Shock Waves in Traffic Streams.

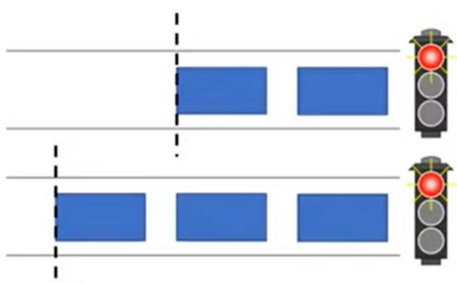
1- Shock Waves

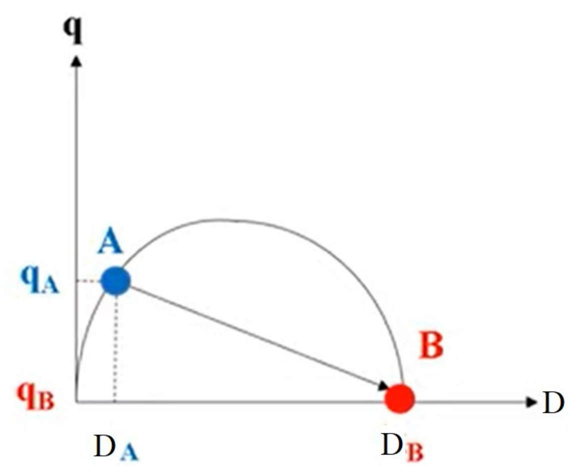
Shock wave is the phenomenon of backups and queuing on a highway due to a sudden reduction of the capacity of the highway (known as a bottleneck condition). The sudden reduction in capacity could be due to a crash, reduction in the number of lanes, restricted bridge size, work zones, a signal turning red, and so forth.

Any change in flow condition will travel in the form of waves. These shock waves can move either in forward direction or in backward direction depending upon the nature of the flow condition.

2-Types of Shockwaves

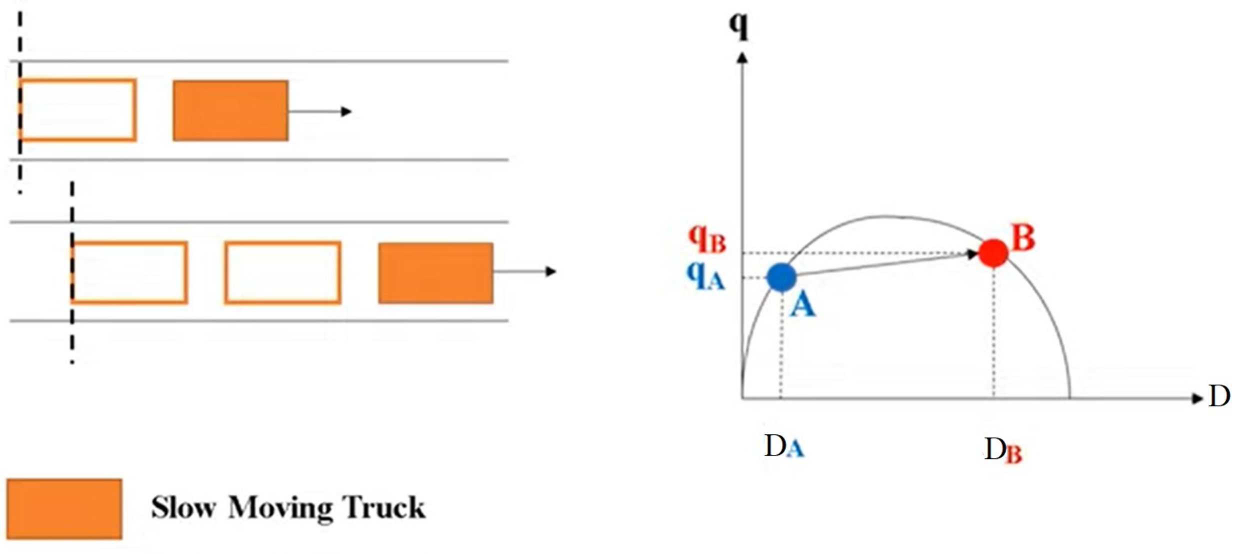
a- Backward Propagating:





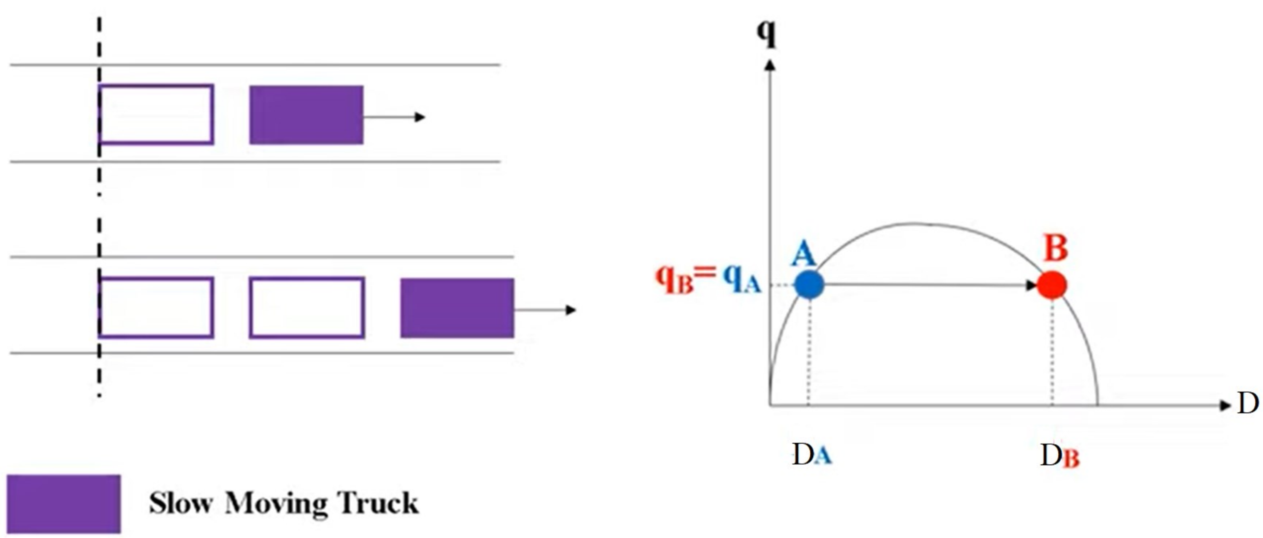
$$w_{AB} = \frac{q_B - q_A}{D_B - D_A} = \frac{-ve}{+ve} = -ve$$

b- Forward Propagating:



$$w_{AB} = \frac{q_B - q_A}{D_B - D_A} = \frac{+ve}{+ve} = +ve$$

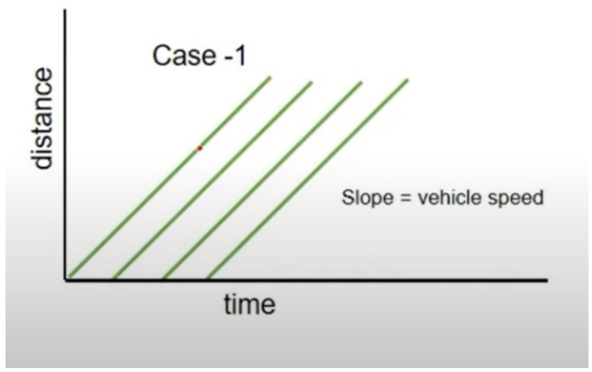
c- Stationary (zero):



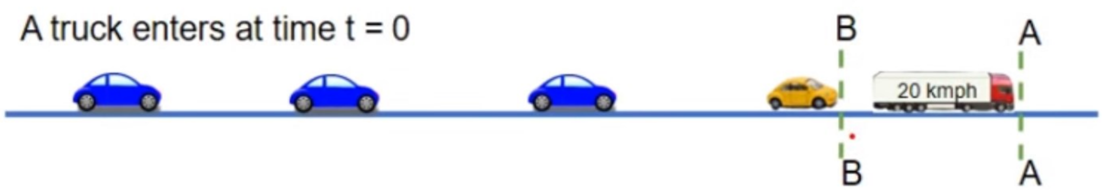
$$w_{AB} = \frac{q_B - q_A}{D_B - D_A} = \frac{0}{+ve} = 0$$

3- Example of Forming Shockwaves Along a Highway.

a. Assume all vehicles travel at the same speed (for example 60km/hr)



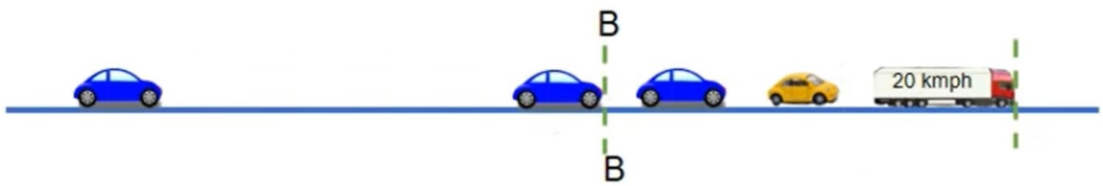
b. A truck moving at a low speed (for example 20km/hr), and the passing is not permitted, then all vehicle which are following the truck will be forced to travel at the same speed. A plateau will be formed behind the truck and this platoon will be moving at the same speed.

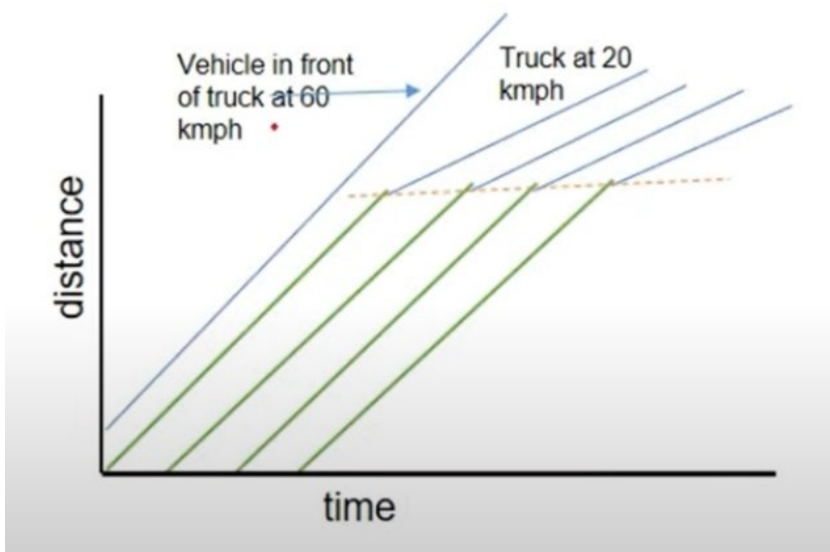


c. At any instant of time, the last vehicle to join the platoon will be travelling at the same speed, but further upstream all the vehicles will be moved in the first speed (60km/hr). Beyond the truck there is no vehicle (free flow condition).

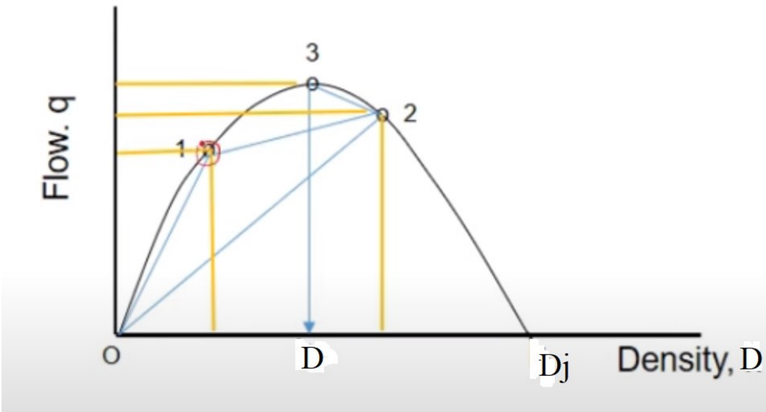
At t = t_1, the truck moves little further and another vehicle joins the truck

d. All the vehicle in the platoon will be travelling at the lower speed (20km/hr) so they will adjust the spacing and the concentration will increase





Flow density curve of the stream.



1- <u>Slope of line 0-1=60kmph</u>(speed of the vehicle before entry of the truck)

2-<u>Slope of line 0-2</u>=20kmph (speed of the vehicle after entry of the truck)

3-<u>Slope of line 1-2</u> is the velocity of shockwave

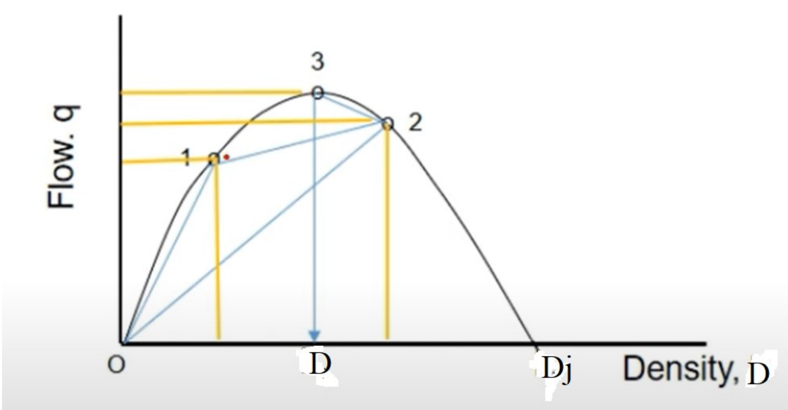
$$= \frac{q_2 - q_1}{D_2 - D_1}$$

If slope is positive the shockwave travel forward

If slope is negative the shockwave travel backward

If slope is zero- stationary with respect to roadway

e- If the truck decides to exit, the vehicles will slowly accelerate and will travel at the capacity of the roadway, and slowly will reach normal speed at 60km/hr.



0-1 Before entry of the truck

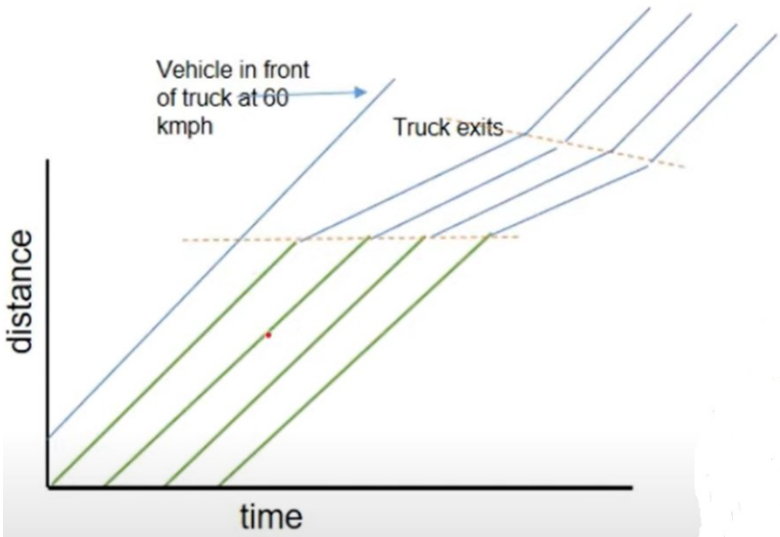
1-2 After entry of the truck

2-3 Slope of line 2-3 is the velocity of shockwave after exit of the truck (the flow is at the capacity)

$$= \frac{q_3 - q_2}{D_3 - D_2}$$

$$q_3 = q_{max}$$

$$D_3 = \frac{D_j}{2}$$



State 1 – free flow
State 2 – platooning behind a slow truck
State 3 – flow with full capacity

Example(1)

the relation between speed and density on a section of highway is given by the following relation:

$$vs = 100 - 0.8D$$

At a flow of 1000veh/hr, a slow moving truck with speed of 20 kmph enters the road and exits after 800m. estimate the speed of the shockwaves.

Solution:

Speed of the shockwaves

<u>For state1</u>

$q = Dvs = 100D - 0.8D^2$

$1000 = 100D - 0.8D2 \rightarrow D = 10.96\frac{veh}{km}$

$\mathbf{q1 = 1000\frac{veh}{hr} \qquad D1 = 10.96\frac{veh}{km}}$

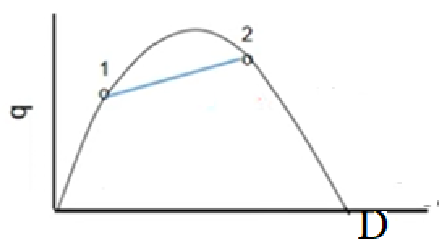
<u>For state 2</u>

After the truck enters, vs =20 km/ hr

$vs = 100 - 0.8D \rightarrow 20 = 100 - 0.8D \rightarrow D = 100\frac{veh}{km}$

$q = Dvs = 100 \times 20 = 2000\frac{veh}{hr}$

$\mathbf{q2 = 2000\frac{veh}{hr} \qquad D2 = 100\frac{veh}{km}}$



<u>Slope of line 1-2</u> is the velocity of shockwave.

$$= \frac{q_2 - q_1}{D_2 - D_1} = \frac{2000 - 1000}{100 - 10.96} = 11.23 \frac{km}{hr}$$

<u>For state 3</u>

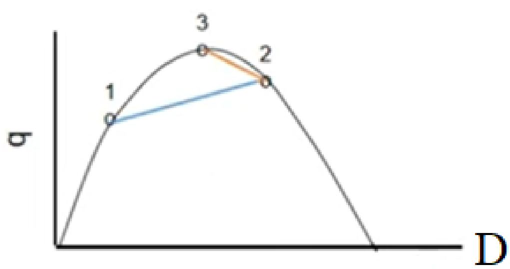
After the truck exit, $q = q_{max}$

$vs = 100 - 0.8D$

$\text{Free Flow Speed} = 100 \frac{km}{hr}, \text{Jam Density} = \frac{100}{0.8} = 125 \frac{veh}{km}$

$\mathbf{q_{max}} = \frac{100}{2} \times \frac{125}{2} = \mathbf{3125 \frac{veh}{hr}}$

$\mathbf{q3 = 3125 \frac{veh}{hr}} \qquad \mathbf{D3 = 62.5 \frac{veh}{km}}$



Slope of line 2-3 is the velocity of shockwave after exit of the truck (the flow is at the capacity)

$$= \frac{q_3 - q_2}{D_3 - D_2} = \frac{3125 - 2000}{62.5 - 100} = -30 \frac{km}{hr}$$

Example(2)

The volume at a section of a two-lane highway is 1500 veh.h in each direction and the density is about 25veh/mi. Alarge dump truck loaded with soil from an adjacent construction site joins the traffic stream and travels at speed of 10mi/h for a length of 2.5 mi along the upgrade befor turning off onto a dump site. Due to the relatively high flow in the opposite direction, it is impossible for any car to pass the truck. Vehicles just behind the truck therfore have to travel at the speed of the truck which results in the formation of a platoon having a density of 100veh/mi and a flow of 1000veh/h. Determine the velocity of the shockwave.

Solution:

$$\text{Velocity of the Shockwave} = \frac{q_2 - q_1}{D_2 - D_1} = \frac{1000 - 1500}{100 - 25} = -6.7\,\frac{\text{mi}}{\text{h}}\ \text{(shockwave is moving backward)}$$

Example(3)

After mall opening, the traffic volume in a 6- lane divided highway at the peak hour is forecasted to be 5200 vph. An accident blocked 1 lane of the highway. it took 15 minutes till the accident is cleared and capacity is fully restored. Use the following speed-density relationship to answer the following questions

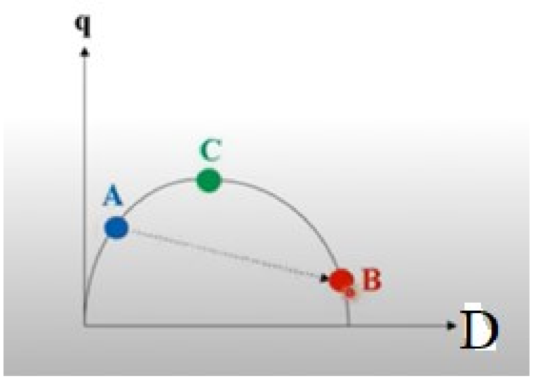
$$vs = 112.81 - 0.583D$$

Where vs is the speed in kph, and D is the density in vpkm

a) Sketch the above incident in a flow density as well as time space diagrams.
b) Speed of the shockwaves.

Solution:

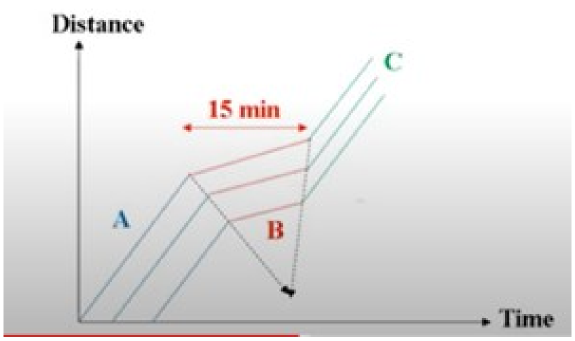
a) Sketch the above incident in a flow density as well as time space diagrams.



State A Free flow state

State B Vehicle slow down due to capacity reduction (due to accident)

State C Vehicles flow with full section capacity.



State A Free flow state

State B Vehicle slow down due to capacity reduction (due to accident)

State C Vehicles flow with full section capacity.

b) Speed of the shockwaves

<u>State A</u>

Free flow state

$$vs = 112.81 - 0.583D$$

$$q = Dvs = 112.81D - 0.583D^2$$

$$q_A = 5200\frac{veh}{hr} \rightarrow 0.583D^2 - 112.81D + 5200 = 0 \rightarrow D = 75.75\frac{veh}{km} \text{ or } D = 117.75\frac{veh}{km}$$

$$\mathbf{D_A = 75.75\frac{veh}{km}}$$

State B

Vehicle slow down due to capacity reduction (due to accident)

After the accident, $q_B = \frac{2}{3} q_{max} = \frac{2}{3}\frac{v_f \times D_J}{4} = \frac{2}{3}\left(\frac{112.81 \times 193.5}{4}\right) = 3638\frac{veh}{hr}$ (2 lanes from 3 working)

$$q = 112.81D - 0.583D^2 \rightarrow D = 40.9\frac{veh}{km} \quad \text{or } D = 152.6\frac{veh}{km}$$

$$\mathbf{D_B = 152.6\frac{veh}{km}}$$

The velocity of vehicles$=\frac{q_B}{D_B} = 23.84$ km/hr

Velocity of the shockwaves

$$= \frac{q_B - q_A}{D_B - D_A} = \frac{3638 - 5200}{152.6 - 75.75} = -20.33\frac{km}{hr}$$

State C

Vehicles flow with full section capacity.

$$q_C = q_{max} = \frac{v_f \times D_J}{4} = \left(\frac{112.81 \times 193.5}{4}\right) = 5457\frac{veh}{hr}$$

$$D_C = \frac{D_j}{2} = 96.75 \text{ veh/km}$$

Velocity of the shockwaves

$$= \frac{q_C - q_B}{D_C - D_B} = \frac{5457 - 3638}{96.75 - 152.6} = -32.57\frac{km}{hr}$$

Headway Distribution in Highways

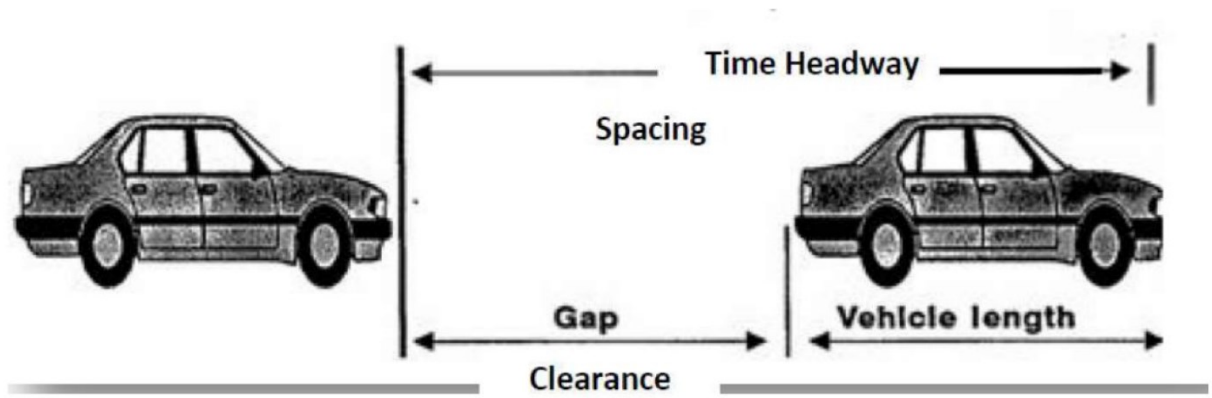
Ref. Lectures of Dr.Tariq Hussein

1- **Headway**

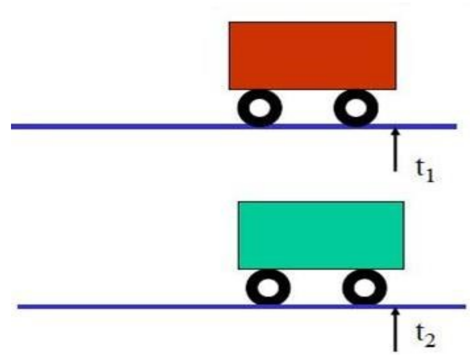
There are Two types of headways describe the traffic characteristics,

1-Space Headway (as described in Lec8)

2-Time headway (h_a): it is the time interval between successive vehicle as they pass a point along a lane of roadway, expressed in seconds.it is used in traffic calculations that are used in highway capacity.



It can be computed as the difference between the time the front of a vehicle arrives at a point on the highway (t_1) and the time the front of the next vehicle arrives at the same point (t_2). It is usually expressed in seconds.

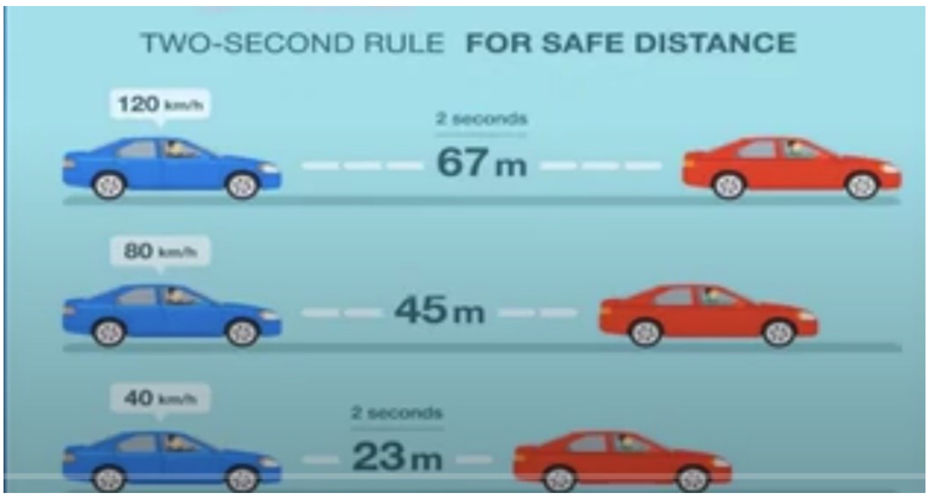


$$h = t_2 - t_1$$

2- The Importance of Time Headway

1- The time headway is one of the most surrogate safety measures that plays a significant role in traffic safety and performance.

2- The allowable following headway with leading vehicle should not be less than 2sec distance since it gives an indication of the probability of two or more vehicles involved in a tailgating collision or rear end collision.



The average time headway in a lane is directly related to the rate of flow:

$$h_a = \frac{3600}{v}$$

Where:

h_a is the average headway in a lane (sec)

v is the rate of flow veh/h/ln

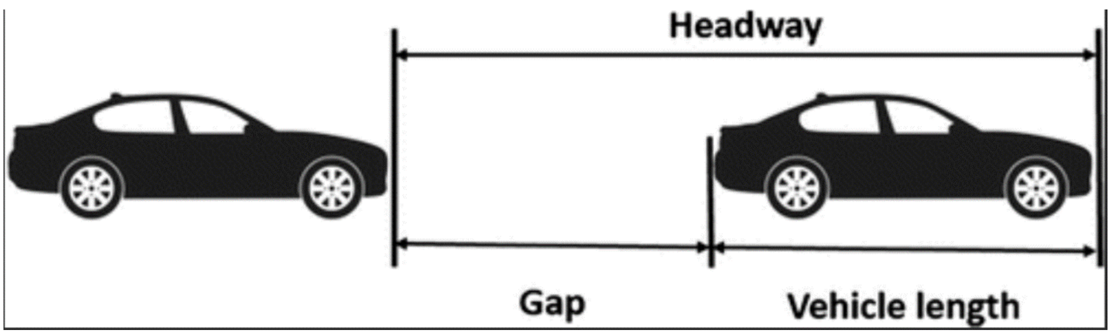
at traffic jam, time headway=0.

There are two to measure time headway of traffic.

1- Electronic equipment that gives a signal when vehicles pass a specified line on the road then record the timing between successive signals to measure the average time headway.
2- Aerial photography that can take a picture at any time.

Gap(g): gap is very similar to headway, except that gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, where headway focuses on front to front times. Gap is usually reported in units of seconds.

Clearance (c): clearance is similar to spacing, except that the clearance is the distance between the rear bumper of the leading vehicle and the front bumper of the following vehicle. The clearance is equivalent to the spacing minus the length of the leading vehicle. Clearance like spacing, is usually reported in units of meters or feet.



3- Headway distribution can be classified into

a. Counting Distribution: Depends on the number of vehicles passing at specified time period.
b. Space distribution: Depends on the time space between Successive vehicles.

Several statical formulas of time headway distributions can be applied to represent the vehicles arrival based on traffic flow rates.

1- **<u>Posson Distribution</u>**: which is appropriate to describe the truly random arrival of vehicles at a certain point on a road.

$$\text{probability (arriving n vehicles at t)} = \frac{(q\,t)^n e^{-q\,t}}{n!}$$

Where:

t is the given time

q is the average number of arrival that point at the given time

n is the number of vehicle

2- **Negative Exponential Distrbution**: which gives the probability of discrete event occuring with a specific time interval.

$$\text{probability (headway} \geq \text{t)} = e^{-q\,t}$$

Example(1)

An obsevation counts 230 veh/hr at a particular location. What is the probabilty of passing 1 vehicle over 30 sec interval. Assume vehicle arrival rate follows poisson distribution.

Solution:

$$\text{probability (n vehicles)} = \frac{(q\,t)^n e^{-q\,t}}{n!}$$

$$\text{probability (n vehicles)} = \frac{(230\ \times \frac{30}{3600})^1 e^{-230\times\frac{30}{3600}}}{1!} = 0.282$$

Example(2)

An observer counts 300veh/hr at a specific highway location. Assuming that the arrival of vehicle at the highway location is poison distributed, what is the probability that

1- The headway between successive vehicles will be less than 6 sec.
2- The headway between successive vehicles will be between 6 and 8sec.

Solution:

1 −**The probability that the headway between seccessive vehicles will be less than 6 sec is givin as**

$\text{probability } (h < t) = 1 - \text{probability } (h \geq t)$=1- $e^{-q\,t}$=$1 - e^{-\frac{300}{3600}\times 6} = 0.3934$

3-The probability that the headway will be between 6 and 8 sec is given as

$\text{probability } (6 < h < 8) = 1 - \text{probabilty}(h < 6) - \text{probabilty}(h \geq 8)$

$\text{probabilty } (h \geq 8) = e^{-\frac{300}{3600}\times 8} = 0.5134$

$\text{probability } (6 < h < 8) = 1 - 0.3934 - 0.5134 = 0.0932$