Traffic studies may be grouped into three main categories:

1. Inventories,
2. Administrative studies, and
3. Dynamic studies.
Traffic Engineering Studies

(1) Inventories:
provide a list or graphic display of existing information, such as:
- street widths,
- parking spaces,
- transit routes,
- traffic regulations.

Traffic Engineering Studies

(2) Administrative studies
- use existing engineering records, available in government agencies and departments.
- include the results of surveys, which may involve:
  - field measurements and/or
  - aerial photography.
(3) Dynamic traffic studies

- involve the collection of data under operational conditions and
- include studies of:
  - speed,
  - traffic volume,
  - travel time and delay,
  - parking, and
  - crashes.
- They are described in detail in this chapter.

4.1 SPOT SPEED STUDIES

- Spot speed studies are conducted to estimate the distribution of speeds of vehicles in a stream of traffic at a particular location on a highway.
- carried out by recording the speeds of a sample of vehicles at a specified location.
Traffic Engineering Studies

- **SPOT SPEED STUDIES**

  Used to:
  - Establish parameters for traffic operation and control, such as:
    - speed zones,
    - speed limits (85th-percentile speed)

Traffic Engineering Studies

- **4.1.1 Locations for Spot Speed Studies**
  - Represent different traffic conditions on a highway for basic data collection.
  - Mid-blocks of urban highways and straight, level sections of rural highways for speed trend analyses.
  - Any location may be used for solution of a specific traffic engineering problem.
4.1.1 Locations for Spot Speed Studies

Should be selected to achieve the following:
- Unbiased data
- Drivers be unaware
- Equipment concealed from the driver,
- Observers inconspicuous.

statistical analysis,
statistically adequate number of vehicle speeds be recorded.
Traffic Engineering Studies

4.1.2 Time of Day and Duration of Spot Speed Studies
- depends on the purpose of the study.
- recommended when traffic is free-flowing,
- during off-peak hours.
- typically:
  - the duration is at least 1 hour and
  - the sample size is at least 30 vehicles.

Traffic Engineering Studies

4.1.3 Sample Size for Spot Speed Studies
- The larger the sample size, will give an estimated mean within acceptable error limits.
  - Average Speed
  - Median Speed
  - Modal Speed
  - The ith-percentile Spot Speed
  - Pace
  - Standard Deviation of Speeds
4.1.4 Methods for Conducting Spot Speed Studies

- manual and automatic
- manual method is seldom used
- automatic devices
  1. road detectors
  2. radar-based
  3. the principles of electronics.

Road Detectors

- pneumatic road tubes & induction loops collect data on speeds & volume at the same time

**Advantage:**
- Human errors are considerably reduced

**Disadvantages:**
- expensive
- may, affect driver behavior,
Traffic Engineering Studies

- Pneumatic road tubes
  - laid across the lane in which data are to be collected.
  - When moving vehicle passes over, an air impulse is transmitted to the counter.
  - two tubes are placed across the lane, 2 m apart.
  - An impulse is recorded when the front wheels of a moving vehicle pass over the first tube;

Traffic Engineering Studies

- Pneumatic road tubes
  - a second impulse is recorded when the front wheels pass over the second tube.
  - The time elapsed between the two impulses and the distance between the tubes are used to compute the speed of the vehicle.
Traffic Engineering Studies

- inductive loop
  - a rectangular wire loop buried under the roadway surface.
  - It operates on the principle that a disturbance in the electrical field is created when a motor vehicle passes across it.

Traffic Engineering Studies

- Radar-Based Traffic Sensors
- Electronic-Principle Detectors
  - traffic characteristics, such as speed, volume, queues, and headways are computed.
  - Using video image processing
Traffic Engineering Studies

(a) RTMS Deployed in the Forward Looking Mode

(b) RTMS Deployed in the Side-fire Mode
Traffic Engineering Studies

(a) Schematic Illustration of the Auto scope

(b) The Auto scope Deployed
4.1.5 Presentation and Analysis of Spot Speed Data

- Statistical methods
- Analyzing data
- frequency histogram
- cumulative frequency distribution curve

Example 4.2 Determining Speed Characteristics from a Set of Speed Data.

Table 4.2 shows the data collected on a rural highway in Virginia during a speed study. Develop the frequency histogram and the frequency distribution of the data and determine:
Traffic Engineering Studies

1. The arithmetic mean speed
2. The standard deviation
3. The median speed
4. The pace
5. The mode or modal speed
6. The 85th-percentile speed

Solution:
The speeds range from 34.8 to 65.0 km/h, giving a speed range of 30.2.
For eight classes, the range per class is 3.75 km/h;
for 20 classes, the range per class is 1.51 km/h.
It is convenient to choose a range of 2 km/h per class which will give 16 classes.
A frequency distribution table can then be prepared, as shown in Table 4.3.
Table 4.2 Speed Data Obtained on a Rural Highway

<table>
<thead>
<tr>
<th>Car No.</th>
<th>Speed (mi/h)</th>
<th>Car No.</th>
<th>Speed (mi/h)</th>
<th>Car No.</th>
<th>Speed (mi/h)</th>
<th>Car No.</th>
<th>Speed (mi/h)</th>
<th>Car No.</th>
<th>Speed (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35.1</td>
<td>23</td>
<td>46.1</td>
<td>45</td>
<td>47.8</td>
<td>67</td>
<td>56.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>44.0</td>
<td>24</td>
<td>54.2</td>
<td>46</td>
<td>47.1</td>
<td>68</td>
<td>49.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45.8</td>
<td>25</td>
<td>52.3</td>
<td>47</td>
<td>34.8</td>
<td>69</td>
<td>49.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>44.3</td>
<td>26</td>
<td>57.3</td>
<td>48</td>
<td>52.4</td>
<td>70</td>
<td>56.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>36.3</td>
<td>27</td>
<td>46.8</td>
<td>49</td>
<td>49.1</td>
<td>71</td>
<td>48.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>54.0</td>
<td>28</td>
<td>57.8</td>
<td>50</td>
<td>37.1</td>
<td>72</td>
<td>45.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>42.1</td>
<td>29</td>
<td>36.8</td>
<td>51</td>
<td>65.0</td>
<td>73</td>
<td>48.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>50.1</td>
<td>30</td>
<td>55.8</td>
<td>52</td>
<td>49.5</td>
<td>74</td>
<td>52.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>51.8</td>
<td>31</td>
<td>43.3</td>
<td>53</td>
<td>52.2</td>
<td>75</td>
<td>49.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>50.8</td>
<td>32</td>
<td>55.3</td>
<td>54</td>
<td>48.4</td>
<td>76</td>
<td>63.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>38.3</td>
<td>33</td>
<td>39.0</td>
<td>55</td>
<td>42.8</td>
<td>77</td>
<td>60.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>44.6</td>
<td>34</td>
<td>53.7</td>
<td>56</td>
<td>49.5</td>
<td>78</td>
<td>48.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>45.2</td>
<td>35</td>
<td>40.8</td>
<td>57</td>
<td>48.6</td>
<td>79</td>
<td>52.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>41.1</td>
<td>36</td>
<td>54.5</td>
<td>58</td>
<td>41.2</td>
<td>80</td>
<td>48.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>55.1</td>
<td>37</td>
<td>51.6</td>
<td>59</td>
<td>48.0</td>
<td>81</td>
<td>61.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>50.2</td>
<td>38</td>
<td>51.7</td>
<td>60</td>
<td>58.0</td>
<td>82</td>
<td>56.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>54.3</td>
<td>39</td>
<td>50.3</td>
<td>61</td>
<td>49.0</td>
<td>83</td>
<td>48.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>45.4</td>
<td>40</td>
<td>50.8</td>
<td>62</td>
<td>41.8</td>
<td>84</td>
<td>62.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>55.2</td>
<td>41</td>
<td>40.3</td>
<td>63</td>
<td>48.3</td>
<td>85</td>
<td>53.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>45.7</td>
<td>42</td>
<td>55.1</td>
<td>64</td>
<td>45.9</td>
<td>86</td>
<td>53.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>54.1</td>
<td>43</td>
<td>45.0</td>
<td>65</td>
<td>44.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>54.0</td>
<td>44</td>
<td>48.3</td>
<td>66</td>
<td>49.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.4 Histogram of Observed Vehicles' Speeds
Table 4.3 Frequency Distribution Table for Set of Speed Data

<table>
<thead>
<tr>
<th>Speed Class (mi/hr)</th>
<th>Class Midvalue, $u_i$</th>
<th>Class Frequency (Number of Observations in Class), $f_i$</th>
<th>$f_iu_i$</th>
<th>Percentage of Observations in Class</th>
<th>Cumulative Percentage of All Observations</th>
<th>$f_i(u_i - u)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>34–35.9</td>
<td>35.0</td>
<td>2</td>
<td>70</td>
<td>2.3</td>
<td>2.30</td>
<td>420.5</td>
</tr>
<tr>
<td>36–37.9</td>
<td>37.0</td>
<td>3</td>
<td>111</td>
<td>3.5</td>
<td>5.80</td>
<td>468.75</td>
</tr>
<tr>
<td>38–39.9</td>
<td>39.0</td>
<td>2</td>
<td>78</td>
<td>2.3</td>
<td>8.10</td>
<td>220.50</td>
</tr>
<tr>
<td>40–41.9</td>
<td>41.0</td>
<td>5</td>
<td>205</td>
<td>5.8</td>
<td>13.90</td>
<td>364.25</td>
</tr>
<tr>
<td>42–43.9</td>
<td>43.0</td>
<td>3</td>
<td>129</td>
<td>3.5</td>
<td>17.40</td>
<td>128.75</td>
</tr>
<tr>
<td>44–45.9</td>
<td>45.0</td>
<td>11</td>
<td>405</td>
<td>12.8</td>
<td>30.20</td>
<td>222.75</td>
</tr>
<tr>
<td>46–47.9</td>
<td>47.0</td>
<td>4</td>
<td>198</td>
<td>4.7</td>
<td>34.90</td>
<td>25.00</td>
</tr>
<tr>
<td>48–49.9</td>
<td>49.0</td>
<td>18</td>
<td>892</td>
<td>21.0</td>
<td>55.90</td>
<td>9.00</td>
</tr>
<tr>
<td>50–51.9</td>
<td>51.0</td>
<td>7</td>
<td>357</td>
<td>8.1</td>
<td>64.00</td>
<td>15.75</td>
</tr>
<tr>
<td>52–53.9</td>
<td>53.0</td>
<td>8</td>
<td>424</td>
<td>9.3</td>
<td>73.30</td>
<td>9.00</td>
</tr>
<tr>
<td>54–55.9</td>
<td>55.0</td>
<td>11</td>
<td>605</td>
<td>12.8</td>
<td>86.10</td>
<td>332.75</td>
</tr>
<tr>
<td>56–57.9</td>
<td>57.0</td>
<td>5</td>
<td>265</td>
<td>5.8</td>
<td>91.90</td>
<td>281.25</td>
</tr>
<tr>
<td>58–59.9</td>
<td>59.0</td>
<td>2</td>
<td>118</td>
<td>2.3</td>
<td>94.20</td>
<td>130.50</td>
</tr>
<tr>
<td>60–61.9</td>
<td>61.0</td>
<td>2</td>
<td>122</td>
<td>2.3</td>
<td>96.50</td>
<td>264.50</td>
</tr>
<tr>
<td>62–63.9</td>
<td>63.0</td>
<td>2</td>
<td>126</td>
<td>2.3</td>
<td>98.80</td>
<td>364.50</td>
</tr>
<tr>
<td>64–65.9</td>
<td>65.0</td>
<td>1</td>
<td>65</td>
<td>1.2</td>
<td>100.00</td>
<td>240.25</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>86</td>
<td>4260</td>
<td>2632.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.5 Frequency Distribution
The median speed is 49 km/h, the 50th-percentile speed.

85th-percentile speed is 54 km/h.
4.2 VOLUME STUDIES
1. **Average Annual Daily Traffic (AADT)**
   the average of 24-hour counts collected every day of the year.
2. **Average Daily Traffic (ADT)**
   the average of 24-hour counts collected over a number of days greater than one but less than a year.
3. **Peak Hour Volume (PHV)**
   the maximum number of vehicles that pass a point on a highway during a period of 60 consecutive minutes.
4. **Vehicle Classification (VC)** with respect to the type of vehicles for cars, two-axle trucks, or three-axle trucks.
5. **Vehicle Miles of Travel (VMT)**
4.2.1 Methods of Conducting Volume Counts

- Manual Method
- Automatic Method
Traffic Engineering Studies

Figure 4.9 Apollo Traffic Counter/Classifier

Traffic Engineering Studies

Figure 4.10 Example of Counters that Require the Laying of Subsurface Detectors
Traffic Engineering Studies

Figure 4.11 Traffic Eye Universal System

Traffic Engineering Studies

Figure 4.12 Example of Station Locations for a Cordon Count
Traffic Engineering Studies

4.2.2 Types of Volume Counts
- Depending on the anticipated use of the data to be collected.
- Intersection Counts
  - vehicle classifications,
  - through movements,
  - turning movements.

4.2.2 Types of Volume Counts
- Pedestrian Volume Counts
- Periodic Volume Counts (AADT)
Traffic Engineering Studies

4.2.3 Traffic Volume Data Presentation

- **Traffic Flow Maps:** volume of traffic on each route is represented by the width of a band. *Figure 4.13 shows a typical traffic flow map.*

*Figure 4.13 Example of a Traffic Flow Map*

Traffic Engineering Studies

- **Intersection Summary Sheets:**

  *Figure 4.14 shows a typical intersection summary sheet.*

*Figure 4.14 Intersection Summary Sheet*
Traffic Engineering Studies

4.2.3 Traffic Volume Data Presentation

- Time-Based Distribution Charts:
  see Figure 4.15

Daily variations:
see Figure 4.15b

Figure 4.15 Traffic Volumes on an Urban Highway (A&B)
Traffic Engineering Studies

Hourly variations in traffic volume:

Figure 4.15 Traffic Volumes on an Urban Highway

Summary Tables:

PHV, Vehicle Classification (VC), and ADT. See Table 4.4

Table 4.4 Summary of Traffic Volume Data for a Highway Section

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHV</td>
<td>430</td>
</tr>
<tr>
<td>ADT</td>
<td>5375</td>
</tr>
<tr>
<td>Vehicle Classification (VC)</td>
<td></td>
</tr>
<tr>
<td>Passenger cars</td>
<td>70%</td>
</tr>
<tr>
<td>Two-axle trucks</td>
<td>20%</td>
</tr>
<tr>
<td>Three-axle trucks</td>
<td>8%</td>
</tr>
<tr>
<td>Other trucks</td>
<td>2%</td>
</tr>
</tbody>
</table>
Traffic Engineering Studies

- Adjustment of Periodic Counts
- Expansion Factors from Continuous Count Stations.
- Hourly expansion factors (HEFs) are determined by the formula
  \[ \text{HEF} = \frac{\text{total volume for 24-hr period}}{\text{volume for particular hour}} \]

Traffic Engineering Studies

- Daily expansion factors (DEFs) are computed as
  \[ \text{DEF} = \frac{\text{average total volume for week}}{\text{average volume for particular day}} \]
- Monthly expansion factors (MEFs) are computed as
  \[ \text{MEF} = \frac{\text{AADT}}{\text{ADT for particular month}} \]
### Table 4.5 Hourly Expansion Factors for a Rural Primary Road

<table>
<thead>
<tr>
<th>Hour</th>
<th>Volume</th>
<th>HEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00–7:00 a.m.</td>
<td>294</td>
<td>42.00</td>
</tr>
<tr>
<td>7:00–8:00 a.m.</td>
<td>426</td>
<td>29.00</td>
</tr>
<tr>
<td>8:00–9:00 a.m.</td>
<td>560</td>
<td>22.05</td>
</tr>
<tr>
<td>9:00–10:00 a.m.</td>
<td>657</td>
<td>18.80</td>
</tr>
<tr>
<td>10:00–11:00 a.m.</td>
<td>722</td>
<td>17.10</td>
</tr>
<tr>
<td>11:00–12:00 p.m.</td>
<td>667</td>
<td>18.52</td>
</tr>
<tr>
<td>12:00–1:00 p.m.</td>
<td>660</td>
<td>18.71</td>
</tr>
<tr>
<td>1:00–2:00 p.m.</td>
<td>739</td>
<td>16.71</td>
</tr>
<tr>
<td>2:00–3:00 p.m.</td>
<td>832</td>
<td>14.84</td>
</tr>
<tr>
<td>3:00–4:00 p.m.</td>
<td>836</td>
<td>14.77</td>
</tr>
<tr>
<td>4:00–5:00 p.m.</td>
<td>961</td>
<td>12.85</td>
</tr>
<tr>
<td>5:00–6:00 p.m.</td>
<td>892</td>
<td>13.85</td>
</tr>
</tbody>
</table>

Total daily volume = 12,350.

### Table 4.6 Daily Expansion Factors for a Rural Primary Road

<table>
<thead>
<tr>
<th>Day of Week</th>
<th>Volume</th>
<th>DEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>7895</td>
<td>9.515</td>
</tr>
<tr>
<td>Monday</td>
<td>10,714</td>
<td>7.012</td>
</tr>
<tr>
<td>Tuesday</td>
<td>9722</td>
<td>7.727</td>
</tr>
<tr>
<td>Wednesday</td>
<td>11,413</td>
<td>6.582</td>
</tr>
<tr>
<td>Thursday</td>
<td>10,714</td>
<td>7.012</td>
</tr>
<tr>
<td>Friday</td>
<td>13,125</td>
<td>5.724</td>
</tr>
<tr>
<td>Saturday</td>
<td>11,539</td>
<td>6.510</td>
</tr>
</tbody>
</table>

Total weekly volume = 75,122.
Traffic Engineering Studies

Table 4.7 Monthly Expansion Factors for a Rural Primary Road

<table>
<thead>
<tr>
<th>Month</th>
<th>ADT</th>
<th>MEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1350</td>
<td>1.756</td>
</tr>
<tr>
<td>February</td>
<td>1200</td>
<td>1.975</td>
</tr>
<tr>
<td>March</td>
<td>1450</td>
<td>1.633</td>
</tr>
<tr>
<td>April</td>
<td>1600</td>
<td>1.481</td>
</tr>
<tr>
<td>May</td>
<td>1700</td>
<td>1.394</td>
</tr>
<tr>
<td>June</td>
<td>2500</td>
<td>0.948</td>
</tr>
<tr>
<td>July</td>
<td>4100</td>
<td>0.578</td>
</tr>
<tr>
<td>August</td>
<td>4550</td>
<td>0.521</td>
</tr>
<tr>
<td>September</td>
<td>3750</td>
<td>0.632</td>
</tr>
<tr>
<td>October</td>
<td>2900</td>
<td>0.948</td>
</tr>
<tr>
<td>November</td>
<td>2000</td>
<td>1.185</td>
</tr>
<tr>
<td>December</td>
<td>1750</td>
<td>1.354</td>
</tr>
</tbody>
</table>

Total yearly volume = 28,450.
Mean average daily volume = 2370.

Traffic Engineering Studies

Example 4.5 Calculating AADT Using Expansion Factors

A traffic engineer urgently needs to determine the AADT on a rural primary road that has the volume distribution characteristics shown in Tables 4.5, 4.6, and 4.7. She collected the data shown below on a Tuesday during the month of May. Determine the AADT of the road.

<table>
<thead>
<tr>
<th>Time</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00–8:00 a.m.</td>
<td>400</td>
</tr>
<tr>
<td>8:00–9:00 a.m.</td>
<td>535</td>
</tr>
<tr>
<td>9:00–10:00 a.m.</td>
<td>650</td>
</tr>
<tr>
<td>10:00–11:00 a.m.</td>
<td>710</td>
</tr>
<tr>
<td>11:00–12 noon</td>
<td>650</td>
</tr>
</tbody>
</table>
4.3 TRAVEL TIME AND DELAY STUDIES

- Travel time: time required to travel from one point to another on a given route.
- the locations, durations, and causes of delays.
- good indication of the level of service
- identifying problem locations,
4.3.1 Applications of Travel Time and Delay Data

- efficiency of a route
- locations with relatively high delays
- causes for delays
- before-and-after studies
- relative efficiency of a route
- travel times on specific links
- economic studies

4.3.2 Definition of Terms Related to Time and Delay Studies

1. **Travel time**: time taken by a vehicle to traverse a given section of a highway.
2. **Running time**: time a vehicle is actually in motion
4.3.2 Definition of Terms Related to Time and Delay Studies

3. **Delay**: time lost due to causes beyond the control of the driver.

4. **Operational delay**: delay caused by the impedance of other traffic. (for example, parking or unparking vehicles),

5. **Stopped-time delay**

6. **Fixed delay**: caused by control devices such as traffic signals, regardless of the traffic volume

7. **Travel-time delay**: difference between the actual travel time and the travel time obtained by assuming that a vehicle traverses at an average speed equal to that for an uncongested traffic flow
4.3.3 Methods for Conducting Travel Time and Delay Studies

- Methods Requiring a Test Vehicle: floating-car, average-speed, and moving-vehicle techniques.

Floating-Car Technique:
- test car is driven by an observer along the test section.
- The driver attempts to pass as many vehicles as those that pass his test vehicle.
- Time taken to traverse the study section is recorded. This is repeated, and the average time is recorded as the travel time.
- sample size s usually less than 30,
Traffic Engineering Studies

**Average-Speed Technique.**
- driving the test car along the length of the test section at a speed that,
- is the average speed of the traffic stream.
- time required to traverse the test section is noted.
- test run is repeated
- the average time is recorded as the travel time.

Traffic Engineering Studies

**Average-Speed Technique.**
- travel time is usually obtained
- the observer starts a stopwatch at the beginning point of the test section and stops at the end.
Traffic Engineering Studies

Table 4.8 Speed and Delay Information

<table>
<thead>
<tr>
<th>Street Name</th>
<th>Date</th>
<th>Time</th>
<th>Traffic Time</th>
<th>Speed Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivy Road</td>
<td>29 North</td>
<td>Clear</td>
<td>Non-peak</td>
<td>2000-3000 p.m.</td>
</tr>
<tr>
<td>Massie Road</td>
<td>1504</td>
<td>42.6</td>
<td>25.4</td>
<td>20.1</td>
</tr>
<tr>
<td>Arlington Blvd.</td>
<td>1320</td>
<td>27.7</td>
<td>32.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Wise Street</td>
<td>792</td>
<td>19.7</td>
<td>27.4</td>
<td>8.9</td>
</tr>
<tr>
<td>Barretts Road</td>
<td>1320</td>
<td>32.1</td>
<td>26.0</td>
<td>15.4</td>
</tr>
<tr>
<td>Angus Road</td>
<td>2244</td>
<td>49.8</td>
<td>30.7</td>
<td>9.2</td>
</tr>
<tr>
<td>Hydraulic Road</td>
<td>1504</td>
<td>24.4</td>
<td>44.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Seminole Court</td>
<td>1504</td>
<td>42.6</td>
<td>25.4</td>
<td>19.5</td>
</tr>
<tr>
<td>Greenbrier Drive</td>
<td>1648</td>
<td>41.5</td>
<td>30.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Premier Court</td>
<td>1320</td>
<td>37.4</td>
<td>24.1</td>
<td>11.8</td>
</tr>
<tr>
<td>Fashion Square I</td>
<td>1504</td>
<td>25.6</td>
<td>45.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Fashion Square II</td>
<td>1056</td>
<td>19.7</td>
<td>36.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Rio Road</td>
<td>1056</td>
<td>20.2</td>
<td>35.6</td>
<td>14.1</td>
</tr>
<tr>
<td>Totals</td>
<td>17292</td>
<td>301.3</td>
<td>30.9</td>
<td>119.5</td>
</tr>
</tbody>
</table>

Note: Segment delay is the difference between observed travel time and calculated ideal travel time.

SOURCE: Study conducted in Charlottesville, VA, by Justin Black and John Ponder.

Traffic Engineering Studies

**Average-Speed Technique.**

- A second stopwatch also may be used to determine the time that passes each time the vehicle is stopped.
- will give the stopped-time delay
- Table 4.8 shows an example of a set of data obtained for such a study.
Moving-Vehicle Technique (moving observer):
- the observer makes a round trip on a test section Figure 4.16,
- The observer starts at section X-X, drives the car eastward to section Y-Y,
- turns the vehicle around
- drives westward to section X-X again

Figure 4.16 Test Site for Moving-Vehicle Method
Moving-Vehicle Technique. The following data are collected as

- The time it takes to travel east from X-X to Y-Y ($Te$), in minutes
- The time it takes to travel west from Y-Y to X-X ($Tw$), in minutes
- The number of vehicles traveling west in the opposite lane while the test car is traveling east ($Ne$)

Figure 4.16 Test Site for Moving-Vehicle Method
Moving-Vehicle Technique.

- The number of vehicles that overtake the test car while it is traveling west from Y-Y to X-X, that is, traveling in the westbound direction \((O_w)\)
- The number of vehicles that the test car passes while it is traveling west from Y-Y to X-X, that is, traveling in the westbound direction \((P_w)\)

The volume \((V_w)\) in the westbound direction can then be obtained from the expression:

\[
V_w = \frac{(N_e + O_w - P_w)60}{T_e + T_w}
\]
Traffic Engineering Studies

- where \((N_e, O_w, P_w)\) is the number of vehicles traveling westward that cross the line \(X-X\) during the time \((T_eT_w)\).
- Similarly, the average travel time in the westbound direction is obtained from

\[
\begin{align*}
\bar{T}_w &= \frac{T_w}{60} - \frac{O_w - P_w}{V_w} \\
\bar{T}_w &= T_w - \frac{60(O_w - P_w)}{V_w}
\end{align*}
\]

Traffic Engineering Studies

**Example 4.6 Volume and Travel Time Using Moving-Vehicle Technique**

The data in Table 4.9 were obtained in a travel time study on a section of highway using the moving-vehicle technique. Determine the travel time and volume in each direction at this section of the highway.

- Mean time it takes to travel eastward \((T_e) = 2.85\) min
- Mean time it takes to travel westbound \((T_w) = 3.07\) min
- Average number of vehicles traveling westward when test vehicle is traveling eastward \((N_e) = 79.50\)
- Average number of vehicles traveling eastward when test vehicle is traveling westward \((N_w) = 82.25\)
- Average number of vehicles that overtake test vehicle while it is traveling westward \((O_w) = 1.25\)
### Table 4.9 Data from Travel Time Study Using the Moving-Vehicle Technique

<table>
<thead>
<tr>
<th>Run Direction / Number</th>
<th>Travel Time (min)</th>
<th>No. of Vehicles Traveling in Opposite Direction</th>
<th>No. of Vehicles That Overtook Test Vehicle</th>
<th>No. of Vehicles Overtaken by Test Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastward</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.75</td>
<td>80</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2.55</td>
<td>75</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2.85</td>
<td>83</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>3.00</td>
<td>78</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>3.05</td>
<td>81</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>2.70</td>
<td>79</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>2.82</td>
<td>82</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>3.08</td>
<td>78</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>2.85</td>
<td>79.50</td>
<td>1.00</td>
<td>1.50</td>
</tr>
</tbody>
</table>

### Table 4.9 Data from Travel Time Study Using the Moving-Vehicle Technique

| Westward               |                   |                                               |                                           |                                          |
|------------------------|-------------------|-----------------------------------------------|-------------------------------------------|                                          |
| 1                      | 2.95              | 78                                            | 2                                         | 0                                        |
| 2                      | 3.15              | 83                                            | 1                                         | 1                                        |
| 3                      | 3.20              | 89                                            | 1                                         | 1                                        |
| 4                      | 2.83              | 86                                            | 1                                         | 0                                        |
| 5                      | 3.30              | 80                                            | 2                                         | 1                                        |
| 6                      | 3.00              | 79                                            | 1                                         | 2                                        |
| 7                      | 3.22              | 82                                            | 2                                         | 1                                        |
| 8                      | 2.91              | 81                                            | 0                                         | 1                                        |
| Average                | 3.07              | 82.25                                         | 1.25                                      | 0.875                                    |

Average number of vehicles that overtake test vehicle while it is traveling eastward \( (O_e) = 1.00 \)

Average number of vehicles the test vehicle passes while traveling westward \( (P_w) = 0.875 \)

Average number of vehicles the test vehicle passes while traveling eastward \( (P_e) = 1.5 \)
Traffic Engineering Studies

Solution:
- From Eq. 4.9, find the volume in the westbound direction.

\[
V_w = \frac{(N_w + O_w - P_w)60}{T_e + T_w}
\]

\[
= \frac{(79.50 + 1.25 - 0.875)60}{2.85 + 3.07} = 809.5 \quad \text{(or 810 veh/h)}
\]

- Similarly, calculate the volume in the eastbound direction.

\[
V_e = \frac{(82.25 + 1.00 - 1.50)60}{2.85 + 3.07} = 828.5 \quad \text{(or 829 veh/h)}
\]

Traffic Engineering Studies

Solution:
- Find the average travel time in the westbound direction.

\[
\bar{T}_w = 3.07 - \frac{(1.25 - 0.875)}{810} \times 60 = 3.0 \text{ min}
\]

- Find the average travel time in the eastbound direction.

\[
\bar{T}_e = 2.85 - \frac{(1.00 - 1.50)}{829} \times 60 = 2.9 \text{ min}
\]
**Traffic Engineering Studies**

- **Methods Not Requiring a Test Vehicle**
  - *License-Plate Observations:*
    - observers at the beginning and end of the test section.
    - Each observer records the last three or four digits of the license plate of each car that passes, together with the time at which the car passes.

- in the office by matching the times of arrival at the beginning and end of the test section for each license plate recorded.
  - difference between these times is the traveling time of each vehicle.
  - average of these is the average traveling time on the test section.
Traffic Engineering Studies

- a sample size of 50 matched license plates.
- **Interviews**: obtaining information from people who drive on the study site regarding their travel times, experience of delays, requires the cooperation of the people.

Traffic Engineering Studies

- **ITS Advanced Technologies**:
  - Advanced technologies
  - Cell phones
  - GPS satellite system
  - technology is used to determine average speeds and travel times along highways
4.4 PARKING STUDIES

- Any vehicle will at one time be parked short time or longer time, provision of parking facilities is essential.
- Need for parking spaces is usually very great in areas of business, residential, or commercial activities.
- Park-and-ride

Traffic Engineering Studies

- Providing adequate parking space to meet the demand for parking in the Central Business District (CBD).
- This problem usually confronts a city traffic engineer.
- Solution is not simple, parking studies are used to determine the demand for and the supply of parking facilities.
4.4.1 Types of Parking Facilities

- **On-Street Parking Facilities**
  - also known as curb facilities. Parking bays are provided alongside the curb on one or both sides of the street.
  - unrestricted parking
  - unlimited and free
  - Restricted parking facilities

- **On-Street Parking Facilities**
  - limited to specific times for a maximum duration.
  - may or may not be free.
  - handicapped parking
  - bus stops
  - loading bays.
Off-Street Parking Facilities
- privately or publicly owned;
- surface lots and garages.
- Self-parking garages
- attendant-parking garages

4.4.2 Definitions of Parking Terms
1. **A space-hour** is a unit of parking that defines the use of a single parking space for a period of 1 hour.
2. **Parking volume** is the total number of vehicles that park in a study area during a specific length of time, usually a day.
3. **Parking accumulation** is the number of parked vehicles in a study area at any specified time.

4. **parking load** the number of space-hours used during the specified period of time.

5. **Parking duration** length of time a vehicle is parked at a parking
   indication of how frequently a parking space becomes available.

6. **Parking turnover**
   rate of use of a parking space.

   Obtained by dividing the parking volume for a specified period by the number of parking spaces.
Traffic Engineering Studies

4.4.3 Methodology of Parking Studies

- **Inventory** of Existing Parking Facilities
  - detailed listing of the location and all other relevant characteristics of each legal parking facility, private and public.
  - The study area includes both on- and off-street facilities.

Traffic Engineering Studies

- Type and number of parking spaces at each parking facility
- Times of operation and limit on duration of parking, if any
- Type of ownership (private or public)
- Parking fees, method of collection
- Restrictions
- Other restrictions, loading and unloading zones, bus stops, taxi ranks
- Permanency
- The inventory should be updated at regular intervals of about four to five years.
4.4.3 Methodology of Parking Studies

- **Collection of Parking Data**
  - **Accumulation:**
    - by checking the amount of parking during regular intervals on different days of the week.
    - Carried out on an hourly or 2-hour basis
    - used to determine hourly variations of parking and peak periods of parking demand.

- **Turnover and Duration:**
  - collecting data on a sample of parking spaces in a given block.
  - recording the license plate of the vehicle parked on each parking space in the sample at the ends of fixed intervals during the study period.
  - The length of the fixed intervals depends on the maximum permissible duration.
Traffic Engineering Studies

- **Turnover and Duration:**
  - For example, if the maximum permissible duration of parking at a curb face is 1 hour, a suitable interval is every 20 minutes.
  - If the permissible duration is 2 hours, checking every 30 minutes would be appropriate. Turnover is then obtained from the equation

\[
T = \frac{\text{number of different vehicles parked}}{\text{number of parking spaces}}
\]

Figure 4.17 Parking Accumulation at a Parking Lot
Traffic Engineering Studies

**Turnover and Duration:**
- manual collection of parking data is still commonly used,
- Possible for all parking data to be collected electronically.
- wireless sensors

**Identification of Parking Generators**
- (for example, shopping centers or transit terminals) and locating these on a map of the study area.

Traffic Engineering Studies

**Parking Demand**
- by interviewing drivers at the various parking facilities
- Interview all drivers using the parking facilities on a typical weekday between 8:00 a.m. and 10:00 p.m.
- Information include (1) trip origin, (2) purpose of trip, (3) driver’s destination after parking.
- the location of the parking facility, times of arrival and departure, vehicle type.
Traffic Engineering Studies

- **Parking Demand**
  - Parking interviews also can be carried out using the postcard technique,
  - about 30 to 50 percent of the cards distributed are returned.

Traffic Engineering Studies

4.4.4 **Analysis of Parking Data**

- Number and duration for vehicles legally parked
- Number and duration for vehicles illegally parked
- Space-hours of demand for parking
- Supply of parking facilities

The space-hours of demand for parking are obtained from the expression
4.4.4 Analysis of Parking Data

\[ D = \sum_{i=1}^{N} (n_i t_i) \]

where
- \( D \) = space vehicle-hours demand for a specific period of time
- \( N \) = number of classes of parking duration ranges
- \( t_i \) = midparking duration of the \( i \)th class
- \( n_i \) = number of vehicles parked for the \( i \)th duration range

The space-hours of supply are obtained from the expression
4.4.4 Analysis of Parking Data

where

\[ S = f \sum_{i=1}^{N} (t_i) \]

- \( S \) = practical number of space-hours of supply for a specific period of time
- \( N \) = number of parking spaces available
- \( t_i \) = total length of time in hours when the \( i \)th space can be legally parked on during the specific period
- \( f \) = efficiency factor

Example 4.7 Space Requirements for a Parking Garage

The owner of a parking garage located in a CBD has observed that 20% of those wishing to park are turned back every day during the open hours of 8 a.m. to 6 p.m. because of lack of parking spaces. An analysis of data collected at the garage indicates that 60% of those who park are commuters, with an average parking duration of 9 hr, and the remaining are shoppers, whose average parking duration is 2 hr. If 20% of those who cannot park are commuters and the rest are shoppers, and a total of 200 vehicles currently park daily in the garage, determine the number of additional spaces required to meet the excess demand. Assume parking efficiency is 0.90.
Traffic Engineering Studies

Solution:
- Calculate the space-hours of demand using Eq. 4.12.

\[ D = \sum_{i=1}^{N} (n_i d_i) \]

- Commuters now being served = \(0.6 \times 200 \times 9 = 1080\) space-hr
- Shoppers now being served = \(0.4 \times 200 \times 2 = 160\) space-hr
- Total number of vehicles turned away = \(\frac{200}{0.8} - 200 = 50\)
- Commuters not being served = \(0.2 \times 50 \times 9 = 90\) space-hr
- Shoppers not being served = \(0.8 \times 50 \times 2 = 80\) space-hr
- Total space-hours of demand = \((1080 + 160 + 90 + 80) = 1410\)
- Total space-hours served = \(1080 + 160 = 1240\)
- Number of space-hours required = \(1410 - 1240 = 170\)

Traffic Engineering Studies

- Determine the number of parking spaces required from Eq. 4.13.

\[ S = f \sum_{i=1}^{N} t_i = 170\) space-hr

- Use the length of time each space can be legally parked on (8 a.m. through 6 p.m. = 10 hr) to determine the number of additional spaces.

\[ 0.9 \times 10 \times N = 170 \]
\[ N = 18.89 \]

At least 19 additional spaces will be required, since a fraction of a space cannot be used.