Why it is necessary to collect traffic data

Useful in following traffic applications:
- control,
- coordination and management,
- enforcement,
- safety systems,
- prediction, planning and statistics,
- ...
- Useful in vehicle systems

Traffic control

- Traffic lights
  - Optimization of individual intersections
  - Optimization of area networks (green wave)
- City traffic control (tunnels)
- Highway traffic control
  - VMS (variable message signs)
    - B20 (speed limit)
    - B22 (no overtaking for heavy vehicles)
    - ...
  - Ramp metering

Coordination and management

- Management
- Traffic information distribution
- Lane management
- Coordination
- Crisis management
- Fleet management

Enforcement

- Enforcement
- Red light crossing detection
- Size enforcement
- Weight in motion
- Speed measurement
- Close area enforcement
Why it is necessary to collect traffic data

Safety systems

- Telematic Applications
- Informative speed measurement
- Detection of ghost vehicles
- Pedestrian detection
- Road condition measurement

Why it is necessary to collect traffic data

Prediction, planning and statistics

- Prediction and planning for purposes of
  - Traffic control
  - Road construction
  - Traffic simulations
  - Statistical evaluation of real impact on
    - environment
    - road users
  - ...

Why it is necessary to collect traffic data

In car applications

- Drivers support systems
- Adaptive cruise control
- Intelligent head lights
- Traffic simulations
- ...
- Active safety systems
- Forward collision warning
- Lateral position monitoring
- Blind spot monitoring
- Safety belts
- ...

Why it is necessary to collect traffic data

Examples

- Pedestrian detection http://www.youtube.com/watch?v=H_wMyUEehzQ
- Blind spot monitoring http://www.youtube.com/watch?v=X-Q8n8wM5PQ
- Enforcement http://www.youtube.com/watch?v=5OpEgT7cWF5 http://www.youtube.com/watch?v=7oRjq_yulN4
- And many others ...

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- Why it is necessary to collect traffic data
- Traffic sensors/detectors
  - Categories
  - Parameters
- Measurement errors
- Detector types
  - Intrusive
  - Nonintrusive
  - Comparison

Discussion

- What is a sensor?
Traffic sensors/detectors

Sensor
A device for translating the magnitude of one quantity to another. The second quantity often has different units of measure and serves to provide a more useful signal. Vibration sensors convert mechanical motion into an electronic typically a voltage proportional) signal.

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Many different classifications:

- By measured quantity
  - speed, vehicle count, temperature, pressure, optical, magnetic, electric, mechanic quantities.
- By physical principle of measuring the quantity
  - inductance, magnetic, piezoelectric, optic, optoelectric.
- By contact with measured quantity
  - Intrusive, non intrusive
- By function in traffic control
  - extension, presence (polling), strategic

Traffic sensors/detectors - Parameters

Static parameters
- Sensitivity
- Threshold
- Dynamic range
- Reproducibility
- Readability / resolution
- Additive and multiplicative errors
- Linearity
- Output parameters

Dynamic Parameters
- Time response
- Frequency bandwidth
- Quantization parameters
- Noise parameters
- ...

Sensitivity:
- the ability of a detector to react to measured quantity, expressed as the minimum quantity required to produce a specified output signal with a given noise level.

- Ideal function \( y = Kx \),

- Where \( K \) is detector sensitivity defined by differences \( \Delta x \) a \( \Delta y \) in following:

\[
K = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} = \frac{dy(x)}{dx}
\]
Traffic sensors/detectors - Parameters

Threshold
- The smallest change in the measured variable that will result in a measurable change in an output signal

Dynamic range
- Is given by the interval of admissible values of measured physical quantity
- Is bounded by the sensitivity threshold and the maximum value of the quantity

Reproducibility
- Is given by the deviation of the measured values while the short sequence constant input quantity is measured

Readability / resolution
- Is the smallest change of measured quantity corresponding to the absolute or relative sensor error
- In analog signal transformation is given by
  \[ r_a = \frac{\delta_s}{y_{\rm max} - y_{\rm min}} \]
- In digital transformation the signal is given by
  \[ r_d = \frac{1}{2^n - 1} \]
  where \( n \) is the number of bits

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- Measurement errors
  - Absolute and relative errors
    - \( y_A \) - measured value
    - \( y_S \) - true value
    - Absolute measurement error \( \Delta_y = y_A - y_S \)
    - Relative measurement error \( \delta_y = \frac{\Delta_y}{y_S} \)
    - Relative sensor error \( \delta_s = \frac{(\Delta_y)}{y_{\rm max} - y_{\rm min}} \)

Measurement errors

Additive measurement error
- Caused by the offset of nominal linear characteristics
- Absolute measurement error is constant
- Relative measurement error depends hyperbolically on \( x \)
Measurement errors

Multiplicative measurement error
- is equivalent to the change of sensitivity of the sensor
- absolute measurement error is dependent on the value of the measured quantity
- relative measurement error is constant

\[ y = (K + \Delta K) \cdot x \]
\[ \Delta y = \Delta K \cdot x \]
\[ \frac{\Delta y}{y} = \frac{\Delta K}{K} = \delta_k = \text{konst.} \]

Linearity error
- given by deviation from an ideal linear characteristic

\[ \delta_L = \frac{y_m - y_L}{y_{\text{max}} - y_{\text{min}}} \]
where \( y_L \) is defined by ideal function \( y = y_L + K^*x \),
- parameter \( K \) can be estimated using linear regression.

Hysteresis
- Non-uniqueness between two variables as a parameter increases or decreases,
- the maximum difference in output at any given value of the measured variable within the specified range, when the value is first approached with an increasing signal and then a decreasing one.

\[ \delta_H = \frac{y_L - y_U}{y_{\text{max}} - y_{\text{min}}} = \frac{\Delta y}{y_{\text{max}}} \]

Random error
- caused by the uncontrolled effects
- error of repeated measurements (and noise) show a statistical patterns
- Gauss distribution, mean value corresponds to the most likely value of repeated measurements

\[ f(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{(x - \mu)^2}{2\sigma^2}} \]

Vehicle Detection and Surveillance

DETECTOR TYPES

Intrusive technologies
- Inductive Loop Detectors
- Fiber Optic Sensors
- Magnetic Sensors
- Piezoelectric Sensors
- Pneumatic Road Tube
- Weigh-in-Motion (WIM)

Non-Intrusive technologies
- Infrared Sensors
- Microwave Radar
- Passive Acoustic Array Sensors
- Ultrasonic Sensors
- Video Image Sensors
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  — Nonintrusive
  — Comparison

Invasive Detector

• Small coil of wire embedded in protective housing and installed under the surface of the roadway
  — Electronic amplifiers required
  — Does not work as a presence detector
  — Minimum speed 3 to 5 mph

Principal Components of Inductive Loop Detector

Pneumatic road tube

• Send a burst of air pressure along a rubber tube when a vehicle’s tires pass over the tube.
  • The pressure pulse closes an air switch, producing an electrical signal that is transmitted to a counter or analysis software.
  • The pneumatic road tube sensor is portable,

Inductive loops

• the most common sensor used in traffic management
• size and shape vary (square, round and rectangular)
• The principal components of an inductive loop detector:
  — One or more turns of insulated wire buried in a shallow sawcut in the roadway,
  — a lead-in cable that runs from a roadside pull box to the controller cabinet, and
  — an electronics unit located in the controller cabinet.

Inductive loops – Prague example
**Piezoelectric cable**

- Piezoelectric materials generate a voltage when subjected to mechanical impact or vibration.
- Electrical charges of opposite polarity appear at the inner and outer faces of the material and induce a voltage.
- The measured voltage is proportional to the force or weight of the vehicle.
- The magnitude of the piezoelectric effect depends upon the direction of the force in relation to the axes of the crystal.
- Since the piezoelectric effect is dynamic, i.e., charge is generated only when the forces are changing, the initial charge will decay if the force remains constant.

**Magnetic sensor**

- Magnetic sensors are passive devices that indicate the presence of a metallic object by detecting the perturbation in the Earth’s magnetic field created by the object.
- Two types of magnetic sensors are used:
  - Two- and three-axis fluxgate magnetometers, detects changes in the vertical and horizontal components of the Earth’s magnetic field produced by a ferrous metal vehicle. These sensors identify stopped and moving vehicles.
  - Magnetic detector (induction or search coil magnetometer)
    It normally detects only moving vehicles by measuring the change in the magnetic lines of flux caused by a moving ferrous metal vehicle. Cannot detect stopped or slow moving vehicles.

**Piezoelectric sensor**

- Piezoelectric WIM systems contain one or more piezoelectric sensors that detect a change in voltage caused by pressure exerted on the sensor by an axle and thereby measure the axle’s weight.
- As a vehicle passes over the piezoelectric sensor, the system records the sensor output voltage and calculates the dynamic load.
- The dynamic load provides an estimate of the static load when the WIM system is properly calibrated.

**Bending plate**

- Bending plate WIM systems utilize plates with strain gauges bonded to the underside.
- As a vehicle passes over the bending plate, the system records the strain measured by the strain gauges and calculates the dynamic load.
- The static load is estimated using the measured dynamic load and calibration parameters.
- The calibration parameters account for factors such as vehicle speed, pavement condition, and suspension dynamics, which influence estimates of the static weight.
Capacitance Mat

- consists of a sandwich of metal steel sheets and dielectric material
- a stainless steel sheet could be surrounded by polyurethane dielectric material on either side. The outer surfaces of the polyurethane layers are enclosed by other stainless steel sheets.

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Non-invasive Detection

- You do not have to alter the pavement to use this system
- Types
  - Radar detectors
  - Sonic detectors
  - Video Image Processing (VIPs)
  - Special purpose detectors

Infrared Sensors

ASIM DT 272 Infrared-ultrasonic sensor, ASIM DT 281 Infrared-Doppler radar sensor

Radar Detection

- Operates on the Doppler effect, as a microwave signal is emitted by the detector and reflected back at the detector by approaching vehicles
- Transmits microwave energy toward the roadway from the detector’s antenna
- Senses the frequency of the microwave change in the reflected energy and obtains vehicle speed from the signal

Radar Detection

- Two types of radar units
  - Antenna and detection electronics is fabricated as a single unit and located over the roadway
  - Separate antenna and detection electronics
Radar Detectors

- Detectors require FCC approval
- Newly developed detectors
  - Detect moving vehicles as well as stopped vehicles
  - Covers single or multiple lanes
  - Provides digital and instantaneous speed information

Sonic Detectors

- Transmit pulses of ultrasonic energy through transducers toward the roadway
- Located over the roadway
- Presence of vehicle causes these ultrasonic beams to reflect back to the transducers and it:
  - Senses the reflected wave
  - Converts to electrical energy
  - Relays the energy to a transceiver which provides vehicle presence information

Video Image Processing System (VIPS)

- Research was conducted in the mid 1970's by the University of Minnesota
  - Camera, digitizer, formatter, interface, electronics, microprocessor and power supply was used
  - Theory: one camera to replace numerous detectors
- 1970's and 80's
  - Japan, UK, Germany, Sweden and France used VIPs successfully

Video Image Detection System (VIDS)

- Algorithm for generating both presence and passage detection and speed
- Problems:
  - Shadows
  - Lighting (illumination) change
  - Reflection (camera difficulties)

Video Image Detection System (VIDS)

- Summary of VIDS and VIPS
  - Entire intersection can be surveyed using one camera
  - Can have remote or automatic control

Vehicle Presence Detection at an Intersection
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Strengths and Weaknesses of ...

Strengths of Inductive loop
- Flexible design to satisfy large variety of applications.
- Mature, well understood technology.
- Large experience base.
- Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, ...).
- Insensitive to inclement weather such as rain, fog, and snow.
- Provides best accuracy for count data as compared with other used techniques.
- Common standard for obtaining accurate occupancy measurements.
- High frequency excitation models provide classification data.

Weaknesses of Inductive loop
- Installation requires pavement cut.
- Improper installation decreases pavement life.
- Installation and maintenance require lane closure.
- Wire loops subject to stresses of traffic and temperature.
- Multiple loops usually required to monitor a location.
- Detection accuracy may decrease (for design with a large variety of vehicle classes.)

Strengths and Weaknesses of ...

Magnetometer

Strengths
- Less susceptible than loops to stresses of traffic.
- Insensitive to inclement weather such as snow, rain, and fog.
- Some models transmit data over wireless (RF) link.

Weaknesses
- Installation requires pavement cut.
- Improper installation decreases pavement life.
- Installation and maintenance require lane closure.
- Models with small detection zones require multiple units for full lane detection.

Strengths and Weaknesses of ...

induction or search coil magnetometer

Strengths
- Can be used where loops are not feasible (e.g., bridge decks).
- Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required.
- Insensitive to inclement weather such as snow, rain, and fog.
- Less susceptible than loops to stresses of traffic.

Weaknesses
- Installation requires pavement cut or boring under roadway.
- Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.

Strengths and Weaknesses of ...

Microwave radar

Strengths
- Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications.
- Direct measurement of speed.
- Multiple lane operation available.

Weaknesses
- Continuous wave (CW) Doppler sensors cannot detect stopped vehicles.
### Strengths and Weaknesses of Active Infrared

**Strengths**

- Transmits multiple beams for accurate measurement of vehicle position, speed, and class.
- Multiple lane operation available.

**Weaknesses**

- Operation may be affected by fog when visibility is less than 20 feet (6 m) or blowing snow is present.
- Installation and maintenance, including periodic lens cleaning, require lane closure.

### Strengths and Weaknesses of Passive Infrared

**Strengths**

- Multizone passive sensors measure speed.

**Weaknesses**

- Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog.
- Some models not recommended for presence detection.

### Strengths and Weaknesses of Ultrasonic

**Strengths**

- Multiple lane operation available
- Capable of overheight vehicle detection.
- Large Japanese experience base.

**Weaknesses**

- Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models.
- Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.

### Strengths and Weaknesses of Acoustic

**Strengths**

- Passive detection.
- Insensitive to precipitation.
- Multiple lane operation available in some models.

**Weaknesses**

- Cold temperatures may affect vehicle count accuracy.
- Specific models are not recommended with slow-moving vehicles in stop-and-go traffic.

### Strengths and Weaknesses of Video Image Processor

**Strengths**

- Monitors multiple lanes and multiple detection zones/lane.
- Easy to add and modify detection zones.
- Rich array of data available.
- Provides wide-area detection when information gathered at one camera location can be linked to another.

**Weaknesses**

- Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway).

**Video Image Processor Weaknesses ... cont**

- Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens.
- Reliable nighttime signal actuation requires street lighting.
- Requires 30- to 50-ft (9- to 15-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement.
- Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure.
- Generally cost effective when many detection zones within the camera field of view or specialized data are required.
Sources

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