JCE 4600
Highway and Traffic Engineering
CE 445
Transportation Systems Analysis

Functional Classification
Basic Flow Theory
Uninterrupted Flow Fundamentals
Car Following Theory
Shock Waves
FUNCTIONAL CLASSIFICATION
Roadway Classification

- Provides hierarchy of purpose/use
- Allows focus of funds/policies on more important facilities
- Assures balance between all levels of roadways
Functional Classification of Roads

- **Arterial** – traffic movement with limited local property access
- **Collector** – between road serving both traffic movement and local property access, bridges between local and arterial roads
- **Local** – provides local property access with limited traffic movement
Access vs. Traffic
Rural Functional Classification

[Diagram showing a legend with categories such as Cities and Towns, Villages, Arterials, Collectors, and Locals]
## Roads and Traffic

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Urban/Suburban Functional Classification
Cul-de-sac Development
St. Louis Region

- East-West Gateway is responsible for maintaining and updating the region’s Roadway Functional Classification System mandated under federal law. Roadways are classified according to:
  - their urban or rural setting
  - and the type of service they provide based on considerations such as:
    - connectivity,
    - mobility,
    - accessibility,
    - vehicle miles traveled,
    - average annual daily traffic, and
    - abutting land use.

- The purpose of roadway functional classification is to describe how travel is channelized through our roadway network and to determine project eligibility for inclusion in the Long Range Plan and short-range Transportation Improvement Program (TIP).
Map 2: St. Louis County Functional Classification

Legend

Classified Roadways
- Local Roads
- Interstate Highways
- Freeways/Expressways
- Principal Arterials

Minor Arterials
Urban Collectors
Rural Major Collectors
Ramps
Planned Minor Arterials
Planned Urban Collectors
2000 Federal-Aid Boundary
County Boundary
BREAK
Basic Flow Fundamentals
Terms and Definitions

- Traffic Flow
  - Characteristics
  - Capacity
  - Demand

- Performance Measures
  - Speed
  - Density
  - Delay
  - Level of Service
What is Traffic Flow

- Definition
- When do you measure?
- How do you measure?
Seasonal Variations

EXHIBIT 8-2. EXAMPLES OF MONTHLY TRAFFIC VOLUME VARIATIONS FOR A FREEWAY

Routes with Significant Recreational Traffic

Routes with Significant Business Traffic

Source: Minnesota Department of Transportation.
Variations by Day of the Week

EXHIBIT 8-4. EXAMPLES OF DAILY TRAFFIC VARIATION BY TYPE OF ROUTE

--- Recreational access route MN 169, North-Central Lake Region, AADT 3,863, 2 lanes, 1981.
--- Suburban freeway, four freeways in Minneapolis-St. Paul, AADTs 75,000-130,000, 6-8 lanes, 1982.
--- Average day.

Source: Minnesota Department of Transportation.
Hourly Variations
What Traffic Flows are Considered in an Operational Analysis?

- What season are you designing for?
  - Urban areas
  - Recreational Areas
    (e.g., Lake of the Ozarks and Branson)

- Do you design for the worst hour of the worst day?
  - Why or why not?

- How is your operational analysis tied to your design hour and criteria?
  - Do you just look at your design hour?
  - Why would you want to look at anything else?
Flow Definitions

- Design Hourly Volume (DHV)
- AADT (Average Annual Daily Traffic)
- K-Factor
- Peak Hour Factor (PHF)
EXHIBIT 8-8. RANKED HOURLY VOLUMES

- Recreation Access Route MN 169
- Main Rural Route I-35
- Urban Circumferential Freeway I-494
- Urban Radial Freeway I-35E

Source: Minnesota Department of Transportation.
Defining Design Hourly Volume

- Design Hourly Volume (DHV) is defined locally by the owning agency (e.g., MoDOT)
- Typically, 30th Highest Hour is used
- However, very rarely does an agency have hourly counts on a facility for an entire year. In fact, many agencies count facilities for 48 hours every 2-5 years.
  - MoDOT has factors that they apply to these counts that are assumed to account for seasonal and daily variations.
- In this case, DHV is often assumed to be 12-15% of “factored” AADT
K-Factor

- Analysis Hourly Volume/AADT
- Normally 8-12%
- Typically
  - the higher the volumes, the lower the K-factor
  - the more urbanized the area, the lower the K-factor
EXHIBIT 8-10. RELATIONSHIP BETWEEN SHORT-TERM AND HOURLY FLOWS

Source: Minnesota Department of Transportation.
Peak Hour Factor (PHF)

- Typically, facilities are designed for peak 15 minute flow interval
- 15 minute flows are accounted for through the Peak Hour Factor (PHF)
- Definition:

\[
\text{Peak Hour Factor (PHF)} = \frac{\text{Hourly Volume}}{\text{Peak 15 Minute Volume} \times 4}
\]

- Typically range from 0.75-0.98
Traffic Flow Characteristics

What does it mean to You?

- Your operational timeframe (i.e., what volumes are you going to use) will be one of the first, and perhaps the most important decision that you will make.

- Rural characteristics are very different from Urban areas.

- Still, what about Rams, Cardinals, and Blues games? Do you take things into account like the VP fair?
**TYPES OF VOLUME STUDIES**

- **Area-wide counting programs**
  - Generate continuing estimates of traffic volumes on extensive highway systems
  - Sampling procedure used to update volumes
    - Permanent count stations: count continuously
    - Control count stations: count one week per month or one week per year
    - Coverage count stations: count one day per year or one day each 2 to 4 years
TYPES OF VOLUME STUDIES

- Street counts; directional counts
- Turning movement counts
- Classification counts
- Occupancy counts
- Pedestrian counts
Volume Adjustment Factors

\[ f_{Tues} = \frac{AADT}{Tuesday\ ADT} = \frac{3419}{3011} = 1.14 \]

Rural State Highway Volume by Day
Volume Adjustment Factors

\[ f_{April} = \frac{AADT}{April \ ADT} = \frac{3419}{3078} = 1.11 \]
JCE 4600
Fundamentals of Traffic Engineering
Data Needs and Collection
Manual Turning Counts

• 15-Minute Intervals
• 12 Hour Counts
• Simple to Operate
• Flexible Intersection Configurations
• Banking Movements (Trucks, Nearby Driveways, etc)
• Pedestrian Counts
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Grand Total

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| Total %    | 2.5  | 0.0 | 5.7  | 0.1 |

| 2.5        | 0.0  | 5.7  | 0.1  |
| 8.3        | 91.6 | 0.2  | 0.0 |
| 3.8        | 42.5 | 0.1  | 0.0 |
| 46.4       | 3.0  | 0.0  | 0.0  | 0.0 |
| 1048       | 3    | 0.0  | 0.0  | 0.0 |
Hose Counts

3-Person Traffic Control Procedure

Extended Count Periods

Simple to Program
Nu-Metrics Counter

Protective Pads
(Nailed to Pavement)
Tape Pads
Over Counters
### Mitron Systems Volume Count Report

**Site Name**: Illinois

**Location Code**: 11600

**Date**: December 03, 2003

| HR Begl | Total | 00-45 | 15-30 | 30-45 | 45-00 | HR Begl | Total | 00-45 | 15-30 | 30-45 | 45-00 | HR Begl | Total | 00-45 | 15-30 | 30-45 | 45-00 | HR Begl | Total | 00-45 | 15-30 | 30-45 | 45-00 |
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| 02      |       |       |       |       |       | 02      |       |       |       |       |       | 02      |       |       |       |       |       | 02      |       |       |       |       |       |
| 03      |       |       |       |       |       | 03      |       |       |       |       |       | 03      |       |       |       |       |       | 03      |       |       |       |       |       |
| 04      |       |       |       |       |       | 04      |       |       |       |       |       | 04      |       |       |       |       |       | 04      |       |       |       |       |       |
| 05      |       |       |       |       |       | 05      |       |       |       |       |       | 05      |       |       |       |       |       | 05      |       |       |       |       |       |
| 06      |       |       |       |       |       | 06      |       |       |       |       |       | 06      |       |       |       |       |       | 06      |       |       |       |       |       |
| 07      |       |       |       |       |       | 07      |       |       |       |       |       | 07      |       |       |       |       |       | 07      |       |       |       |       |       |
| 08      |       |       |       |       |       | 08      |       |       |       |       |       | 08      |       |       |       |       |       | 08      |       |       |       |       |       |
| 09      |       |       |       |       |       | 09      |       |       |       |       |       | 09      |       |       |       |       |       | 09      |       |       |       |       |       |
| 10      |       |       |       |       |       | 10      |       |       |       |       |       | 10      |       |       |       |       |       | 10      |       |       |       |       |       |
| 11      |       |       |       |       |       | 11      |       |       |       |       |       | 11      |       |       |       |       |       | 11      |       |       |       |       |       |
| 12      |       |       |       |       |       | 12      |       |       |       |       |       | 12      |       |       |       |       |       | 12      |       |       |       |       |       |
| 13      |       |       |       |       |       | 13      |       |       |       |       |       | 13      |       |       |       |       |       | 13      |       |       |       |       |       |
| 14      |       |       |       |       |       | 14      |       |       |       |       |       | 14      |       |       |       |       |       | 14      |       |       |       |       |       |
| 15      |       |       |       |       |       | 15      |       |       |       |       |       | 15      |       |       |       |       |       | 15      |       |       |       |       |       |
| 16      |       |       |       |       |       | 16      |       |       |       |       |       | 16      |       |       |       |       |       | 16      |       |       |       |       |       |
| 17      |       |       |       |       |       | 17      |       |       |       |       |       | 17      |       |       |       |       |       | 17      |       |       |       |       |       |
| 18      |       |       |       |       |       | 18      |       |       |       |       |       | 18      |       |       |       |       |       | 18      |       |       |       |       |       |
| 19      |       |       |       |       |       | 19      |       |       |       |       |       | 19      |       |       |       |       |       | 19      |       |       |       |       |       |
| 20      |       |       |       |       |       | 20      |       |       |       |       |       | 20      |       |       |       |       |       | 20      |       |       |       |       |       |
| 21      |       |       |       |       |       | 21      |       |       |       |       |       | 21      |       |       |       |       |       | 21      |       |       |       |       |       |
| 22      |       |       |       |       |       | 22      |       |       |       |       |       | 22      |       |       |       |       |       | 22      |       |       |       |       |       |
| 23      |       |       |       |       |       | 23      |       |       |       |       |       | 23      |       |       |       |       |       | 23      |       |       |       |       |       |

#### AM Peak Hour Start
- 11:00

#### AM Peak Hour Total
- 13:00

#### PM Peak Hour Start
- 16:30

#### PM Peak Hour Total
- 13:00
Hose Count Summary In Excel

IL 13 SCAT - Thurs
(West of Halfway)

Volume (vph)

Time (Hr Begin)
Econolite Autoscope Solo Pro

Typically Mounted on Luminaire Or Pole Extension

Color Camera

70 Degree Cone of Vision

Microprocessor Inside Camera

Multiple Movements Per Camera

Counts, Classification, Speed
Other Count Methods
Data Collection Tradeoffs

- Manual Counts:
  - Advantages
    - Highly Accurate
    - Each Movement Counted Separately
    - Ideal for Peak Period Counts (ex. 7-9am, 11-1pm, 4-6pm)
  - Disadvantages
    - Manpower Intensive (Often Limits Duration and Times of Count)

- Machine Counts:
  - Advantages
    - Easy Setup and Summarize
    - Can Count for Extended Periods of Time
    - Reliable if Installed Correctly
    - Cost Effective
  - Disadvantages
    - Requires 3 Person Crew to Install and Remove
    - Limited Ability to Gather Specific Movements
“...the maximum hourly rate at which persons or vehicles can be expected to traverse a point or a uniform section of a lane or roadway given a time period under prevailing roadway, traffic, and control conditions.” (HCM 2000, p 2-2)
What Factors Determine Capacity

- **Facility Type**
  - Freeway, Rural Highway, Multimodal

- **Roadway Conditions**
  - Weather, Pavement Condition, Geometric Design

- **Traffic Conditions**
  - Vehicle Mix (e.g., Trucks, RV, SUV, Taxis)
  - Driver Mix (e.g., Commuter versus Recreational Traffic, Geographic location)

- **Traffic Control**
  - Traffic Signals, ITS, Work Zones
Demand

“. . .the principal measure of the amount of traffic using a given facility. Demand relates to vehicles arriving; volume relates to vehicles discharging. If there is no queue, demand is equivalent to the traffic volume at a given point on the roadway.” (HCM 2000, p 2-2)
How do you Measure Demand?

- Uncongested Facilities
- Congested Facilities
  - Latent Demand and System Impacts
- Route 40 Improvements at Missouri River Crossing
  - See next slide
  - WB bridge - 32’ wide, built 1935, 2 lanes to 3
  - EB bridge is 48’ wide, built 1985, 3 lanes to 4
  - Volumes increased by 30% almost overnight

- It is difficult to measure demand in a congested network. Travel Demand Modeling (TDM) techniques have been developed to study demand in urban areas.
What about Future Demand

- Governed largely by land use
- Interesting Trends
Population Trends

Historical & Projected U.S. Population

Source: http://www.theglitteringeye.com/images/usprojgrowth.jpg
Changes in population age distribution, 1960 to 2020

Largest population group in U.S. is persons 55 and older as of 2020
Households by Type, 1970 to 2012: CPS
(In percent)

U.S. Population: Urban, Suburban, and Rural

In Millions

- **Suburban**
  - 101 (1980)
  - 115 (1990)
  - 141 (2000)
  - 157 (2010)
  - 208 (2040)

- **Urban**
  - 68 (1980)
  - 78 (1990)
  - 85 (2000)
  - 102 (2010)
  - 141 (2040)

- **Rural**
  - 57 (1980)
  - 56 (1990)
  - 55 (2000)
  - 51 (2010)
  - 35 (2040)

(10-Year Trend)
Emerging Megaregions in the U.S.
Estimated Vehicle Miles Traveled on All Roads

- Recessions
- Miles Traveled: 12 Month Moving Average

Nov 2007

Nov 2011 trough at 48 months after peak, 3.65% off high

39 months below previous peak -3.2% at trough

A Close Look Since 2007
Estimated Vehicle Miles Traveled on All Roads

Latest down 3.16% from peak
11.8 years later

55 months total,
21 months to
5.0% trough

Jan 1971

Jun 2005

Population adjusted using the BEA Mid-month population estimates
[FRED POPTHM]
Peak-Period Congestion on High-Volume Truck Portion: 2011

Notes: High-volume truck portions of the National Highway System carry more than 6,500 trucks per day, including freight-hauling long-distance trucks, freight-hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95.

The volume/service flow ratio is estimated using the procedures outlined in the HPMS Field Manual, Appendix N.

PEAK-PERIOD CONGESTION ON HIGH-VOLUME TRUCK PORTION: 2040

Notes: High volume truck portions of the National Highway System carry more than 8,500 trucks per day, including freight-hauling long-distance trucks, freight hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95. The volume/service flow ratio is estimated using the procedures outlined in the HCM Field Manual, Appendix N.

Standard Performance Measures

- Speed
- Density
- Delay
- Level of Service
**Speed (HCM 7-3)**

- **Average running speed** — A traffic stream measure based on the observation of vehicle travel times traversing a section of highway of known length. It is the length of the segment divided by the average running time of vehicles to traverse the segment. Running time includes only time that vehicles are in motion.

- **Average travel speed / Space mean speed** — A traffic stream measure based on travel time observed on a known length of highway. It is the length of the segment divided by the average travel time of vehicles traversing the segment, including all stopped delay times. It is also a space mean speed. It is called a space mean speed because the average travel time weights the average to the time each vehicle spends in the defined roadway segment or space.

- **Time mean speed** — The arithmetic average of speeds of vehicles observed passing a point on a highway; also referred to as the average spot speed. The individual speeds of vehicles passing a point are recorded and averaged arithmetically.

- **Free-flow speed** — The average speed of vehicles on a given facility, measured under low-volume conditions, when drivers tend to drive at their desired speed and are not constrained by control delay.
Speed

Distance Traveled per Unit of Time

**Time Mean Speed (TMS):** Time mean speed is defined as the average speed of all vehicles passing a point over a specified time period.

**Space Mean Speed (SMS):** Space mean speed is defined as the average speed of all vehicles occupying a given section of roadway over a specific time period.
\[ TMS = \frac{\sum d}{n} \quad SMS = \frac{d}{\sum t_i} = \frac{nd}{\sum t_i} \]

TMS = time mean speed (m/sec or km/h [feet/sec or mph])
SMS = space mean speed (m/sec or km/h [feet/sec or mph])

d = distance traveled (m or km [ft or miles])
n = number of vehicles observed
t_i = travel time for the \(i^{th}\) vehicle (sec)
Traffic Density

- Expressed as
  - vehicles per mile
- Affects freedom of movement
- Critical parameter in uninterrupted flow facilities
- Discuss in further detail
Delay

- Several Types of Delay
  - Control
  - Geometric
  - Total

- Expressed as seconds per vehicle

- Critical parameter in interrupted flow facilities (e.g., traffic signals)

- Discuss in further detail
Level of Service

Read “Historical Overview of the Committee on Highway Capacity and Quality of Service” for historical context and development.

Traffic Service Levels A-F
- A is “free flow” conditions
- E is capacity conditions
- F is breakdown conditions
- C, D are USUALLY design criteria

Criteria to determine is function of facility type
- Freeways – Density
- Intersections - Delay
LOS Origins

- “E” - “possible capacity” (1950 Highway Capacity Manual)
- “D” - maximum sustainable everyday volumes (CA freeways)
- “C” - “practical capacity” (1950 Highway Capacity Manual)
- “B” - “practical capacity in a rural environment”
- “A” - service higher than “practical capacity” (NJ Turnpike)

Possible Capacity: The maximum number of vehicles that can pass a given point on a lane or roadway during one hour, under the prevailing roadway and traffic conditions.

Practical Capacity: The maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour with the traffic density being so great as not to cause unreasonable delay, hazard, or restriction to the drivers’ freedom to maneuver under the prevailing roadway and traffic conditions.
Travel Time Reliability

How traffic conditions have been communicated:

- Annual average
- Travel Time

What travelers experience:

- Travel times vary greatly day-to-day
- Travel Time

Small improvement in average travel times:

- Average day
- Travel Time

Larger improvement in travel time reliability:

- Worst day of the month
- Travel Time

Source: Federal Highway Administration
## Multi-Modal LOS (2013 Florida DOT Quality / Level of Service Handbook)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Automobile</th>
<th>Bicycle</th>
<th>Pedestrian</th>
<th>Bus Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume and Lanes</td>
<td>Volume and Lanes</td>
<td>Other Traffic and Roadway Characteristics</td>
<td>Arterial Running Speed</td>
<td>Sidewalk</td>
</tr>
<tr>
<td>Arterial Running Time</td>
<td>Bicycle LOS Score</td>
<td>Pedestrian LOS Score</td>
<td>Adjusted Bus Frequency</td>
<td></td>
</tr>
<tr>
<td>Control Characteristics</td>
<td>HCM LOS Criteria</td>
<td>HCM LOS Criteria</td>
<td>TCQSM LOS Criteria</td>
<td></td>
</tr>
<tr>
<td>Control Delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Service Measure**
- Average Travel Speed
- Bicycle LOS Score
- Pedestrian LOS Score
- Adjusted Bus Frequency

**LOS Determinator**
- HCM LOS Criteria
- HCM LOS Criteria
- TCQSM LOS Criteria
Other Measures?
BREAK
Uninterrupted Flow
Fundamentals
Uninterrupted Flow Fundamentals

- Basic Traffic Flow Variables
  - Flow, Speed, Density, Headway, and Spacing
- Basic car following theory
- Shock wave theory
  - An application of basic traffic flow theory
- Basic car following theory and shock wave theory are NOT covered in any great detail in the course reference materials
Traffic Flow

- Traffic flow is a rate
  - typically expressed in vehicles per hour (vph)
- Traffic volume is a number
  - vehicles that pass by a point in a given period of time
- Traffic flow is usually expressed as vph, but is usually expressed from a 15 minute volume through the use of a PHF
Speed (HCM, p7-2)

- Rate of motion per unit of time
- A representative value is used (individual speeds vary)
- Time Mean Speed (average spot speeds) are usually collected in field data collection efforts

Average travel speed is used in the HCM

- It is computed from observation of individual vehicles
- It is the most statistically relevant measure
- Divide the length of the segment by the average travel time of the vehicles traversing it.
Traffic Density (HCM, p7-4)

- The number of vehicles occupying a section of roadway
- Usually averaged over time
- Usually expressed as vehicles or passenger cars per mile.
- Direct measurement of density in the field is difficult. Density can be computed from the average travel speed and flow rate.

\[ D = \frac{V}{S} \]

where

- \( V \) = flow rate (veh/h),
- \( S \) = average travel speed (mi/h), and
- \( D \) = density (veh/mi).
Headway and Spacing (HCM, p7-4)

- Spacing is the **distance** between successive vehicles, measured from the same point on each vehicle.
- Headway is the **time** between successive vehicles, also measured from the same point on each vehicle.
Definitions
- Speed (distance/time)
- Density (vehicles/distance)
- Spacing (distance/vehicle)
- Headway (time/vehicle)
- Flow (vehicles/time)

Relationships
- Spacing and Density are Inverse
- Headway and Flow are Inverse
- Speed * Density = Flow
If you remember from physics...

\[ x = v_0 t + \frac{1}{2} at^2 \]

- \( x \) = distance traveled during acceleration
- \( v_0 \) = initial velocity
- \( t \) = time
- \( a \) = acceleration

\[ x = \frac{v^2 - v_0^2}{2a} \]

\( v \) = final velocity
Applied to a Simple Car Following Model

\[ s = (v_f t_{pr} + \frac{v_f^2}{2a_f} + x_o + L) - \frac{v_{l2}^2}{2a_l} \]

*Resulting Speed/Flow Curve*
Theoretical Speed / Flow Curve

- Speed: \( u_f \), \( u_0 \)
- Flow: \( q_{\max} \)

Uncongested Flow

High Density

Congested Flow
Field Speed / Flow Plots

2-lane German Freeway

5-lane US Freeway
Empirically Derived Speed Flow Curve (HCM, p13-3)
Impact of Multiple Lanes

Flow (vph)

Density (veh/mile)

Speed = 20 mph
EXHIBIT 7-2. GENERALIZED RELATIONSHIPS AMONG SPEED, DENSITY, AND FLOW RATE ON UNINTERRUPTED-FLOW FACILITIES

Source: Adapted from May (2).
Shock Wave Theory
Applying Basic Traffic Flow Theory

• *Shock wave* - a motion or propagation of change in traffic conditions (speed, density, and flow)
• A moving boundary between two different traffic states
• Forward, backward, and stationary shock waves
• \( q = k \times u \)
• [www.youtube.com/watch?v=iHzzSao6ypE&feature=youtu.be](http://www.youtube.com/watch?v=iHzzSao6ypE&feature=youtu.be)
In time “t” the number of vehicles crossing “s” is:

\[ n = (u_1 - u_w)k_1 = (u_2 - u_w)k_2 \]
Shock Waves

\[(u_1-u_w)k_1=(u_2-u_w)k_2\]

\[u_1k_1-u_wk_1 = u_2k_2-u_wk_2\]

\[u_wk_2-u_wk_1 = u_2k_2-u_1k_1\]

\[u_w(k_2-k_1) = q_2-q_1\]

\[u_w = \frac{(q_2-q_1)}{(k_2-k_1)}\]

\[u_w = \text{slope} = \frac{\Delta q}{\Delta k}\]
Density Flow Curves

Flow (vph)

Flow (veh/mile)

$q_1$

$q_2$

$u_1$

$u_2$

$u_w$

$k_1$

$k_2$
Example Problem

• Initial State
  – \( q = 3000 \text{ vph} \)
  – \( u = 60 \text{ mph} \)

• Queued State (6 minutes)
  – \( q = 0 \text{ vph} \)
  – \( u = 0 \text{ mph} \)
  – \( K_{jam} = 880 \text{ vpm} \)

• Release State
  – \( q = 8,800 \text{ vph} \)
  – \( u = 30 \text{ mph} \)

• Simulation
q/k Curve

Flow (vph)

$q_{max} = 8800$

$q_i = 3000$

$U_i = 60$

$U_{f2} = 30$

$u_{wb1}$

$u_{wf1}$

$u_{wf2}$

Density (veh/mile)

$0 \rightarrow k_i \rightarrow k_{jam}$
How far did the shockwave move upstream before the front of the queue started to dissipate?

\[ u_{\text{back wave 1}} = \frac{(q_{\text{Queue}} - q_{\text{initial}})}{(k_{\text{Queue}} - k_{\text{initial}})} \]

\[ = \frac{(0 \text{ vph} - 3000 \text{ vph})}{(880 \text{ vpm} - k_{\text{initial}})} \]

\[ k_{\text{initial}} = \frac{3000 \text{ vph}}{60 \text{ mph}} = 50 \text{ vpm} \]

\[ u_{\text{back wave 1}} = \frac{(0 \text{ vph} - 3000 \text{ vph})}{(880 \text{ vpm} - 50 \text{ vpm})} \]

\[ = 3.6 \text{ mph} \]

\[ 3.6 \text{ mph} \times 0.1 \text{ hour} = 0.36 \text{ miles or 1900 feet} \]

This is the Maximum Length of the Queue
Group Calculations

• What was the maximum distance that the shockwave moved upstream? How many total cars were delayed by the queue?
BREAK

BACK 'N 5 MIN
Other Queuing Models

\[ E_m = \frac{\lambda^2}{\mu(\mu - \lambda)} \]
\[ E_w = \frac{\lambda}{\mu(\mu - \lambda)} \]
\[ P(n > N) = (\frac{\lambda}{\mu})^{N+1} \]

\( E_m \) = Mean queue length (veh)
\( E_w \) = Mean waiting time in queue (min.)
\( P(n > N) \) = Probability of more than \( N \) vehicles in the queue
\( \lambda \) = Arrival flow rate (veh/min.)
\( \mu \) = Departure flow rate (veh/min.)
JCE 4600 – Homework 1

1. A roadway carries 1000 vph in the peak flow direction at 50 mph. A farm tractor enters the highway and travels 1 mile at 15 mph. No vehicles are able to pass. Assume that the maximum flow rate that can be sustained is 1700 vph at 40 mph, and the density in the queue is 70 vpm.

   a.) Sketch the q - k curve and plot the slopes of the shock waves immediately after the tractor leaves the highway.

   b.) Draw a time / space diagram which illustrates the growth and dissipation of the queue. Identify and calculate the maximum number of vehicles in the queue, the total time that the queue is on the highway.

2. A school zone (speed limit = 10 mph) of 1 / 4 mile length is located on a 40 mph roadway. Up stream of the school zone the normal flow is 1000 vph at 40 mph, in the school zone the flow is 900 vph at 10 mph, and the maximum flow of the highway is 1200 vph at 30 mph.

   a.) Sketch the q-k curve and identify the critical values.

   b.) What is the speed and direction of all shock waves?

   c.) If the school zone is open for 30 minutes, what is the maximum length of the queue?

   d.) Plot a time versus distance curve for this situation.
3. The $u - k$ relationship for a particular freeway lane was found to be:

$$20u+52 = 0.02(k - 240)^2$$

Given that the speed is in mph and the density is in vpm find the mean free speed, jam density, maximum flow rate, and prevailing speed at the maximum flow rate. Calculate the values mathematically and plot a $q - k$ curve.

4. Interstate 70 west of Columbia is a four lane divided freeway (2 lanes in each direction) in rolling terrain. During peak hour on Friday night, there are an average of 2500 vehicles traveling in the westbound direction at 60 mph. (STATE ALL ASSUMPTIONS WHEN REQUIRED DATA IS NOT GIVEN)

a.) Assume that capacity of the freeway is 4400 vph at 40 mph, the free flow speed is 75 mph. Assume that $K_{jam}$ for the only lane cross-section is one-half of that of the two-lane section. Plot the $q - k$ curve and label the jam density, maximum flow rate, and the speed at capacity.

b.) Assume that a 10 mile segment is being reconstructed and only 1 lane will be available for the westbound traffic. Redraw the $q-k$ curve from above and account for the construction zone. Assume that the capacity of the construction zone is 1800 vph average speed at capacity is 30 mph in the construction zone and 15 mph upstream of the construction zone. Assume the jam density in the construction zone is 110 vpm.

c.) What is the speed and flow rate of: 10 mile segment under construction, the queue immediately upstream of the single lane segment, upstream of the queue, downstream of the construction zone (assume a speed of 65 mph)? What is the speed and direction of movement of the three shock waves?

d.) Assume that after 1 hour the incoming flow rate drops to 1000 vph at 70 mph. Show the resulting shock waves on the $q$-$k$ curve. Draw a time/space diagram showing the growth and reduction of the queue upstream of the construction zone. How many total vehicles were affected?