# PART 5

# FUNDAMENTALS OF TRAFFIC ENGINEERING

# Traffic Volume Studies

- The purpose of the traffic volume studies is to obtain factual data concerning the movement of vehicles and/or persons at selected locations on the street or highway system.

- Volume data are expressed in relation to time. The time basis may be less than an hour, hourly, daily, monthly, seasonal or yearly, depending on the type of information desired and the application in which it is to be used.

# Traffic Volume Studies

- **Annual Traffic (**vehicles per year) is used for:

  a. Determining annual travel in a geographic area.

  b. Estimating expected highway user revenue.

  c. Computing accident rates.

  d. Indicating trends in volume, especially on toll facilities.

# Traffic Volume Studies

- **Average Daily Traffic** (ADT) or **Average Annual Daily Traffic** (AADT) are expressed in vehicles per day and are computed as the total traffic volume divided by the number of days in the referred period. They are used for:

  a. Measuring the present demand for service by the street or highway.

  b. Evaluating the present traffic flow with respect to the street system.

  c. Developing the major or arterial street system.

  d. Locating areas where new facilities or improvements to existing facilities are needed.

  e. Programming capital improvements.

# Traffic Volume Studies

- **Hourly Traffic** in vehicles per hour is used for:
  a. Determining length and magnitude of peak periods.
  b. Evaluating capacity deficiencies.
  c. Establishing traffic controls - volume is usually among the warrants for the:
     1. Installation of signs, signals, and markings.
     2. Designation of through streets, one-way streets, unbalanced flow, and traffic routing.
     3. Prohibition of parking, stopping, and turning.
  d. Geometric design or redesign of streets and intersections.

# Traffic Volume Studies

- **Short Term Counts** (covering 5, 6, 10, or 15 min. intervals) are usually expanded into hourly flow rates. Such counts are primarily used to analyze:
  a. Maximum flow rates.
  b. Flow variations within peak hours.
  c. Capacity limitations on traffic flow.
  d. Characteristics of peak volumes.

# Traffic Volume Studies

- **Volume Characteristics:**
  - Traffic volumes tend to have general characteristics depending upon certain variables present.
  - Variables which affect volume characteristics include:

    a. Type or classification of street or highway.

       1. Rural - Interstate, state, county.
       2. Urban - Freeways, arterials, collector, residential, etc.

    b. Types of use - intercity or interstate, farm service, recreational, commercial, land service, commuter, general purpose, etc.

    c. Composition of traffic - proportions of autos, buses, etc.

    d. Time variation - by hour of day, day of week, month of year.

# Traffic Volume Studies

- **Rural Characteristics**

  a. *A recreational* route with high summer traffic and a high Sunday peak.

  b. *A general purpose state* route having no Sunday peak.  However, high summer volumes exist due to the heavier long-distance pleasure travel.

  c. *A farm service* route which has little variation between days of the week or months of the year.

  d. *A general purpose, winter resort* route with high Sunday peak and higher winter and spring volume.

# Traffic Volume Studies

- **Urban Characteristics:** differ from rural in that volumes are higher and usually more concentrated during certain hours of the day.

  a. Peak hour volumes are usually quite pronounced and directional in nature on radial streets used by commuters. Circumferential streets, on the other hand, do not have such sharp peaking characteristics

  b. Duration of peak flows may vary and is important in planning controls which affect traffic flow (such as signal timing). A sustained peak volume may be more critical than a higher peak which is sharp but of short duration.

  c. Within an hourly volume, arrival rates can vary considerably.

# Traffic Volume Studies

- **Design Hourly Volume** (**DHV**):
  - Design hourly volumes are used by highway engineers for designing the geometry (layout) of new facilities.

  - In traffic analysis a procedure for selecting an appropriate hourly volume is needed to evaluate the **level of service** (service quality) and to determine **the number of lanes** that need to be provided in a new roadway design to achieve some specified level of service.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**
  - The selection of an appropriate hourly volume is complicated by two issues. First, there is considerable variability in traffic volume by time of day, day of week, time of year, and type of roadway (Figures 5.1 and 5.2).

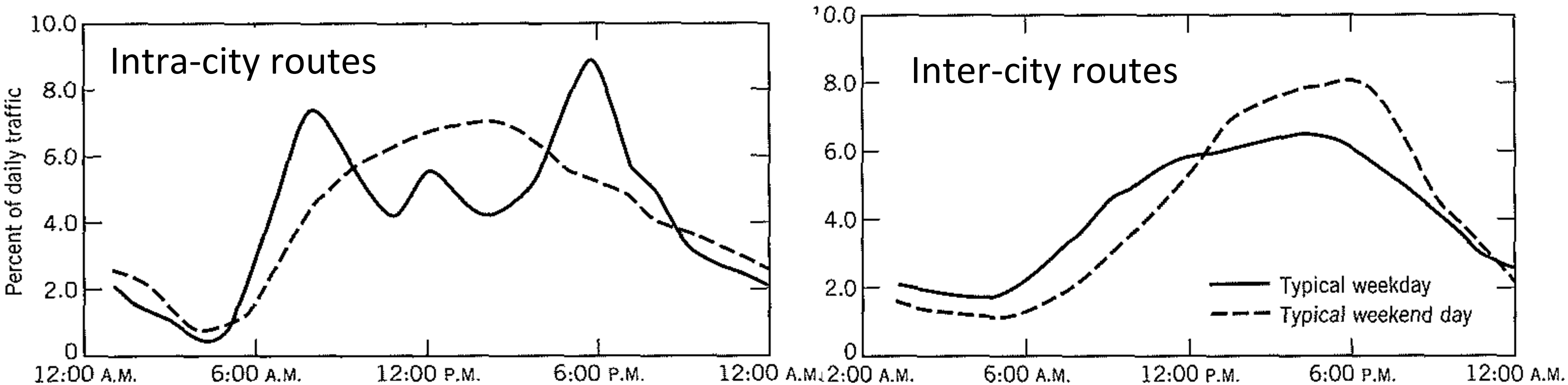


**Figure 5.1. Examples of hourly traffic variations for intra-city and inter-city routes.**

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

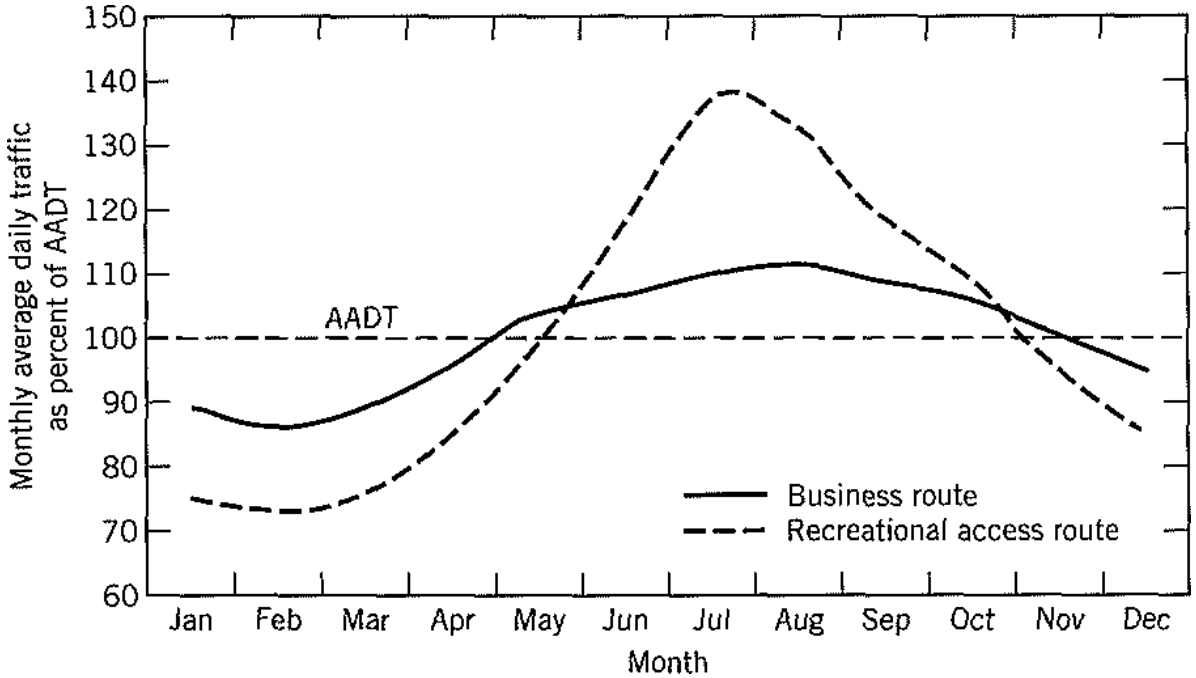


**Figure 5.2. Example of monthly traffic volume variations for business and recreational access routes**

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

  - The second concern is an outgrowth of the first: Given the temporal variability in traffic flow, what hourly volume should be used for design and/or analysis?

  - The example diagram shown in Figure 5.3 can be used to answer this question. The figure plots hourly volume (as a percentage of AADT) against the cumulative number of hours that exceed this volume, per year.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

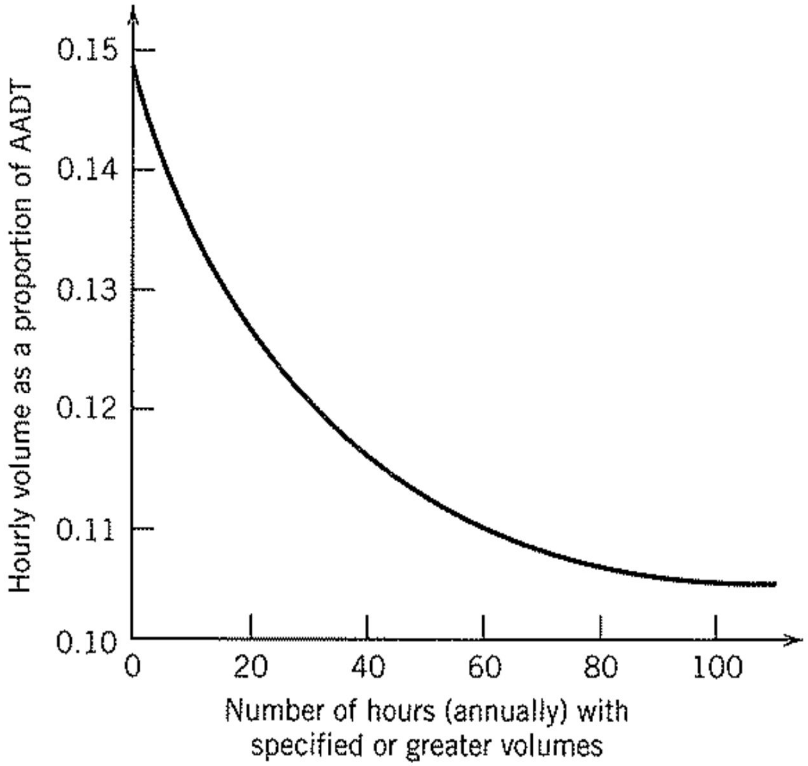


**Figure 5.3 Highest 100 hourly volumes over a one-year period for a typical roadway**

For this example; the highest traffic flow in the year would have an hourly volume of 0.148 x AADT (an hourly volume that is not exceeded throughout the year). Sixtieth highest hourly volume would be about 0.11 x AADT and this hourly volume would be exceeded only 59 hours during the year.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**
  - In determining the number of lanes that should be provided on a new or redesigned roadway, it is obvious that using the worst single hour in a year (the hour with the highest traffic flow, which would be 0.148 x AADT from Fig.5.3) would be a wasteful use of resources because additional lanes would be provided for a relatively rare occurrence.
  - In contrast, if the 100th highest volume is used for design, the design level of service will be exceeded 100 times a year, which will result in considerable driver delay.
  - Clearly, some compromise between the expense of providing additional capacity (such as additional lanes) and the expense of incurring additional driver delay must be made.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

  - A common practice in the United States is to use a design hour-volume (DHV) that is between the $10^{th}$ and $50^{th}$ highest-volume hours of the year, depending on the type and location of the roadway (urban freeway, rural/suburban multilane highway, etc.), local traffic data, and engineering judgment.

  - Perhaps the most common hourly volume used for roadway design is the $30^{th}$ highest of the year.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

  - If continuous volume counts are available for similar locations the 30th highest hours can be taken off the records, and the DHV calculated by appropriate estimates of future traffic growth.

  - When continuous volume counts are not available. The 30th highest hourly traffic volume of the year can be obtained by estimating the relationship between AADT and $30^{th}$ highest hourly volume.

  - Based on many research results, in rural areas the 30th highest hour is from 12 to 16% of AADT while in urban areas the range is 9 to 13%.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

  - In practice, the K-factor is used to convert annual average daily traffic (AADT) to the 30$^{th}$ highest hourly volume. K is defined as

$$K = \frac{Design\ Hour\ Volume}{Annual\ Average\ Daily\ Traffic} = \frac{DHV}{AADT} \tag{5.1}$$

  Where, **K =** factor used to convert annual average daily traffic to a specified annual hourly volume, **DHV =** design hour-volume (typically, the 30th highest annual hourly volume), and **AADT =** roadway's annual average daily traffic in veh/day.

  - As an example, a sample relation between hourly volumes and AADT is shown on Fig. 5.3 where K value corresponding to the 30$^{th}$ highest hourly volume is 0.12.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**

  - More generally, $K_i$ can be defined as the K-factor corresponding to the $i^{th}$ highest annual hourly volume.

  - Again, for example, the $20^{th}$ highest annual hourly volume would have a value, $K_{20}$, of 0.126, from Fig. 5.3.

  - If K is not subscripted, the $30^{th}$ highest annual hourly volume is assumed ($K = K_{30}$).

  - Finally, in the design and analysis of some highway types (such as freeways and multilane highways), the concern lies with directional traffic flows.

# Traffic Volume Studies

- **Design Hourly Volume (Continued)**
  - Thus a factor is needed to reflect the proportion of peak-hour traffic volume traveling in the peak direction.
  - This factor is denoted D and is used to arrive at the directional design-hour volume (DDHV) by application of

$$\mathrm{DDHV} = \mathrm{KxDxAADT} \tag{5.2}$$

Where,

**DDHV =** directional design-hour volume, **D =** directional distribution factor to reflect the proportion of peak-hour traffic volume traveling in the peak direction, and **AADT and K** are as defined previously.

# Traffic Volume Studies

- **Peak Hour Factor (PHF)**
  - Capacity and short term traffic analyses are generally based on the conditions over a full hour and the hourly volumes.
  - Since traffic flow fluctuates within an hour and hence there will be peaks within the critical hours, it may be required to consider peaking characteristics for periods less than one hour.
  - The relationships between the short interval and the full hour are represented by means of the peak hour factor (PHF).
  - PHF is the ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time interval within the hour.

# Traffic Volume Studies

- Peak hour factor can be calculated as

$$PHF = \frac{Peak\ Hour\ Volume}{(Number\ of\ Intervals)x(Interval\ Peak\ Volume)} \qquad (5.3)$$

- Generally 5-min or 15-min time intervals are used depending on the peaking characteristics. Then;

$$PHF = \frac{V}{4\ x\ V_{15}} \qquad (5.4)$$

Or

$$PHF = \frac{V}{12\ x\ V_5} \qquad (5.5)$$

Where;

$V$ = hourly volume for hour of analysis,

$V_{15}$ = maximum 15-min flow rate within the analysis hour

$V_5$ = maximum 5-min flow rate within the analysis hour

# Traffic Stream Flow

**Motivation:**

- It is important to realize that the primary function of a highway is to provide mobility.
- This mobility must be provided with safety in mind, while achieving an acceptable level of performance (such as acceptable vehicle speeds).
- Many of the safety-related aspects of highway design were discussed in design criteria, and focus is now shifted to **measures of performance.**
- The analysis of vehicular traffic provides the basis for measuring the operating performance of highways.

# Traffic Stream Flow

- In undertaking such an analysis, the various dimensions of traffic, such as **number of vehicles per unit time (flow)**, **vehicle types**, **vehicle speeds**, and **the variation in traffic flow over time**, must be addressed, because they all influence **highway design** (the selection of the number of lanes, pavement types, and geometric design) and **highway operations** (selection of traffic control devices, including signs, markings, and traffic signals), both of which impact the performance of the highway.

- In light of this, it is important for the analysis of traffic to begin with theoretically consistent quantitative techniques that can be used to model traffic flow, speed, and temporal fluctuations.

# Traffic Stream Flow

- Traffic streams can be characterized by a number of different operational performance measures.
- A traffic stream that operates free from the influence of any traffic control devices (such as, signals and stop signs) is classified as **uninterrupted flow.**
  - *This type of traffic flow is influenced primarily by roadway characteristics and the interactions of the vehicles in the traffic stream.*
  - *Freeways, multilane highways, and two-lane highways often operate under uninterrupted flow conditions.*

# Traffic Stream Flow

- Traffic streams that operate under the influence of signals and stop signs are classified as **interrupted flow.**
  - *Although all the concepts in this chapter are generally applicable to both types of flow, there are some additional complexities involved with the analysis of traffic flow at signalized and unsignalized intersections.*

# Traffic Stream Flow Variables

- **Traffic flow (q), Speed (u) and density (k)** are variables that form the underpinnings of traffic analysis. To begin the study of these variables, the basic definitions of traffic flow, speed, and density must be presented.

## Traffic Flow (q):

- Traffic flow is defined as

$$q = \frac{n}{t} \tag{5.6}$$

Where; ***q* =** traffic flow in vehicles per unit time,

**n =** number of vehicles passing some designated roadway point during time and,

***t* =** duration of time interval.

# Traffic Stream Flow Variables

- Flow is often measured over the course of an hour, in which case the resulting value is typically referred to as volume. Thus, when the term **"volume"** is used, it is generally understood that the corresponding value is in **units of vehicles per hour (veh/h)**.
- The definition of flow is more generalized to account for the measurement of vehicles over any period of time. In practice, the analysis flow rate is usually based on the peak 15-minute flow within the hour of interest. This aspect will be described in more detail later.
- Aside from the total number of vehicles passing a point in some time interval, the total time between the passages of successive vehicles (or time between the arrivals of successive vehicles) is also of interest.
-

# Traffic Stream Flow Variables

- **Time Headway (h):** The time between the passages of the front bumpers of successive vehicles, at some designated highway point, is known as the **time headway**.
- The time headway is related to t (duration)as defined in Eq. 5.6 by

$$t = \sum_{i=1}^{n} h_i \tag{5.7}$$

where,

***t*** **=** duration of time interval,

$\mathbf{h_i}$ **=** time headway of the $i^{th}$ vehicle (the elapsed time between the arrivals of vehicles i and i-1), and

**n =** number of measured vehicle time headways at some designated roadway point

# Traffic Stream Flow Variables

- Substituting Eq. 5.7 into Eq. 5.6 gives

$$q = \frac{n}{\sum_{i=1}^{n} h_i} \tag{5.8}$$

or

$$q = \frac{1}{\bar{h}} \tag{5.9}$$

Where;

$\bar{h}$= average time headway in unit time per vehicle and given by

$$\bar{h} = \frac{\sum_{i=1}^{n} h_i}{n} \tag{5.10}$$

# Traffic Stream Flow Variables

**Speed (u):**

- In the general sense speed can be defined as the rate of movement of vehicular traffic or of a specified component of traffic expressed in distance per unit time.
- There are different speed measures used in traffic analysis. The commonly used are:
  - Time-mean speed
  - Space-mean speed

# Traffic Stream Flow Variables

- **Time-mean speed ($\bar{u}_t$) :** The arithmetic mean of the spot speeds of vehicles observed at some designated point along the roadway. The time-mean speed is expressed as

$$\bar{u}_t = \frac{\sum_{i=1}^{n} u_i}{n} \tag{5.11}$$

Where;

**$u_t$** = time-mean speed in unit distance per unit time,

**$u_i$** = spot speed (the instantaneous speed of the vehicle at the designated point on the highway, as might be obtained using a radar gun) of the $i^{th}$ vehicle, and

**n**= number of measured vehicle spot speeds.

# Traffic Stream Flow Variables

- **Space Mean Speed ($\bar{u}_s$):** Space-mean speed can be defined as the average speed of the vehicles based on the total time spent travelling over a given length of the roadway. It is calculated by the ratio of the total distance travelled by the vehicles to the summation of the travel times of these vehicles.
- Space mean speed is more useful in the context of traffic analysis since it is a characteristic speed based on both the distance travelled and the travel times.
- Space-mean speed is the speed variable used in traffic stream models.

# Traffic Stream Flow Variables

- Space- mean speed is calculated by

$$\bar{u}_s = \frac{n\ell}{\sum_{i=1}^{n} t_i} = \frac{\ell}{\bar{t}} \qquad (5.12)$$

Where, $\boldsymbol{\ell}$ = length of roadway used for travel time
$\boldsymbol{t_i}$ = time necessary for vehicle *i* to travel a roadway section of length $\boldsymbol{\ell}$,
$\boldsymbol{n}$ = number of vehicles
$\boldsymbol{\bar{t}}$ = average vehicle travel time and given by

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n} \qquad (5.13)$$

# Traffic Stream Flow Variables

- Space-mean speed can also be calculated by taking the harmonic mean of the average travel speeds of the vehicles measured for the given length of the roadway as

$$\bar{u}_s = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\left[\frac{\ell}{t_i}\right]}} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{u_i}} \tag{5.14}$$

Where, $t_i$, $\ell$, and $n$ are as defined before, and

$u_i$ = average speed of $i^{th}$ vehicle

# Traffic Stream Flow Variables

**Example 5.1**

The speeds of five vehicles were measured (with radar) at the midpoint of a 0.8 km section of roadway. The speeds for vehicles 1, 2, 3, 4, and 5 were 71, 68, 82, 79, and 74 km/h, respectively.

a) Calculate time-mean speed

b) Calculate space mean speed (Assuming all vehicles were traveling at constant speed over the roadway segment)

**Solution:**

a) Time-mean seed:

$$\bar{u}_t = \frac{\sum_{i=1}^{n} u_i}{n} = \frac{71+68+82+19+84}{5} = 76.80 \text{ km/h}$$

b) Space-mean speed:

$$\bar{u}_s = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\left(\frac{\ell}{t_i}\right)}} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{u_i}} = \frac{1}{\frac{1}{5}}\frac{1}{\left[\frac{1}{71}+\frac{1}{68}+\frac{1}{82}+\frac{1}{79}+\frac{1}{84}\right]}$$

$$\bar{u}_s = \frac{1}{0.013431} = 74.45 \text{ km/hr}$$

Note that the space-mean speed will always be lower than the time-mean speed, unless all vehicles are traveling at exactly the same speed, in which case the two measures will be equal.

# Traffic Stream Flow Variables

**Density (k):**

- Traffic density is defined as

$$k = \frac{n}{\ell} \tag{5.15}$$

Where;

***k* =** traffic density in vehicles per unit distance,

***n* =** number of vehicles occupying some length of roadway at some specified time, and

**$\ell$ =** length of roadway.

# Traffic Stream Flow Variables

- The density can also be related to the individual spacing between successive vehicles (measured from front bumper to front bumper).
- The roadway length ℓ, in 5.13 can be defined as

$$\ell = \sum_{i=1}^{n} s_i \qquad (5.16)$$

where;

**$s_j$ =** spacing of the ith vehicle (the distance between vehicles *i* and *i*-1, measured from front bumper to front bumper)

***n*** = number of measured vehicle spacings.

# Traffic Stream Flow Variables

- Substituting Eq. 5.16 into Eq. 5.15 gives

$$k = \frac{n}{\sum_{i=1}^{n} s_i} \tag{5.17}$$

or

$$k = \frac{1}{\bar{s}} \tag{5.18}$$

Where $\bar{s}$ is average spacing in unit distance per vehicle and can be expressed by

$$\bar{s} = \frac{\sum_{i=1}^{n} s_i}{n} \tag{5.19}$$

# Traffic Stream Flow Variables

- **Fundamental relation between traffic steam flow variables:**

  - The main parameters of traffic stream as discussed previously are:
    - Flow rate (q) : expressed in veh/h.
    - Average speed (u) : expressed in km/h.
    - Average density (k) : expressed in veh/km.
  - The fundamental relation between these parameters is given by:

$$q = u \times k \tag{5.20}$$

  - It should be noted that the average speed in this relation should be a representative of speed of vehicles for a given period of time over a given section of the roadway. Therefore space-mean-speed should be used. Hence the flow rates and densities are also average representative values for the section and for the period of interest.

# Traffic Stream Flow Variables

- **Measurement of variables:**
  - There are several methods to measure the variables. In general they are referred as “Point measurements” or “Section Measurements”.
  - **Point Measurement:** Point measurement is simply the counting of the vehicles as they pass from a point of a lane or lanes in one direction, or in both directions of a roadway during a specified period of time.
    - Counting may be manual count or instrument count.
    - Lane volumes, directional volumes or total volumes can be obtained. And the flow rates (q) corresponding to those measured volumes can be calculated.
    - Spot speeds of vehicles can also be recorded if special instruments (video recorders, speed radars) are used.

# Traffic Stream Flow Variables

- **Section Measurement:** These measurements are carried out for a length (section) of a roadway. Two simultaneous point measurements are conducted at two ends of the section.
- The recorded data should include license plated of vehicles and their entry, exit times to and from the section.
- From the section measurement, average speeds of individual vehicles and space mean speed for these vehicles can be calculated. The end point flow rates and instantaneous densities can be obtained.
- Aerial photographs or aerial video recordings can also be used to evaluate traffic flow characteristics over a roadway section.

**Example 5.2**

Vehicle time headways and spacings were measured at a point along a highway, from a single lane, over the course of an hour. The average values were calculated as 2.5 s/veh for headway and 60 m/veh for spacing. Calculate the average speed of the vehicle.

**Solution:**

To calculate the speed, the fundamental relation **(q = u x k )** will be used, but first the flow (q) and the density (k) must be calculated from the data.

q= 1/ 2.5 = 0.40 veh/s → q =0.40 x 3600 s/hr = **1440 veh/h**

k= 1/60 veh/m = 0. 0167→ k= 0.0167 x 1000 m/km = **16.7 veh/km**

u= q/k = 1440/ 16.7 = **86**.4 km/h

# Basic Traffic Stream Models

- The preceding definitions and relationships provide the basis for the measurement and calculation of traffic stream parameters.
- But, it is essential to also understand the interaction of the individual macroscopic measures in order to fully analyze the operational performance of the traffic stream.
- The models that describe these interactions link specific models of traffic into a consistent, generalized model.

# Basic Traffic Stream Models

- The most intuitive starting point for developing a consistent, generalized traffic model is to focus on the relationship between speed and density.
- To begin, consider a section of highway with only a single vehicle on it. Under these conditions, the density (veh/km) will be very low and the driver will be able to travel freely at a speed close to the design speed of the highway. This speed is referred to as the **free-flow speed** because vehicle speed is not inhibited by the presence of other vehicles.
- As more and more vehicles begin to use a section of highway, the traffic density will increase and the average operating speed of vehicles will decline from the free-flow value as drivers slow to allow for the maneuvers of other vehicles.

# Basic Traffic Stream Models

- As more and more vehicles begin to use a section of highway, the traffic density will increase and the average operating speed of vehicles will decline from the free-flow value as drivers slow to allow for the maneuvers of other vehicles.

- Eventually, the highway section will become so congested (will have such a high density) that the traffic will come to a stop **($u = 0$),** and the density will be determined by the length of the vehicles and the spaces that drivers leave between them.

- This high-density condition is referred to as the **jam density.**

# Basic Traffic Stream Models

## Linear Model:

- **Speed-density relationship for the linear model**: One possible representation of the process described above is the assumed linear relationship  between speed and density as shown in figure 5.4

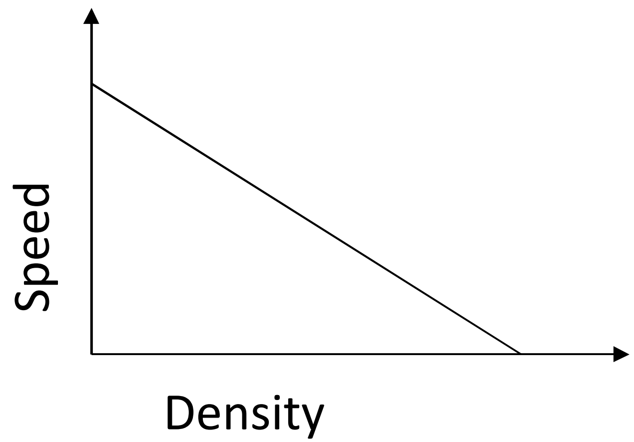


**Figure 5.4 Linear speed-density relationship for the linear model**

# Basic Traffic Stream Models

- Mathematical representation of the linear speed-density model can be written as

$$u = u_f \left(1 - \frac{k}{k_j}\right) \tag{5.21}$$

Where;

***u*** = space-mean speed in (km/h),

$u_f$ = free-flow speed in (km/h),

***k*** = density in (veh/km), and

$k_j$ = jam density in (veh/km).

# Basic Traffic Stream Models

- **Flow-Density relation for the linear model:** Using the assumption of a **linear speed-density relationship** as given by Eq.5.21, a parabolic flow-density relation can be obtained by applying Eq.5.20 (q = u x k)

$$q = u_f \left( k - \frac{k^2}{k_j} \right) \tag{5.22}$$

Figure 5.5 shows the plot of parabolic speed-density relation

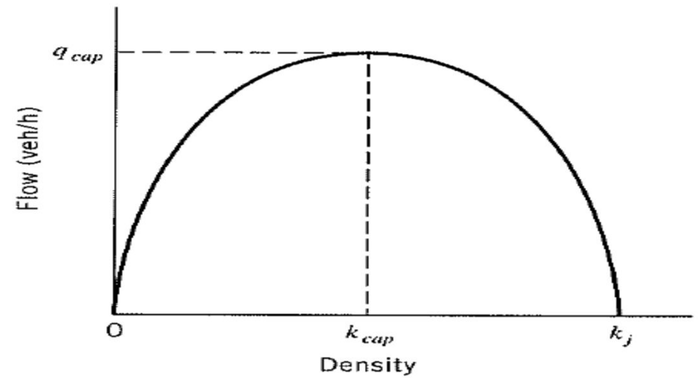


**Figure 5.5. Parabolic flow-density relationship for the linear model**

# Basic Traffic Stream Models

- Note that in Figure 5.4 the maximum flow rate, $\boldsymbol{q_{cap}}$, represents the highest rate of traffic flow that the highway is capable of handling. This is referred to as the **traffic flow at capacity**, or simply the **capacity** of the roadway.
- The traffic density that corresponds to this capacity flow rate is $k_{cap}$ and the corresponding speed is $u_{cap}$.
- With these definitions it follows:

$$q_{max} = q_{cap} \rightarrow \frac{\partial q}{\partial k} = 0 = u_f \left[1 - 2\left(\frac{k}{k_j}\right)\right] \rightarrow k_{cap} = \frac{k_j}{2}$$

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

# Basic Traffic Stream Models

$$q_{cap} = u_{cap} k_{cap} = \frac{u_f}{2} \frac{k_j}{2} = \frac{u_f k_j}{4} \qquad (5.23)$$

- **Speed- Density Relation for the linear Model:**

  **The linear speed-density relationship** given by Eq. 5.21 can be represented in the following form by rearranging the terms

$$k = k_j \left(1 - \frac{u}{u_f}\right) \qquad (5.24)$$

# Basic Traffic Stream Models

- a parabolic Speed-density relationship can be obtained for the linear model by using the **linear speed-density relationship** in Eq. 5.24, a parabolic flow-density model can be obtained by applying Eq.5.21 (q = u x k)

$$q = u\,k = u\,k_j\left(1 - \frac{u}{u_f}\right) = k_j\left(u - \frac{u^2}{u_f}\right) \qquad (5.25)$$

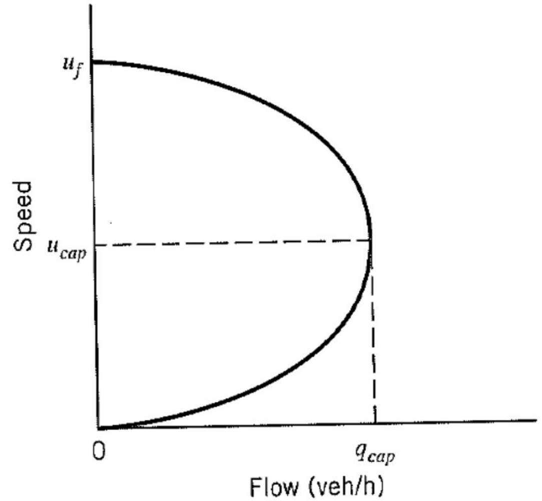


**Figure 5.6. Parabolic flow-speed relationship for the linear model**

# Basic Traffic Stream Models

- Note that Fig. 5.6 shows that two speeds are possible for flows, q, up to the highway's capacity, $q_{cap}$ (this follows from the two densities possible for given flows as shown in Fig. 5.5). It is desirable, for any given flow, to keep the average space-mean speed on the upper portion of the speed-flow curve (above $u_{cap}$). When speeds drop below $u_{cap}$, traffic is in a highly congested and unstable condition.

- Three relationships between flow, speed, and density and their interactions are graphically represented in Fig. 5.7.

# Basic Traffic Stream Models

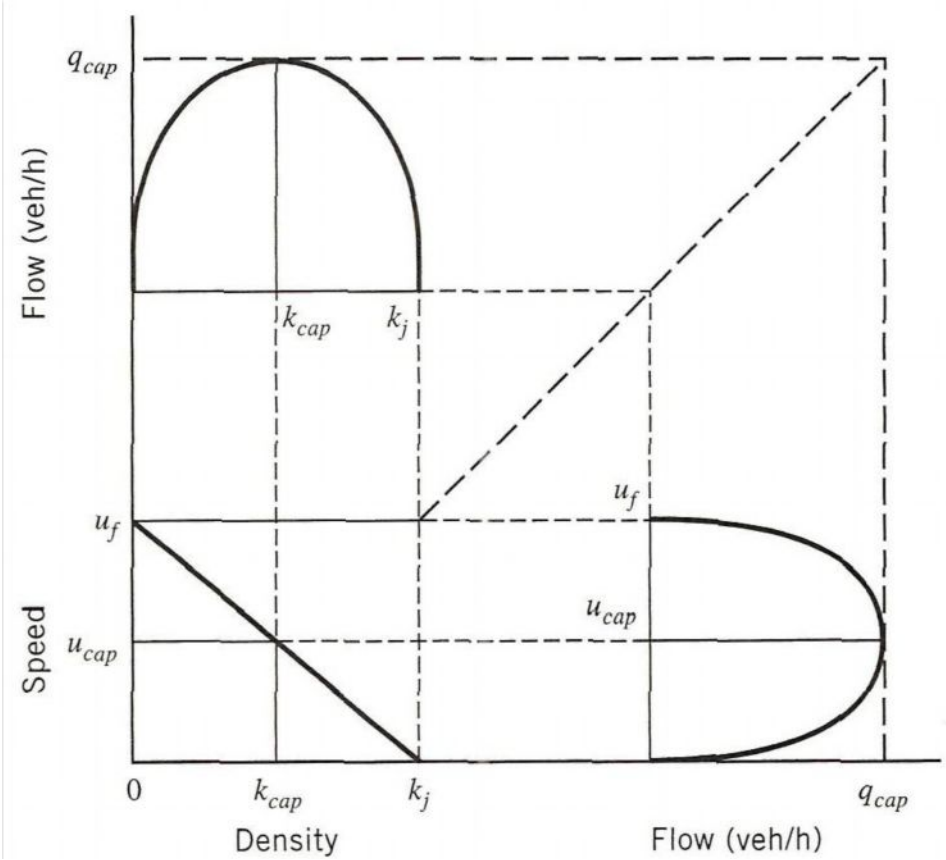


**Fig. 5.7 Flow-density, speed-density and speed flow relationships for the linear model**

# Basic Traffic Stream Models

- The advantage of using a linear representation of the speed-density relationship is that it provides a basic insight into the relationships among traffic flow, speed, and density interactions without clouding these insights by the additional complexity that a nonlinear speed-density relationship introduces.
- However, it is important to note that field studies have shown that the speed-density relationship tends to be nonlinear at low densities and high densities (those that approach the jam density).

# Basic Traffic Stream Models

- In fact, the overall speed-density relationship is better represented by three relationships:

  (1) a nonlinear relationship at low densities that has speed slowly declining from the free flow value,

  (2) a linear relationship over the large medium-density region (speed declining linearly with density as shown in Fig.5.4), and

  (3) a nonlinear relationship near the jam density as the speed asymptotically approaches zero with increasing density.

- For this purpose, there exist some basic nonlinear traffic stream models. The commonly known models are logarithmic  Model (Greenberg Model), negative exponential model (Underwoods Model)

**Example:**

A section of highway is known to have a free flow speed of 90 km/hr and a capacity of 3600 veh/h. In a given hour, 1920 vehicles were counted at a specific point along this highway section. IF the linear speed-density relationship applies, estimate the space mean speed of these 1920 vehicles.

The parameters of traffic flow:

$u_f$ = 90 km/hr (given)

$q_{cap}$ = 3600 veh/h (given)

$q$ = 1920 veh/h (given for the specific hour)

$u$ = ?

q-u relation is given by (Eq. 5.25)

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

From Eq. 5.23

$$k_j = \frac{4q_{cap}}{u_f} = \frac{4\ x3600}{90} = 160\ veh/h$$

From Eq.5.25

$1920 = 160\ (u - u^2/90)$

u = 75.74 km/h

or

u= 14.26 km/h