Instructor Notes
Traffic Flow Theory

Module Overview

This module introduces **traffic flow as a system of interacting vehicles and drivers**, focusing on:

- Core variables: **speed, flow, density**
- Mathematical relationships between them
- Differences between **theoretical models and real-world behavior**

Key Message for Instructors

Traffic flow is not a perfect physical system; it is influenced by **human behavior**, making it inherently variable and complex.

Learning Objectives

By the end of this lecture, students should be able to:

- Define key traffic stream parameters, including speed, flow, and density
- Differentiate between time-mean speed (TMS) and space-mean speed (SMS), and calculate TMS and SMS using given data sets and formulas
- Calculate traffic flow and density based on observed headways and spacings
- Apply the fundamental relationship among speed, flow, and density ($q = u \times k$)
- Interpret Greenshield's linear speed–density model and derive flow–density and speed–flow relationships
- Evaluate how theoretical models compare to real-world traffic behavior and assess their limitations

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Teaching Flow / Suggested Lecture Structure

A. Introduction to Traffic Flow (10–15 min)
Key Concepts

- Traffic = system of **vehicles + drivers + environment**

- Unlike fluids:
  - Drivers behave differently
  - No perfect predictability

Why Study Traffic Flow?

- Evaluate roadway performance
- Design infrastructure
- Improve efficiency and safety

Instructor Prompt:

- “Why can’t we model traffic like water flow?”

B. Levels of Traffic Flow Analysis (10 min)

1. Microscopic

- Individual vehicles
- Driver behavior

2. Mesoscopic

- Groups of vehicles

3. Macroscopic

- Aggregate traffic behavior

Instructor Tip:

Relate levels to:

- **TMS → microscopic**
- **SMS → macroscopic**

C. Core Traffic Parameters (25–30 min)

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1. Speed (u)

Two Types

- **Time-Mean Speed (TMS)**
  - Measured at a point
  - Example: radar gun
- **Space-Mean Speed (SMS)**
  - Measured over a segment
  - More relevant for macroscopic analysis

Key Insight:

SMS is always ≤ TMS

Instructor Tip:

Students often confuse these; use a simple example with slow/fast vehicles.

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2. Flow (q)

- Number of vehicles passing a point per time
- Units: **veh/hr**

Headway Relationship

- Headway = time between vehicles
- Flow ≈ inverse of average headway

Important Concept:

Links **microscopic → macroscopic analysis**

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3. Density (k)

- Vehicles per unit length (veh/mi)

Measurement Methods

- Aerial (drones)
- Loop detectors (occupancy)

Key Insight

Density is the **best indicator of congestion/demand**

D. Fundamental Traffic Flow Relationship (15 min)

Central equation:

$$q = u \times k$$

Interpretation

- Flow depends on:
  - Speed
  - Density

Important Insight

- Holds under **all traffic conditions**

Instructor Prompt:

- "Can high flow occur at low speed?" (Yes—congestion case)

E. Greenshield Model (25–30 min)

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1. Speed–Density Relationship

$$u = u_f\left(1 - \frac{k}{k_j}\right)$$

Where:

- u_f= free-flow speed
- k_j= jam density

Key Ideas

- Linear decrease of speed with density
- At:

- $k = 0$→ maximum speed
- $k = k_j$→ speed = 0

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2. Flow–Density Relationship

- Derived using $q = u \cdot k$
- Produces **parabolic curve**

3. Capacity Concept

- Maximum flow occurs at:
  - **Half of jam density**
- Corresponds to:
  - Optimal balance of speed and density

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4. Speed–Flow Relationship

- Shows two regimes:
  - Free-flow
  - Congested

Critical Insight:

Same flow can represent:

- High speed (light traffic)
- Low speed (congested traffic)

F. Real-World vs Theoretical Models (15 min)

Observed Differences

- Real data ≠ perfect parabola
- Driver behavior introduces variability

Example Source

- Caltrans sensor data (PeMS)

Key Takeaway

Models are:

- Simplifications
- Useful, but not exact

G. Future Perspective: Autonomous Vehicles (10 min)

Potential Benefits

- Reduced variability
- Better coordination
- Higher efficiency

Concept

AVs could make traffic behave **closer to theoretical models**

Discussion Prompt:

- "Would AVs eliminate congestion?"

Key Concepts to Reinforce

- Traffic flow = **interaction of humans + vehicles**
- Three core variables:
  - Speed
  - Flow
  - Density
- Fundamental relationship is universal
- Models are **approximations, not reality**
- Density is the **true measure of demand**

Common Student Misconceptions

- Confusing flow vs density
- Assuming higher speed = better flow
- Thinking models perfectly represent reality
- Mixing up TMS and SMS

Suggested Examples / Activities

- Calculate:
  - Flow from headway
  - Density from spacing
- Plot:
  - Speed–density graph
- Compare:
  - Model vs real data

Assessment Ideas

- Quiz on traffic stream parameters
- Numerical problems:
    - Compute q, u, k
- Conceptual:
    - Interpret traffic states
- Graph-based:
    - Identify capacity point

Closing Summary for Instructors

Emphasize:

- Traffic flow theory provides a **foundation for all traffic engineering**
- Real-world variability requires **engineering judgment**
- Future technologies may **reduce uncertainty and improve system performance**

References

- Standard traffic engineering textbooks