



Lecture 3: ITS Sensors and Architectures

ITS Sensors and Architectures

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Module "Vehicle-2-X: Communication and Control"



Contents

- Sensor types and applications
- Sensor applications to traffic management

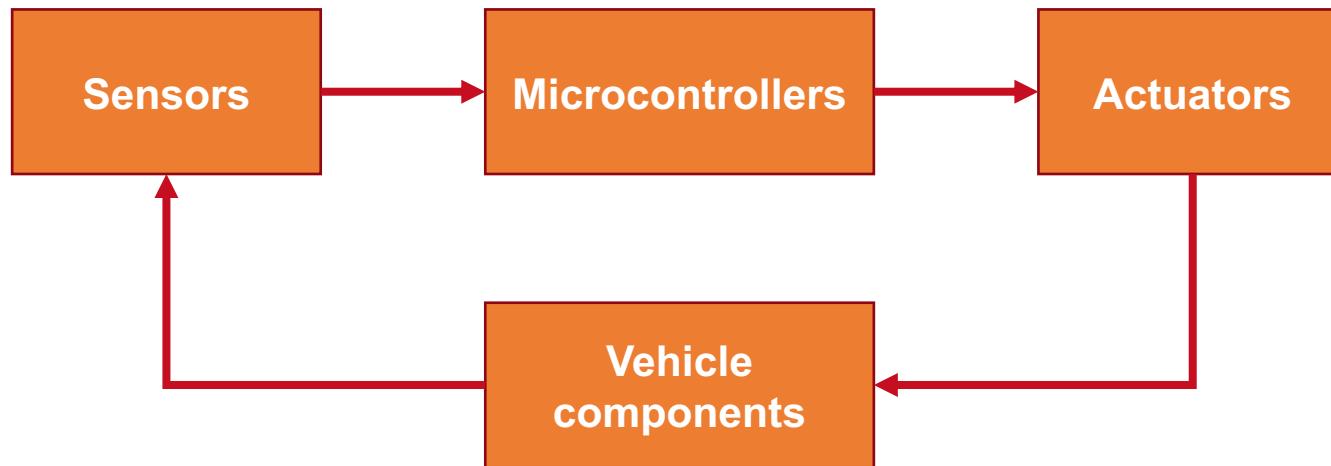


Introduction

- More and more parts of the vehicle control is done now by electronic systems
 - Drive-by-wire
 - Steer-by-wire
 - X-by-wire
- Electronic control is enabling higher levels of vehicle control and safety

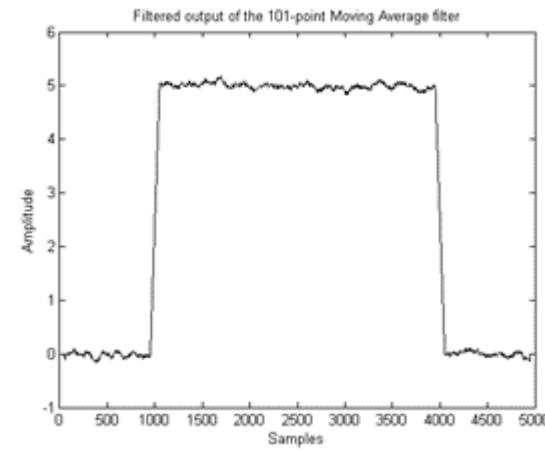
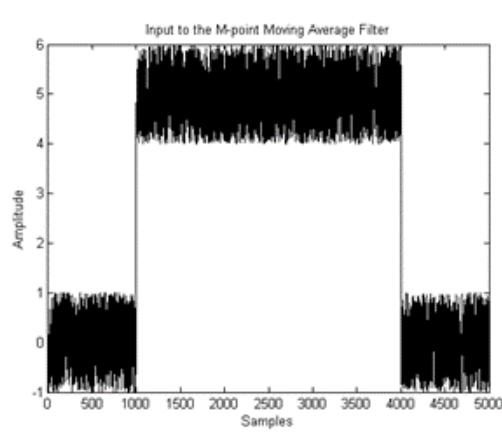
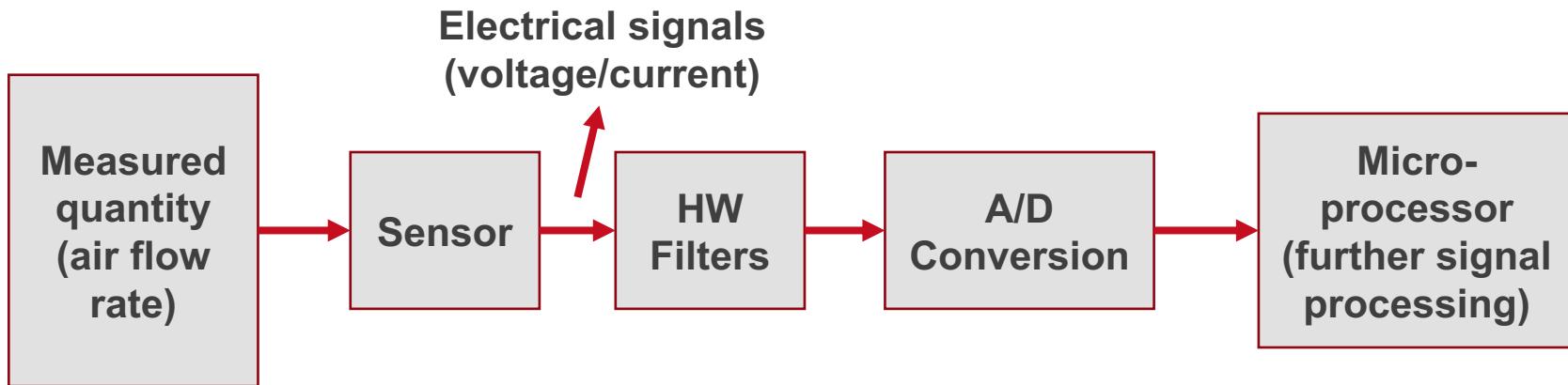


- Sensors and actuators are essential parts in electronic control
- Sensors – Inputs
- Actuators – Outputs



Sensing System

- Sensors, filters, Analog-to-digital conversion



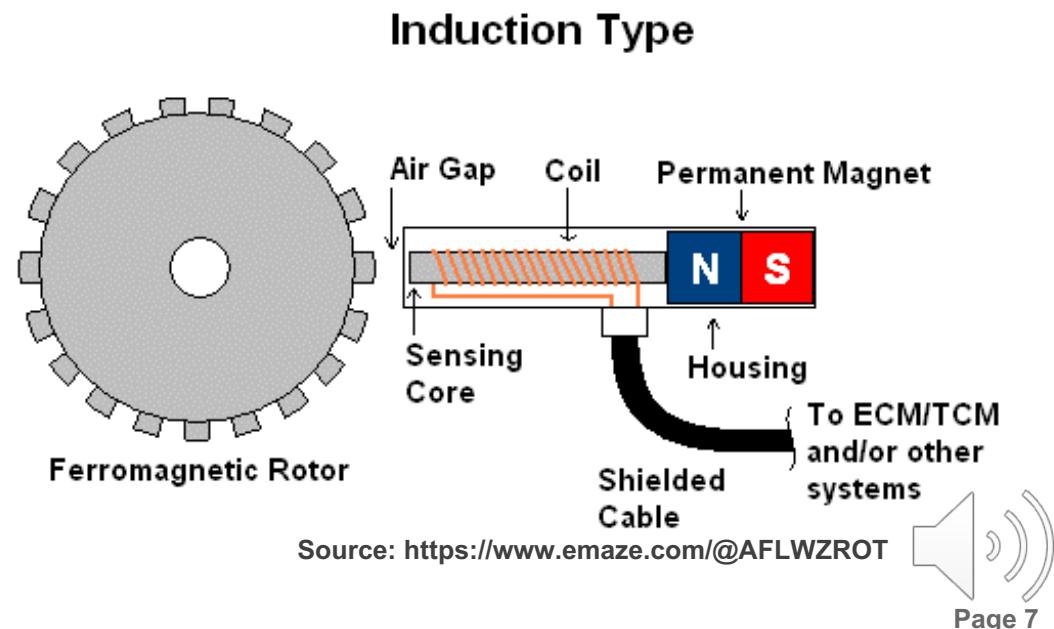
Types of Automotive Sensors

- Inductor loop detector
- Magnetic sensors
- Microwave radar
- Cameras
- LIDAR
- GPS



Magnetic Sensors

- Variable reluctance (VR) sensors
- Electro-magnetic device with a permanent magnet wound by a wire
- Rotation of a wheel with teeth can be detected by changing magnetic flux
- Applications
 - Electronically controlled transmissions
 - Vehicle speed sensing
 - Wheel speed sensing for ABS and traction control



Potentiometer

- Resistance varies according to change in position
- Application
 - Acceleration pedals, etc



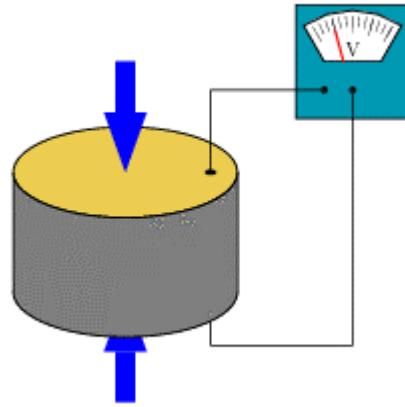
6mm SHAFT



Acceleration pedals



- Piezoelectric sensors can measure acceleration
- Converts force on the mass to an electrical signal (voltage)
- In reality, it will be implemented on a chip
- Applications
 - Accelerometer
 - Yaw rate sensor

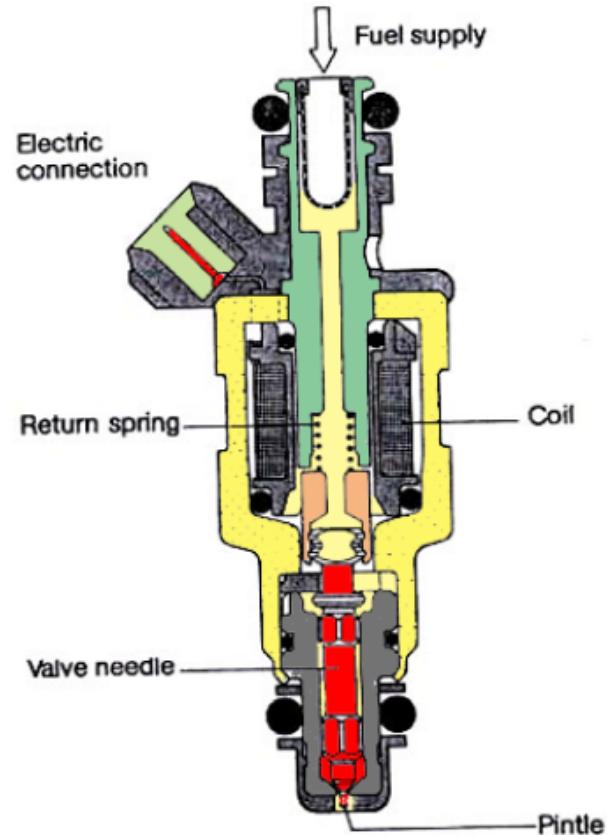


Source: Bosch

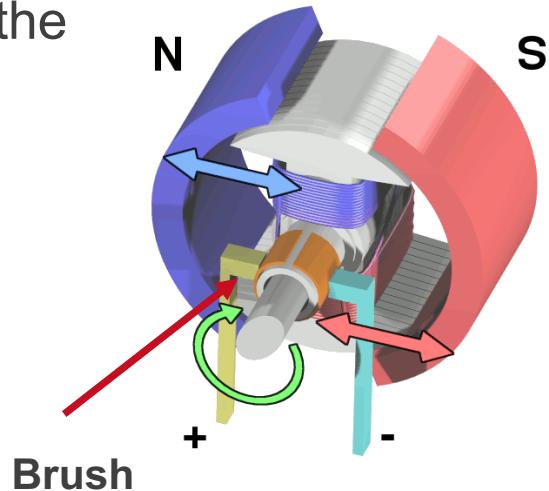
- Actuator is the output of the control mechanism
- Connects the microcontroller to the plant (instance to be controlled)
- Examples
 - DC Motors
 - Solenoids
 - Stepper motors
 - Etc..

Solenoids

- Coil of wire commonly in the form of a long cylinder such that armature (movable core) moves inside the coil
- Used for controlling small movements
 - Fraction of mm
 - E.g., fuel injector
- Induction of the coil plays an important role in the reaction time for solenoid



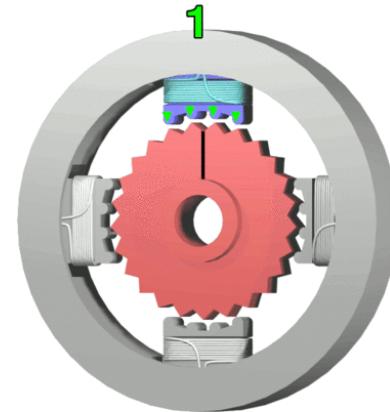
- Rotary electrical motors that converts direct current (DC) electrical energy into mechanical energy
- Permanent magnets or electromagnets (currents) are used to generate magnetic flux
- Electrical current through the rotor rotates it
- Brush is used for physical contact between the rotating part and the static part
- Brushless DC (BLDC) motor
 - Instead of using a physical brush, you rotate the magnetic field itself by controlling the electromagnets
- Applications: tools, toys, early EV motors (now being replaced with AC motors)



Source: Wikipedia

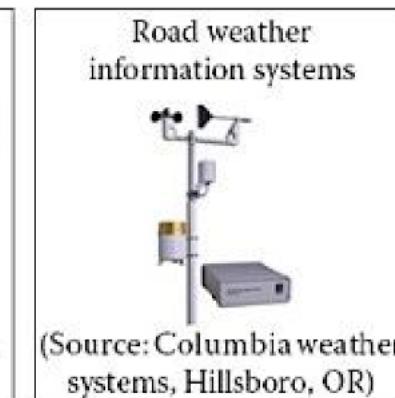
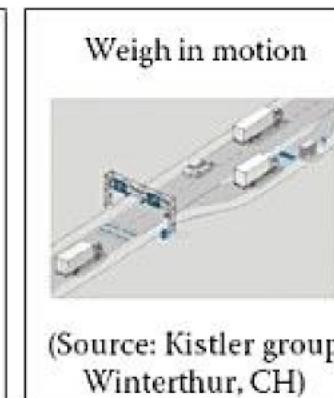
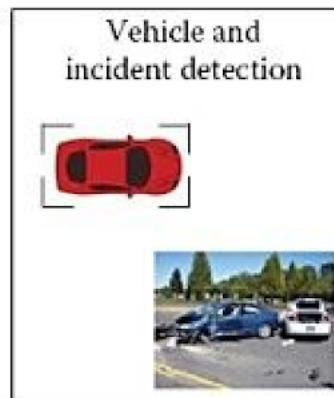
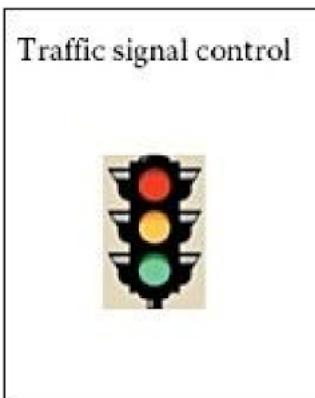
Stepper Motors

- A type of BLDC that divides a full rotation into a number of equal steps
- Motor's angular position can be set and held without any position sensor
 - If you set the rotor position to a certain angle, the motor will resist the force applied by your finger to hold the position
- Electromagnets (4 protruded parts inside the ring) will attract the teeth of the rotor to be aligned
- By controlling the right combination of the electromagnets, the angular position of the rotor can be precisely controlled
- Applications: Steering systems, CNC machines camera lenses, etc.



Source: Wikipedia

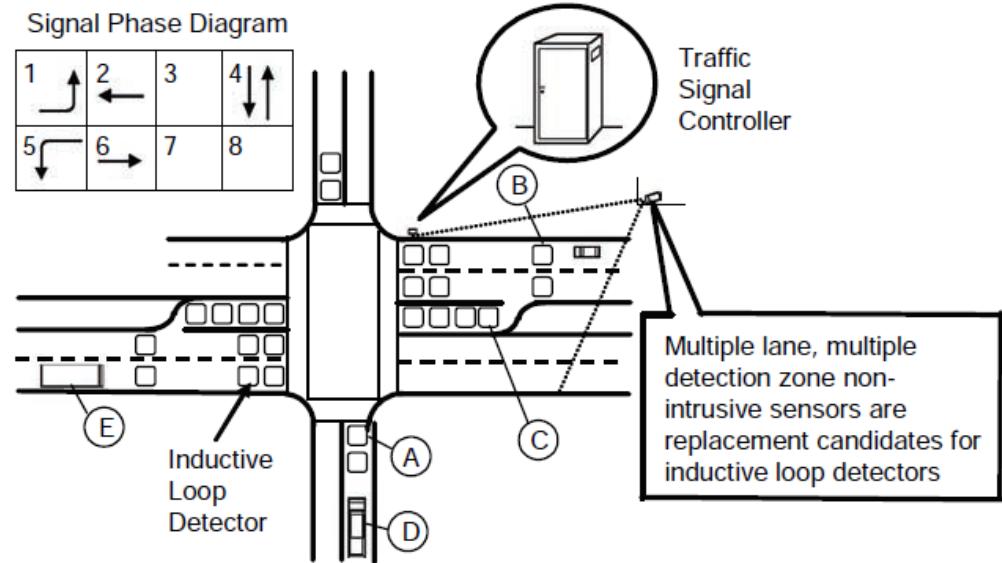
- Sensors are not only related to vehicle control, but also to traffic management
 - Flow rate, lane occupancy, and density
 - Count, presence, and passage
 - Speed of individual vehicles and platoons
 - Vehicle class
 - Queue lengths
 - Origin destination pairs



L.A. Klein, „ITS sensors and Architectures for Traffic Management and Connected Vehicles“

Sensor Applications to ITS

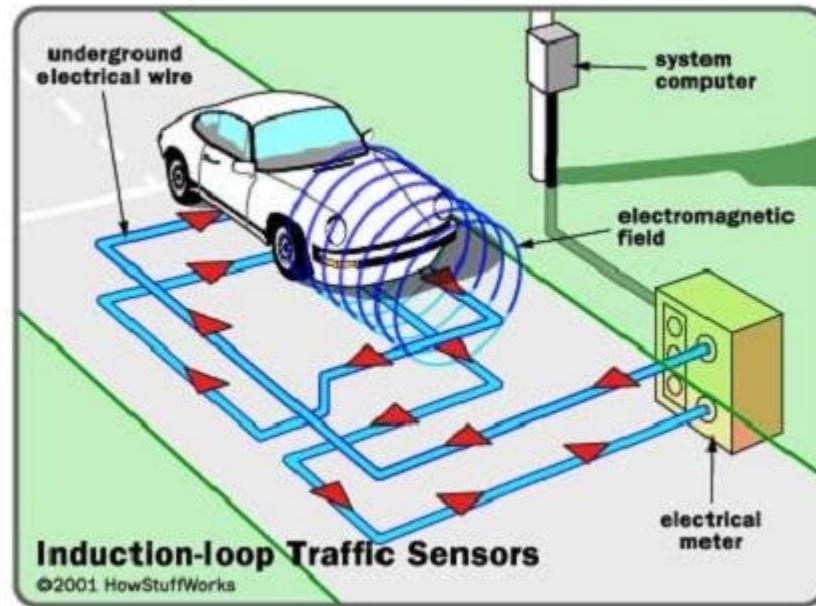
- Local isolated intersection control
 - Pre-timed control: sensors not required
 - Actuated control
 - Stopline sensors (A)
 - Upstream of the stopline (B)
 - Left-turn lanes (C)
 - Emergency detection positions (D)
 - Transit vehicles (E)



Source: Traffic Detection Handbook, 3rd Edition

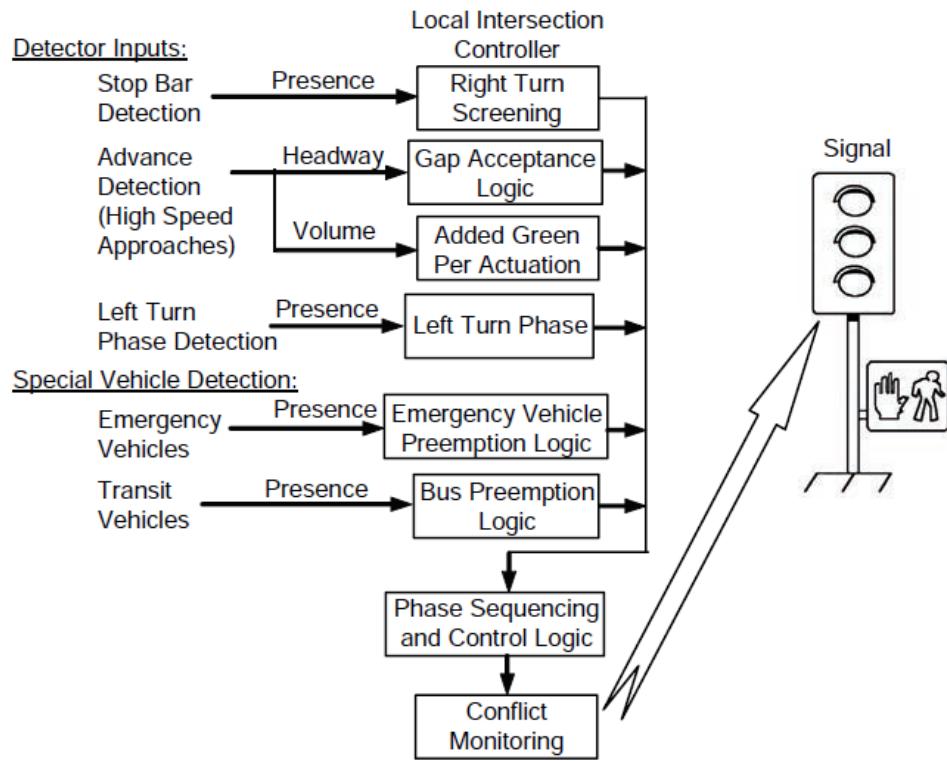
Inductive Loop Detector

- Detects presence of metal using electromagnetic induction



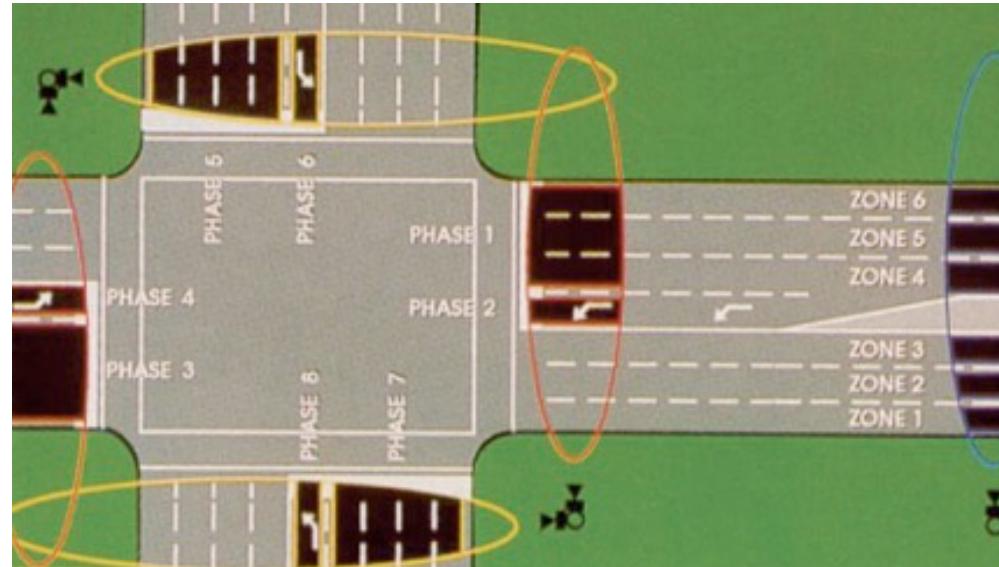
Source: Review of traffic data collection methods for driver's car – following behavior model under various weather conditions

- Data processing examples
 - Semi-actuated controls: Major streets operate in non-actuated mode (always green) unless minor street actuation is received
 - Suitable for random vehicle approaches
 - Small minor street volumes
 - Long distances between signalized intersections
 - Fully actuated controls:
 - Takes into account from all intersections (RHS figure)



Source: Traffic Detection Handbook, 3rd Edition

- Presence-detecting microwave radar sensor application to actuated control
 - Side-looking sensors mounted on a pole
 - Radar sensors are non-intrusive, but tall vehicles may occlude small vehicles



Source: Traffic Detection Handbook, 3rd Edition

- Video detection systems (VDC) application
 - Positioning is important to ensure detection (as high as possible)
 - Sun glint is problematic when placed east-west

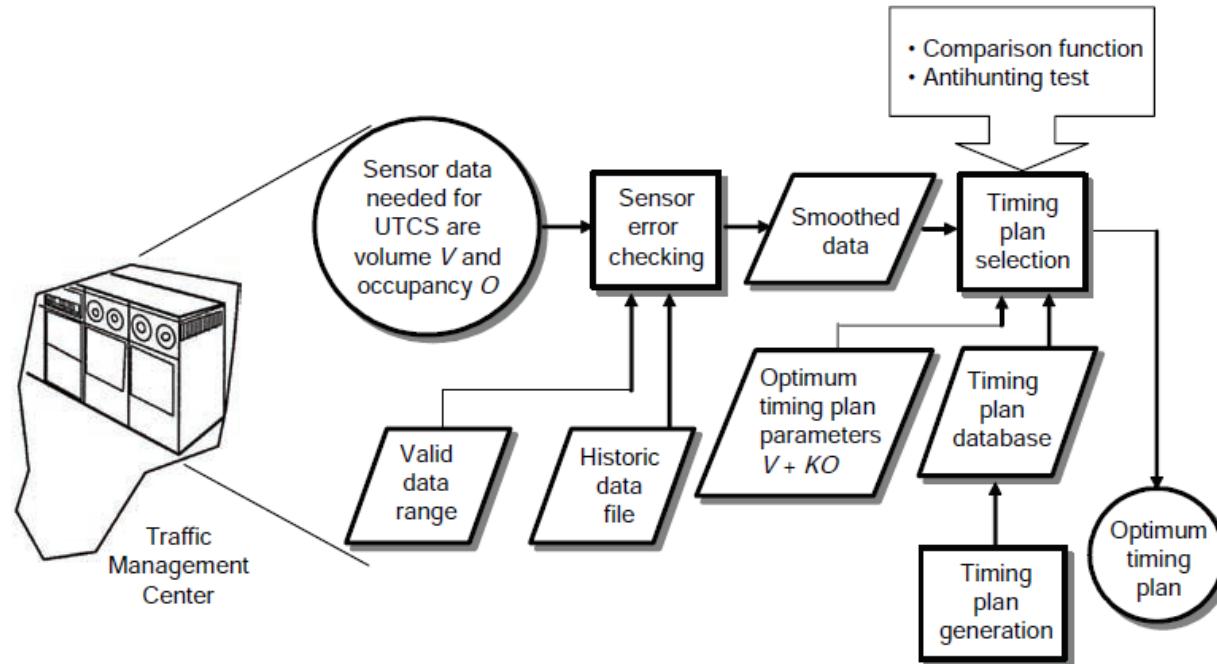


Source: Traffic Detection Handbook, 3rd Edition

- Traffic responsive control
 - Selects among a library of prestored signal timing plans that best match current traffic flow conditions
 - Signal timing plans can also be generated online in real-time based on current traffic flow conditions
- Urban Traffic Control System (UTCS)
 - US FHWA (Federal Highway Administration) selects from among prestored timing plans that best match the volume and occupancy conditions on the roadway

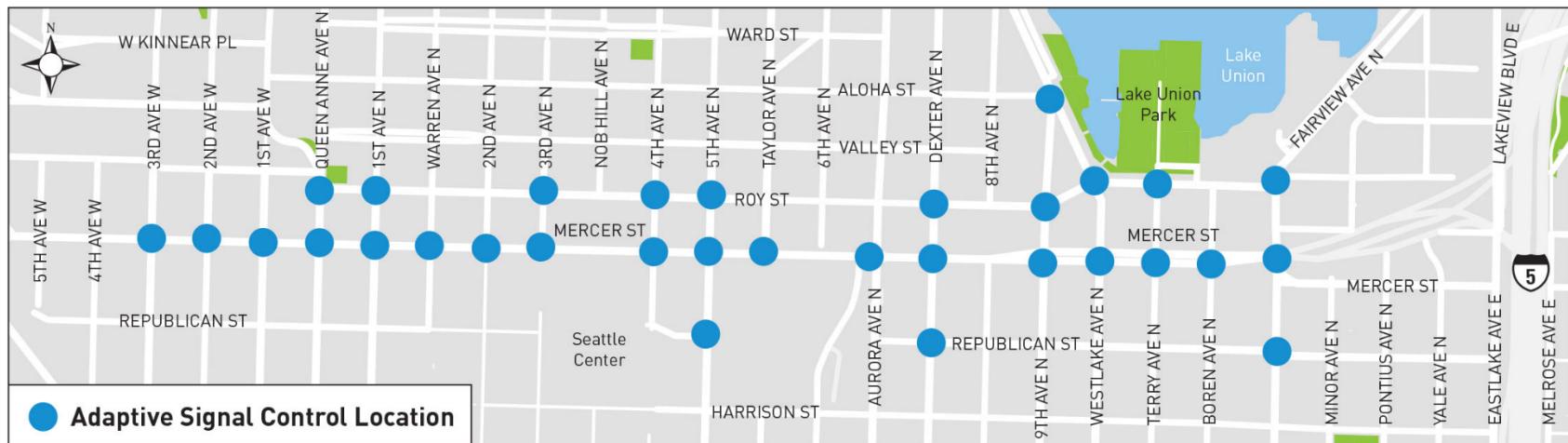
Interconnected Intersection Control

- Urban Traffic Control System (UTCS)
 - Considers both volume V (traffic flow) and occupancy (O) data
 - What happens if you only use the volume data? (recall traffic modeling)
 - Too much traffic -> volume drops -> wrong signal!
- $V+KO$



Interconnected Intersection Control

- Prestored timing plans developed offline are best suited for traffic flow on a normal day
- Cannot cope with situations which are significantly different (football matches?!)
- „City of Seattle introduces Mercer adaptive signal system to keep traffic moving“, April 24, 2017
 - Split cycle offset optimization technique (SCOOT)



Source: seattle.gov

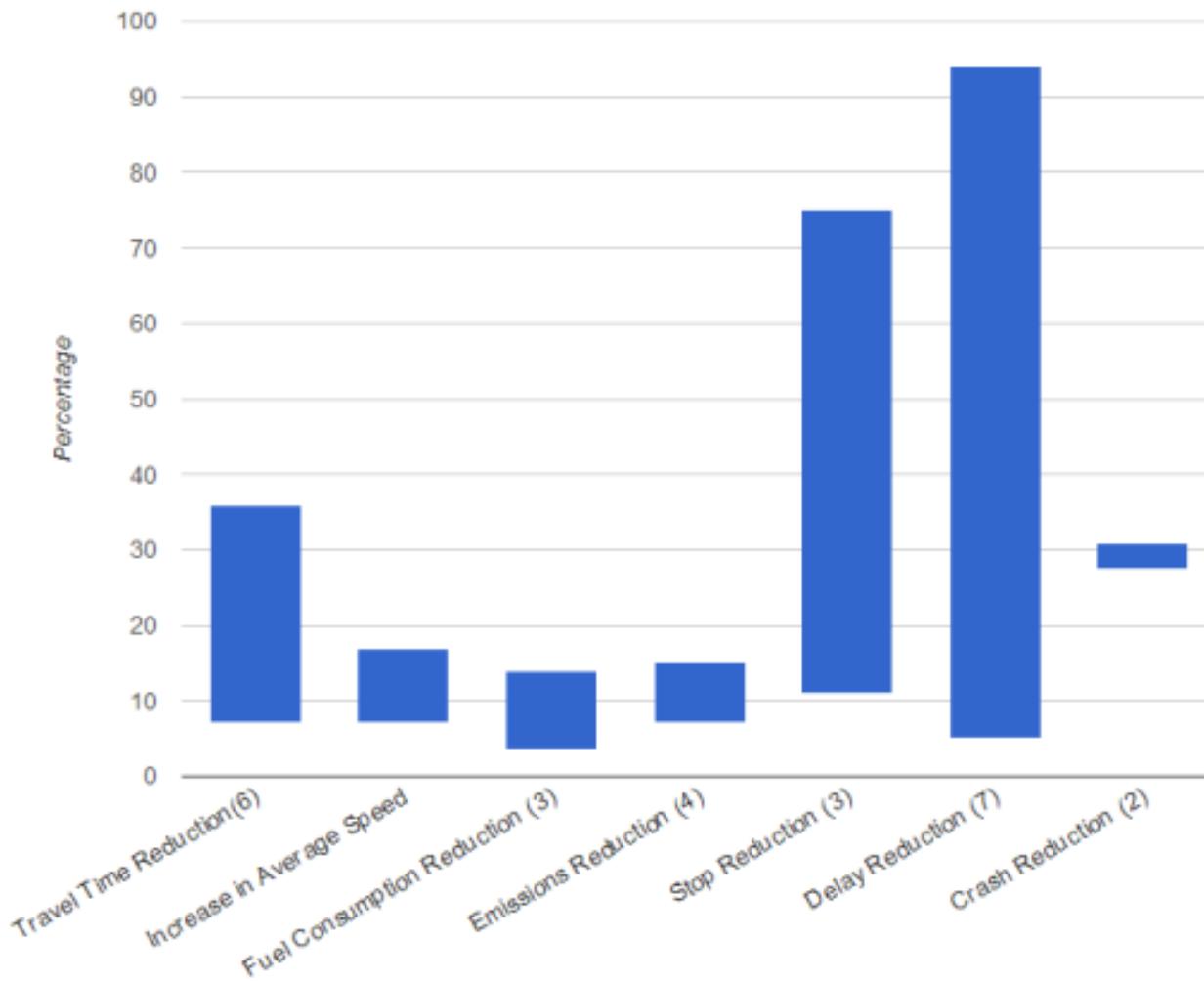
Initial Capital Cost per Intersection

- Such adaptive systems require greater number of sensors, computers and manpower

System	Initial Capital cost per intersection (USD)	System developer	System distributor
SCOOT	30,000-60,000	Transport research laboratory, UK	Siemens UK
SCATS	25,000-30,000	Road transit authority, Sydney	TransCore
OPACS	20,000-50,000	University of Massachusetts	PB Farradyne
RHODES	30,000-50,000	University of Arizona	Siemens ITS
ACS-Lite	8,000-12,000	FHWA, USA	Siemens ITS
LA-ATCS	30,000-60,000	LA Dept. Of Transportation	McTrans Center
InSync	25,000-35,000	Rhythm Engineering	Rhythm Engineering

- SCOOT
- Sensor technology
 - ILD (2 m in direction of travel), VDS, possibly presence detecting microwave radar
- Sensor locations
 - Approx. 15 m downstream of the previous intersection
- Data collected
 - Volume, occupancy
- Data processing interval and location
 - Second by second interval, Central
- Backup if real-time sensor data not available
 - Default parameters based on time of day (TOD) and day of week

Benefits of Traffic Adaptive Signal Control



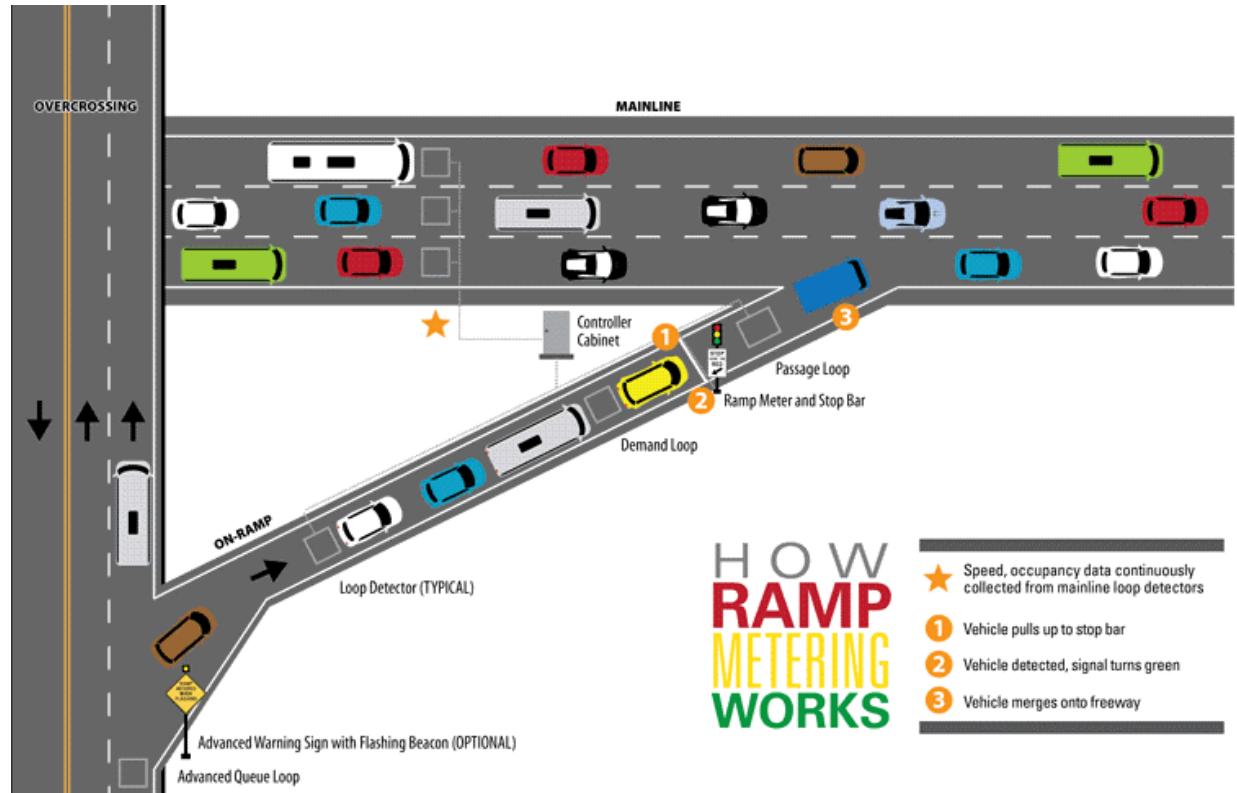
Source: FHWA, Depart of Transporation, USA

Other ITS Sensor Applications

- Red-light running vehicle detection
 - Vast majority of serious red-light running accidents are caused by driver-error due to impaired vision, poorly engineering signal timing, tiredness and distraction, and medical emergency
 - Alternatives to cameras include improved signal timing
 - Increased yellow light timing by 0.3 seconds reduce violations by 70-80% (California)
 - But of course at a cost of reduced traffic flow
- Travel time notification
 - Encourages drivers to take other routes

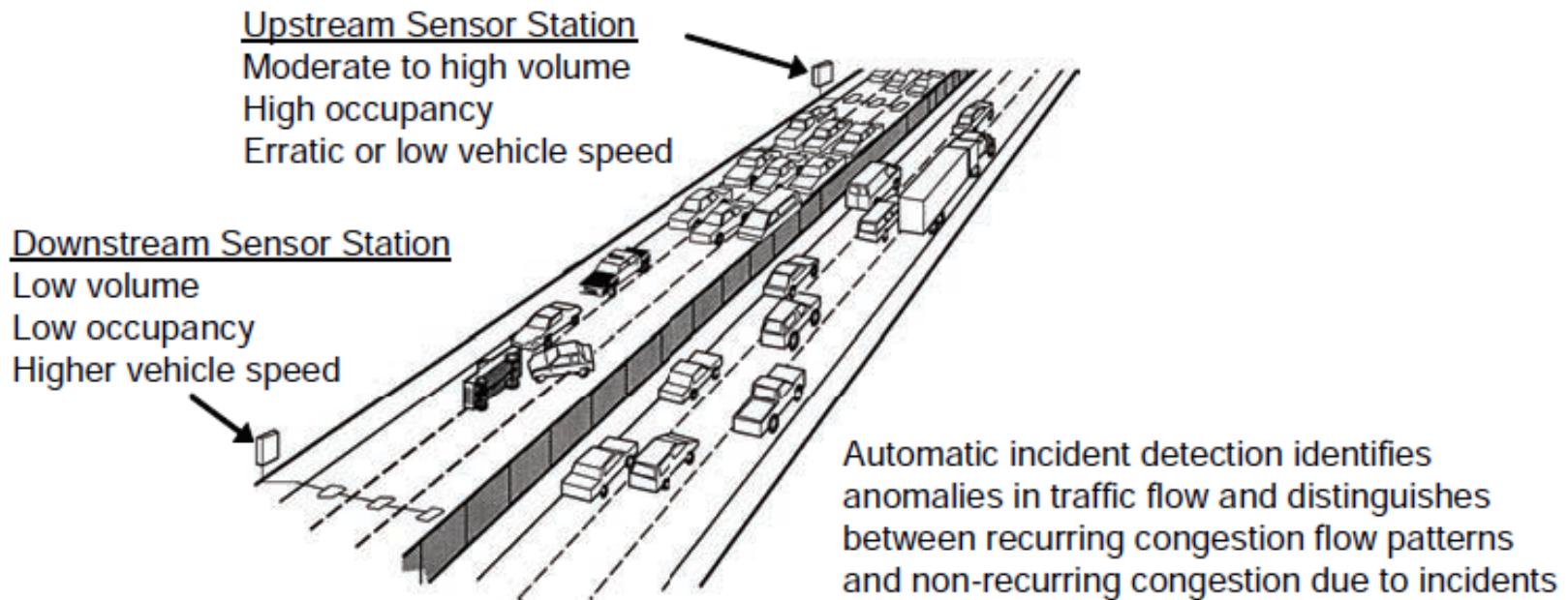
Other ITS Sensor Applications

- Ramp metering
 - Common technique for addressing recurring congestion on freeways
- Sensor locations
 - Speed and occupancy continuously logged from mainline loop
 - Sensors at the ramp detect passage
 - Sensor at arterial road detect spilling over



Other ITS Sensor Applications

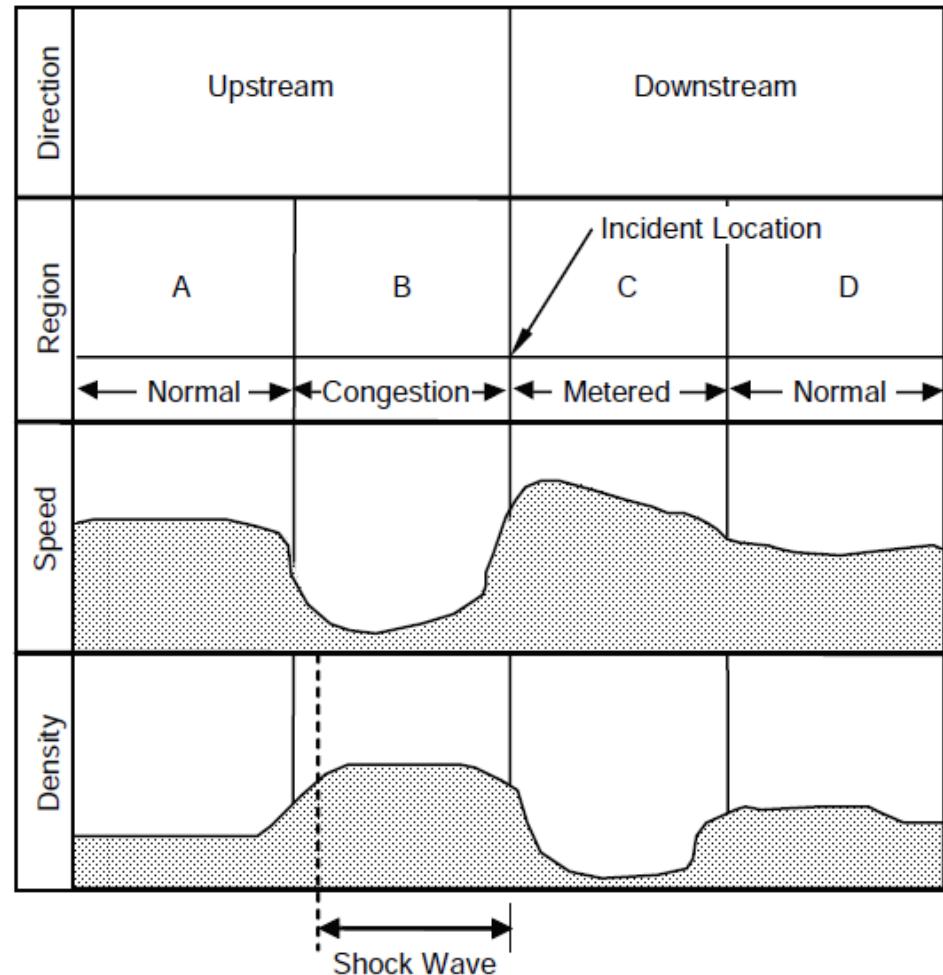
■ Automatic incident detection



L.A. Klein, ITS Sensors and Architectures for Traffic Management and Connected Vehicles

Other ITS Sensor Applications

- Automatic incident detection
 - A is far away
 - B is congested
 - C is fast
 - D is normal again



Active Transportation and Demand Management

- Active transportation and demand management (ATDM)
 - Dynamic management
 - Control
 - Influence of travel demand
 - Traffic demand
 - Facility demand on the entire system

ATDM strategy	Amount congestion reduction (%)
Car pooling	5
Alternate route	5
Flexible working hours	35
Working at home	25
Working at another location	5
Traveling with public transportation	10
Cycling	15

Yet Other Options

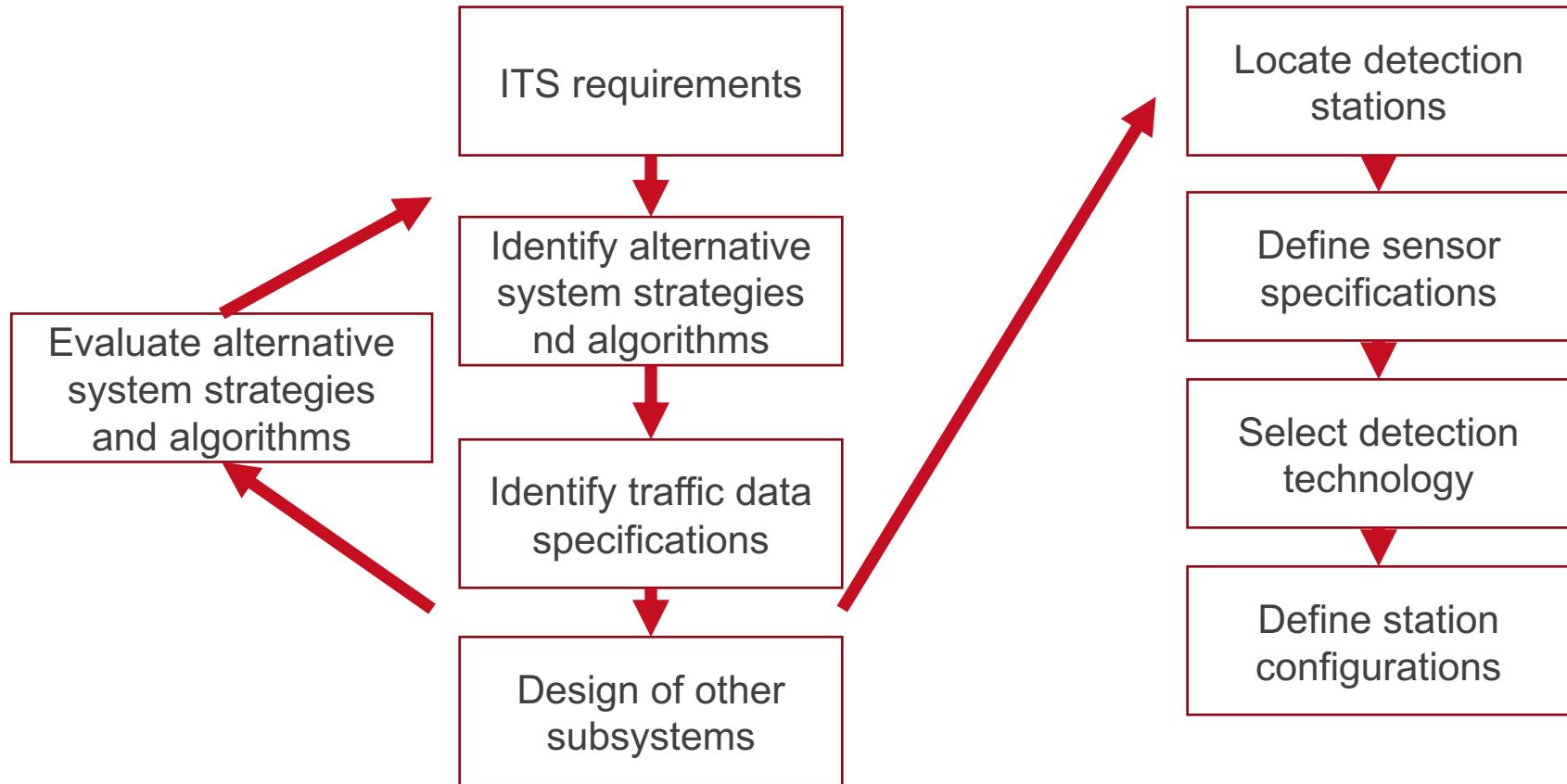
- Toll-paying vehicles – dynamic pricing
- High-occupancy lanes
- Express lanes



Source. US DOT

Sensor Data Requirements

- How do we determine sensor requirements and sensor specifications?



■ Incident detection algorithms

- McMaster Algorithm, time series algorithm, and the high occupancy algorithm
- Volume error within +-1 veh/min at flows of 2000 veh/h
- Lane occupancy accuracy is +-1%
- HIOCC algorithm triggers alarm when occupancy increased abnormally during consecutive 1-s observation intervals

	Traffic variables			Data collection interval		Number of stations	
Algorithm	Flow rate	Occ.	Speed	1 s	30-60 s	Single	Adjacent
Comparative		*			*		*
McMaster	*	*	*		*	*	*
Time seires	*	*			*	*	*
HIOCC		*		*		*	

Sensor Data Requirements: Example

- Signalized intersection control traffic parameter specifications (US DOT)
- Approach flow profiles (veh)
 - Collection interval 1s
 - Allowable error: +- 2 veh/signal cycle
- Turning movement flow rate (veh)
 - Collection interval: 1 cycle
 - Allowable error: +- 2 veh/signl cycle
- Average link travel time (s)
 - Collection interval: 1 cycle
 - Allowable error: +- 2s
- Average approach speed (mi/h)
 - Collection interval: 1 cycle
 - +- 2 (mil/h)
- ...

Modern Traffic Flow Sensor Technologies

■ Inductive loops

- Speed measurement with speed trap measurement
- $S = \frac{d}{\Delta T}$
- Vehicle classification
 - Special configurations of inductive loops are able to detect axles and their relative position in vehicles

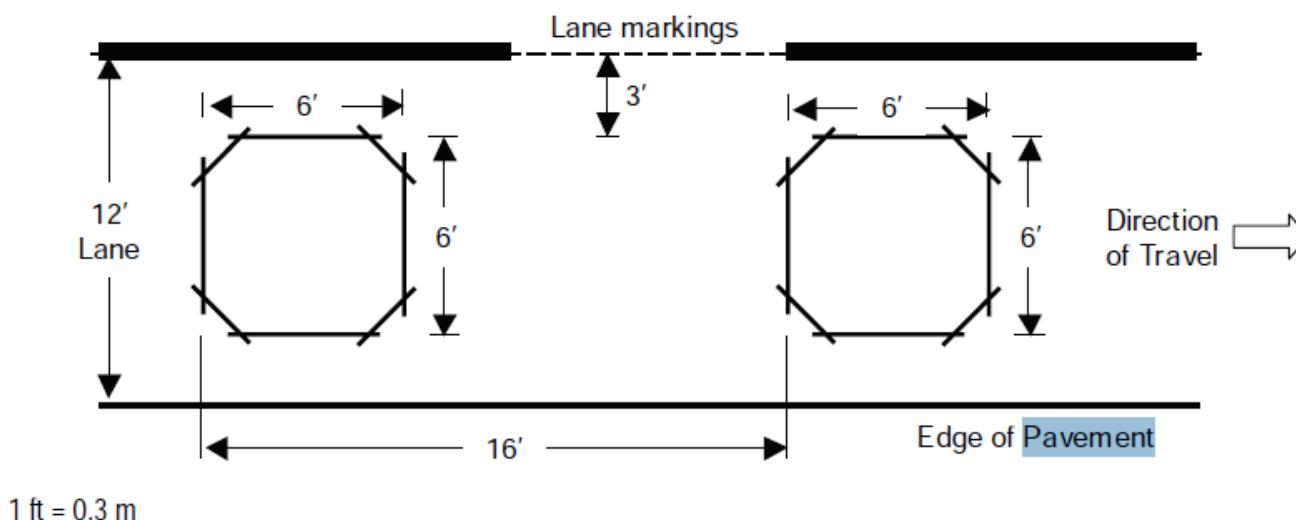
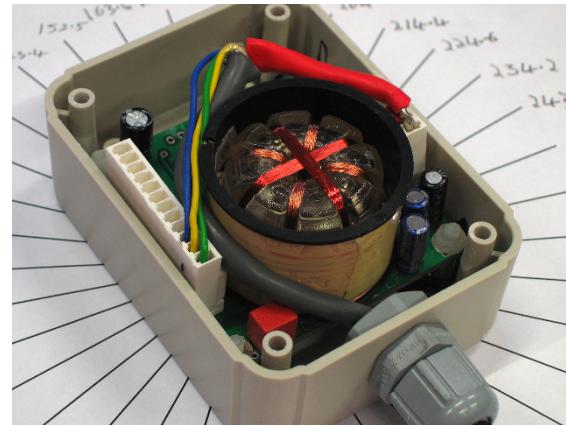


Figure 3-1. Vehicle speed measurement using two inductive-loop detectors placed a known distance apart.

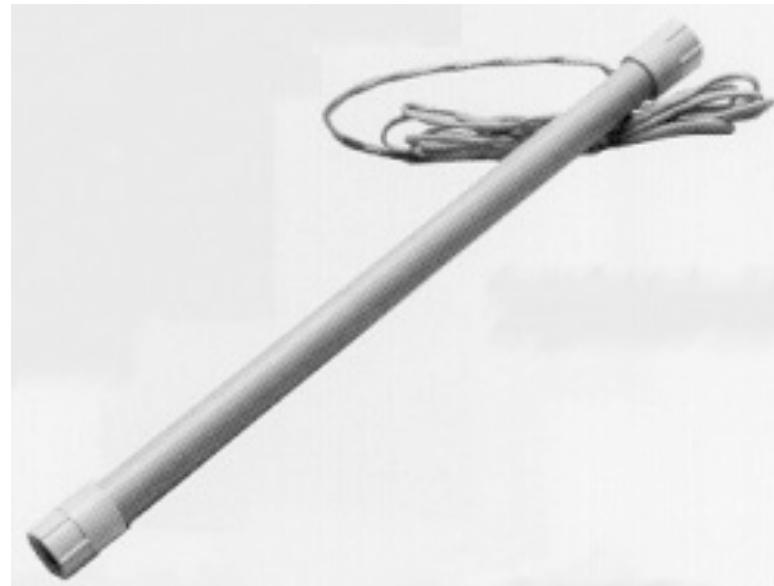
- Inductive loops
- Output data
 - Count, presence, lane occupancy
 - Average vehicle speed
 - Single installation with vehicle length assumption
 - Speed-trap configuration
 - Vehicle-class when operated at high-frequency control unit
- Installed in roadway
- Advantages
 - Low per unit cost
 - Mature well-understood tech
- Limitations
 - Traffic interrupt for repair
 - Susceptible to damage by heavy vehicles

- Magnetometer sensors
 - While inductive loops is active sensing, this is passive sensing
 - Detects metallic objects by perturbation in the Earth's magnetic field
 - Similar to a compass



- Magnetic detectors

- Search coil magnetometer (like mine detectors)
- Earth's magnetic field is perturbed when a ferromagnetic object perturbs the field
- Can't detect a still vehicle



- Magnetic sensors
- Typical output
 - Count
 - Presence: Magnetometer (yes), magnetic detectors (no)
 - Lane occupancy
 - Vehicle speed with speed-trap configuration
- Embedded in roadway
- Advantages
 - Low per unit cost
 - Can detect small vehicles including bicycles
- Disadvantages
 - Traffic interrupted for repair
 - Hard to distinguish closely placed vehicles or line straddling vehicles such as motor cycles

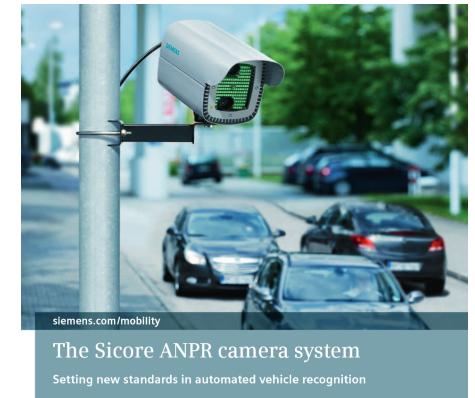
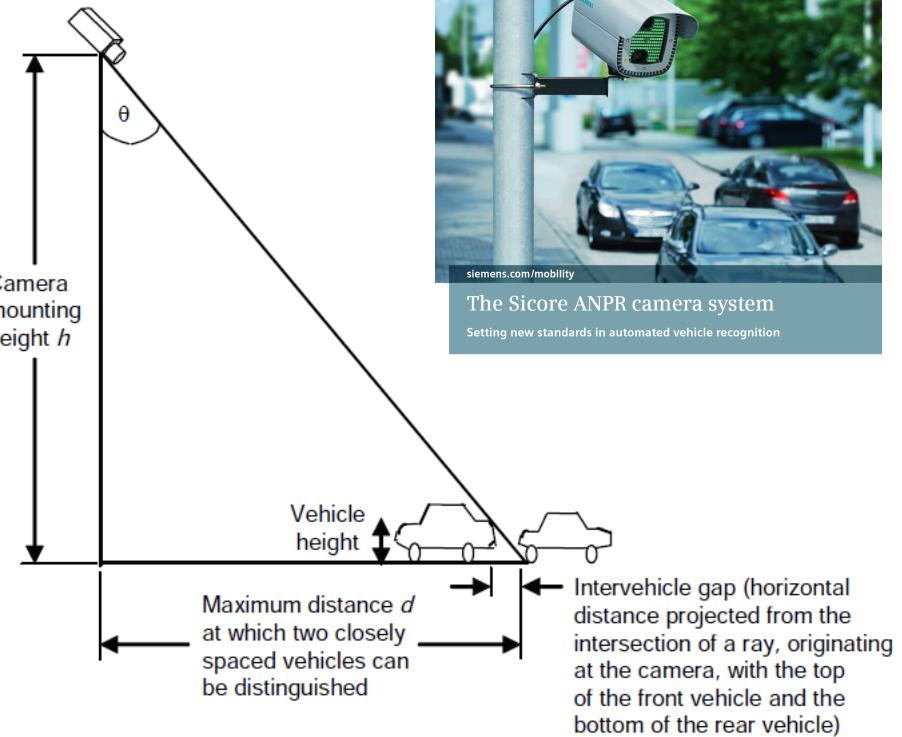
Modern Traffic Flow Sensor Technologies

■ Video Detection System (VDS)

- Requires significant video image processing (VIP)
- Vehicle identification, speed detection, position, etc
- Kalman filtering techniques could be used to track vehicles
- Height is important in separately identifying vehicles

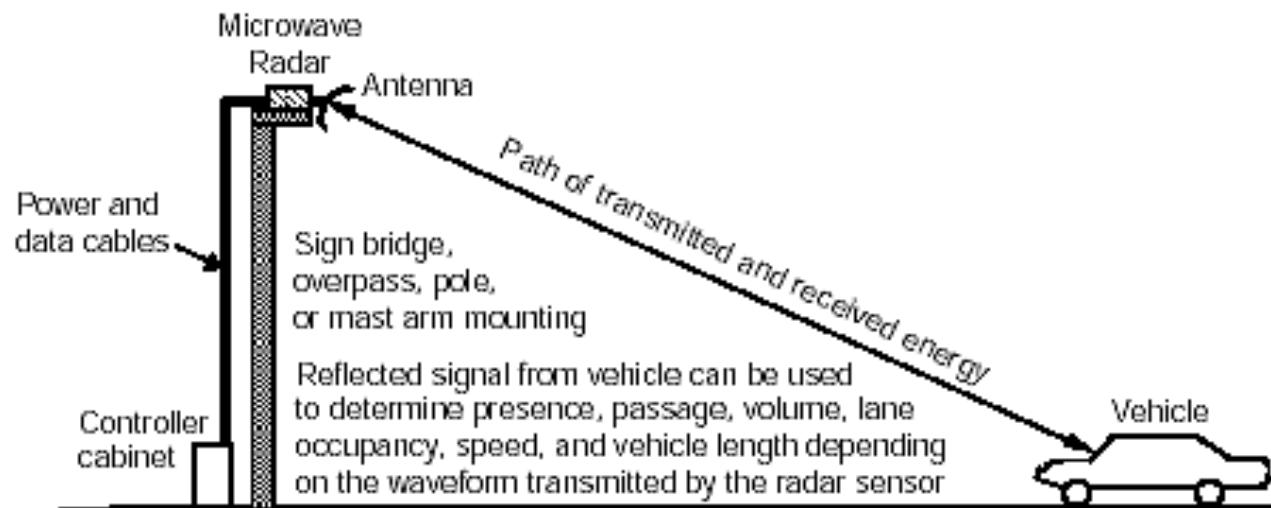


VIP in a roadside cabinet



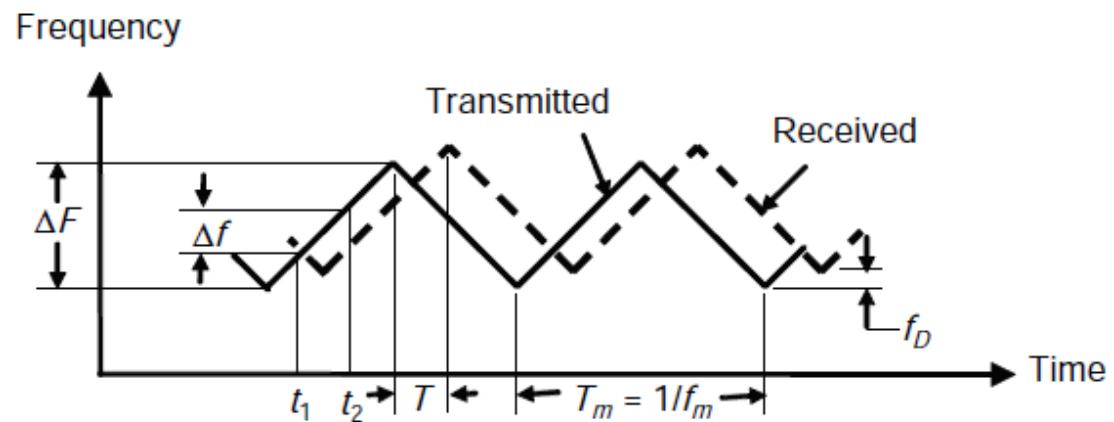
- VDS
- Overhead installation
- Advantages
 - Repair don't disrupt traffic
 - Single camera can serve multiple lanes
 - Rich array of data available
- Disadvantages
 - Large vehicles project/mask image into adjacent lanes
 - Shadows, reflections from wet pavement, day/night transitions
 - Reliable night detection requires street lighting

- Microwave radar sensors
 - Presence detecting: stopped vehicles - intersections
 - Doppler: requires minimum vehicle speed - highways



Modern Traffic Flow Sensor Technologies

- Microwave radar sensors
 - Vehicle speed is proportional to the frequency change
 - $f_D = \frac{2SF\cos\theta}{c}$, S is vehicle speed, F is transmitted frequency, θ is the angle of radar wave and vehicle movement

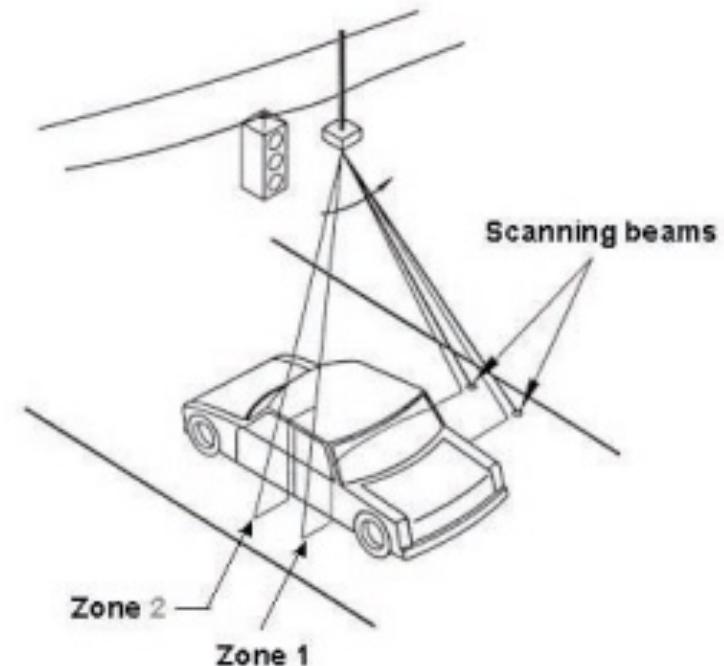
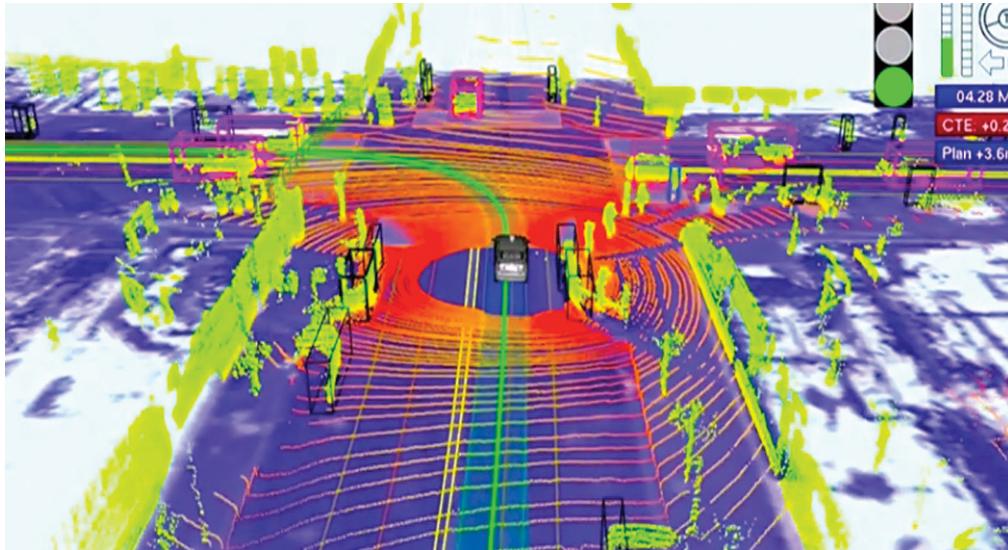


- Microwave radar
- Overhead installation
- Advantages
 - No traffic disruption
 - Direct measurement of speed
 - Multilane data collection
 - Day/night operation
- Disadvantages
 - Side-mounting can be affected by tall-vehicles occluding lanes behind
 - Vehicle undercounting in heavy congestion
 - Stochastic property radar detection (scatter etc.) may miss some vehicles

Modern Traffic Flow Sensor Technologies

■ LIDAR sensors

- Illuminates detection zones with energy transmitted by laser diodes operating in the near-infrared region $0.85 \mu\text{m}$
- A portion of energy is reflected and scattered back to the sensor
- Typically the laser beams are projected at different angles (several degrees) and scanned across using a rotating mirror



- LIDAR sensors
- Overhead or side installation
- Advantages
 - No traffic interruption
 - Day/night operation
 - Multilane operation
- Disadvantages
 - Performance degraded under heavy fog or blowing snow
 - Poor foliage (leaves) penetration

- Costs of sensors are getting cheaper as technology matures

LIDAR: From \$70,000 to \$250

2015 GEN 1 LIDAR

\$1,000

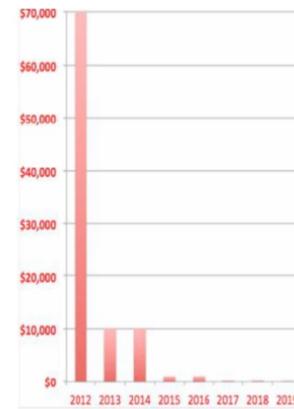
2016 GEN 2 SOLID STATE LIDAR

\$250



GEN 3 (POSTAGE STAMP)

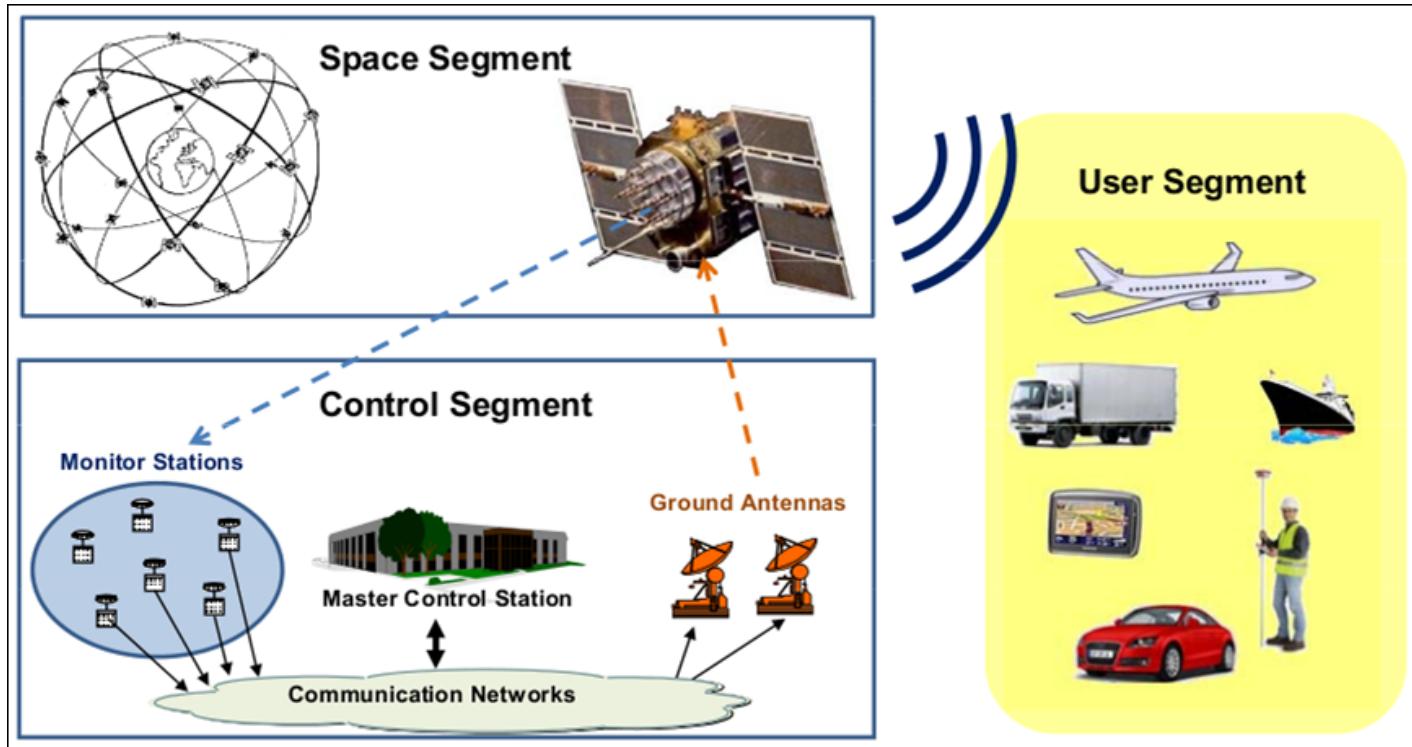
\$90



<https://electrek.co/2016/05/19/the-math-and-evidence-all-around-you-that-shows-shared-autonomous-vehicles-powered-by-solar-power-and-batteries-are-inevitable/>

Alternative Sources of Navigation and Traffic Flow

- Global navigation satellite systems (GNSS)
 - Russia, the EU, China, India, and Japan are developing GNSS constellations similar to those in the US
- US GPS architecture



- The US GPS is committed to maintaining availability of 24 satellites (out of 31), 95% percent of the time
- Each satellite circles the earth twice a day at an altitude of 20,200 km
- The receiver obtains the distance to satellites and their positions, which is broadcast, and triangulates and compensates for local clock bias
- GPS accuracy
 - A standard, inexpensive (US\$200~400) single-frequency GPS receiver tracks the code signal of the NAVSTAR constellation at the frequency of 1575 MHz
 - Accuracy depends on the receiver location, difference in clock time between the satellite and the receiver caused by special and general relativity, etc
 - Worst case pseudo-range accuracy of 7.8 m at a 95% confidence level

- Vehicle tracking in urban areas is limited by
 - Foliage
 - Inability to access signals blocked by buildings
- Inertial measurement units (IMU) can be used to augment the GPS information for better navigation
- $v = \int_0^{t_1} a \, dt$
- INS is used when GPS is blocked and GPS compensates and calibrates the INS in normal operation

- L.A. Klein, ITS sensors and architectures for traffic management and connected vehicles