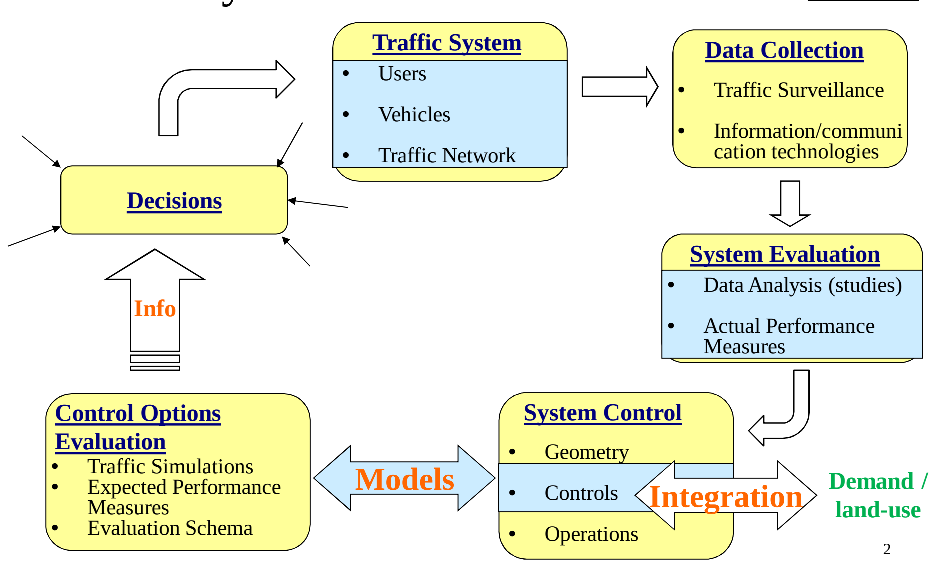
Traffic Engineering - Lecture 4: Shockwave Analysis

Hoda Talaat, PhD
Assistant Professor
Public Works Dept.
Faculty of Engineering
Cairo University

1

WHAT?
WHY?
HOW?

Course Syllabus



2

Shockwaves

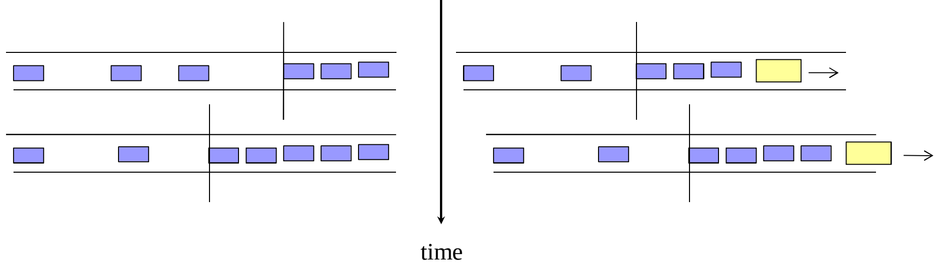
- What?
  - Backup or queuing as a results of a sudden decrease in roadway capacity (reduction in number of lanes, red traffic signal, accidents., slow moving truck …etc).

Hoda Talaat 3

Shockwaves…TYPES

1) Backward Propagating

2) Forward Propagating

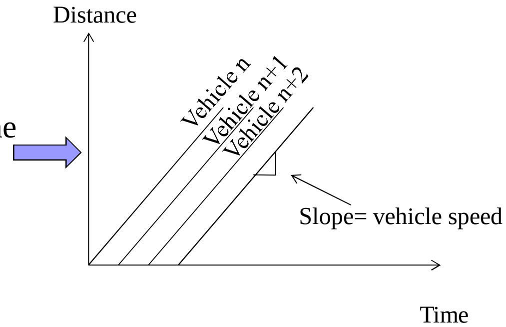


3) Stationary

Hoda Talaat 4

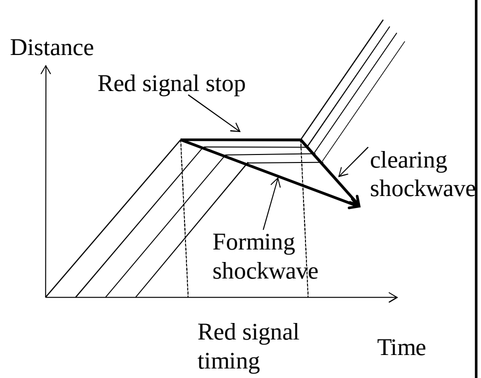
Space-Time Diagrams

- Assuming that all vehicles are travelling with a constant speed, the space-time diagram will look like this



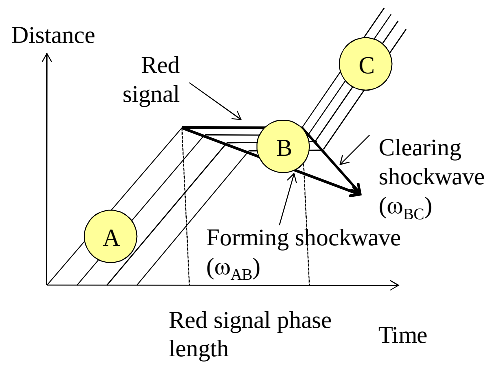
Space-time Diagram at signalized intersections

- Basic Concepts:
  - Space-time Slopes: represent speeds
  - Traffic State: an area with steady-state vehicle speeds (consistent space-time slopes)
  - Shockwave speed (ω): is the slope of the boundary between two traffic states



Shockwaves at signalized intersections

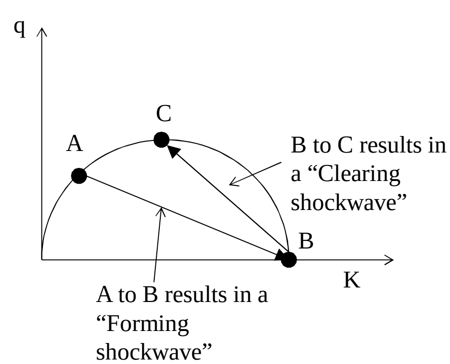
- Basic Concepts:
  - State A: Free-Flow State
  - State B: Vehicles Stopping State (red signal)
  - State C: Vehicles flow at full section capacity



Hoda Talaat 7

Shockwaves at signalized intersections

- Basic Concepts:
  - State A: Free-Flow State
  - State B: Vehicles Stopping State (red signal)
  - State C: Vehicles flow at full section capacity



Hoda Talaat 8

Shockwaves at signalized intersections

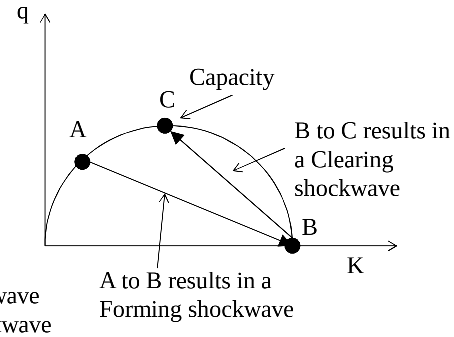
- Estimation of Shockwave Speed

$$\mu_{AB} = \frac{q_A - q_B}{k_A - k_B}$$

$$\mu_{BC} = \frac{q_B - q_C}{k_B - k_C}$$

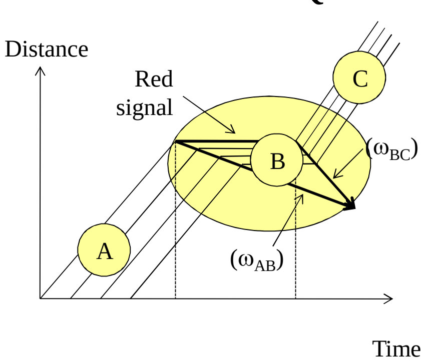
$$\Rightarrow \mu = \frac{\Delta q}{\Delta k}$$

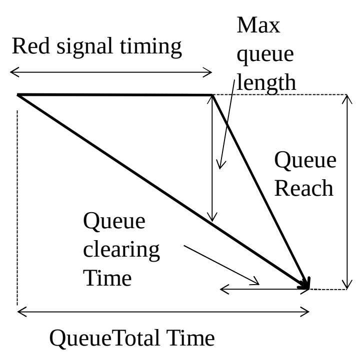
+ve value for forward propagating shockwave
-ve value for backward propagating shockwave



Shockwaves at signalized intersections

- Estimation of Queue Characteristics





Shockwaves at signalized intersections

- Example: Signalized intersection
  - Vehicles are flowing with a rate of 1000 veh/hr
  - Approached a red signal (with 60 sec red phase)
  - Estimate the speed of the forming/ clearing shockwaves.
  - Estimated the max queue length
  - Estimated the distance the queue will reach
  - Consider the model u=80-0.8k

Shockwaves at signalized intersections

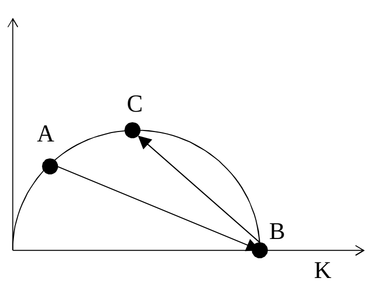
- Example: Signalized intersection
  - State A:

q_A= 1000 veh/hr

$$q_A = 1000 = 80k_A - 0.8k_A^2$$

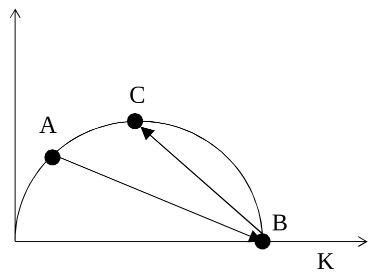
$$k_A = \frac{80 \pm \sqrt{(80)^2 - 4(0.8)(1000)}}{2(0.8)}$$

$$k_A = 85.35 \; or \; 14.64 \; veh/km$$



Shockwaves at signalized intersections

- Example: Signalized intersection
  - State B:
    - $q_B = 0$
    - $k_B = k_j = 80/0.8 = 100$veh/km
  - State C:
    - $q_C = q_{max} = 80*100/4 = 2000$ veh/hr
    - $k_C = k_j/2 = 100/2 = 50$veh/km



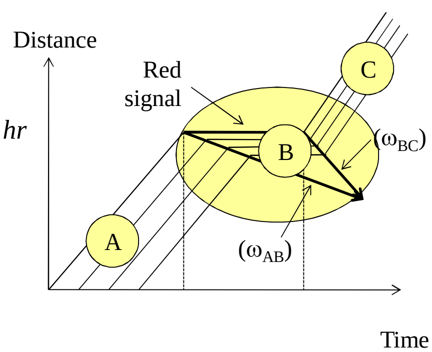
Hoda Talaat 13

Shockwaves at signalized intersections

- Example: Signalized intersection

$$\mu_{AB} = \frac{q_A - q_B}{k_A - k_B} = \frac{1000-0}{14.46-100} = -11.69 km/hr$$

$$\mu_{BC} = \frac{q_B - q_C}{k_B - k_C} = \frac{0-2000}{100-50} = -40 km/hr$$



Hoda Talaat 14

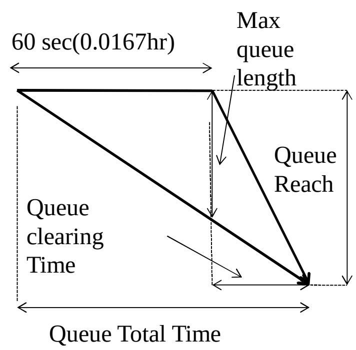
Shockwaves at signalized intersections

- Example: Signalized intersection

$$\mu_{AB} = -11.69 km/hr$$
$$\mu_{BC} = -40 km/hr$$

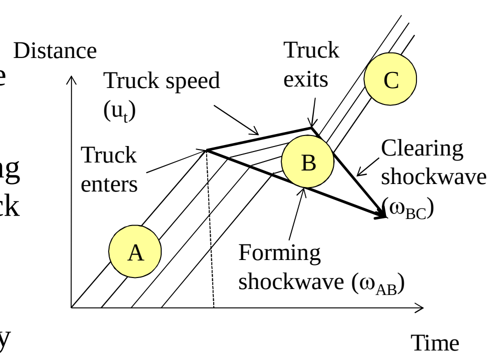
$$Max - Queue = 11.69 * 0.0167 = 0.195 km$$

$$\frac{Q_{reach} - Q_{\max}}{\mu_{AB}} = \frac{Q_{reach}}{\mu_{BC}}$$
$$\frac{Q_{reach} - 0.195}{11.69} = \frac{Q_{reach}}{40}$$
$$Q_{reach} = 0.275 km$$



Space-time Diagram along a highway with a slow moving truck

- Basic Concepts:
  - State A: Free-Flow State
  - State B: Vehicles_slowing down behind a slow truck
  - State C: Vehicles flow with full section capacity



Shockwaves along a highway with a slow moving truck

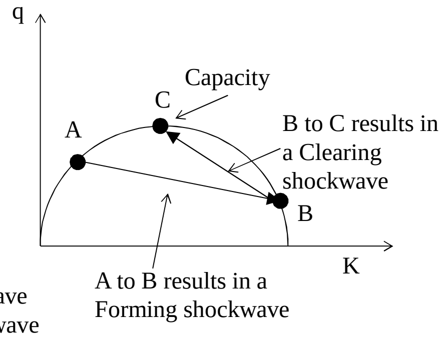
- Estimation of Shockwave Speed

$$\mu_{AB} = \frac{q_A - q_B}{k_A - k_B}$$

$$\mu_{BC} = \frac{q_B - q_C}{k_B - k_C}$$

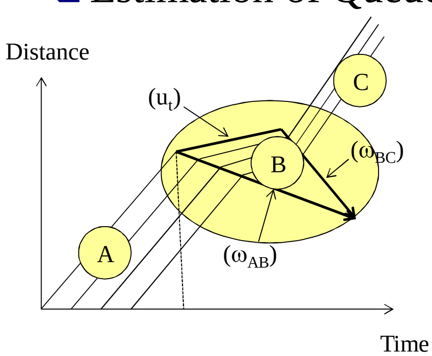
$$\Rightarrow \mu = \frac{\Delta q}{\Delta k}$$

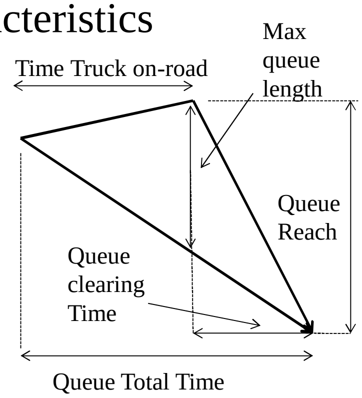
+ve value for forward propagating shockwave
-ve value for backward propagating shockwave



Shockwave along a highway with a slow moving truck

- Estimation of Queue Characteristics





Shockwaves along a highway with a slow moving truck

- Example: slow moving truck
  - Vehicles are flowing with a rate of 1000 veh/hr
  - A slow moving truck (with 20 km/hr) entered the highway and exists after 500 m.
  - Estimate the speed of the forming/ clearing shockwaves.
  - Estimated the max queue length.
  - Estimated the distance the queue will reach
  - Consider the model u=80-0.8k.

Hoda Talaat 19

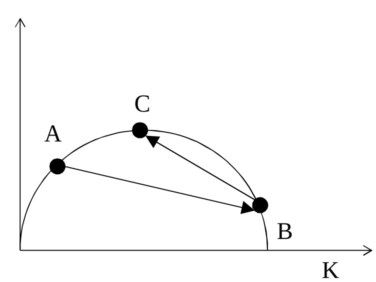
Shockwaves along a highway with a slow moving truck

- Example: slow moving truck
  - State A:
    - q_A= 1000veh/hr

$$q_A = 1000 = 80k_A - 0.8k_A^2$$

$$k_A = \frac{80 \pm \sqrt{(80)^2 - 4(0.8)(1000)}}{2(0.8)}$$

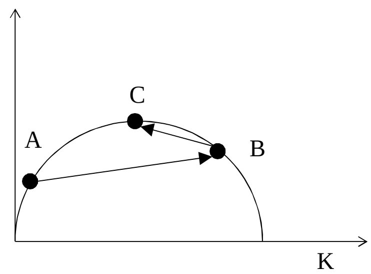
$$k_A = 85.35 or 14.64 veh/km$$



Hoda Talaat 20

Shockwaves along a highway with a slow moving truck

- Example: slow moving truck
  - State B:
    - u_B= 20 km/hr
    - k_B= (80-20)/0.8=75 veh/km
    - q_B= 75(20)=1500 veh/km
  - State C:
    - q_C= q_{max}=80*100/4=2000 veh/hr
    - k_C=k_j/2= 100/2=50veh/km



Hoda Talaat 21

Shockwaves along a highway with a slow moving truck

- Example: slow moving truck

$$\mu_{AB} = \frac{q_A - q_B}{k_A - k_B} = \frac{1000 - 1500}{14.64 - 75} = 8.28 km/hr$$

Note the sign

$$\mu_{BC} = \frac{q_B - q_C}{k_B - k_C} = \frac{1500 - 2000}{75 - 50} = -20 km/hr$$

Hoda Talaat 22

Shockwaves along a highway with a slow moving truck

- Example: slow moving truck

$$\mu_{AB} = 8.28 km/hr$$
$$\mu_{BC} = -20 km/hr$$

$$Time-Truck-on-road = 0.5/20 = 0.025hr$$
$$Q_{reach} = 0.5km$$
$$Max-Queue = 0.5 - 8.28 * 0.025 = 0.293km$$