AN INTRODUCTION TO
Traffic flow, Control, Capacity,
Level of Service, ITS technologies,
AND ALL THAT

Professor Michael Zhang
One of the challenges in transportation: traffic congestion
The problem of PEAKING

Directional Flow Variation: of I-94 WB/EB in San Diego

Flow Rate (veh/hr)

Time of Day

Westbound traffic
Eastbound traffic
THE LAW OF CONGESTION

DEMAND > CAPACITY

FLOW RATE

Demand

Capacity

Observed flow

8 am 5 pm t
FROM A DIFFERENT ANGLE

\[ N(t) \]
THE CONCEPT OF HIGHWAY CAPACITY: FIELD OBSERVATIONS
APPROXIMATE RELATIONS

\[ q_{max} = ? \]
\[ K_c = ? \]
\[ U_f = ? \]
Capacity

The capacity of a transportation system: The maximum number of vehicles/passengers “per unit time” that can be accommodated under given conditions w/ a reasonable expectation of occurrence.

– Capacity is independent of demand
– Capacity depends on traffic composition
– Capacity depends on road and environmental conditions.
Ideal capacity

- Maximum hourly flow rate under ideal conditions
  - Lane width (>= 12FT)
  - Lateral clearance (>=6FT)
  - Number of lanes (>= 5/DIR)
  - Interchange density(<=0.5/MILE)
  - All passenger cars
  - Familiar drivers
  - Good weather conditions
### Table 3-1. LOS Criteria for Basic Freeway Sections

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Maximum Density (pcu/mi/ln)</th>
<th>Minimum Speed (mph)</th>
<th>Maximum Service Flow Rate (pcphpl)</th>
<th>Maximum v/c Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Free-Flow Speed = 75 mph</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>10.0</td>
<td>75.0</td>
<td>750</td>
<td>0.31</td>
</tr>
<tr>
<td>B</td>
<td>15.0</td>
<td>75.0</td>
<td>1,200</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>24.0</td>
<td>71.0</td>
<td>1,704</td>
<td>0.71</td>
</tr>
<tr>
<td>D</td>
<td>32.0</td>
<td>65.0</td>
<td>2,080</td>
<td>0.87</td>
</tr>
<tr>
<td>E</td>
<td>45.0</td>
<td>53.0</td>
<td>2,400</td>
<td>1.00</td>
</tr>
<tr>
<td>F</td>
<td>&gt;45.0</td>
<td>&lt;53.0</td>
<td>&lt;2,400</td>
<td>&lt;1.00</td>
</tr>
</tbody>
</table>

Free-Flow Speed = 70 mph

| A                 | 10.0    | 70.0    | 700    | 0.29 |
| B                 | 15.0    | 70.0    | 1,120  | 0.47 |
| C                 | 24.0    | 66.0    | 1,632  | 0.68 |
| D                 | 32.0    | 64.0    | 2,048  | 0.85 |
| E                 | 45.0    | 53.0    | 2,400  | 1.00 |
| F                 | var     | var     | var    | var |

Free-Flow Speed = 65 mph

| A                 | 10.0    | 65.0    | 650    | 0.28 |
| B                 | 15.0    | 65.0    | 1,040  | 0.44 |
| C                 | 24.0    | 64.5    | 1,548  | 0.66 |
| D                 | 32.0    | 62.0    | 1,984  | 0.84 |
| E                 | 45.0    | 52.0    | 2,350  | 1.00 |
| F                 | var     | var     | var    | var |

Free-Flow Speed = 60 mph

| A                 | 10.0    | 60.0    | 600    | 0.26 |
| B                 | 15.0    | 60.0    | 960    | 0.42 |
| C                 | 24.0    | 60.0    | 1,440  | 0.68 |
| D                 | 32.0    | 58.0    | 1,856  | 0.81 |
| E                 | 45.0    | 51.0    | 2,300  | 1.00 |
| F                 | var     | var     | var    | var |
ADJUSTMENT FOR NON IDEAL CONDITIONS

FFS = BFFS – \( f_{LW} \) – \( f_{LC} \) – \( f_N \) – \( f_{ID} \)

FFS = estimated free-flow speed,
BFFS = base free-flow speed; typically, 110 (urban)
  or 120 km/hr (rural)
\( f_{LW} \) = adjustment for lane width, HCM TABLE 3.6
\( f_{LC} \) = adjustment for right shoulder clearance HCM TABLE 3.7
\( f_N \) = adjustment for number of lanes HCM TABLE 3.8
  \((f_N = 0 \text{ for rural freeway section})\)
\( f_{ID} \) = adjustment for interchange density HCM TABLE 3.9
CONTROL OF URBAN ARTERIALS

1. No control (e.g., roundabouts)
2. Stop/Yield control
3. Signal control
Roundabouts
Stop/Yield controlled intersections
Signal controlled intersections

- Multiple conflicting movements
- Take turns for ROW
- Cyclic
- Lights with Green-Yellow-Red
- Movements, Phase, & Cycle
Warrants of Traffic Signals

- Signals may be installed if one or more of the following MUTCD (Manual on Uniform Traffic Control Devices) warrants are met.

- Warrant 1: **Minimum vehicular volume**
  - Whether to install signals or not is mainly decided by traffic volume.
  - Usally examine each hour of an 8-hour period on an average day.
## Warrant 1: Traffic Volume Requirement

<table>
<thead>
<tr>
<th>Number of lanes</th>
<th>Volume on major (both approaches)</th>
<th>Volume on minor (one direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Minor</td>
<td>Vehicles/hour</td>
<td>Vehicles/hour</td>
</tr>
<tr>
<td>1 1</td>
<td>500</td>
<td>150</td>
</tr>
<tr>
<td>2/more 1</td>
<td>600</td>
<td>150</td>
</tr>
<tr>
<td>1 2/more</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>2/more 2/more</td>
<td>600</td>
<td>200</td>
</tr>
</tbody>
</table>
Warrant 2:

- **Interruption of continuous traffic (8hr period)**
- Applies when the minor traffic suffers undue delay or hazard in entering or crossing the major street.

<table>
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<th>Number of lanes</th>
<th>Volume on major (both approaches)</th>
<th>Volume on minor (one direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Minor</td>
<td>Vehicles/hour</td>
<td>Vehicles/hour</td>
</tr>
<tr>
<td>1 1</td>
<td>750</td>
<td>75</td>
</tr>
<tr>
<td>2 /more 1</td>
<td>900</td>
<td>75</td>
</tr>
<tr>
<td>1 2 /more</td>
<td>750</td>
<td>100</td>
</tr>
<tr>
<td>2 /more 2 /more</td>
<td>900</td>
<td>100</td>
</tr>
</tbody>
</table>
Warrants 3 & 4

- **#3: Minimum pedestrian volume (8hr period)**
  - Applies when the pedestrian volume crossing the major street is **100** or more for **each of any 4 hrs** or **190** or more in any one hour

- **#4: School crossing**
  - Applies when the number of admissible crossing gaps in the traffic stream during the period when the children are crossing is less than the number of minutes in the same period.
Warrants 5 & 6

• **#5: Progressive movement**
  – To maintain progressive traffic movement along a major street (so that drivers can stay in platoons)
  – Volumes at this intersection may not justify installation
  – Often applied when there is predominantly heavy unidirectional traffic on major street

• **#6: Accident experience**
  – 5 or more accidents within a 12-month period
  – Other remedies have been tried and failed
  – Signals can reduce crossing and left-turn accidents, but could lead to more rear-end collisions.
Warrants 7&8&9&10&11

• Address system needs (System warrant, to preserve system integrity for future traffic conditions)

• Addresses shorter peak periods (volumes and delay may not warrant a signal in the 8-hour period, but could if a shorter period [4-hour] is used)
Traffic signal control: NEMA diagram, phases

One Cycle, at least 30s.
Signal Control Operations

• Pre-timed or fixed-time
  – Cycle length, phase sequences, green times, offsets are all pre-determined and fixed for a period of time (such as morning peak)
  – Generally needs no sensors
  – Mostly found on downtown streets, or streets with fixed traffic demand patterns.

• Semi-actuated
  – Sensors are installed on minor street to detect vehicle presence. Green rest on main street until a vehicle call from minor street
  – Responsive to traffic demand changes
  – Usually found on major/minor street intersections
  – Cycle length and phase sequences are variable

• Fully-actuated
  – Sensors are installed on all approaches
  – Responsive to changes in traffic demand
  – Cycle length and phase sequences are variable
Controllers (solid-state)

Econolite 2070

Controller cabinet

Eagle 2070

Inside a controller cabinet
Actuated signals

- A signal that is actuated by the arrival of individual vehicles on one or more approaches. The phases and green times vary from cycle to cycle. Cycle length can also change in response to traffic demand.
Signal coordination

FOR GOOD PROGRESSION AND LESS DELAY

\[ t_{\text{offset}} = \text{block length} / \text{progression speed} \]

\[ = \frac{L}{S} \]

Coordination for NB Traffic
Some commonly used coordination schemes
LOS for signals

The Level of Service is obtained by the average stopped delay per vehicle.

<table>
<thead>
<tr>
<th>LEVEL OF SERVICE</th>
<th>CONTROL DELAY PER VEHICLE (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤10</td>
</tr>
<tr>
<td>B</td>
<td>&gt;10 and ≤20</td>
</tr>
<tr>
<td>C</td>
<td>&gt;20 and ≤35</td>
</tr>
<tr>
<td>D</td>
<td>&gt;35 and ≤55</td>
</tr>
<tr>
<td>E</td>
<td>&gt;55 and ≤80</td>
</tr>
<tr>
<td>F</td>
<td>&gt;80</td>
</tr>
</tbody>
</table>
ITS technologies

• On the road
• Inside the vehicle
• In the control room
“EYES” OF THE ROAD

- Loop detector
- Infrared detector
- Video detector
- Ultrasonic detector
SMART ROADS
Smart Apps

NextBus

Waze
SMART CONTROL ROOM
ITS TRENDS: MULTOMODALISM, USER-CENTRIC SENSING AND CONTROL

• MULTI-MODAL INTEGRATION
• The mobile internet/phone revolution
• Connected Vehicles
• Autonomous driving cars
Connected Vehicles

Hey how fast do you think we should be going?

Charlie said he is going about 40. I’ll go 45.
Platooning

HYPERDRIVE | 10 April 2013, BBC
Robot truck platoons roll forward

Autonomous Driving

Terrafugia is Working on Flying Autonomous Cars That Take Off and Land by Themselves by Kevin Lee, 03/04/14

http://inhabitat.com/terrafugia-is-working-on-flying-autonomous-cars-that-take-off-and-land-by-themselves/
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- ECI 256 Urban Traffic Congestion and Control
- ECI 257 Flows in Transportation Networks