TRAFFIC ENGINEERING

SAB3843

FUNDAMENTAL THEORY OF TRAFFIC FLOW

CHE ROS BIN ISMAIL

and

OTHMAN BIN CHE PUAN

Chapter Outline:

1. Introduction
2. Basic Concepts
   a. Volume (q)
   b. Speed (V)
   c. Density (D)
3. Relationships between QVD
4. Level of Service

Introduction

Road traffic system consists of road users (drivers and pedestrians), vehicles, and road network that interact between one and another.

It is important to study each of these elements for the planning, design, and analysis of an efficient, safe road traffic system.

1) Road Users

- Consist of drivers, passengers, motorcyclists, cyclists, pillions, and pedestrians.

- Characteristics and behaviour of a driver are influenced by three factors:
  1. Physical
  2. Environment
  3. Psychology

Physical Factors

Two main factors considered are:

1. Perception–Reaction Time
2. Vision

Perception–Reaction Time of a driver

It is a combination of four consecutive tasks:

1. *Perception*
2. *Identification*
3. *Emotion*
4. *Volition*

Perception-Reaction time of a driver varies and is influenced by factors such as:

Age, fatigue, disability, experience, complexity of a situation, drivers physical characteristics, alcohol or drugs, etc.

Average time: 0.5 – 3.0 seconds

Example: approaching STOP sign

Vision

The most important physical factors for road users:

1. *Visual acuity – static and dynamic (cone of vision)*
2. *Depth perception – estimate distance and speed*
3. *Peripheral vision - field of view beyond cone of vision*
4. *Glare and recovery - time needed to adjust to light*
5. *Visual deterioration – age, disease*

Environmental Factors

These include:

1. Weather & lighting – rain, dark, glare
2. Traffic volumes – emotion, aggressiveness
3. Road geometry – curve, gradient, lane width, access, condition

Psychological Factors

- Motive of the journey – business, social, recreation
- Emotion – attentiveness, impatience, traffic event, companions etc

2) Vehicles

- Characteristics of vehicles on roads vary in terms of shape, dimension, performance, etc. (turning radius, acceleration, braking, height)

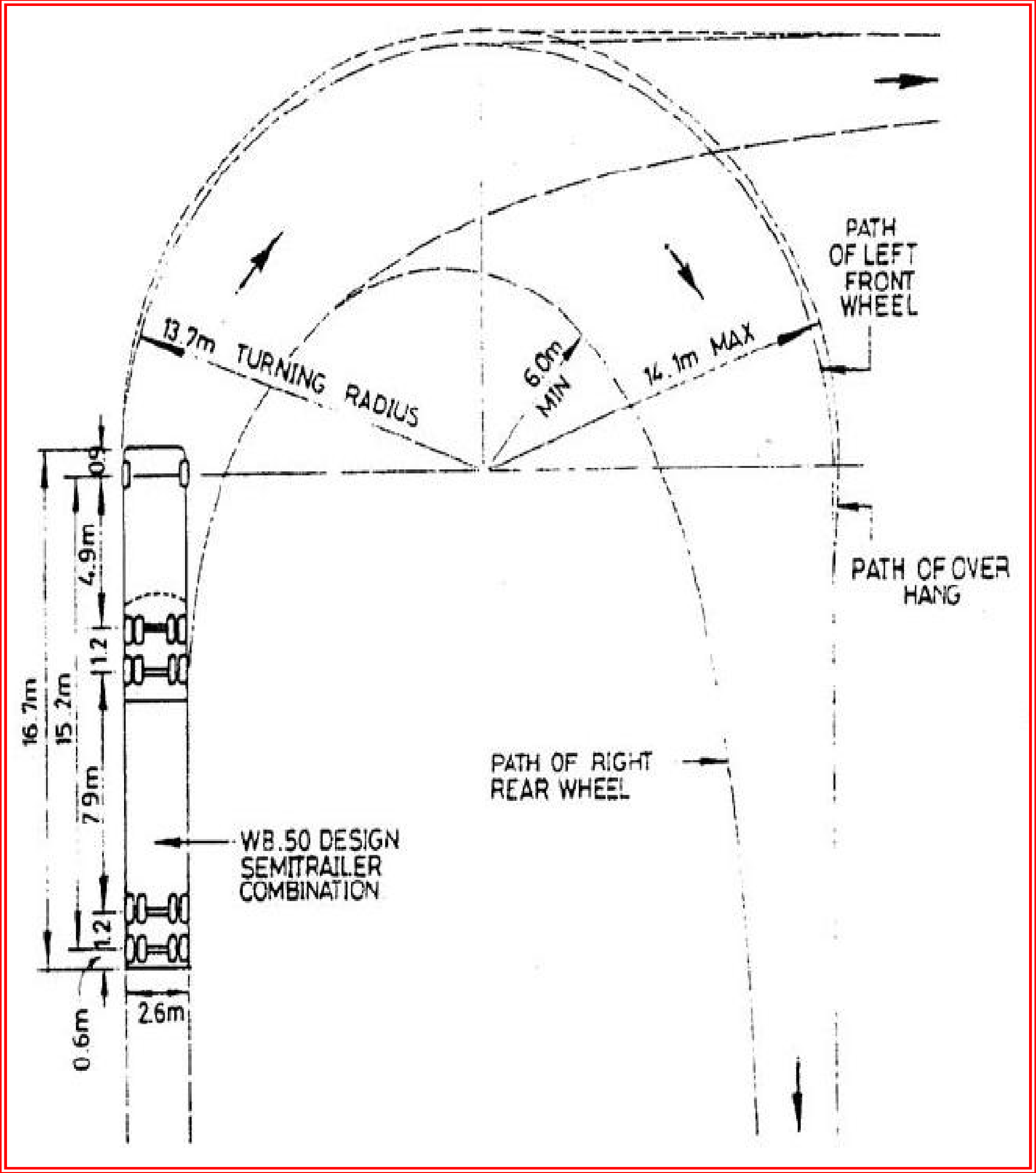
- Road must be designed to cater almost all types of vehicles.

Design Vehicle - Dimensions

Design Vehicle		Dimension in metre						Turning Radius (m)
Type	Symbol	Wheel Base	Overall		Overall Lenght	Overall Width	Height	
			Front	Rear				
Passenger Car	P	3.4	0.9	1.5	5.8	2.1	1.3	7.3
Single Unit Truck	SU	6.1	1.2	1.8	9.1	2.6	4.1	12.8
Truck Combination	WB-50	7.9	0.9	0.6	16.7	2.6	4.1	13.7

REAM-GL 2/2002

Design Vehicle – Turning radius



REAM-GL 2/2002

3) Road Network

- Varies in terms of standards and geometry – Urban and Rural (i.e. expressway, highway, primary, arterial, collectors)

- Categorised into 5 for administrative purposes:
    1. Toll highway
    2. Federal highway
    3. State road
    4. Municipal/local council road
    5. Other small road

Type of Facilities

- Uninterrupted flow
  - – Freeways
  - – Multilane highways
  - – Two-lane highways

- Interrupted flow
  - Signalized streets
  - Un-signalized streets with stop signs
  - Transit lanes
  - Pedestrian walkways

Basic Concept

Traffic parameters divided into 2: macroscopic (overall), and microscopic (individual)

Common macroscopic traffic parameters that are of traffic engineers / planners interest include:

- Traffic Flow or Volume
- Speed
- Density or Concentration
- Headway

Volume

Traffic Flow or Volume (q)

- The number of vehicles (n) passing some designated roadway point in a given time interval (t)

$$\boxed{q = \frac{n}{t}}$$

- The count can be directional or all directions
- Units are typically vehicles/hour

Veh/day, veh/year

Traffic flow data is usually collected to obtain factual data concerning the movement of vehicles at selected points on the street., example:

(a) Annual Traffic

- (i) To compute crash rates
- (ii) To indicate trends in volume

(b) Average Daily Traffic (ADT) &
Annual Average Daily Traffic (AADT)

(i) To measure present demand
(ii) To programme capital improvements

(c) Hourly Traffic

(i) To determine peak periods
(ii) To evaluate capacity deficiencies
(iii) To establish traffic controls
(iv) To determine geometric design parameters

Volume – Traffic Compositions

Vehicular traffic consists of various types of vehicle – i.e. various sizes, performances, and characteristics.

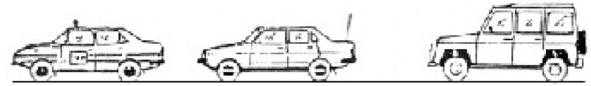
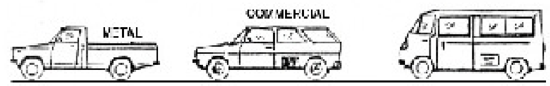
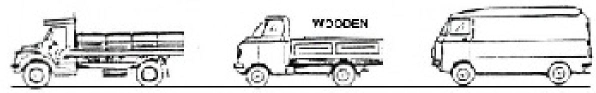
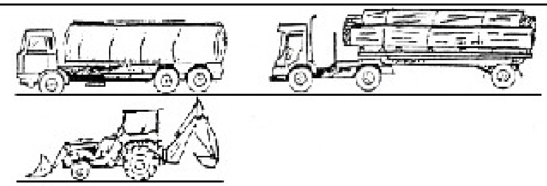
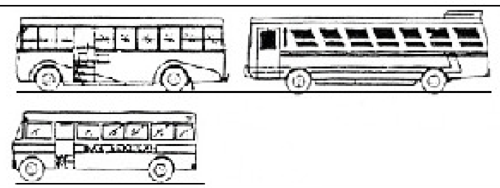
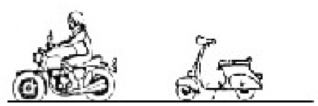
All vehicles are converted into their Equivalent Passenger Car unit (PCU or UKP) for consistency in interpreting road traffic performance, congestion, road geometry and traffic signal analysis and design.

Traffic is expressed in passenger cars per lane per hour (pc/ln/hr or pcplph)

Typical PCU values for Roadways

Types of vehicle	*Rural road*	*Urban road*
Cars	1.0	1.0
Utilities & small vans	2.0	2.0
Medium lorries & large vans	2.5	2.5
Large lorries & heavy vehs	3.0	3.0
Buses	3.0	3.0
Motorcycles	1.0	0.75

VEHICLE CLASSIFICATION

1	Motor Cars & Taxis	
2	Small Vans & Utilities (Light 2-axles)	
3	Lorries & Large Vans (Heavy 2-axles)	
4	Lorries with 3-axles (Heavy 3-axles and above)	
5	Buses	
6	Motorcycles & Scooters	

RTVM 2010

Volume – Data Collection Methods

1. Manual – simple, accurate, comprehensive
   - Tally counter, form, stationary, tiring, manpower, classification
2. Automatic – pneumatic tube, radar, infrared, video, inductive loop, magnetic, radio frequency, microwave, acoustic, GPS
   - Connect to data logger, computer, classify based on length
3. For road with many access point/junction – moving observer method, plate matching (able to study speed, delay)

Appendix "A"

Borang JKR P.10(Pin.1/98)

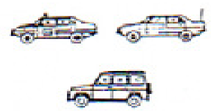
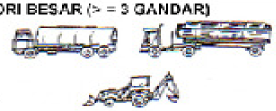
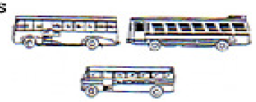
BANCI LALULINTAS KEBANGSAAN
BORANG KIRAAN KENDERAAN

BAHAGIAN PERANCANG JALAN
KEMENTERIAN KERJA RAYA

PENGHITUNG ______ DAERAH ______ NEGERI ______

JAM BERMULA DARI ______ TARIKH ______ HARI ______ CUACA ______

NOMBOR STESEN ______ ARAH DARI ______ KE ______

	5	10	15	20	25	30	35	40	45	50	55	
KERETA & TEKSI  1												
VAN KECIL & UTILITI  2												
LORI SEDANG & VAN BESAR  3												
LORI BESAR (> = 3 GANDAR)  4												
BAS  5												
MOTORSIKAL  6												

RTVM 2010

Example application of PCU values:

- Traffic volumes on a section of rural road during morning peak hour is 500 veh/h and during the evening peak hour is also 500 veh/h.

  Can you comment on the traffic flow conditions for both situations? (e.g. which peak hour traffic would you think is the busiest or congested condition compare to the other?)

Answer:

It would be difficult for us to say which peak hour is representing the congested situation as both traffic volumes are equal in terms of veh/h.

Now,
If information of traffic compositions for both peak-hours are available as follows:

For AM Peak: 50% cars, 20% medium lorries, 10% buses, and 20% m/cycles.
For PM Peak: 30% cars, 25% medium lorries, 15% heavy lorries, 15% buses, 15% m/cycles.

Can you describe the differences between the two peak hour traffic in terms of traffic flow conditions?

Answer:

Let us express the peak hour traffic in terms of pcu/h, i.e.

AM Peak: (0.5x1 + 0.2x2.5 + 0.1x3.0 + 0.2x1) x 500 = 1.5 x 500 = 750 pcu/h

PM Peak: (0.3x1 + 0.25x2.5 + 0.15x3.0 + 0.15x3.0 + 0.15x1) x 500 = 1.975x500 = 988 pcu/h

This shows that the evening peak hour traffic is busiest compare to the morning traffic.

Volume Study

Example 2

Evaluate the following traffic data obtained for 7 consecutive days on a stretch of road section.

Day	Traffic volume (veh/day)
Monday	3231
Tuesday	3011
Wednesday	3137
Thursday	3247
Friday	3065
Saturday	3240
Sunday	1530

Solution 2

Compute the average traffic volume per day:

Day	Traffic volume (veh/day)
Monday	3231
Tuesday	3011
Wednesday	3137
Thursday	3247
Friday	3065
Saturday	3240
Sunday	1530

Average = total traffic/7	= 20461/7 = **2923 veh/day**

By definition, the average volume of 2923 veh/day can be reported as the PLH or Purata Lalu Lintas Harian for the road.

But, certain traffic analyst may remove the data taken on Sunday because we have 6 data points with more than 3000 & only 1 data is much lesser. PLH is not representative.

The reported PLH would be

= 18931/6 = 3155 veh/day

Speed

Speed (u)

Speed is defined as the distance travelled per unit time.

Speed is usually used to describe the quality of journey and the performance of road network in accommodating traffic demand.

Depends on – driver characteristics, vehicle, traffic composition, time, area type, surrounding environment

Types of speed:

1. spot speed;
2. journey speed;
3. running speed;
4. time mean speed; and
5. space mean speed.

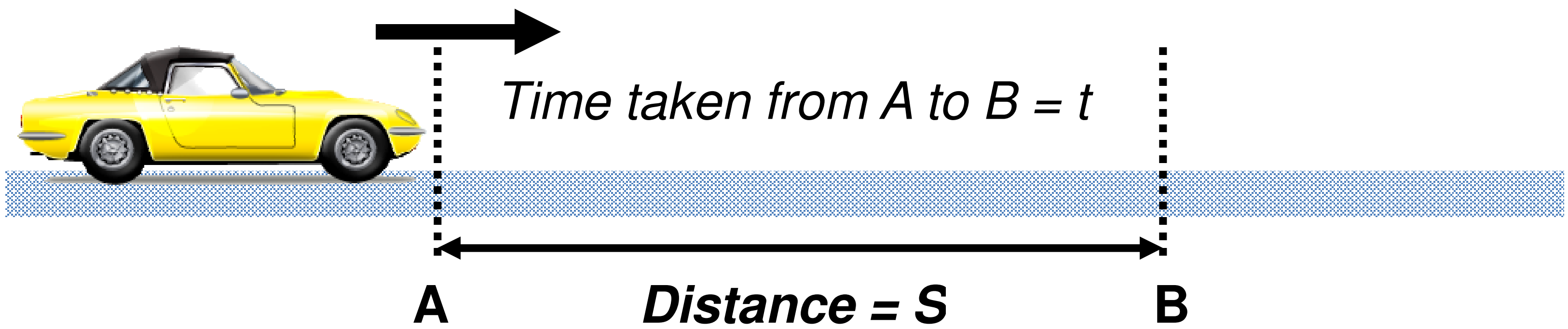
Speed – spot speed

Spot speed - the instantaneous speed of a vehicle passing a point on the roadway. Data represent the speed characteristics of vehicles passing the site.

Typical use:

1. To establish speed trends
2. Traffic control planning - speed limits, safe speeds at curves, location for traffic signs, lengths of no–passing zones, intersection sight distance
3. Before–and–after studies
4. Accident analysis
5. Geometric design – i.e. road alignments and stopping sight distance

Definition of spot speed



Speed = Distance/Time

If S ≤ 100 meters, then the speed measured is known as Spot Speed.

Spot speed measurement

1. Enoscope
2. Pneumatic tubes
3. Video recording
4. Radar gun/camera

Statistics

Analysis – frequency table, histogram, cumulative frequency curve, mean, standard deviation

Speed – journey and running speed

Journey speed is the distance divided by total journey time. Total journey time includes all delays due to traffic.

Journey speed = distance/total journey time

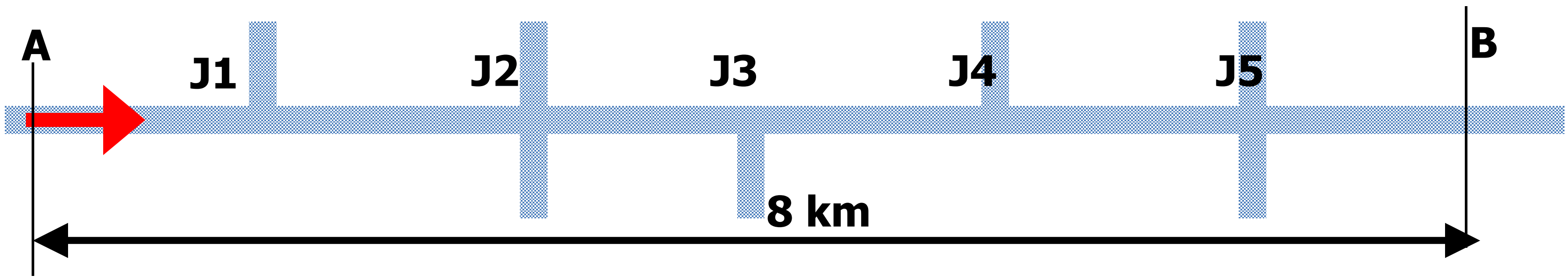
Running speed is the distance divided by running time, i.e. total journey time minus delays. (Running time is the time that the vehicle is actually in motion.)

Running speed = distance/(total journey time – delays)

Both speeds are usually as a result of travel time and delay study – used to evaluate road performance.

Example:

Evaluate journey & running speeds for the following situation & interpret the result:



Average Total travel time including delay due to traffic = 32 minutes

Average Delays at each junction: J1 = 5 min, J2 = 5 min, J3 = 3 min, J4 = 4 min, and J5 = 6 min.

Answer:

Average Journey Speed = 8km x (1 h x 60 min) /32 min = **15 km/h.**

Average Running Speed = 8km x (1 h x 60 min)/(32 – 23)min = **53.3 km/h**.

Interpretation:

Since Journey speed <<< running speed → drivers experience heavy traffic flow & inefficient traffic control system at junctions. System requires improvements.

Speed – TMS and SMS

- Time mean speed
  - Arithmetic mean of all instantaneous vehicle speeds at a given point on a roadway section
- Space mean speed (u)
  - The mean travel speed of vehicles traversing a roadway segment of a known distance (d)
  - More useful for traffic applications. It is a harmonic mean

Space mean speed is always less than time mean speed

Speed Study

Density

Density (D)

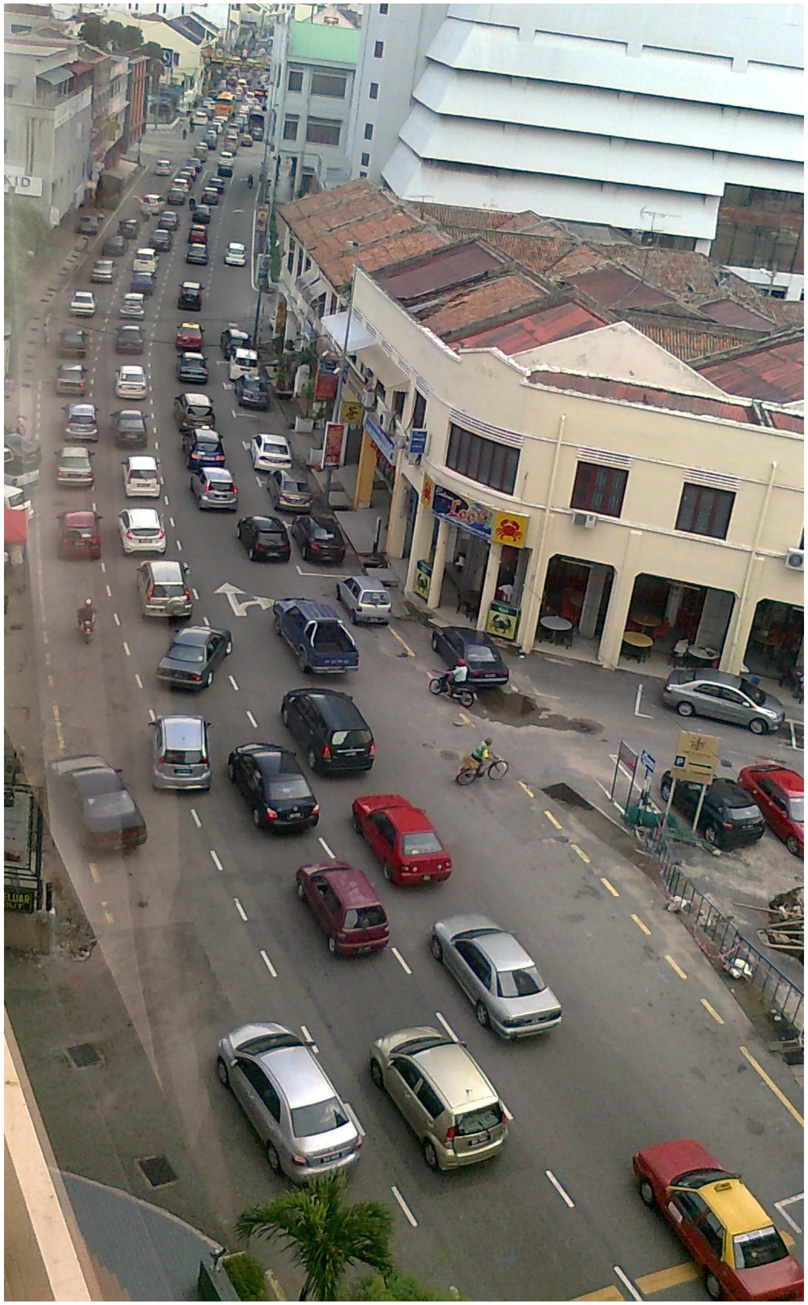
- Density (D) or concentration (k) is the number of vehicles (n) occupying a given length (l) of a lane or roadway at a particular instant

- A common parameter used to describe road performance

- Unit of density is vehicles per km (v/km).

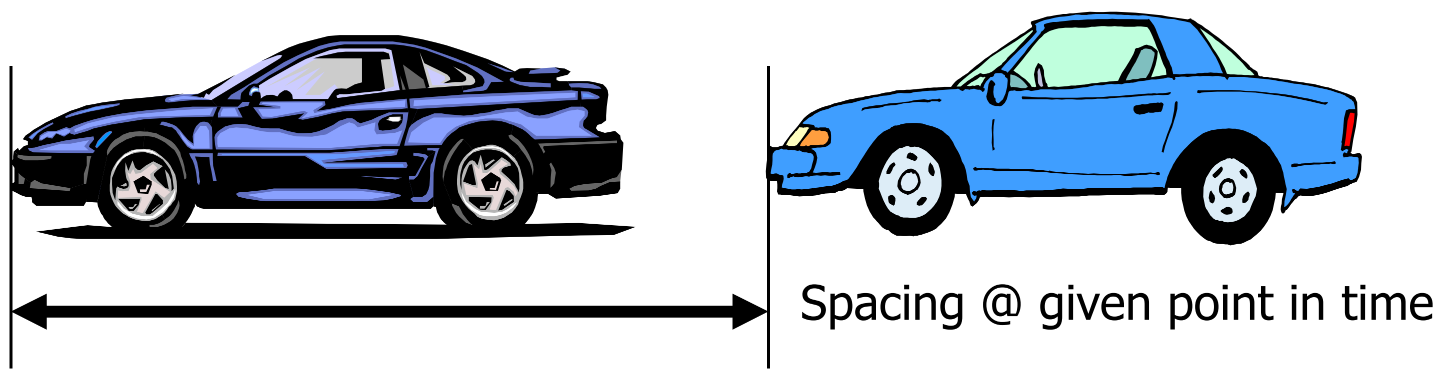
$$\boxed{k = \frac{n}{l} = \frac{q}{u}}$$

Density:
Vehicle/ length of road



Spacing (or space headway)

- The distance (m) between successive vehicles in a traffic stream, as measured from front bumper to front bumper

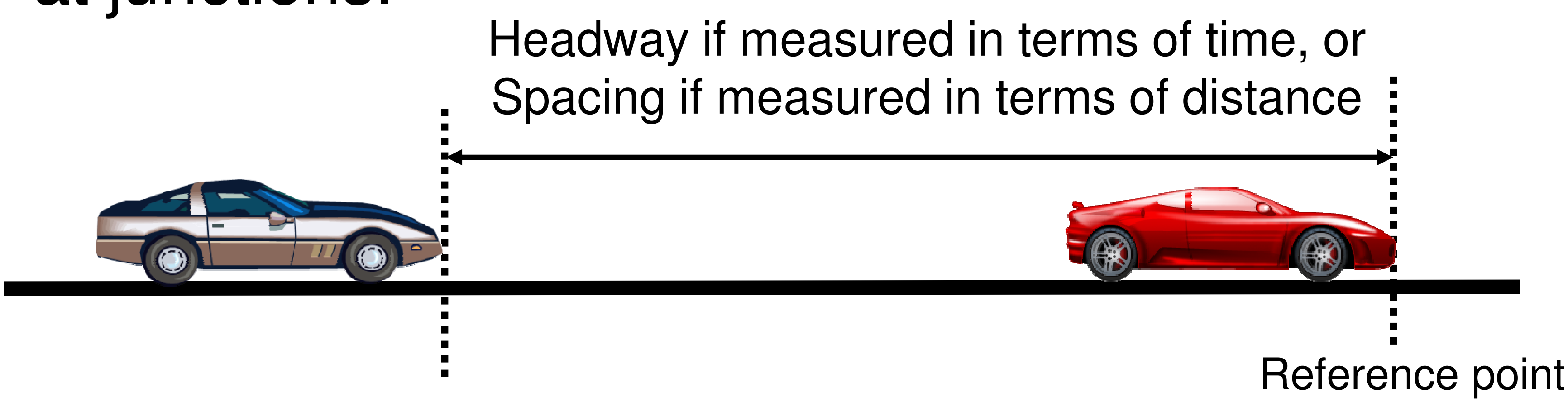


Headway (h)

- The time (in seconds) between successive vehicles, as their front bumpers pass a given point.

Headway and spacing are microscopic measures of flow as they apply to pairs of vehicles in the traffic stream.

These parameters are important in determining the number of gaps in a traffic stream for vehicles or pedestrians to cross and for measuring operations at junctions.



Basic Traffic Stream Parameters:

Parameter	Symbol	Typical units	Reciprocal	Symbol	Typical Units
Flow	***q***	**vph**	**Headway**	***h***	**sec/veh**
Speed	***u***	**km/h**	**Travel time**	***T***	**sec/km**
Density	***k***	**veh/km**	**Spacing**	***s***	**m/veh**

From HCM 2000

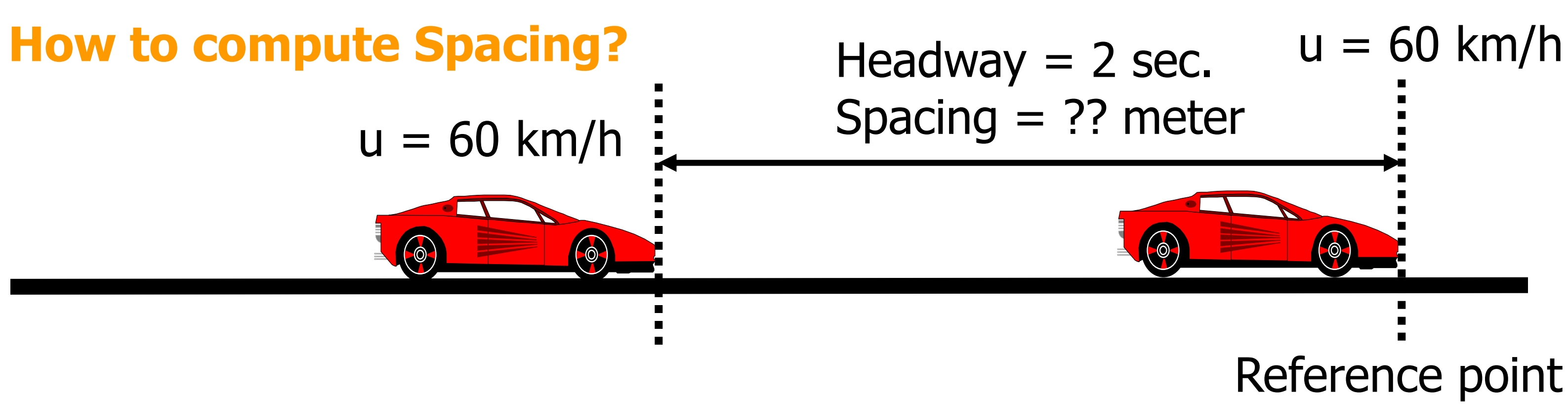
Example:

1. What is the average headway of vehicles if the traffic volume in a lane is 1800 veh/h assuming there is no m/cycle in the system? What is the average inter-vehicle spacing if the average vehicle’s speed is 60 km/h?

Answer:

h = 1/q = 1 x 3600 sec/1800 = <u>2 sec</u>.

How to compute Spacing?



Speed, flow & density relationship

Flow = Speed *x* Density

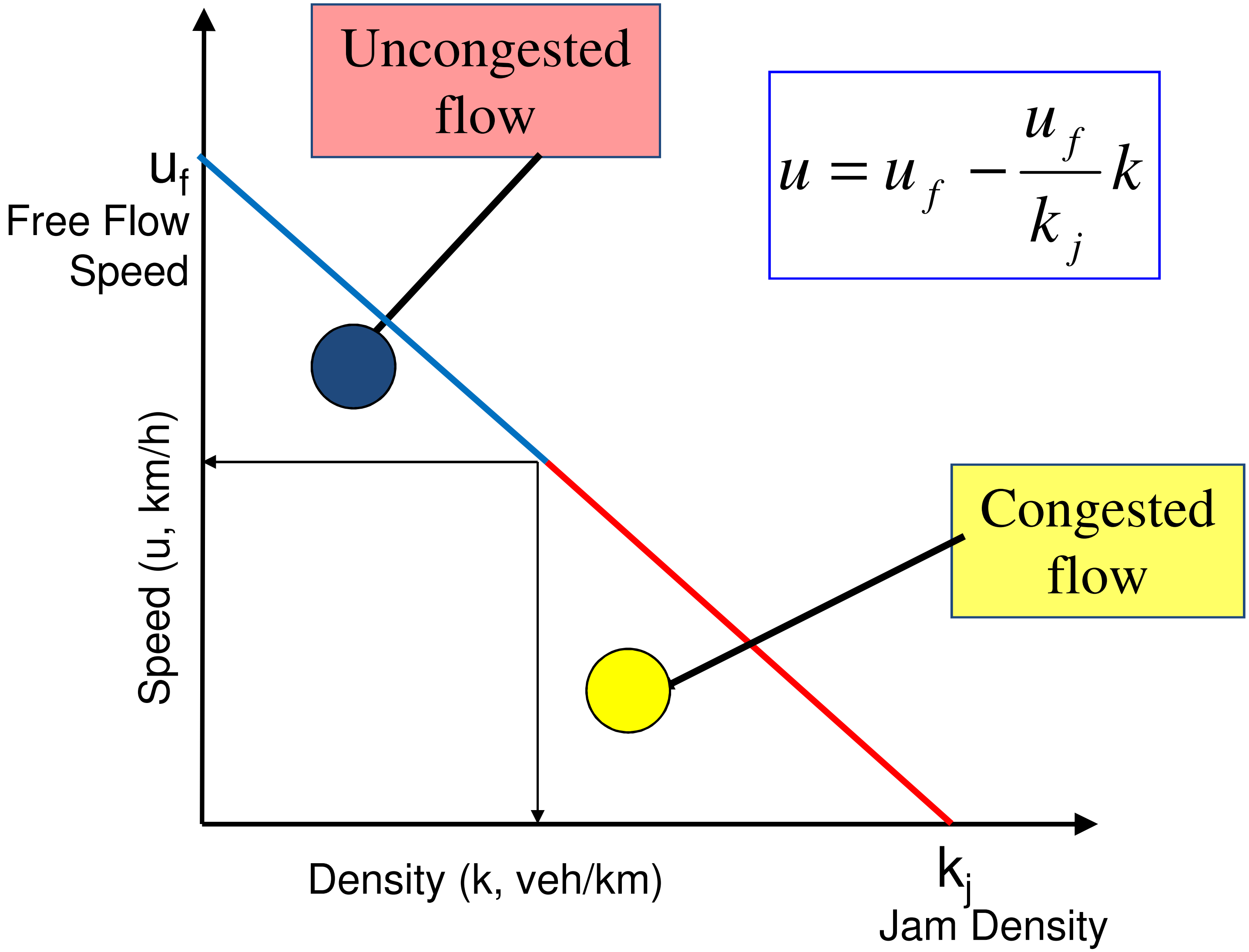
$$q = uk$$

- Free-flow speed (u_f), critical speed ($u_c = u_f/2$)
- Jam density (k_j), critical density ($k_c = k_j/2$)
- Capacity (q_m)

$$q_m = u_c k_c$$

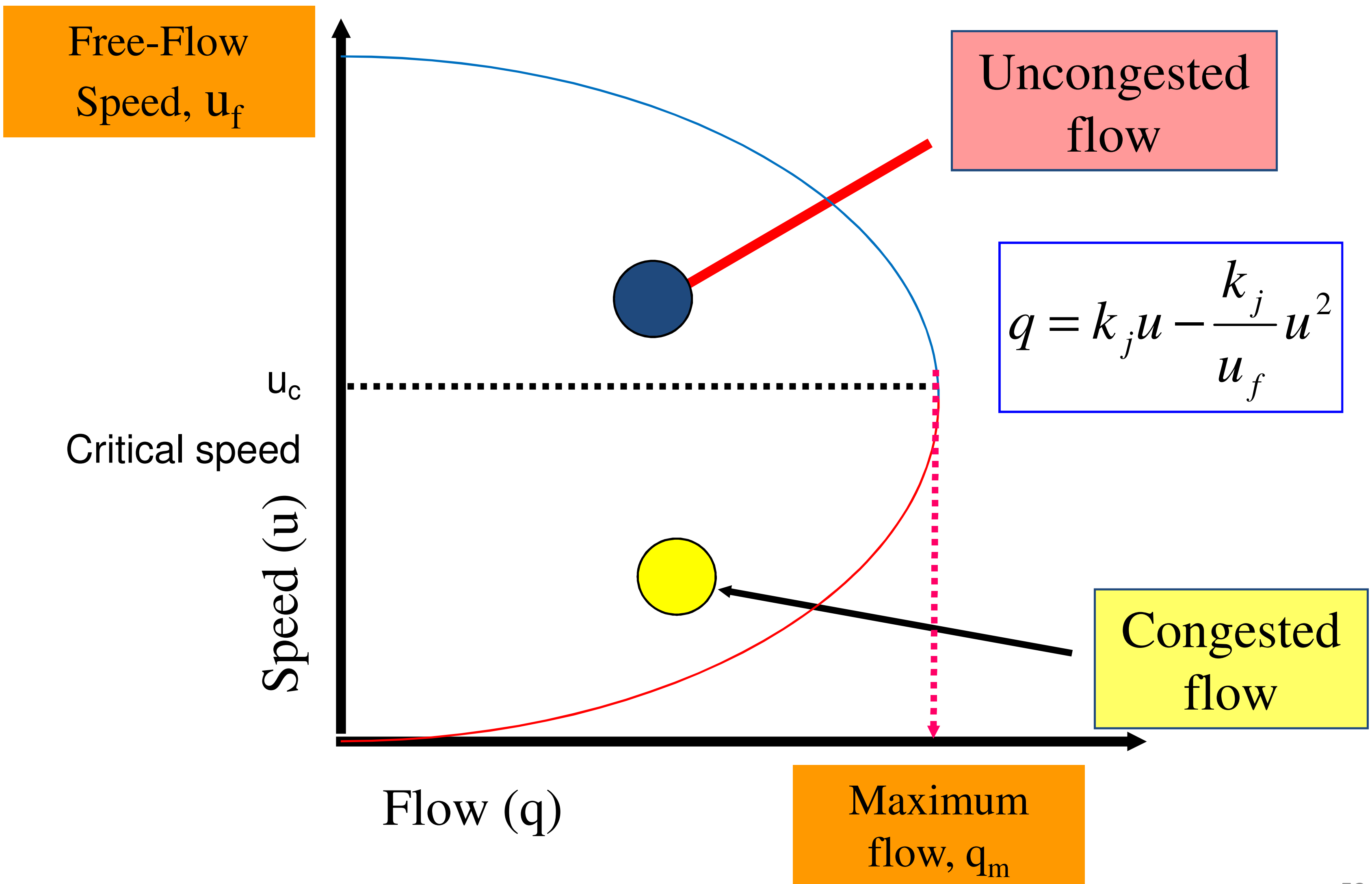
$$= u_f k_j / 4$$

1. Speed-Density Relationship

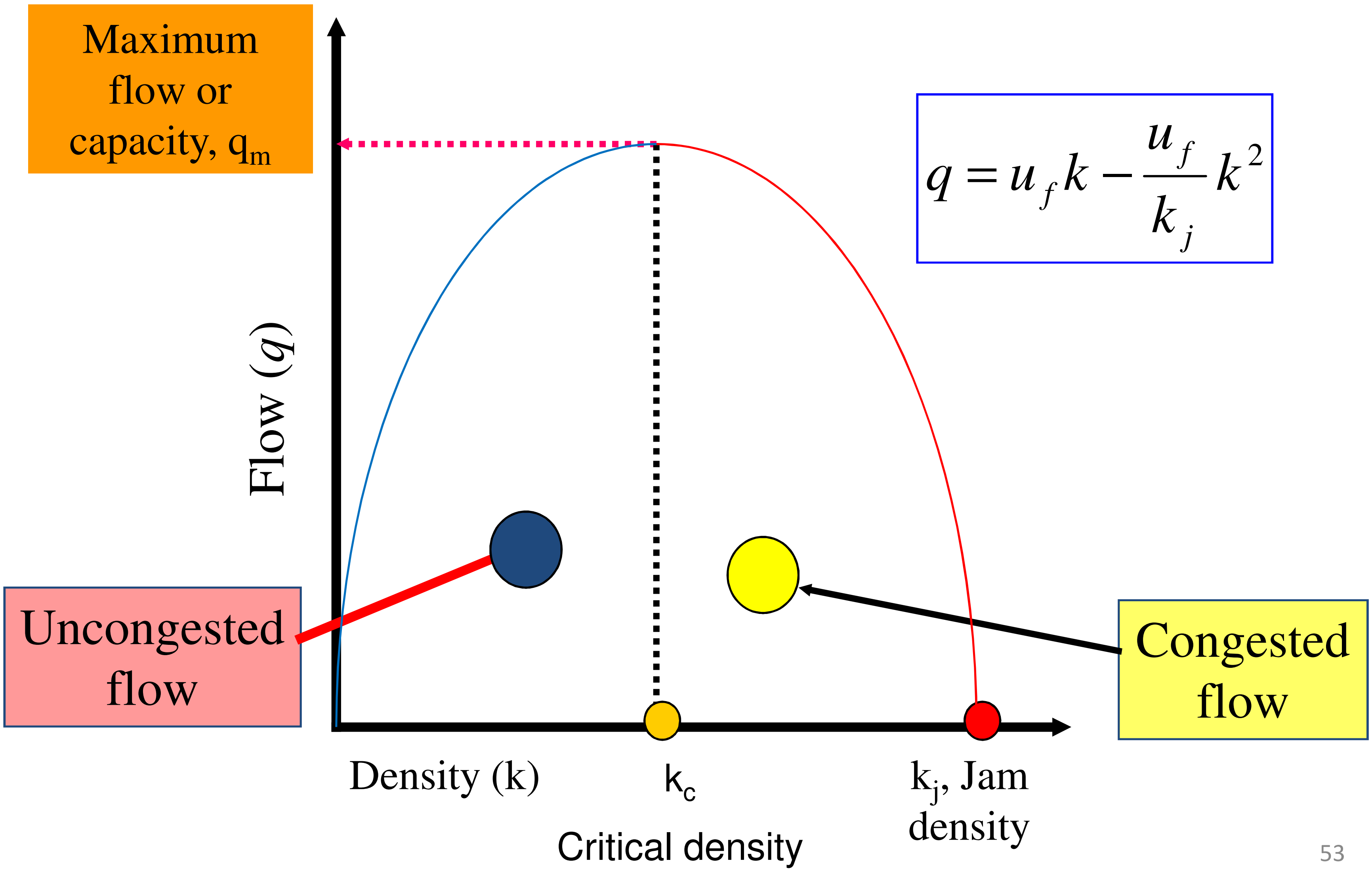


$$u = u_f - \frac{u_f}{k_j} k$$

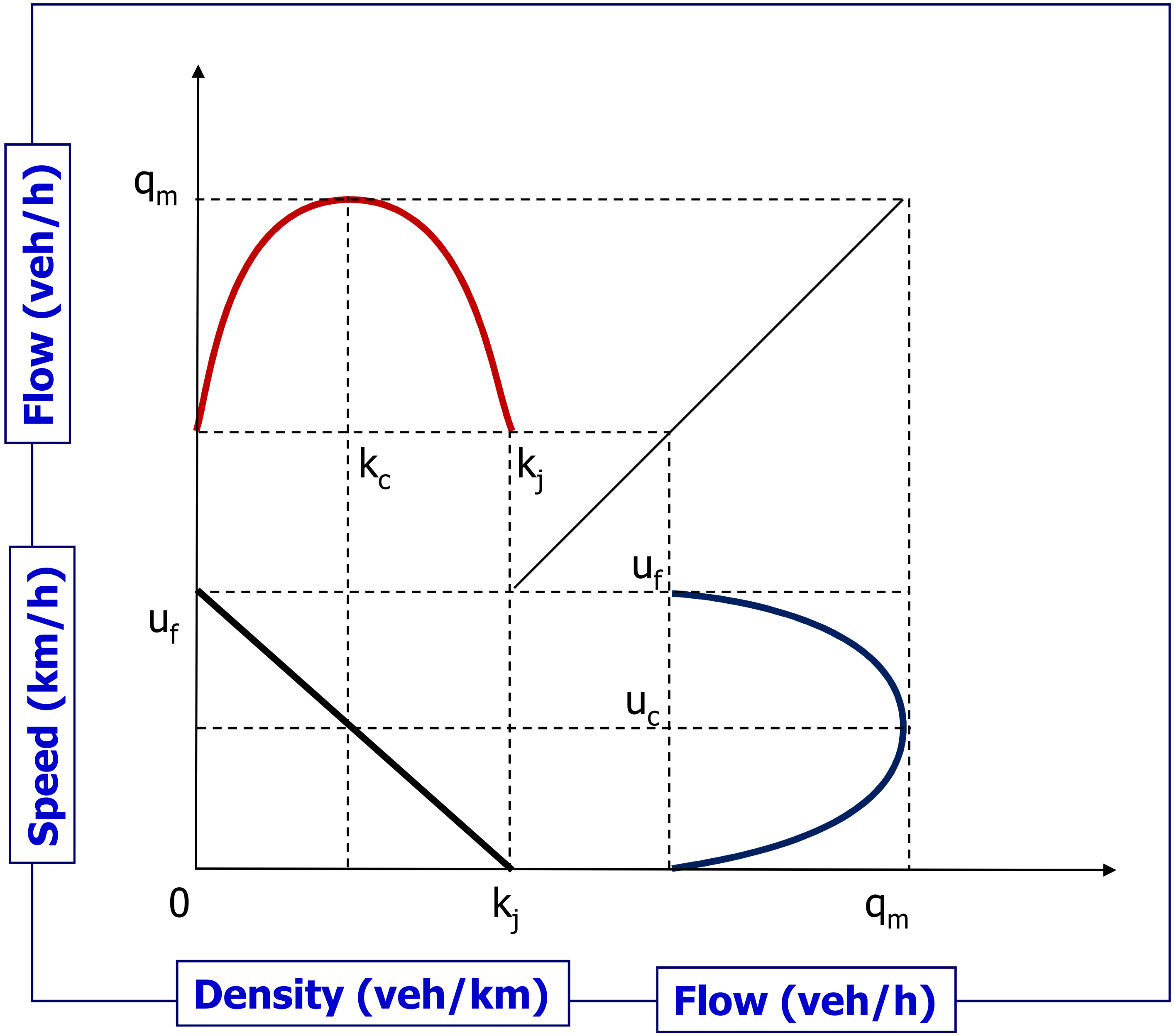
2. Speed-Flow Relationship



3. Flow-Density Relationship



$$q = u_f k - \frac{u_f}{k_j} k^2$$

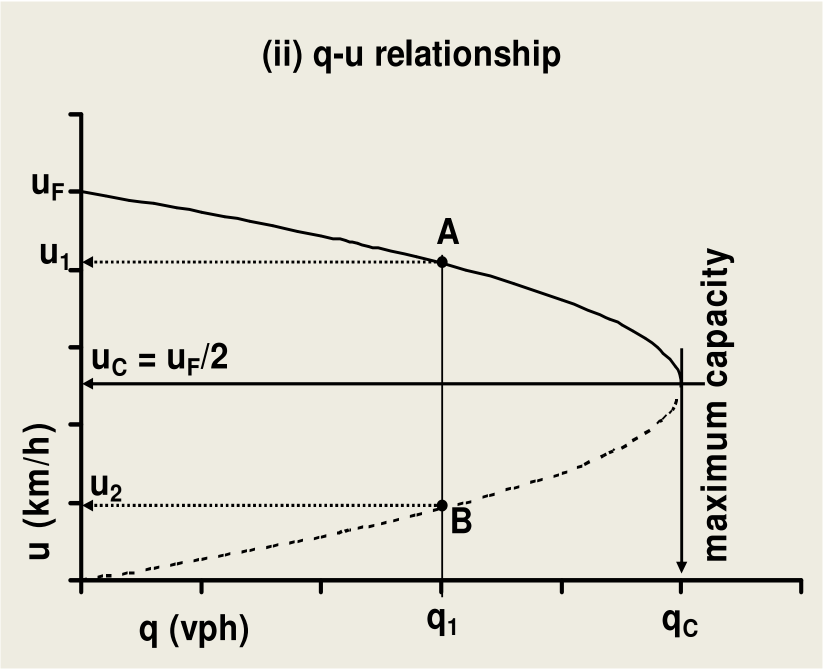

Flow (veh/h)
Speed (km/h)
Density (veh/km)
Flow (veh/h)
q_m
k_c
k_j
u_f
u_c
0
k_j
q_m

Example:

Traffic volume during a stable free-flowing condition is 600 veh/h with an average speed of 75 km/h. Estimate the average speed of traffic under congested situation for the same volume of traffic if speed & density are linearly related. The maximum free-flow speed for the road section is 90 km/h.

Solution:

First, sketch the parabolic curve for q–u relationship.



q_1 = 600 veh/h; u_f = 90 km/h

Point A represent the stable flow region with the corresponding speed u_1 = 75 km/h.

Point B represent congested flow for q_1 = 600 veh/h.

$\therefore$ u_2 = 90-75 = **15 km/h**

Example

Vehicles in a traffic stream moved at an average headway of 2.2 sec. The average speed is 80 km/h. Estimate the flow rate & density of that traffic stream.

Solution:

Using $q = uk = 1/h$, then

$q = 1/h = 1/(2.2/3600) = \underline{1636 \text{ veh/h}}$.

Using $q = uk$, then $k = q/u$

$\therefore$ density of the flow, $k = 1636/80 = \underline{20.45 \text{ veh/km}}$

Example 1.8

Free-flow speed of vehicles on a road section is 88 km/h. Jammed density is 228 veh/km. Estimate the traffic density on the road if traffic flow is at a maximum level. Estimate also the possible maximum flow for the road section and the average speed of vehicles at that maximum traffic volume.

Solution:

Density when traffic flow reaches the maximum volume,

$k_c = k_j/2 = 228/2 =$ **114 veh/km**.

Expected maximum flow, $q_c = u_f k_j/4 = (88 \times 228)/4$

$=$ **5016 veh/h**

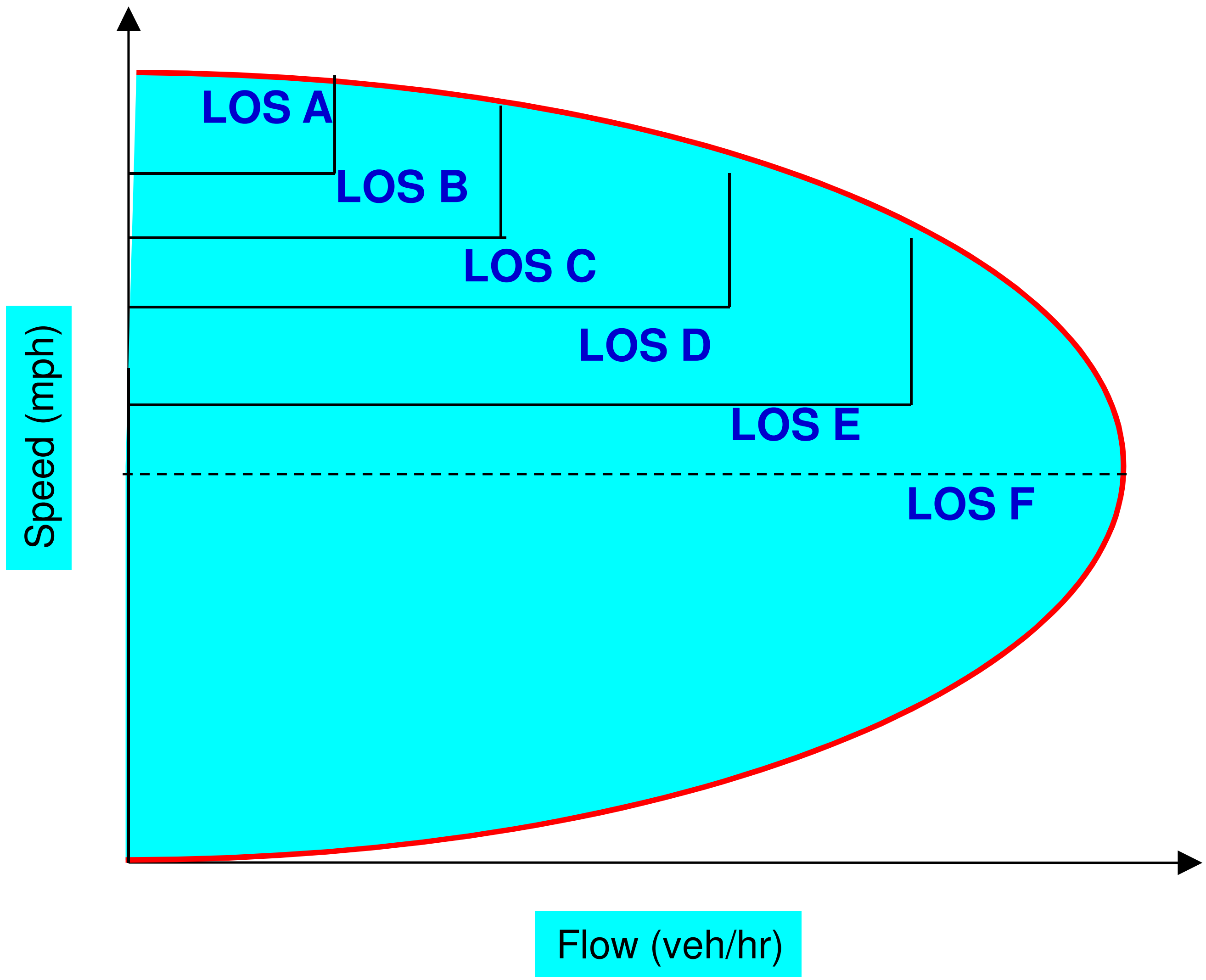
Average speed at q_c, $u_c = u_f/2 = 88/2 =$ **44 km/h**

Level of Service

Definitions – Level of Service (LOS)

- measure the quality of service of the facilities
  - Describes operational conditions within a traffic stream (level of congestion).
  - Does not reflect safety but speed, travel time, and freedom to maneuver.
  - Different measures used for different facilities (e.g. speed and density for expressway, delay for signalized intersection, walking speed for pedestrian)
- Six levels (A through F)

LOS Diagram



Levels of Service

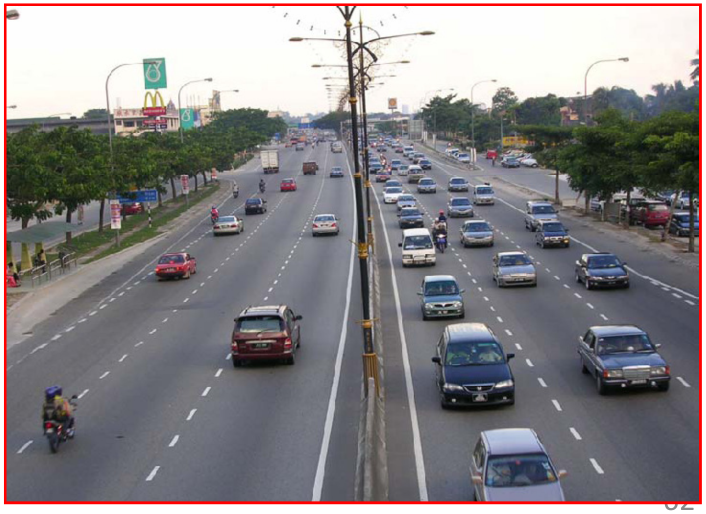
- LOS A
- Free Flow with low volumes, densities and high speeds.
- Drivers can maintain their desired speeds with little or no delay.
- v/c = 0.15

- LOS B
- Stable Flow.
- Operating speeds beginning to be restricted somewhat by traffic conditions.
- Some slight delay.
- v/c = 0.27

Levels of Service

- LOS C
- Stable Flow.
- Speeds and maneuverability are more closely controlled by higher volumes.
- Acceptable delay.
- v/c = 0.43

- LOS D
- Approaching Unstable Flow.
- Tolerable operating speeds which are considerably affected by operating conditions.
- Tolerable delay.
- v/c = 0.64



Levels of Service

- LOS E
- Unstable Flow.
- Yet lower operating speeds and perhaps stoppages of momentary duration.
- Volumes are at or near capacity congestion and intolerable delay.
- v/c = 1.0

- LOS F
- Forced Flow.
- Speeds and volume can drop to zero. Stoppages can occur for long periods.
- Queues of vehicles backing up from a restriction downstream.

REFERENCES

1. Othman Che Puan. Modul Kuliah Kejuruteraan Lalu Lintas. Published for Internal Circulation, 2004.
2. Dorina Astana, Othman Che Puan, Che Ros Ismail, TRAFFIC ENGINEERING NOTES, Published for Internal Circulation, 2011.
3. Garber, N.J., Hoel, L.A., TRAFFIC AND HIGHWAY ENGINEERING,4th Edition, SI Version., Cengage Learning, 2010.
4. Ministry of Works Malaysia, ROAD TRAFFIC VOLUME MALAYSIA 2010 (RTVM 2010), Highway Planning Unit, 2011.
5. Road Engineering Association of Malaysia, A GUIDE ON GEOMETRIC DESIGN OF ROADS, REAM-GL 2/2002, 2002.
6. Roess, R.P, Prassas, E.S. and McShane, W.R., TRAFFIC ENGINEERING, Pearson/Prentice Hall, 2004.
7. May, A.D., TRAFFIC FLOW FUNDAMENTALS, Prentice Hall, 1990
8. Transportation Research Board, HIGHWAY CAPACITY MANUAL, Washington D.C., 2000.