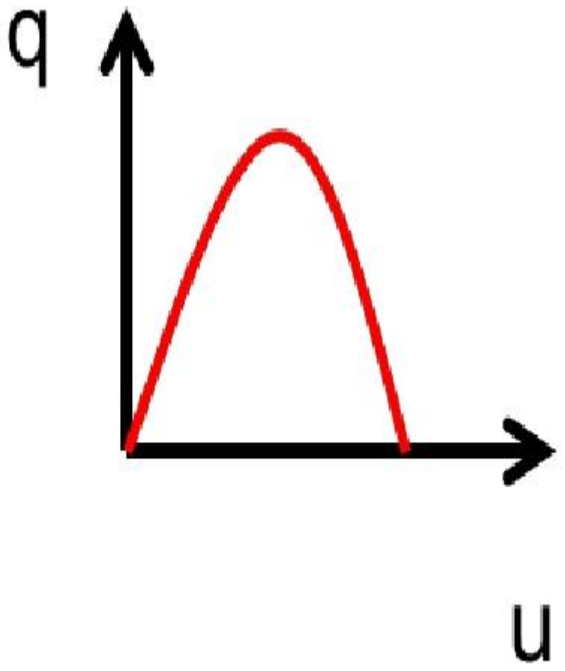
$q = v_s * k$

$v_s = 57.5*(1-0.008\ k)$

Rearranging the above equation and k is

$v_s/57.5 = 1-0.008k$

$1- v_s/57.5=0.008K$



$k = 125 - 0.46 v_s$, then

$q = v_s * k = v_s*(125 - 0.46v_s)$

$= 125\ v_s - 0.46\ v_s^2$

Tutorial Questions……..cont.

Relationships *q-k*?

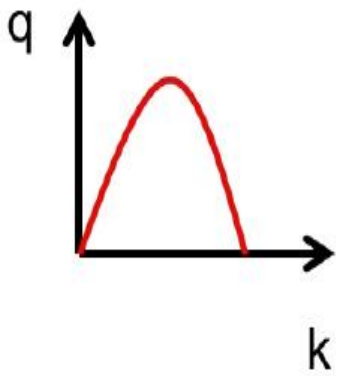
$q = v_s * k$, $v_s = q/k$

$v_s = 57.5*(1-0.008\ k)$,

then

$q/k = 57.5*(1-0.008k)$

$q = 57.5k - 0.46k^2$



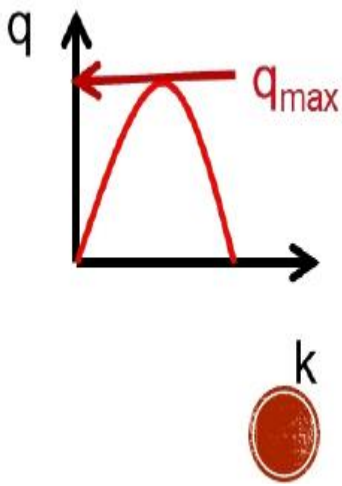
Q_{max} capacity?

$q = 57.5k - 0.46k^2$

$d(q)/d(k) = 0, \quad 57.5 - 0.92k = 0$

$k_m = 62.5$

$q_{max} = 1796$ veh/hour



Tutorial Questions……..cont.

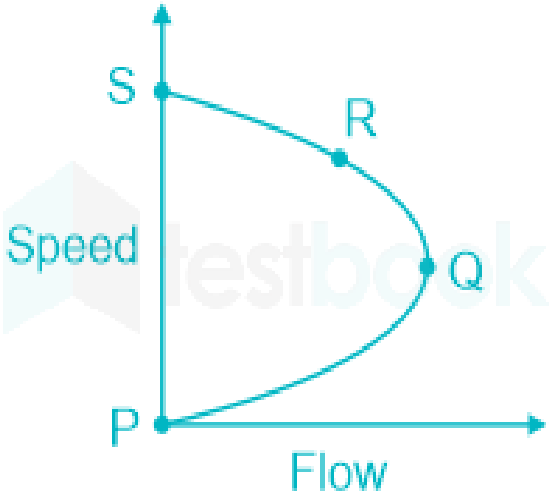
Q10. Consider the four points P, Q, R and S shown below in the Greenshields fundamental speed flow diagram. Denote their corresponding traffic densities by K_P, K_Q, K_R and K_S respectively. The correct order of these densities is

A. $k_P > k_Q > k_R > k_s$

B. $k_S > k_R > k_Q > k_P$

C. $k_Q > k_R > k_S > k_P$

D. $k_Q > k_R > k_P > k_S$



Tutorial Questions…….cont.

- At point S, speed is non zero but flow is zero, so density will be zero to get zero flow. So K_s will be minimum.
- At point P, speed is zero which means it is the jam condition so the density will be maximum.SO Kp will be maximum.
- So from point S to point P the density will increase gradually.
- So the correct order of density will be $k_P > k_Q > k_R > k_s$.

QUESTIONS?