Traffic flow Theory
(Traffic Stream Characteristics)

Dr. Gang-Len Chang
Professor and Director of
Traffic Safety and Operations Lab.
University of Maryland-College Park
Traffic Flow Variables of Interest

- **Density** (vehicles per unit distance)
- **Spacing**, or space headway between vehicles (distance per vehicle)
- **Time headway** between vehicles (seconds)
- **Rates of flow** (vehicles per unit time)
- **Speeds** (distance per unit time)
- **Travel time** over a known length of road
- **Occupancy** (% of time a point on the road is occupied by vehicles)
- **Concentration** (measured by density or occupancy)

1. Measurement capabilities for obtaining traffic data have been changed.
2. Measurement procedures estimated from variables will be discussed.
3. **Uninterrupted flow facility**: No external factors cause periodic interruption to the traffic stream.
Four Methods of obtaining traffic data (modified from Drew 1968, Figure 12.9)

- **Freeway Lanes**
  - Distance (m)
  - Time (sec)
  - Measurement at a Point
  - Short Section
  - Along a Length of Road
  - Moving Observer Method

Distance (m): 500, 1000, 1500, 2000, 2500

Time (sec): 0, 30, 60, 90, 120
### Measurement at a Point

<table>
<thead>
<tr>
<th>Tube</th>
<th>Inductive Loop</th>
<th>Spot Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Tube Image" /></td>
<td><img src="image2.png" alt="Inductive Loop Image" /></td>
<td><img src="image3.png" alt="Spot Speed Image" /></td>
</tr>
</tbody>
</table>

- **Direct measurements at a point**: flow rate, headways, and speeds
- **Density**, which is defined as vehicles per unit length, does not make sense for using a point measurement.
- A second observation location is necessary -> measurements over a short section
Paired inductive loops spaced five to six meters apart.

- Provide direct measurement of **volume, time headways, and speed**.
- Provide **occupancy** data by continuous reading, but does not permit direct measurement of density.
Several frames provide data for the estimation of speed and density.

- It provides true journey times over a lengthy section of road, but that would require better computer vision algorithms (few practical implementations).
- Makagami et al. (1971), Persaud and Hurdle (1988b) constructed cumulative arrival curves at several locations, hereby average flow rate & average density within a section, and consequently the average speeds through it.
Floating car behaves as an average vehicle within the traffic stream

- Method is effective for obtaining qualitative information about freeway operations without the need for elaborate equipment or procedures
- Method cannot give precise average speed data

Wardrop and Charlesworth (1954): obtain speed & volume measurements

- Rural expressway data collection without automatic systems
- Urban arterials with identifying progression speeds for coordinated signals

Wright (1973): Revisited the theory behind this method

- Driver should fix the journey time in advance, and keep to it
- Turning traffic (exitng or entering) can upset the calculations done using this method
variables of interest

Flow Rates

\[ q = \frac{\sum N_i}{T} = \frac{N}{T} \]
(flow rate)

Total elapsed time: sum of the headways for each vehicle

1985 HCM suggests using at least 15-minute intervals
(detail provided by 5-minute or 1-minute data is valuable)

Effect of different measurement intervals on the nature of resulting data (Rothrock and Keefer, 1957)

Different types of measured traffic flow or volumes
Time Mean Speed

Arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time.

$$\text{TMS} = \frac{(80) + (40)}{2} = 60 \text{kph}$$

Space Mean Speed

Average speed of vehicles measured at an instant of time over a specified stretch of road.

$$\text{SMS} = \frac{20 + 20}{3/4} = 53.3 \text{kph}$$
Two mean speeds differ by the ratio of the variance to the SMS

\[ u_t = u_s + \frac{\sigma_s^2}{u_s} \quad \text{(Wardrop, 1952)} \]

Breakdown from uncongested to stop & go conditions:

: considerable difference

Gerlough and Huber (1975):

Relatively uniform flow and speeds, SMS & TMS are likely to be equivalent for practical purposes.
Those systems that do not measure speeds (single-loop detector stations) sometimes calculate speeds from flow and occupancy data (Athol, 1965).

**Occupancy**

\[
\frac{N}{T} = \frac{1}{\bar{h}}
\]

\[
\bar{N} = \frac{1}{T} \sum_i \frac{L_i}{u_i}
\]

\[
q = \frac{N}{T}
\]

\[
\frac{d}{u_s} = \frac{D}{N} \sum_i t_i
\]

\[
\bar{u}_s = \frac{\bar{N}}{\bar{N}} \sum_i \frac{1}{u_i}
\]

\[
q = \bar{u}_s k
\]

\[
\frac{d}{u_s} = \frac{1}{\bar{h}} \cdot L \cdot \frac{1}{N} \sum_i \frac{1}{u_i} + d \cdot k
\]

\[
\frac{d}{u_s} = L \cdot \frac{q}{u_s} + d \cdot k
\]

\[
\frac{d}{u_s} = (L+d)k = c_k k
\]
Broader term encompassing density (measure of concentration over space) and occupancy (measure concentration over time of the same vehicle stream).

Traffic stream: a number of sub-streams (constant spacing & speed).

Point measurements (single-loop) method strictly correct only under restricted conditions.

Sub-streams with constant speed (Wardrop) is approximately true for uncongested traffic.

Stochastic Real traffic flows: not be consistent with the measured data (Newell 1982).
Making more use of occupancy

Hurdle (1994) : the concept of acceleration in Newtonian physics
- There will be continued use of occupancy and density
Traffic Stream Models

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

(Jam density)

1. Greenshields 1935

- Speeds remain nearly constant even at quite high flow rates
- Reduction in flow rates within the bottleneck at the time that the queue forms upstream


3. Hall and Brilon (1994)
   Hall and Montgomery (1993)

The breakpoints at which speeds started to decrease from free-flow, and the speeds at capacity

- Important for freeway management strategies
- Will be of fundamental importance for ITS implementation of alternate routing

Flow (veh/hr)

Speed (mph)

- Speeds remain flat as flow increases, and small Decreases at capacity

- Uncongested
- Queue Discharge
- Congested

HCM 1994 / HCM 2000

113km/h
105km/h
97km/h
89km/h
Traffic Stream Models

1. Greenshields 1935
   
   \[ u = u_f \left(1 - \frac{k}{k_j}\right) \]

   Free Flow Speed

   Jam Density

2. Huber 1957
   
   \[ S = 38.05 - 0.2416D \]

   Linear fit

3. Greenberg 1959
   
   \[ u = c \ln\left(\frac{k}{k_j}\right) \]

   Speed

   Logarithmic fit

Greenshields 1935

Huber 1957

Greenberg 1959

Jam Density

Free Flow Speed

Density (veh/km)

Density (veh/km)

Density (veh/km)
Flow-concentration models can be derived from assumptions about the shape of the speed-concentration curve.

Duncan's (1979): minor changes in the speed-density function led to major changes in the speed flow function.

Empirical flow concentration data frequently have discontinuities in the vicinity of what would be maximum flow.

**Need for Direct Flow-Concentration Relationship**

Flow-concentration models can be derived from assumptions about the shape of the speed-concentration curve.

Duncan's (1979): minor changes in the speed-density function led to major changes in the speed flow function.
The models often do not fit the data well at **capacity**

Little consistency in parameters from one **location** to another

Different **days** required quite different parameters

**Use of volume & occupancy** together to identify the onset of **congestion**

**Transitions** between uncongested and congested operations at volume slower than capacity

**Use of time-traced plots** to better understand the **operations**.
Five different colors represent different speed ranges. (Area A ~ E)

Conventional theory is insufficient to explain the data

- Control variables (flow & occupancy) exhibit smooth continuous change
- State variable (speed) undergo a sudden 'catastrophic' jump in its value
- Further studied by Acha-Daza and Hall (1993), Pushkar et al. (1994)
- It illustrates graphically that
  1. Freeway operations do not have to stay on the curve; jumps are possible from one branch to the other
  2. Different locations will yield different types of data
The relation between density and occupancy is weak.

Transforming variables, fitting equations, and then transforming the equations back to the original variables can lead to biased results.

Provide challenges for applying this improvement in understanding, how traffic operates, especially on freeways.

ITS will likely provide the opportunity for acquiring more and better data to further advance understanding of these issues.