Traffic Flow Characteristics

CIVL 4162/6162
(Traffic Engineering)
Lesson Objective

• Define traffic stream parameters

• Establish the relationship between traffic stream parameters

• Calculate and compute parameters with given data
What is a Traffic Stream

- Traffic streams are made up of
  - Individual drivers
  - Vehicles
  - Roadway and environment

- Driver behavior and vehicle characteristics typically vary

- No two traffic streams will behave exactly in the same way
Variability in Traffic Stream (1)

- Traffic flow (movement of vehicles) involves variability
  - Unlike pipe flow (homogeneous)
- A given traffic flow will vary
  - By time
  - By space
- Constraints are defined by
  - Physical constraints
  - Complex driver characteristics
Variability in Traffic Stream (2)

- Although traffic characteristics vary there is a reasonable range
  - Example: In a 65 miles/hr roadway some drivers will drive 50 miles/hr and some will drive 80 miles/hr
  - There exists a range

- Before we study traffic characteristics let us see what are
  - Facilities
  - Basic flow parameters
Types of Facilities

- **Uninterrupted Flow Facilities**
  - No external interruptions
  - Primarily on freeways
  - Also on certain segments of long rural highways
  - In peak hours also freeways are uninterrupted

- **Interrupted Flow Facilities**
  - External interruptions exists
  - Most frequent are signals, stop/yield signs
  - Creates platoons of vehicles progress in traffic stream
Types of Facilities and Major Difference

- The major difference between two facilities
  - Impact of time (no interventions at any time)
  - Availability of roadways
    - On uninterrupted facilities roadways are available to users all the time
    - But sections of roadway are not available to users because of traffic control (signal, stop, and yield signs)
Traffic Stream Parameters

Macroscopic
- Volume
- Speed
- Density

Microscopic
- Speed of individual vehicles
- Headway
- Spacing

*These characteristics are primarily for uninterrupted flow
Volume

• Traffic volume is defined as the number of vehicles passing a point on highway or a given lane or direction of a highway in a specific time

• Unit: vehicles per unit time

• Usually expressed as vehicles / hour

• Denoted as veh/hr
Rate of Flow

- Rate of flow are generally expressed in units of “veh/hr” but represents flows that exist for a period of time less than an hour.
- Example: 200 vehicles are observed for 15 min.
- The equivalent hourly volume will be 800 veh/hr.
- Even though 800 veh/hr would not be observed if one hour was counted.
Daily Volumes (1)

- **Average Annual Daily Traffic (AADT)** -
  - The average 24 hour volume at a given location over a full 365 day year.
  - avg. 24-hour volume at a site over a full year

- **Average Annual Weekday Traffic (AAWT)** -
  - The average 24 hour volume at a given location occurring on weekdays over a full 365 day year.
  - Usually 260 days week days per year
Daily Volumes (2)

- **Average Daily Traffic (ADT)** - The average 24 hour volume at a given location over a defined time period less than a year

- **Average Weekday Traffic (AWT)** - The average 24 hour weekday volume at a given location over a defined period less than one year
Example: Daily Volume

Table 5.1: Illustration of Daily Volume Parameters

<table>
<thead>
<tr>
<th>Month</th>
<th>2. No. of Weekdays in Month (days)</th>
<th>3. Total Days in Month (days)</th>
<th>4. Total Monthly Volume (vehs)</th>
<th>5. Total Weekday Volume (vehs)</th>
<th>6. AWT 5/2 (veh/day)</th>
<th>7. ADT 4/3 (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>22</td>
<td>31</td>
<td>425,000</td>
<td>208,000</td>
<td>9,455</td>
<td>13,710</td>
</tr>
<tr>
<td>Feb</td>
<td>20</td>
<td>28</td>
<td>410,000</td>
<td>220,000</td>
<td>11,000</td>
<td>14,643</td>
</tr>
<tr>
<td>Mar</td>
<td>22</td>
<td>31</td>
<td>385,000</td>
<td>185,000</td>
<td>8,409</td>
<td>12,419</td>
</tr>
<tr>
<td>Apr</td>
<td>22</td>
<td>30</td>
<td>400,000</td>
<td>200,000</td>
<td>9,091</td>
<td>13,333</td>
</tr>
<tr>
<td>May</td>
<td>21</td>
<td>31</td>
<td>450,000</td>
<td>215,000</td>
<td>10,238</td>
<td>14,516</td>
</tr>
<tr>
<td>Jun</td>
<td>22</td>
<td>30</td>
<td>500,000</td>
<td>230,000</td>
<td>10,455</td>
<td>16,667</td>
</tr>
<tr>
<td>Jul</td>
<td>23</td>
<td>31</td>
<td>580,000</td>
<td>260,000</td>
<td>11,304</td>
<td>18,710</td>
</tr>
<tr>
<td>Aug</td>
<td>21</td>
<td>31</td>
<td>570,000</td>
<td>260,000</td>
<td>12,381</td>
<td>18,387</td>
</tr>
<tr>
<td>Sep</td>
<td>22</td>
<td>30</td>
<td>490,000</td>
<td>205,000</td>
<td>9,318</td>
<td>16,333</td>
</tr>
<tr>
<td>Oct</td>
<td>22</td>
<td>31</td>
<td>420,000</td>
<td>190,000</td>
<td>8,636</td>
<td>13,548</td>
</tr>
<tr>
<td>Nov</td>
<td>21</td>
<td>30</td>
<td>415,000</td>
<td>200,000</td>
<td>9,524</td>
<td>13,833</td>
</tr>
<tr>
<td>Dec</td>
<td>22</td>
<td>31</td>
<td>400,000</td>
<td>210,000</td>
<td>9,545</td>
<td>12,903</td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
<td>365</td>
<td>5,445,000</td>
<td>2,583,000</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

$$AADT = \frac{5,445,000}{365} = 14,918 \text{ veh/day}$$

$$AAWT = \frac{2,583,000}{260} = 9,935 \text{ veh/day}$$
Hourly Volume

- Measured in volume/hour
- Used for design and operational purposes
- The hour with highest volume is referred as Peak hour
  - Peak hour
- Peak hour volume is stated as directional volume
- Sometimes referred as Directional Design Hourly Volume (DDHV)
DDHV

- DDHV = directional design hourly volume
  \[ DDHV = AADT \times K \times D \]
  where \( K \) = proportion of AADT that occurs during design hour
  \( D \) = proportion of peak hour traffic traveling in the peak direction
K-Factor

- Typically, K factor represents proportion of AADT occurring during 30th peak hour of the year
- How does K-factor vary by urban density?
  - Urban, suburban, and rural
- D Factors
  - More variable than K
  - Influenced by development density, radial vs. circumferential route
# K and D Factor

## Table 5.2: General Ranges for K and D Factors

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Normal Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K-Factor</td>
</tr>
<tr>
<td>Rural</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td>Suburban</td>
<td>0.12–0.15</td>
</tr>
<tr>
<td>Urban:</td>
<td></td>
</tr>
<tr>
<td>Radial Route</td>
<td>0.07–0.12</td>
</tr>
<tr>
<td>Circumferential Route</td>
<td>0.07–0.12</td>
</tr>
</tbody>
</table>

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### Table 5.3: Illustration of Volumes and Rates of Flow

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Volume for Time Interval (vehs)</th>
<th>Rate of Flow for Time Interval (vehs/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00–5:15 PM</td>
<td>1,000</td>
<td>1,000/0.25 = 4,000</td>
</tr>
<tr>
<td>5:15–5:30 PM</td>
<td>1,100</td>
<td>1,100/0.25 = 4,400</td>
</tr>
<tr>
<td>5:30–5:45 PM</td>
<td>1,200</td>
<td>1,200/0.25 = 4,800</td>
</tr>
<tr>
<td>5:45–6:00 PM</td>
<td>900</td>
<td>900/0.25 = 3,600</td>
</tr>
<tr>
<td>5:00–6:00 PM</td>
<td>( \Sigma = 4,200 )</td>
<td></td>
</tr>
</tbody>
</table>
Volume vs. Flow Rate

If capacity is 4,200 vph:

Table 5.4: Queuing Analysis for the Data of Table 5.3

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Arriving Vehicles (vehs)</th>
<th>Departing Vehicles (vehs)</th>
<th>Queue Size at End of Period (vehs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:00–5:15 PM</td>
<td>1,000</td>
<td>1,050</td>
<td>0</td>
</tr>
<tr>
<td>5:15–5:30 PM</td>
<td>1,100</td>
<td>1,050</td>
<td>0 + 1,100 − 1,050 = 50</td>
</tr>
<tr>
<td>5:30–5:45 PM</td>
<td>1,200</td>
<td>1,050</td>
<td>50 + 1,200 − 1,050 = 200</td>
</tr>
<tr>
<td>5:45–6:00 PM</td>
<td>900</td>
<td>1,050</td>
<td>200 + 900 − 1,050 = 50</td>
</tr>
</tbody>
</table>

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Peak Hour Factor

15 minutes is considered to be minimum period of time over which traffic can be considered statistically stable.

Peak hour factor (PHF) represents the uniformity of flow in the peak hour.

\[ PHF = \frac{V}{4 \times V_{m15}} \]

where:
- \( V \) = hourly volume, vehs
- \( V_{m15} \) = max 15 min volume within the hour, vehs
Peak Hour Factor (2)

- \( \text{PHF} = \frac{4200}{(4 \times 1200)} = 0.875 \)

### Table 5.3: Illustration of Volumes and Rates of Flow

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<tr>
<td>5:15–5:30 PM</td>
<td>1,100</td>
<td>1,100/0.25 = 4,400</td>
</tr>
<tr>
<td>5:30–5:45 PM</td>
<td>1,200</td>
<td>1,200/0.25 = 4,800</td>
</tr>
<tr>
<td>5:45–6:00 PM</td>
<td>900</td>
<td>900/0.25 = 3,600</td>
</tr>
<tr>
<td>5:00–6:00 PM</td>
<td>( \Sigma = 4,200 )</td>
<td></td>
</tr>
</tbody>
</table>
Peak Hour Factor (3)

- Peak hour factor lie between 0.25-1
  - 0.25 when all traffic is concentrated in one 15 minute period
  - 1.0 when traffic on all 15 minute period are same
- Under very congested conditions PHF~1
- Practical studies show that
  - PHF~0.7 for rural roadways
  - PHF~0.98 in dense urban roadways
Speed

- Speed and travel time are inversely related
  - \( S = \frac{d}{t} \)
  - Where \( S \rightarrow \) speed in mi/hr; \( d \rightarrow \) distance traversed in mi; \( t \rightarrow \) time to traverse distance \( d \) in hr

- Average speed in a traffic stream can be computed in two ways:
  - Time mean speed (TMS) - average speed of all vehicles passing a point over a specified time period.
  - Space mean speed (SMS) - average speed of all vehicles occupying a given section of roadway over a specific time period.
TMS and SMS

- **TMS**
  \[ TMS = \frac{\sum_i \left( \frac{d}{t_i} \right)}{n} \]

- **SMS**
  \[ SMS = \frac{d}{\sum_i \left( \frac{t_i}{n} \right)} \]

- **Where**
  - \( d \rightarrow \) distance traversed, ft
  - \( n \rightarrow \) number of observed vehicles
  - \( t_i \rightarrow \) time for vehicle “i” to traverse the distance \( d \)
### Example: TMS and SMS

#### Table 5.5: Illustrative Computation of TMS and SMS

<table>
<thead>
<tr>
<th>Vehicle No.</th>
<th>Distance (ft)</th>
<th>Travel Time (s)</th>
<th>Speed (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000</td>
<td>18.0</td>
<td>1,000/18 = 55.6</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>20.0</td>
<td>1,000/20 = 50.0</td>
</tr>
<tr>
<td>3</td>
<td>1,000</td>
<td>22.0</td>
<td>1,000/22 = 45.5</td>
</tr>
<tr>
<td>4</td>
<td>1,000</td>
<td>19.0</td>
<td>1,000/19 = 52.6</td>
</tr>
<tr>
<td>5</td>
<td>1,000</td>
<td>20.0</td>
<td>1,000/20 = 50.0</td>
</tr>
<tr>
<td>6</td>
<td>1,000</td>
<td>20.0</td>
<td>1,000/20 = 50.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,000</strong></td>
<td><strong>119</strong></td>
<td><strong>303.7</strong></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>6,000/6 = 1,000</strong></td>
<td><strong>119/6 = 19.8</strong></td>
<td><strong>303.7/6 = 50.6</strong></td>
</tr>
</tbody>
</table>

TMS = 50.6 ft/s

SMS = 1,000/19.8 = 50.4 ft/s

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Example: Time Mean vs Space Mean Speed

![Diagram showing Time Mean Speed and Space Mean Speed](image)

**Figure 5.1** Time Mean Speed and Space Mean Speed Illustrated

\[
TMS = \frac{88n+44n}{2n} = 66 \text{ ft/sec}
\]

\[
SMS = \frac{88n+44 \times 2n}{3n} = 58.7 \text{ ft/sec}
\]
Traffic Flow Basics (1)

Consider a long, uninterrupted, single-lane roadway:

No passing, no opposing traffic, no intersections
Traffic Flow Basics (2)
Traffic Flow Basics-Speed

Distance \((x)\) vs. Time \((t)\)
Traffic Flow Basics - Trajectories

Distance ($x$) vs. Time ($t$)
Traffic Flow Basics - Trajectory Plots

This is called a **time-space** diagram
Consider a horizontal “slice” of the diagram.
Traffic Flow Basics-Volume

The number of trajectories crossing this line is the number of vehicles passing a fixed point on the road.

This is called the **volume** or **flow**, and has units of vehicles per time (usually veh/hr).
What does a vertical slice tell us?
The number of trajectories crossing this line is the number of vehicles on the road at one instant in time. This is called the density, and has units of vehicles per distance (usually veh/mi).
Density

- Most direct measure of traffic demand
- Difficult to measure directly
- Important measure of quality of traffic flow
- Occupancy is related, and can be measured directly
- Occupancy - proportion of time that a detector is occupied by a vehicle in a defined time period.
Density and Occupancy

Figure 5.2 Density and Occupancy Illustrated
## Traffic Flow Basics-Summary (1)

<table>
<thead>
<tr>
<th>Flow</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>veh/hr</td>
<td>veh/mi</td>
</tr>
<tr>
<td>Measured over time at a fixed point</td>
<td>Measured over space at a fixed time</td>
</tr>
<tr>
<td>How many vehicles are getting somewhere?</td>
<td>How crowded is the roadway?</td>
</tr>
<tr>
<td>Can measure with a point detector</td>
<td>Can measure with an aerial photo</td>
</tr>
<tr>
<td>$q$</td>
<td>$k$</td>
</tr>
</tbody>
</table>
# Traffic Flow Basics-Summary (1)

<table>
<thead>
<tr>
<th>Individual vehicle</th>
<th>Traffic stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [L/T]</td>
<td>Flow [V/T]</td>
</tr>
<tr>
<td></td>
<td>Density [V/L]</td>
</tr>
</tbody>
</table>
Traffic Flow Basics-Summary (3)

Classify the quantities

<table>
<thead>
<tr>
<th>Individual vehicle</th>
<th>Traffic stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [L/T]</td>
<td></td>
</tr>
<tr>
<td>Flow [V/T]</td>
<td></td>
</tr>
<tr>
<td>Density [V/L]</td>
<td></td>
</tr>
</tbody>
</table>

Brackets describe units… L = Length, T = time, V = vehicles
Let's try to fill in the rest of the table.

<table>
<thead>
<tr>
<th>Individual vehicle</th>
<th>Traffic stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [L/T]</td>
<td></td>
</tr>
<tr>
<td>Time Headway [T]</td>
<td>Flow [V/T]</td>
</tr>
<tr>
<td></td>
<td>Density [V/L]</td>
</tr>
</tbody>
</table>
The **time headway** is the time between two vehicles passing a point.
Headway

On a space-time diagram, it is the **horizontal distance** between two adjacent trajectories.
Traffic Flow Basics-Summary (5)

Let’s try to fill in the rest of the table.

<table>
<thead>
<tr>
<th>Individual vehicle</th>
<th>Traffic stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [L/T]</td>
<td></td>
</tr>
<tr>
<td>Time Headway [T]</td>
<td>Flow [V/T]</td>
</tr>
<tr>
<td>Space Headway [L]</td>
<td>Density [V/L]</td>
</tr>
</tbody>
</table>
Traffic Flow Basics - Space Headway (1)

The **space headway** is the distance between two vehicles.
Traffic Flow Basics - Space Headway (2)

On a space-time diagram, it is the **vertical distance** between two adjacent trajectories.
<table>
<thead>
<tr>
<th>Individual vehicle</th>
<th>Traffic stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed [L/T]</td>
<td>Average Speed [L/T]</td>
</tr>
<tr>
<td>Time Headway [T]</td>
<td>Flow [V/T]</td>
</tr>
<tr>
<td>Space Headway [L]</td>
<td>Density [V/L]</td>
</tr>
</tbody>
</table>

Let’s try to fill in the rest of the table.
Basic Equation for Uninterrupted Flow:

\[ q = ku \ (v = SD \text{ in your book}) \]

where:

\[ q = \text{flow rate, vph or veh/h/ln} \]
\[ k = \text{density, veh/mi or veh/mi/ln} \]
\[ u = \text{space mean speed, mph} \]
Figure 5.4  Relationships among Speed, Flow, and Density (Source: Used with permission of Transportation Research Board, National Research Council, from Highway Capacity Manual, 3rd Edition, Special Report 209, pp. 1-7, Washington DC, 1994.)
Three Parameters of Traffic Flow

- Macroscopic:
  - Speed \((V)\)
  - Density \((K)\)
  - Flow \((Q)\)

\[ Q = KV \]
Spacing

• **Spacing** is defined as the distance between successive vehicles in a traffic lane; measured from common reference
  - Front bumper or
  - Front wheels

• **Average spacing** in a traffic lane is related to density
  \[ d_a = \frac{5280}{k} \]

  Where,
  \( k = \text{density in veh/mile/lane} \)
  \( d_a = \text{Average spacing between vehicles in ft} \)
Headway

- **Headway** is defined as the time interval between successive vehicles as they pass along a lane.
- Also measured between common point of reference.

\[ h_a = \frac{3,600}{q} \]

Where,
- \( q \) = traffic volume in veh/hour/lane
- \( h_a = \text{Average headway in the lane} \) in sec
Example

- Traffic in an interstate at 7:15 AM is observed to have spacing of 250 feet; and average headway of 3 sec. Estimate
  - Volume
  - Density
  - Speed
Solution

Step1: Calculate flow
\[ q = \frac{3,600}{h_a} = \frac{3,600}{3} = 1,200 \text{ veh/hour/lane} \]

Step-2: Calculate density
\[ k = \frac{5,280}{d_a} = \frac{5,280}{250} = 21.12 \text{ veh/miile/lane} \]

Step-3: Calculate Speed
\[ q = uk \Rightarrow u = \frac{q}{k} = \frac{1200}{21.12} = 56.81 \text{ miles/hour} \]
Example

A study of freeway flow at a particular site has resulted in a calibrated speed-density relationship as follows: (Note the difference in notation)

\[ S = 57.5(1 - 0.008D) \]

For this relationship, determine:

a. Free-flow speed
b. Jam density
c. Speed-flow relationship
d. Flow-density relationship
e. Capacity