PHILADELPHIA UNIVERSITY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING.

Transportation and Traffic Engineering

Fundamental parameters of traffic flow

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Eng. Amany Assouli

Overview

- The **traffic stream** itself is having some **parameters** on which the characteristics can be predicted.
- The traffic stream includes a **combination of driver and vehicle behavior.**
- The driver or human behavior being **non-uniform**, **traffic stream is also non-uniform in nature.**
- They will vary both by **location and time** corresponding to the changes in the **human behavior**.
- The traffic engineer, for the purpose of planning and design, assumes that these changes are within certain ranges which can be predicted.

Traffic stream parameters:

Macroscopic parameters:

- Speed = **u** (mile per hour, mph; km/hr) .
- Flow = **q** (vehicle per hour, v/h) .
- Density= **k** (vehicle per mile, v/m; v/km)

- **Microscopic parameters:**

- Time Headway = h (sec/ veh) .
- Spacing (Space headway)= s (km/veh) , (ft/ veh)

Speed

- *Speed (u) is the distance traveled by a vehicle during a unit of time.*

It can be expressed in miles per hour **(mi/h),** kilometers per hour **(km/h),** or feet per second **(ft /sec**).

Mathematically speed or velocity is given as:

$$u = \frac{d}{t}$$

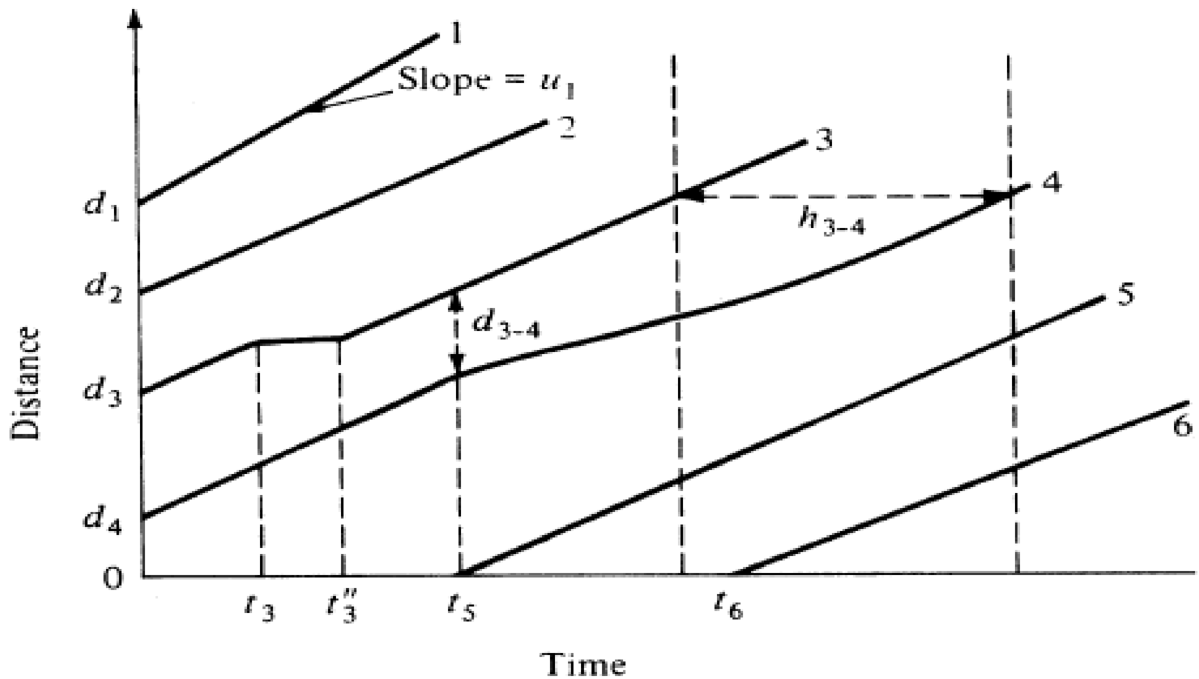
where,

u :is the speed of the vehicle

d: is distance traveled in m in time t seconds.

Time-Space Diagram

- 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



Speed

- **Time mean speed**: point measure of speed.
- **Space mean speed**: measure relating to length of roadway.
- **Running Speed**: the total time during which vehicle is in motion while traveling a roadway segment (Stopping time is excluded).
- **Operating speed**: maximum safe speed a vehicle can be driven without exceeding design speed.
- **Posted speed** = speed limit .
- **Average travel time: total time to traverse a** roadway.
- **85th percentile speed: speed at which 85 % of** vehicles are traveling at or below.

Time mean speed

- Time mean speed (spot speed) : is the **arithmetic mean** of the speeds of vehicles passing a point on a highway during an interval of time.(using radar or very short section)

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

Where:

ut: Time mean speed.

ui: Spot speed of the vehicle (i).

n: Number of spot speeds.

Space Mean Speed

- is the **harmonic mean** of the speeds of vehicles passing a point on 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.
- **T** ... **eed that is involved in flow-d** ... **onships.**

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

- The time mean speed is equal or higher than the space mean speed. $\bar{u}_s \leq \bar{u}_t$

Example 1

Assume a road section of 88 feet long . Four cars are timed through the section. Their times were: 1 , 1 , 2 , and 1.5 sec.

What is the Time mean speed (TMS) ?

What is the space mean speed (SMS)?

Solution 1

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

Note: SMS is always less than or equal to TMS

TRAVEL TIME AND SPACE MEAN SPEED/ EXAMPLE 2

Four cars traveling a section road of 300 m.

The travel times for the road section are shown in the following table:

Vehicle No.	Distance (m)	Travel time (s)
1	300	35
2	300	25
3	300	30
4	300	27

F
Mean Speed?.

Travel Time and Space Mean Speed

Solution 2:

Average travel time= (35+25+30+27)/4

= 29.25 sec.

The average space mean speed= 300 / 29.25

= 10.25 m/sec

=36.9 km/hr.

Flow (q)

- Flow or volume, which is defined as the number of vehicles (n) that pass a point on a highway or a given lane or direction of a highway during a specific time interval (T) .

- Units typically (vehicles/hour)

$$q = \frac{n \times 3600}{T} \text{ veh/h}$$

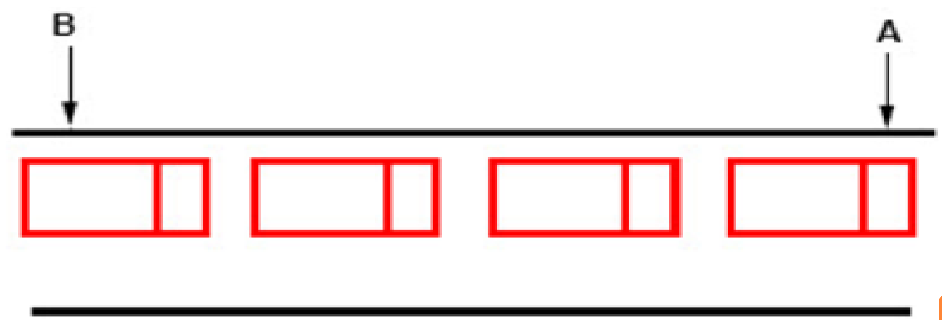
n: number of vehicles passing a point in the roadway in T sec.

q: the equivalent hourly flow.

DENSITY

Density (concentration) is defined as the number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per km/mile. One can photograph a length of road (l), count the $n_r$mber of vehicles( ) in one lane of the road at that point of time and derive the density k as:

$$k = \frac{n_r}{l}$$



Time headway (headway)

- *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.
- Time headway is usually expressed in **seconds**
- The microscopic character related to volume is the time headway or simply headway.

- If all headways **h in time period, t , over which flow has been measured are added then,**

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

But the flow is defined as the number of vehicles n measured in time interval t, that is:

$$q = \frac{n}{\sum_{i=1}^{n} h_i} = \frac{1}{\bar{h}}$$

$$Flow\ rate\ (veh/hr) = \frac{3{,}600}{headway\ (s/veh)}$$

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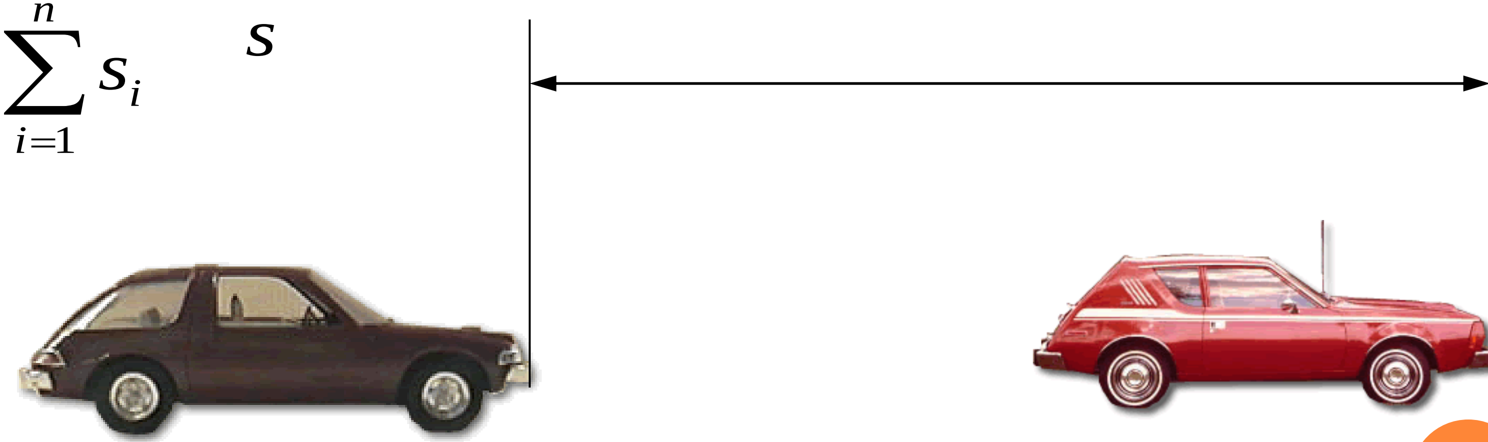
)Spacing (Space Headways

Space headway (S) is the distance between the front of a vehicle and the front of the following vehicle and is usually expressed in **feet**

$$k = \frac{n}{\sum_{i=1}^{n} s_i} = \frac{1}{\bar{s}}$$



EXAMPLE 3/ HEADWAY AND FLOW

The following headway values were measured:
2, 3, 5, 6, 8, 1, 3, 5 sec.
Compute average headway and flow ?.

Solution 3:

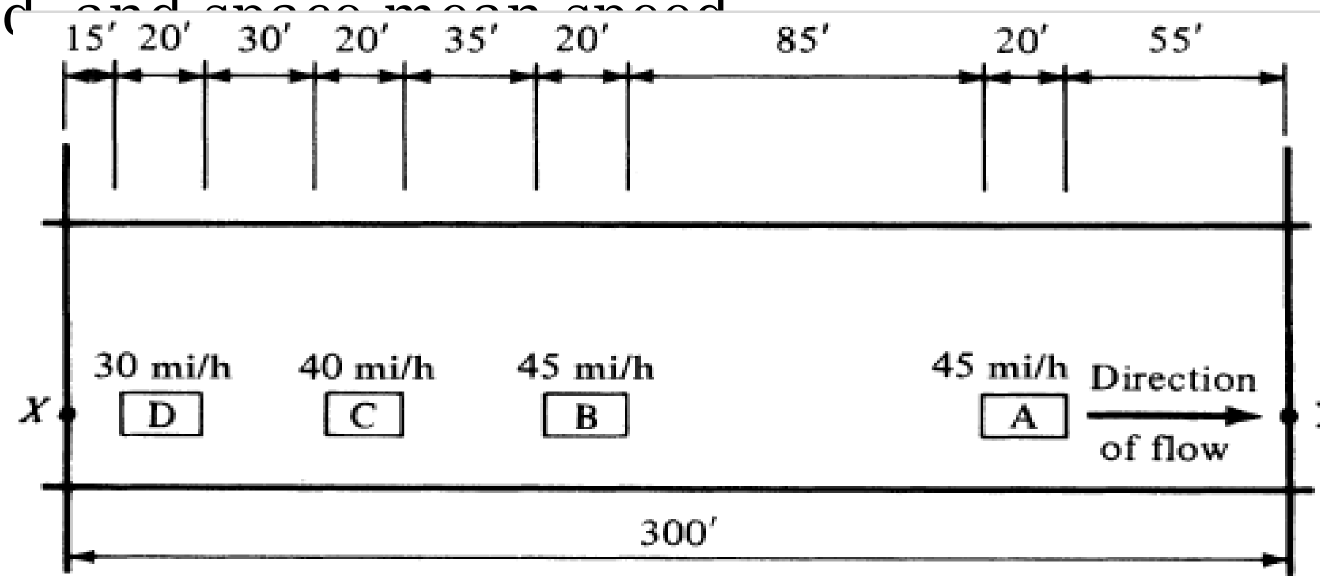
Number of headways= 8 .

Average ḧ = (2+3+5+6+8+1+3+5)/8 = 4.125 sec.

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

Determining Flow, Density, Time Mean Speed, and Space Mean Speed/ Example 4

Figure shows Locations and speeds of 4 vehicles travelling between section x & y on a 2 lane highway at an instant of time by photography. An observer located at point *X observes the* **four** *vehicles* passing point *X during a period of **15*** **sec**. *The velocities of the vehicles are measured* as **45, 45, 40, and 30 mi/h**, respectively. Calculate the flow, density, time mean speed, and space mean speed.



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SOLUTION

- The flow is calculated by:

$$q = \frac{n \times 3600}{T} \text{ veh/h}$$

q = 4*3600 /15 = 960 (veh/h)

- With *L equal to the distance between X and Y (ft), density*

$$k = \frac{n}{L} = \frac{4}{300} \times 5280 = 70.4 \text{ veh/mi}$$

- by

$$u_t = \frac{1}{n}\sum_{i=1}^{n} u_i = \frac{30 + 40 + 45 + 45}{4} = 40 \text{ mi/h}$$

- The space mean speed is found by :

note:
1 mile= 5280 ft
1 mi/hr = 1.47 ft/sec

$$\overline{u}_s = \frac{n}{\sum_{i=1}^{n}(1/u_i)} = \frac{Ln}{\sum_{i=1}^{n} t_i} = \frac{300n}{\sum_{i=1}^{n} t_i}$$

$$t_i = \frac{L}{1.47u_i}\ \text{sec}$$

$$t_A = \frac{300}{1.47 \times 45} = 4.54\ \text{sec}$$

$$t_B = \frac{300}{1.47 \times 45} = 4.54\ \text{sec}$$

$$t_C = \frac{300}{1.47 \times 40} = 5.10\ \text{sec}$$

$$t_D = \frac{300}{1.47 \times 30} = 6.80\ \text{sec}$$

$$\overline{u}_s = \frac{4 \times 300}{4.54 + 4.54 + 5.10 + 6.80} = 57\ \text{ft/sec} = 39.0\ \text{mi/h}$$

where ti : is the time it takes the ith vehicle to travel from X to Y at speed ui, and L (ft): is the distance between X and Y.

TRAFFIC FLOW

Uninterrupted flow:

A vehicle traversing a section of lane or roadway is not required to stop by any cause external to the traffic stream (Ex: Freeways)

Interrupted flow:

A vehicle traversing a section of a lane or roadway is required to stop by a cause outside the traffic stream, such as signs or signals at intersections or junctions (Ex: Urban Arterials).

- Stoppage of vehicles by a cause internal to the traffic stream does not constitute interrupted flow

Relationships among macroscopic traffic flow parameters

- The three basic macroscopic parameters of a traffic stream (flow, speed and density) are related to each other by the following equation:
- Flow = density * space mean speed

$$q = k * u_s$$

Traffic Flow Principles More Flow-density Relationships

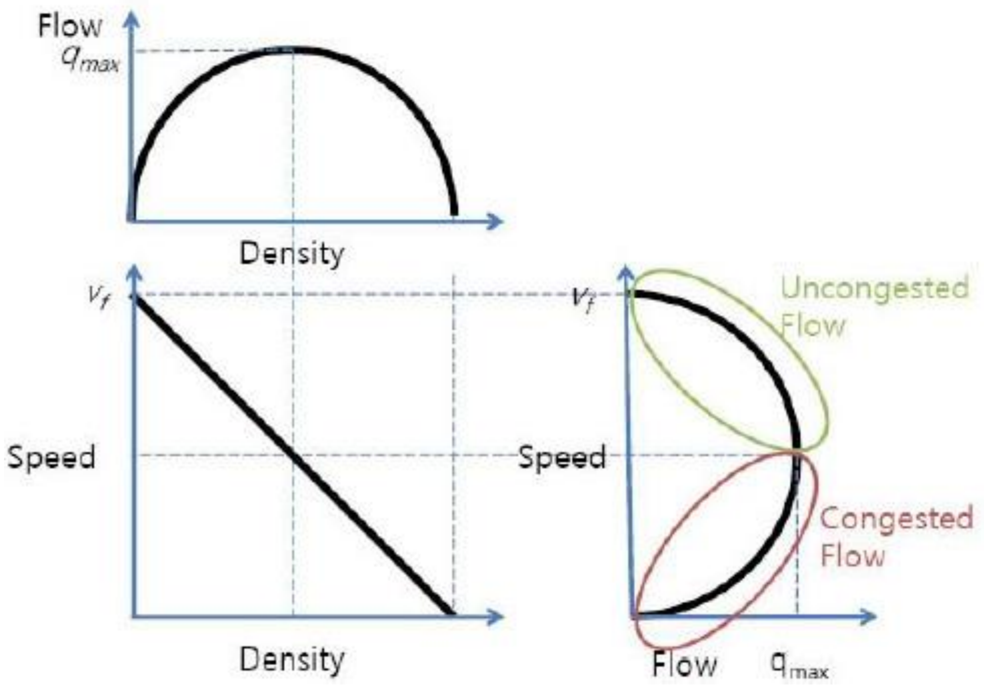
- Flow (q) =1/ ave. headway (h)
- ave. Space Mean Speed (u) = Flow (q) x ave. Spacing (s)
- Density (k) = 1/ ave. Spacing (s)
- average space headway = space mean speed * average time headway
- Density =flow * ave. travel time for unit distance

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

- Average time headway= ave. space headway* average travel time for unit distance

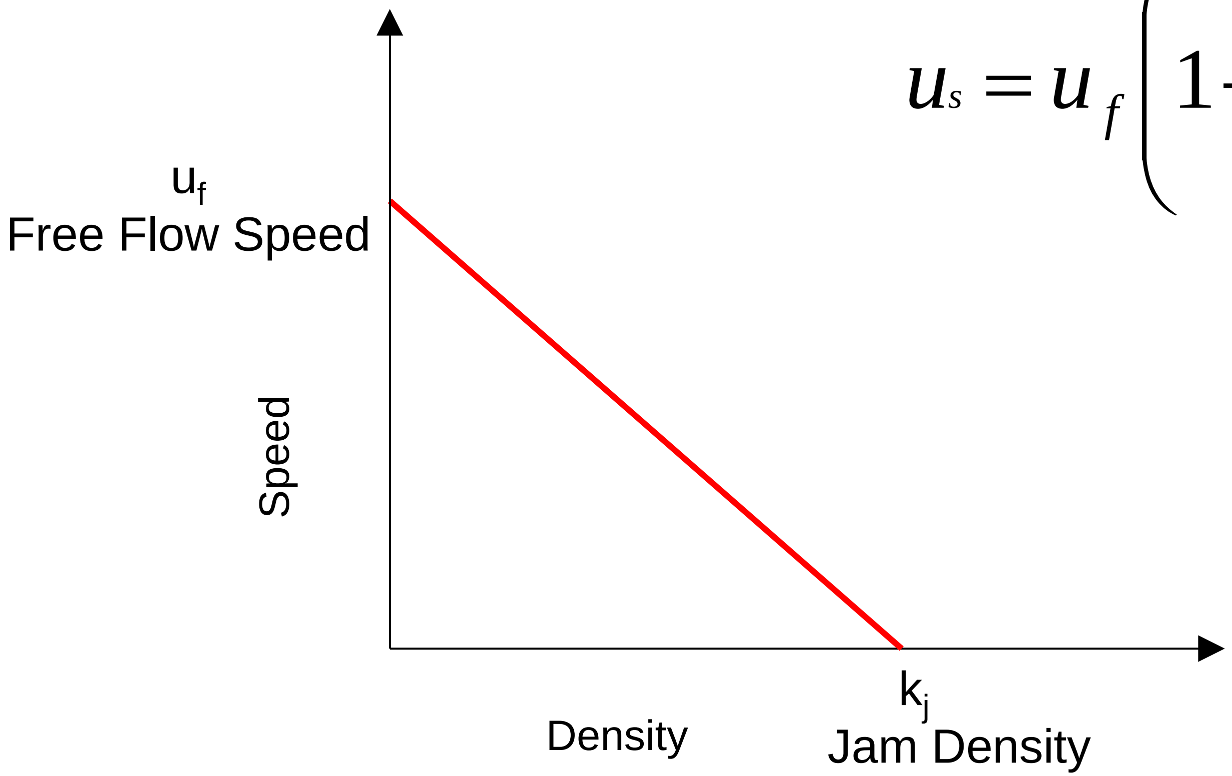
$$ave.spaceSpeed = \frac{spacing}{headway}$$

Fundamental Diagram



Speed vs. Density

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



Fundamental Diagram

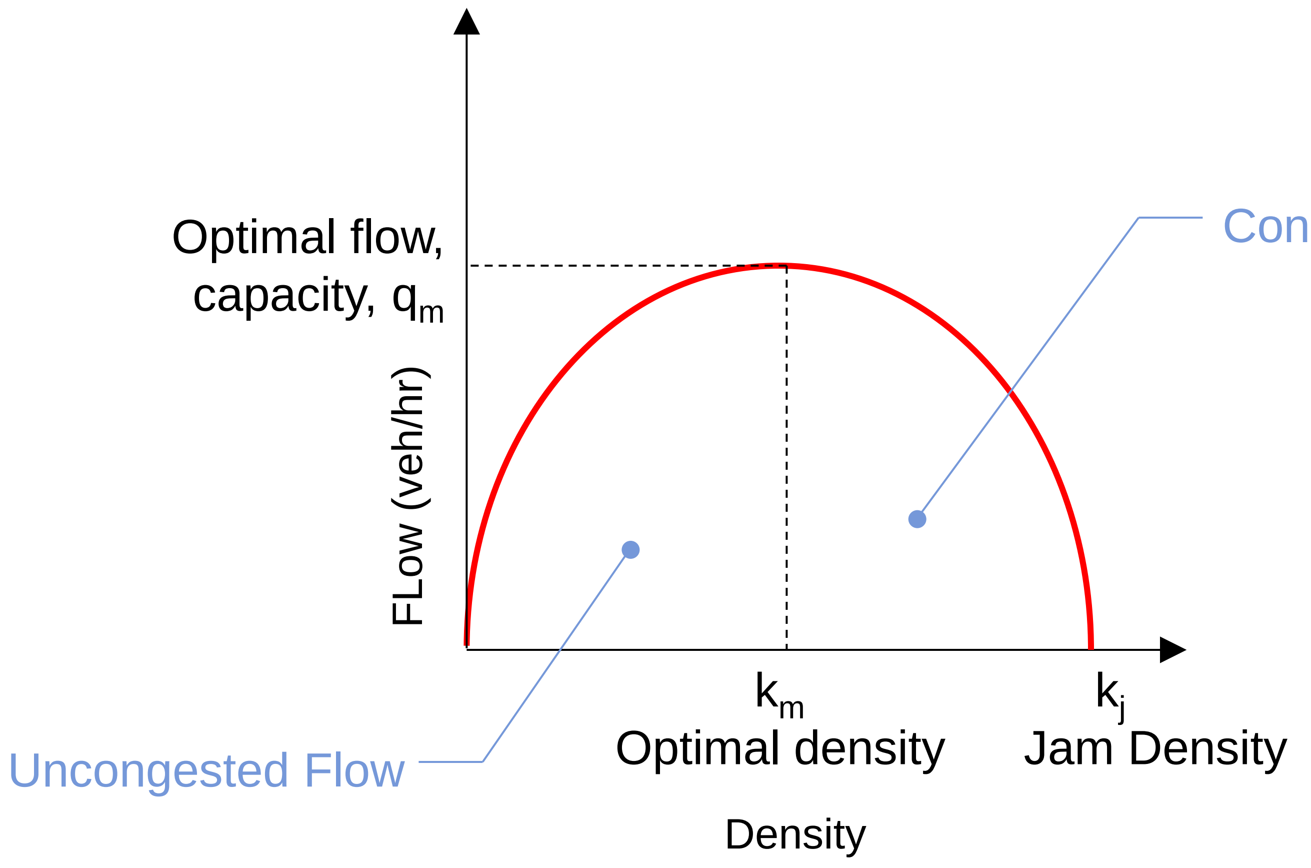
- Speed-Density relationship

—If density is 0 (No vehicle), Maximum speed is available

—As density increases from 0, speed decreases initially

—If density is maximum, speed is 0

Flow vs. Density



FUNDAMENTAL DIAGRAM

- Flow-Density relationship

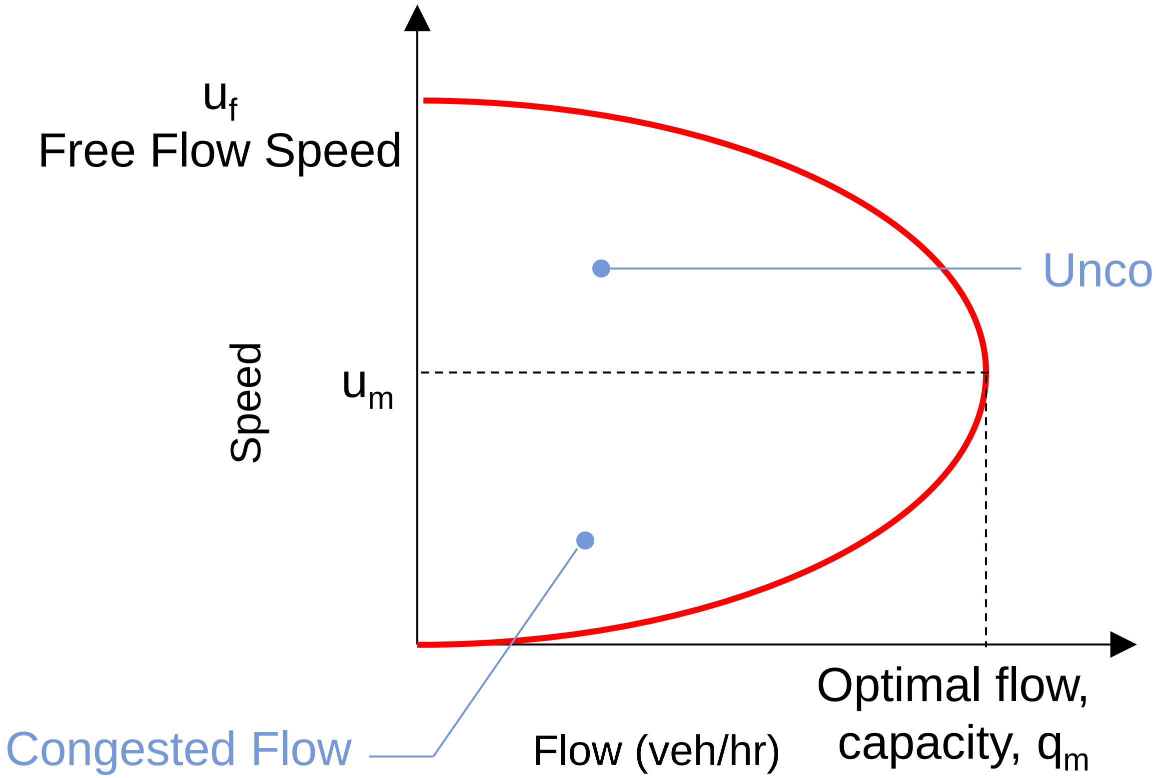
—If density is 0, flow is 0 (No vehicle).

—As density increases from 0, flow increases initially.

—After the max flow point (qmax),flow decreases as density increases.

—flow is 0 (Traffic Jam), Maximum jam density (kj).

Flow vs. Speed



Fundamental Diagram

Flow-Speed relationship

—If flow is 0 (No vehicle), Maximum speed is available.

—As flow increases from 0, speed decreases initially (Uncongested flow).

—After the max flow point (q_{max}),speed decreases as flow decreases(Congested flow).

- **This equation states that the flow or traffic volume is equal to the product of speed and density.**
- So if a 1-mile of a roadway contains 20 vehicles, and the mean speed of the 20 vehicles is 40 mile/h.
- After 1 hour, 800 vehicles (40 x 20) would have passed.
- The value of the flow (q) or traffic volume in this case would be equal to 800 v/hr.

EXAMPLE 5:

Data obtained from aerial photography showed 8 vehicles on a 250-m-long section of highway. Traffic data collected at the same time indicated an average time headway of 3 sec. **Determine :**

- the density on the highway.
- the flow on the highway.
- the mean speed.

SOLUTION 5:

- The density could be calculated as follows:

Density (k)= 8/0,250 = 32 v/km.

- Flow (q) = 1/average time headway

= (1/3) x 3600 = 1200 v/hr.

Finally we have:

q= u*k then u = q / k.

- Speed (u) = 1200/32 = 37.5 km / h.

Mathematical Relationships Describing Traffic Flow

Macroscopic Approach

Greenshields Model:

He hypothesized that a linear relationship existed between speed and density which he ex

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

Corresponding relationships for flow and density and for flow and speed can be developed. Since , substituting for *k* in p :

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

Also substituting q/k for in Eq. g

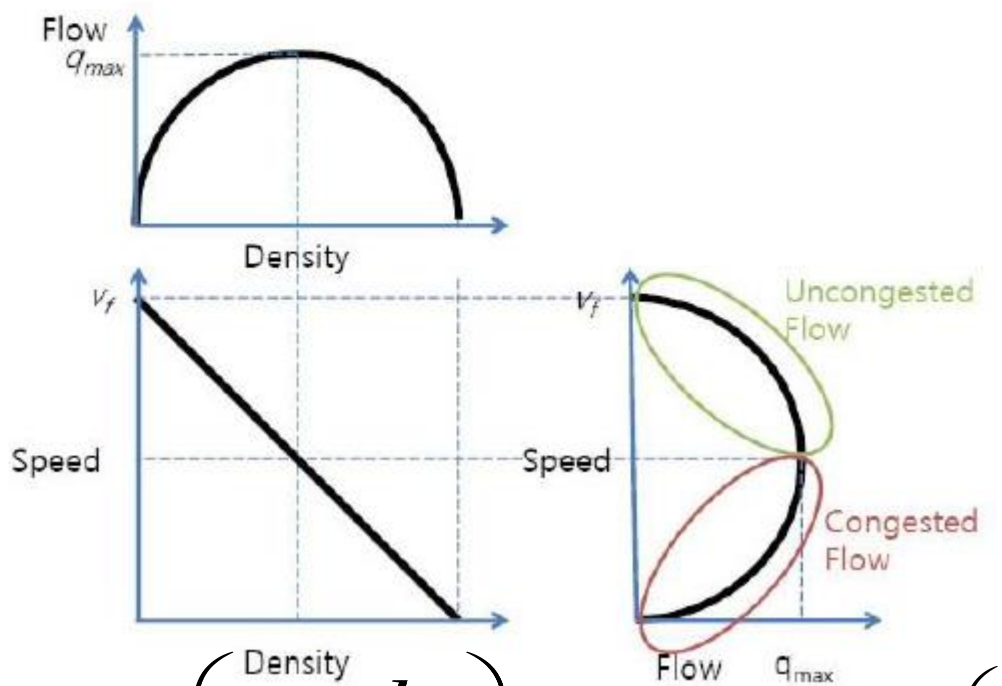
$$q = u_f k - \frac{u_f}{k_j} k^2$$

The maximum flow for the Greenshields relatio

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

Fundamental Diagram

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



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

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

Calibration of Macroscopic Traffic Flow Models

-The traffic models discussed thus far can be used to determine specific characteristics, such as the speed and density at which maximum flow occurs, and the jam density of a facility.

-This usually involves collecting appropriate data on the particular facility of interest and fitting the data points obtained to a suitable model. The most common method of approach is ***regression analysis***.

-This is done by minimizing the **squares of the differences** between the **observed** and **expected** values of a dependent variable.

When the dependent variable is linearly related to the independent variable, the process is known as ***linear regression analysis***.

Calibration of Macroscopic Traffic Flow Models

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

$$y = a + bx$$

Calibration of Macroscopic Traffic Flow Models

The constants *a* and *b* could be determined from Eqs. :

$$a = \frac{1}{n}\sum_{i=1}^{n} y_i - \frac{b}{n}\sum_{i=1}^{n} x_i = \bar{y} - b\bar{x}$$

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

where

n :number of sets of observations

xi : *i*th observation for *x*

yi: *i*th observation for *y*

COEFFICIENT OF DETERMINATION R^2

A measure commonly used to determine the suitability of an estimated regression function is the coefficient of determination (or square of the estimated correlation coefficient) R^2, which is given by:

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

where Y_i is the value of the dependent variable as computed from the regression equations.

- The closer $R2$ is to 1, the better the regression fits-

Example 6.2 Fitting Speed and Density Data to the Greenshields Model

Let us now use the data shown in Table 6.1 (columns 1 and 2) to demonstrate the use of the method of regression analysis in fitting speed and density data to the macroscopic models discussed earlier.

Solution: Let us first consider the Greenshields expression

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

Comparing this expression with our estimated regression function, Eq. 6.21, we see that the speed $\bar{u}_s$ in the Greenshields expression is represented by y in the estimated regression function, the mean free speed u_f is represented by a, and the value of the mean free speed u_f divided by the jam density k_j is represented by $-b$. We therefore obtain

$$\sum y_i = 404.8 \qquad \sum x_i = 892 \qquad \bar{y} = 28.91$$

$$\sum x_i y_i = 20619.8 \qquad \sum x_i^2 = 66{,}628 \qquad \bar{x} = 63.71$$

- Using Eqs. 6.22 and 6.23, we obtain

$$a = 28.91 - 63.71b$$

$$b = \frac{20{,}619.8 - \dfrac{(892)(4048)}{14}}{66{,}628 - \dfrac{(892)^2}{14}} = -0.53$$

or

$$a = 28.91 - 63.71(-0.53) = 62.68$$

Since $a = 62.68$ and $b = -0.53$, then $u_f = 62.68$ mi/h, $u_f/k_j = 0.53$, and so $k_j = 118$ veh/mi, and $\overline{u}_s = 62.68 - 0.53k$.

- Using Eq. 6.24 to determine the value of R^2, we obtain $R^2 = 0.95$.
- Using the above estimated values for u_f and k_j, we can determine the maximum flow from Eq. 6.18 as

$$q_{\max} = \frac{k_j u_f}{4} = \frac{118 \times 62.68}{4}$$
$$= 1849 \text{ veh/h}$$

- Using Eq. 6.16 we also obtain the velocity at which flow is maximum, that is, (62.68/2) = 31.3 mi/h, and Eq. 6.17, the density at which flow is maximum, or (118/2) = 59 veh/h.

Speed, u_s (mi/h) y_i	Density, k (veh/mi) x_i	$x_i y_i$	x_i^2
53.2	20	1064.0	400
48.1	27	1298.7	729
44.8	35	1568.0	1,225
40.1	44	1764.4	1,936
37.3	52	1939.6	2,704
35.2	58	2041.6	3,364
34.1	60	2046.0	3,600
27.2	64	1740.8	4,096
20.4	70	1428.0	4,900
17.5	75	1312.5	5,625
14.6	82	1197.2	6,724
13.1	90	1179.0	8,100
11.2	100	1120.0	10,000
8.0	115	920.0	13,225
$\Sigma = 404.8$	$\Sigma = 892$	$\Sigma = 20,619.8$	$\Sigma = 66,628.0$
$\bar{y} = 28.91$	$\bar{x} = 63.71$		

Variation of Traffic Volume

Several types of measurements of volume are commonly adopted which will be used in many design purposes:

1- Average Annual Daily Traffic (AADT):

The average 24-hour traffic volume at a given location over a full 365-day year, i.e. the total number of vehicles passing the site in a year divided by 365.

2- Average Annual Weekday Traffic(AAWT):

The average 24-hour traffic volume occurring On Week days over a full year. It is computed by dividing the total weekday traffic volume for the year by 260.

3- Average Daily Traffic (ADT):

An average 24-hour traffic volume at a given location for some period of time less than a Year. It may be measured for six months, a season, a month, a week, or as little as two days.

4- Average Weekday Traffic (AWT):

An average 24-hour traffic volume occurring on weekdays for some period of time less than one year, such as for a month or a season.

TRAFFIC FORECASTING

Traffic forecasting is the process of estimating the number of vehicles or people that will use a specific transportation facility in the future.

Future AADT = Current AADT x ((1 + AAGR) ^ n)

Where n = number of years.

- **AAGR is the Average Annual Growth Rate used to develop the future traffic forecast.**

TRAFFIC FORECASTING

Example:

If AADT for the year 2015 = 2500 veh/day.

Find the AADT for the year 2035,

if the AAGR = 3%.

Solution:

2035 AADT = 2015 AADT x ((1 + AAGR) ^ n).

= 2500 x ((1+0.03) ^ 20).

= 2500 x 1.806 = 4515 veh/day.

Design Hourly volume

- In design, peak-hour volumes are sometimes estimated from projections of the AADT (Both directions).
- Design hourly volume (DHV):

- Traffic volume used for design calculations
- Typically between 10th and 50th highest volume hour of the year.

DESIGN HOURLY VOLUME

Which hour?

-Usually use 30 highest hourly volume of the year.

Why 30 DHV?

Compromise: too high is wasteful

too low poor operation

Design Hourly Volume (DHV):

- Future hourly volume (both directions) used for design, typically 30 DHV in the design year

- **Usually choose 30th highest hour**

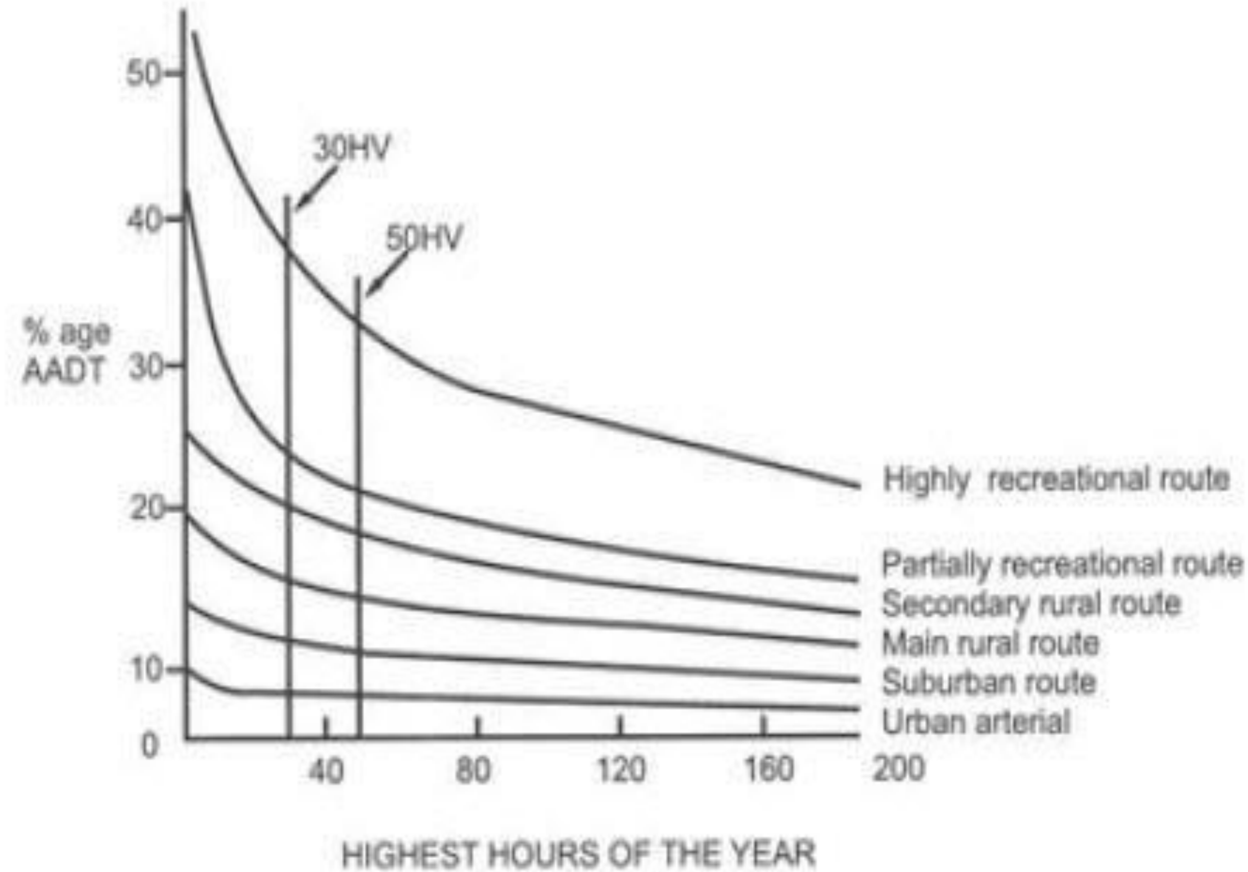


Figure 5.2 Typical Relationships between Hourly Volumes and AADT (Source: Austroads, 1988a)

Design Hourly volume

DHV = K * AADT

K: is defined as the proportion of annual average daily traffic occurring in an hour

<u>Directional Design Hourly Volume</u> (DDHV):

DDHV = AADT*K*Dion factor (D):

- Factor reflecting the proportion of peak-hour traffic traveling in the peak direction.
- Often there is much more traffic in on direction than the other.

Example

Urban freeway, 2 lanes each direction. ,Passenger car only facility, AADT = 35000 v/day, D = 65 %.

Find the Directional Design Hourly Volume DDHV.

Solution:

K= 0.12 (urban freeway).

Directional Design Hourly Volume (DDHV):

DDHV = AADT*K*D

= 3500 *0.12*0.65 = 2730 v/h.

Rates of flow

Generally stated in units of "vehicles per hour," but represent flows that exist for periods of time less than one hour.

- A volume of 200 vehicles observed over a 15-minute period may be expressed as a rate of 200 * 4 = 800 v/h even though 800 vehicles would not be observed if the full hour were counted.

800 v/h becomes a rate of flow that exists a 15-minute interval.

Volume & Flow rate

The distinction between volume and flow rate

is important.

Volume is the number of vehicles observed or predicted to pass a point during a time interval.

Flow rate represents the number of vehicles passing a point during a time interval less than

1 h, but expressed as an equivalent hourly rate.

For example, a volume of 100 vehicles observed in a 15-min period implies a flow rate of 100 v/0.25h or 400 v/h.

Example

Traffic volume and equivalent hour flow:

Time interval	Volume (v)	Traffic Flow (v/h)
5:00 – 5:15	1000	4000
5:15 – 5:30	1200	4800
5:30 – 5:45	1100	4400
5:45 – 6:00	1000	4000

Example

Find the volume and the flow rate?

Solution:

The total volume for the hour is the sum of these counts, or 4,300 v/h.

The flow rate, however, varies for each 15-min period. During the I5-min period of maximum flow, the flow rate is 1,200 v/0.25h, or 4,800 v/h.

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:

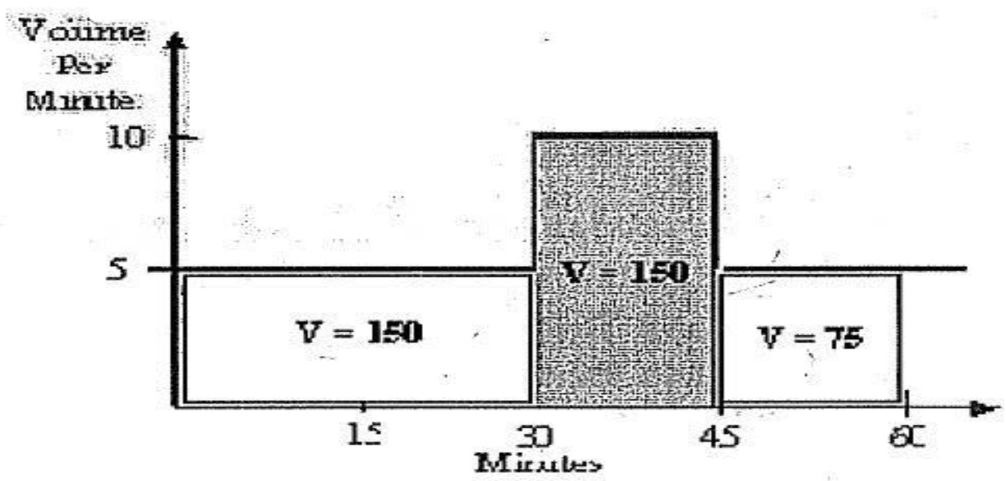
PHF = peak- hour factor

V = hourly volume (v/h) and

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

EXAMPLE/

Peak Hour Factor



Then from the figure:

Hourly volume = 75+75+150+75= 375 v/h.

Peak flow rate = 4*150= 600 v/h.

PHF = 375 / 600 = 0.625.

Passenger car unit

Different types of vehicles in a traffic stream have different characteristics like width, length and height and sometimes they produce inconvenience for other vehicles, so for expressing highway capacity, a unit is used called PASSENGER CAR UNIT.

In this one car is considered as one unit.

Passenger car unit table

Vehicle Type	Equivalent Factor
PC	1
Bus	2
SUT	2.5
Trailer	3.5

Number of lane

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p}$$

where

v_p = 15-min passenger-car equivalent flow rate (pc/h/ln),
V = hourly volume (veh/h),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = heavy-vehicle adjustment factor, and
f_p = driver population factor.