Traffic Flow Models

CIVL 4162/6162
(Traffic Engineering)

Lesson Objective

- Demonstrate traffic flow characteristics using observed data
- Describe traffic flow models
  - Single regime
  - Multiple regime
- Develop and calibrate traffic 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

- 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

$$u = u_0 \; * \, ln\left(\frac{k_j}{k}\right)$$

- 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

$$u = u_f \ * e^{-\left(\frac{k}{k_0}\right)}$$

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.

$$u = u_f * e^{-\frac{1}{2\left(\frac{k}{k_0}\right)^2}}$$

- 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

Single Regime Model Comparisons (1)

- 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 overestimate speed and capacity

Single Regime Model Comparisons (2)

- 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

Single Regime Model Comparisons (3)

Flow Parameter	Data Set	Greenshields	Greenberg	Underwood	Northwestern
Max. Flow (qm)	1800-2000	1800	1565	1590	1810
Free-flow speed (uf)	50-55	57	--inf..	75	49
Optimum Speed (u0)	28-38	29	23	28	30
Jam Density (kj)	185-250	125	185	..inf..	..inf..
Optimum Density (k0)	48-65	62	68	57	61
Mean Deviation	-	4.7	5.4	5.0	4.6

Multiregime Models (1)

- 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)

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

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

Model Calibration (1)

- In order calibrate any traffic stream model, one should get the boundary values,
  - free flow speed () and jam density ().
- 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 = a+bx; 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

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

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.

k *(veh/km)*	*u* *(km/hr)*
171	5
129	15
20	40
70	25

Model Calibration *(1)*

x(*k*)	y(*u*)	$(x_i - \overline{x})$	$(y_i - \overline{y})$	$(x_i - \overline{x})*(y_i - \overline{y})$	$(x_i - \overline{x})^2$
171	5	73.5	-16	-1198	5402.3
129	15	31.5	-6.3	-198.5	992.3
20	40	-78	18.7	-1449	6006.3
70	25	-28	3.7	-101.8	756.3
390	***85***			***-2948.7***	***13157.2***

$$\overline{x} = \frac{\sum x}{n} = \frac{390}{4} = 97.5$$

$$\overline{y} = \frac{\sum y}{n} = \frac{85}{4} = 21.3$$

$$b = \frac{2947.7}{13157.2} = -0.2$$

$$a = y - b\overline{x} = 21.3 + 0.2 * 97.5 = 40.8$$

$$\boldsymbol{u = 40.8 - 0.2k}$$

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

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

Model Calibration *(2)*

$u = 40.8 - 0.2k \Rightarrow u_f$=40 and $\frac{u_f}{k_j} = 0.2$

$$k_j = \frac{40.8}{0.2} = 204\, veh/mi$$

$$q_m = \frac{u_f k_j}{4} = \frac{40.8 * 204}{4} = 2080.8\, veh/hr$$

Density corresponding to speed of 30 km/hr is given by

$$30 = 40.8 - 0.2k \Rightarrow k = \frac{40.8 - 30}{0.2} = 54\, veh/km$$