Design Vehicle Detection System for Better Data Accuracy

Jillian Scholler and Jingcheng Wu
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Outline

• Objectives and introduction
• Type of detectors
• Detector measurement and data examples
• How detectors collect volume, speed and occupancy
• TSM&O applications utilizing detector data
• Detector data collection challenges
• Demonstrate vehicle detection system design using microwave sensor as an example
• Lessons learned
Objectives

• Provide an introduction to traffic detectors
• Understand how traffic detectors collect volume, speed and occupancy data
• Design a Vehicle Detection System to provide better data accuracy
Introduction

• The National Electrical Manufacturers Association (NEMA) defines a detector as a device for indicating the presence or passage of vehicles or pedestrians.

• Type of Detection As Defined by NEMA TS 2
  • Advisory Detection
    • Actuation for traffic signal operations
  • Passage Detection
    • Detect the passage of a vehicle moving through detection zone
    • Ignore the presence of a vehicle stopped within detection zone
  • Presence Detection
    • Sense a vehicle in detection zone, whether moving or stopped
Detector Functional Types as Defined in FDOT Standard Specification

• Vehicle Presence Detection Systems
• Traffic Data Detection Systems
  • Provide presence, volume, occupancy, and speed data
• Probe Data Detection Systems
  • Provide speed data and travel times for a road segment
Detector Type by Installation

• Non-intrusive vs. intrusive

Video Image Detector

Sunpass Reader

Inductive Loops
Detection Technologies

- Inductive loops
- Magnetic sensors
- Video image detectors
- Microwave radar sensors
- Infrared sensors
- Laser radar sensors
- Ultrasonic sensors
- Acoustic sensors
- Probing technique
Detector Technology Types as Defined in FDOT Standard Specification

- Inductive Loop
- Video
- Microwave
- Wireless Magnetometer

- Automatic Vehicle Identification
  - Toll tag transponder reader
  - Bluetooth reader
  - License plate reader

Measure all vehicles or Population
Measure a subset of all vehicles or probe-based monitoring or Sample
Probe-based Monitoring Techniques

- Vehicle re-identification or vehicle signature matching
- Media Access Control (MAC) address matching
- Vehicle license plate matching
- Vehicle toll tag matching
- Floating car technique
- Global Positioning System (GPS) devices
- Cellular phones
- Radio communication systems
- Transit vehicles equipped with automatic vehicle locators
- Aerial photographs
- Mechanical devices attached to odometers
- Pickup-delivery trucks
What does a detector measure?

• Point measurement (Measure all vehicles)
  • The most common data are volume, speed and occupancy

• Link measurement (Probe-based monitoring)
  • Include space mean speed, travel time, density, vehicle queue length and space occupancy

• Vehicle Trajectory (Connected and automated vehicles)
  • When a vehicle travels along a roadway, the position of the vehicle can be expressed as a coordinate in time and space.
Point Measurement Data Example

- 24-hour microwave sensor speed data at a signalized arterial mid-block location
- Data collection interval is 10 seconds
- X-Axis is time of day
- Y-Axis is speed in miles per hour
Link Measurement Data Example

- 24-hour Individual Vehicle Travel Time on Lexington Ave. between 42nd St. and 49th St in Manhattan
Vehicle Trajectory Data Example (AV/CV)

- 253,994 data records of 433 vehicles during 17 minutes
Detector Volume

• Volume = the number of vehicles passing detection zone

• The equivalent hourly volume is often treated as the flow rate

• flow rate = \( \frac{volume}{T} \)

• \( T \geq 15 \text{ minutes} \)
Detector Speed

- Time mean speed is the arithmetic average of vehicle speeds passing a point on a roadway
  \[ \overline{S} = \frac{\sum_{i=1}^{N} (S_i)}{N} \]

- Space mean speed is the length of the link divided by the travel time of vehicles traversing the link
  \[ \overline{S} = \frac{N \times L}{\sum_{i=1}^{N} \left( \frac{L}{S_i} \right)} \]
Detector Speed

- Detector speed is the harmonic mean speed of vehicles passing detection zone.
- \( S_{detector} = \frac{1}{\sum_{i=1}^{N} \left( \frac{1}{\frac{L_i + L_d}{t_i}} \right)} \)
- Detector effective detection length is the vehicle physical length plus the detection zone length
Detector Occupancy

• Detector occupancy is time occupancy
• Defined as the percentage of time detection zone is occupied by a vehicle

\[ O_{time} = \frac{\sum_{i=1}^{N} (t_i)}{T} \]
Detector Data Accuracy Requirements in FDOT Standard Specification

- Vehicle Presence Detection Accuracy, 98%
- Probe Data Detection System Accuracy
  - Penetration rate (probing or sampling rate), 75% of all vehicles
  - Match rate, 5% of all vehicles
  - Segment speed and travel time, 90%
- Traffic Data Detection System Data Accuracy
  - Volume, 95%
  - Occupancy, 90%
  - Speed, 90%
TSM&O Detector Applications

- Express Lanes
- Ramp Metering
- Freeway Speed Monitoring
- Speed Advisory DMS
- Travel Time Messaging
- Active Traffic Monitoring (ATM)
TSM&O Applications – Express Lanes

- Toll Calculation Based on Real-time Traffic Flow Data used to calculate Average Traffic Density per segment every 15 mins

- Travel Time Calculation

- Speed Monitoring
TSM&O Applications – Ramp Metering

• Freeway Detectors
  1. MVDS (Passage Style)
  2. Loops
  3. Magnetic Sensors

• Ramp Detectors
  1. Loops
  2. Magnetic Sensors
  3. Video (Required on Bridges)
  4. MVDS (Presence Style)
TSM&O Applications – Speed Monitoring

• Data Analysis and Reporting Tool (DART)
• Speed Graphs Displayed inside TMC
• I-95 & I-75
• Displays Active Incidents
• Benefits
  • Incident Detection
  • MVDS Failures
TSM&O Applications – Speed Advisory DMS

- Speed Detection and Advisory System
- Collects speed from each lane
- Posts excessive speed advisory message
TSM&O Applications – Travel Time

• Freeway – MVDS
  • Displayed on select DMS throughout District
  • Updated every minute
  • Strategically selected destinations
  • Messages displayed secondary to lane blockage messages
TSM&O Applications – Travel Time

- Arterial - Bluetooth
  - Anonymous Signal via mobile devices
  - Real-time speed and travel time
  - Updated every minute
  - Devices installed at major intersections and on DMS Structures
- Travel time & speed calculated between 2 paired devices
TSM&O Applications – Active Traffic Mgmt

- Dynamic Lane Use
- Dynamic Merge
- Dynamic Shoulder Use
- Dynamic Speed Limit
TSM&O Applications – Other

• Automatic Vehicle Identification (AVI)
  • Tolls
  • SunPass

• Speed Enforcement
  • Point to Point Enforcement
  • Used in Australia & New Zealand with positive results
Challenges

• Express Lanes
  • Real time data - Tolls updated every 15 minutes
  • Motorist incorrectly charged Low/High Tolls
  • Poor System Reliability
• Ramp Metering
  • Real-time Data – Metering Rate Calculated based on one-minute moving average
  • Freeway Congestion or Excessive Queues on Ramps
• Arterials & Speed Advisory DMS
  • Incorrect messages
  • Driver Confusion
Common Detector Data Collection Errors

• Double count
  • Count a vehicle more than once

• Miss count
  • Fail to detect a vehicle
Common Detector Data Collection Errors

- **Occlusion**
  - Detector signal is blocked

- **Phantom detection**
  - Fail to detect the correct vehicle position

[diagram showing occlusion and phantom detection]
Challenges Probing Techniques Facing

- Privacy issues
- Minimum sample size or probing rates required
- Biased results because of differences between the population and the samples
- High implementation costs
- Fixed infrastructure constraints
- Multiple routes between data collection points
- No point measurements of performance or queue length data directly available
- Cannot be used for signal actuation
Vehicle Detection System Design

• Facility
  • Freeway mainline, ramp or arterial

• Performance measurement
  • Point measurement vs. link measurement

• Traffic flow conditions

• Detector technologies

• Design Criteria
  • Single detector or separate detectors for mainline vs. ramp, Express Lanes vs. General Use Lanes, different directions
  • Detector spacing
  • Detector mounting
  • Communication
  • Power
Freeway Microwave Sensor Design

- Traffic Data Detection System
- Provide presence, volume, occupancy, and speed data
- Microwave sensor signal
- Detector location selection
  - Vehicle movement vs. detection zone
  - Avoid areas vehicles changing movements
    - Merging area, diverging area, weaving area, etc.
  - Avoid obstruction of detector microwave signal
    - Cross sections are important
  - Avoid reflection of detector microwave signal
  - Avoid stop and go area
  - Stay within detector microwave signal range
- Determine detector mounting height vs. detector offset
Microwave Sensor Signal

• Example 1

Average Coverage (Radar)
The Sx-300 detection field of view covers the area defined by:
- Elevation angle 50 degrees
- Azimuth 12 degrees
- Range 0 to 76 m (0 to 250 ft)

Frequency Bands
- K band, model Sx-300 operates at high resolution in the 24 GHz band

• Example 2

Radar Design
- Operating frequency 24.0–24.25 GHz (K-band)
- Dual-radar
- No manual tuning to circuitry
- Transmits modulated signals generated digitally
- No temperature-based compensation necessary
- Bandwidth stable within 1%
- Printed circuit board antennas
- Antenna vertical 6 dB beam width (two-way pattern): 65°
- Antenna horizontal 6 dB beam width (two-way pattern): 6°
- Antenna two-way sidelobes: -40 dB
- Transmit bandwidth: 245 MHz
- Un-windowed resolution: 2 ft. (0.6 m)
- RF channels: 4
- EIRP: 18.1 dB
- Antenna gain: 14 dB
Microwave Sensor Signal

- Vertical angle
- Horizontal angle
Vehicle Movement vs. Detection Zone

- $L_{d1} > L_d$
- $L_{v1} > L_v$
- $S_{detector} = \sum_{i=1}^{N} \left( \frac{1}{L_i + L_d} \right) t_i$
- $O_{time} = \frac{\sum_{i=1}^{N} (t_i)}{T}$
Avoid Areas Vehicles Changing Movements
Avoid Obstruction of Detector Signal
Avoid Obstruction of Detector Signal

Average Coverage (Radar)
The Sx-300 detection field of view covers the area defined by:

- Elevation angle
  - 50 degrees
- Azimuth
  - 12 degrees
- Range
  - 0 to 76 m (0 to 250 ft)
Avoid Obstruction of Detector Signal
Avoid Reflection of Detector Signal
## Mounting Height vs. Offset

### Figure 1.1 – Recommended Mounting Height

<table>
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<th>Offset from first detection lane (ft / m)</th>
<th>Recommended mounting height (ft / m)</th>
<th>Minimum mounting height (ft / m)</th>
<th>Maximum mounting height (ft / m)</th>
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*Maximum Mounting Height may vary due to environmental factors.*
Mounting Height vs. Offset

Figure 2-4: Setback Distance Chart

Figure 2-5: Mounting Height Chart.
Mounting Height vs. Offset

• Detector mounting height is measured from the edge of the closest travel lane to the bottom of the detector.

• Offset is measured from the front face of the pole to the edge of the closest travel lane.
Lessons Learned

• FDOT standard specification section 660-2.3.1.3
  • Traffic Data Detection System Field Acceptance Testing: Verify detection accuracy at installed field sites using a reduced method similar to those described in 660-2.3.1. Compare sample data collected from the detection system with ground truth data collected by human observation. For site acceptance tests, collect samples and ground truth data for each site for a minimum of five minutes during a peak period and five minutes during an off-peak period. Perform site acceptance tests in the presence of the Engineer.

• Data collection time interval or polling interval
• Valid data vs. invalid data
• By per lane vs. by per direction
• Occupancy data testing
  • Time occupancy is about 0.35 seconds for a vehicle travels at 50MPH and human perception reaction time is about 1.4 seconds
• Ground truth data
Questions

• Jillian Scholler, PE
  Managed Lanes Coordinator
  AECOM
  SMART SunGuide RTMC
  2300 West Commercial Blvd.
  Fort Lauderdale, FL 33309
  JScholler@smartsunguide.com

• Jingcheng Wu, PhD, PE, PTOE
  ITS Project Manager
  HDR
  3250 W. Commercial Blvd., Suite 100
  Fort Lauderdale, FL 33309
  jingcheng.wu@hdrinc.com