Agenda for Today

- Review of last lecture
- Field observations
- Examples of four highways
- Various Flow Models
- Calibration of Flow Models
Field Observations (1)

- The relationship between speed-flow-density is important to observe before proceeding to the theoretical traffic stream models.
- Four sets of data are selected for demonstration
  - High speed freeway
  - Freeway with 55 mph speed limit
  - A tunnel
  - An arterial street
High Speed Freeway

- Figure 10.3
High Speed Freeway (1)

- This data is obtained from Santa Monica Freeway (detector station 16) in LA
- This urban roadway incorporates
  - high design standards
  - Operates at nearly ideal conditions
- A high percentage of drivers are commuters who use this freeway on regular basis.
- The data was collected by Caltrans
High Speed Freeway (2)

- Measurements are averaged over 5 min period
- The speed-density plot shows
  - a very consistent data pattern
  - Displays a slight S-shaped relationship
High Speed Freeway: Speed-Density

- Uniform density from 0 to 130 veh/mi/lane
- Free flow speed little over 60 mph
- Jam density can not be estimated
- Free flow speed portion shows like a parabola
- Congested portion is relatively flat
High Speed Freeway: Flow-Density

- Maximum flow appears to be just under 2000 veh per hour per lane (vhl)
- Optimum density is approx. 40-45 veh/mile/lane (vml)
- Consistent data pattern for flows up to 1,800 vhl
High Speed Freeway: Flow-Speed

- Consistent data pattern for flows up to 1,800 vhl
- Optimum speed is not well defined
  - But could range between 30-45 mph
- Relationship between speed and flow is not consistent beyond optimum flow
Break-Out Session (3 Groups)

- Find out important features from
  - Figure 10.4
  - Figure 10.5
  - Figure 10.6
Difficulty of Speed-Flow-Density Relationship (1)

- A difficult task
- Unique demand-capacity relationship vary
  - over time of day
  - over length of roadway
- Parameters of flow, speed, density are difficult to estimate
  - As they vary greatly between sites
Difficulty of Speed-Flow-Density Relationship (2)

- Other factors affect
  - Design speed
  - Access control
  - Presence of trucks
  - Speed limit
  - Number of lanes

- There is a need to learn theoretical traffic stream models
Individual Models

- **Single Regime model**
  - Only for free flow or congested flow

- **Two Regime Model**
  - Separate equations for
    - Free flow
    - Congested flow

- **Three Regime Model**
  - Separate equations for
    - Free flow
    - Congested flow
    - Transition flow

- **Multi Regime Model**
Single Regime Models

- Greenshield’s Model
  - Assumed linear speed-density relationships
  - All we covered in the first class
  - In order to solve numerically traffic flow fundamentals, it requires two basic parameters
    - Free flow speed
    - Jam Density

\[ u = u_f - \left( \frac{u_f}{k_j} \right) * k \]
Single Regime Models: Greenberg

- Second regime model was proposed after Greenshields
- Using hydrodynamic analogy he combined equations of motion and one-dimensional compressive flow and derived the following equation

\[ u = u_f \times \ln \left( \frac{k_j}{k} \right) \]

- Disadvantage: Free flow speed is infinite
Single Regime Models: Underwood

- Proposed models as a result of traffic studies on Merrit Parkway in Connecticut
- Interested in free flow regime as Greenberg model was using an infinite free flow speed
- Proposed a new model

\[ u = u_f \times e^{-\left(\frac{k}{k_0}\right)} \]
Single Regime Models: Underwood (2)

- Requires free flow speed (easy to compute)
- Optimum density (varies depending upon roadway type)
- Disadvantage
  - Speed never reaches zero
  - Jam density is infinite
Single Regime Models: Northwestern Univ.

- Northwestern University
  \[ u = u_f * e^{-\frac{1}{2 \left( \frac{k}{k_0} \right)^2}} \]
- Formulation related to Underwood model
- Prior knowledge on free flow speed and optimum density
- Speed does not go to “zero” when density approaches jam density
All models are compared using the data set of freeway with speed limit of 55mph (see fig. 10.4).

Results are shown in fig. 10.7.

Density below 20vml:
  - Greenberg and Underwood models underestimate speed.

Density between 20-60 vml:
  - All models underestimate speed and capacity.
Density from 60-90 vml
  - all models match very well with field data

Density over 90 vml
  - Greenshields model begins to deviate from field data

At density of 125 vml
  - Speed and flow approaches to zero
<table>
<thead>
<tr>
<th>Flow Parameter</th>
<th>Data Set</th>
<th>Greenshields</th>
<th>Greenberg</th>
<th>Underwood</th>
<th>Northwestern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Flow (qm)</td>
<td>1800-2000</td>
<td>1800</td>
<td>1565</td>
<td>1590</td>
<td>1810</td>
</tr>
<tr>
<td>Free-flow speed (uf)</td>
<td>50-55</td>
<td>57</td>
<td>--inf..</td>
<td>75</td>
<td>49</td>
</tr>
<tr>
<td>Optimum Speed (ko)</td>
<td>28-38</td>
<td>29</td>
<td>23</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>Jam Density (kj)</td>
<td>185-250</td>
<td>125</td>
<td>185</td>
<td>..inf..</td>
<td>..inf..</td>
</tr>
<tr>
<td>Optimum Density</td>
<td>48-65</td>
<td>62</td>
<td>68</td>
<td>57</td>
<td>61</td>
</tr>
<tr>
<td>Mean Deviation</td>
<td>-</td>
<td>4.7</td>
<td>5.4</td>
<td>5.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Eddie first proposed two-regime models because:
- Used Underwood model for Free flow conditions
- Used Greenberg model for congested conditions

Similar models are also developed in the era.

Three regime model:
- Free flow regime
- Transitional regime
- Congested flow regime
## Multiregime Models (2)

<table>
<thead>
<tr>
<th>Multiregime Model</th>
<th>Free Flow Regime</th>
<th>Transitional Flow Regime</th>
<th>Congested Flow Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eddie Model</td>
<td>$u = 54.9e^{-k/163.9}$, $k \leq 50$</td>
<td>NA</td>
<td>$u = 26.8\ln\left(\frac{162.5}{k}\right)$, $k \geq 50$</td>
</tr>
<tr>
<td>Two-regime Model</td>
<td>$u = 60.9 - 0.515k$, $k \leq 65$</td>
<td>NA</td>
<td>$u = 40 - 0.265k$, $k \leq 65$</td>
</tr>
<tr>
<td>Modified Greenberg Model</td>
<td>$u = 48$, $k \leq 35$</td>
<td>NA</td>
<td>$u = 32\ln\left(\frac{145.5}{k}\right)$, $k \geq 35$</td>
</tr>
<tr>
<td>Three-regime Model</td>
<td>$u = 50 - 0.098k$, $k \leq 40$</td>
<td>$u = 81.4 - 0.91k$, $40 \leq k \leq 65$</td>
<td>$u = 40 - 0.265k$, $k \geq 65$</td>
</tr>
</tbody>
</table>
Multiregime Models (3)

- **Challenge**
  - Determining breakeven points

- **Advantage**
  - Provide opportunity to compare models
  - Their characteristics
  - Breakeven points
Summary

- Multiregime models provide considerable improvements over single-regime models
- But both models have their respective
  - Strengths
  - Weaknesses
- Each model is different with continuous spectrum of observations
In order to calibrate any traffic stream model, one should get the boundary values,
- free flow speed \( c \) and jam density \( j \).

Although it is difficult to determine exact free flow speed and jam density directly from the field, approximate values can be obtained.

Let the linear equation be \( y = ax + b \); such that is
- \( y \) denotes density (speed) and \( x \) denotes the speed (density).
Model Calibration (2)

- Using linear regression method, coefficient $a$ and $b$ can be solved as

$$b = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

$$a = \bar{y} - b\bar{x}$$
Example

- For the following data on speed and density, determine the parameters of the Greenshields' model. Also find the maximum flow and density corresponding to a speed of 30 km/hr.

<table>
<thead>
<tr>
<th>k</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>5</td>
</tr>
<tr>
<td>129</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>70</td>
<td>25</td>
</tr>
</tbody>
</table>
## Model Calibration

<table>
<thead>
<tr>
<th>x(k)</th>
<th>y(v)</th>
<th>( y_i - \bar{y} )</th>
<th>(*y_i - \bar{y})</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>5</td>
<td>73.5</td>
<td>-16.3</td>
<td>-1198.1</td>
</tr>
<tr>
<td>129</td>
<td>15</td>
<td>31.5</td>
<td>-6.3</td>
<td>-198.5</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>-77.5</td>
<td>18.7</td>
<td>-1449.3</td>
</tr>
<tr>
<td>70</td>
<td>25</td>
<td>-27.5</td>
<td>3.7</td>
<td>-101.8</td>
</tr>
<tr>
<td>390</td>
<td>85</td>
<td></td>
<td>-2947.7</td>
<td>13157.2</td>
</tr>
</tbody>
</table>