TÉCNICO LISBOA

02
Vehicle to Infrastructure Interaction (V2I)

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Dense urban areas, with a wide variety of activities, generate large flows of movement of people and goods.

These movements consume energy, take time, occupy space, and have polluting and greenhouse effects.

Mobility needs are met by a combination of equipment and infrastructure.

The means used for travel are called *transport modes* (on foot, by car, by bus, …).

- Transport equipment

  Light modes – on foot, bicycle

  Non-light modes – car, bus, train

- Capacity – mass transit (train, metro)

Plan

Vehicle sensing

- Local sensing
  - Inductive loop detectors
  - Magnetic sensors
  - Ultrasound
  - Microwave
  - Video capture and processing
- Global sensing

Sensors

- Devices that detect or measure a physical property, or its variation, an convert it on an electrical signal which can be automatically processed
- The following sensing devices and equipments do not require vehicle cooperation, the detect vehicles *as they move by*

Inductive loop detectors

- Most common vehicle sensor
- Detects the inductance change when a vehicle passes over a coil
- Several physical configurations area able to support diverse applications
  - Counting
  - Speed measurement
  - Vehicle classification

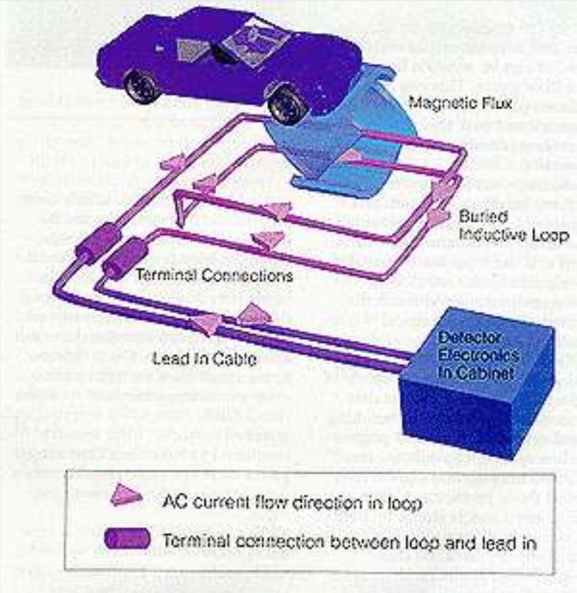

Figure 1 — Car passing over inductive loop buried in pavement.

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Event processing

Sensed signals are processed to generate events.

Example: a sensor can be designed to generate two states

- OFF – absence of object (vehicle)
- ON – presence of object (vehicle)

A single sensor can **count** the number of vehicles that have passed it.

Event processing

For two ILD sensors in the same lane *d* metres apart:

time (sensor, event) function returns the time of the event on a sensor

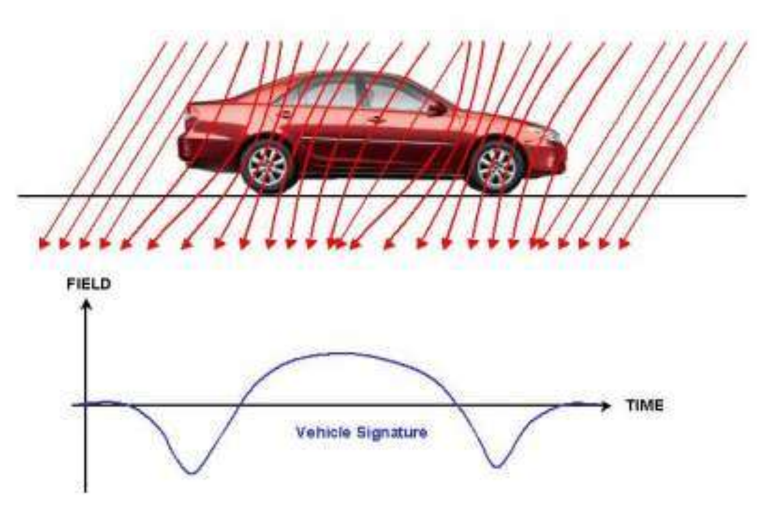
speed = d / [time(ILD1, ON) – time(ILD2, ON)]

Vehicle classification:

length = speed x [time(ILD1, ON) – time(ILD1, OFF)]

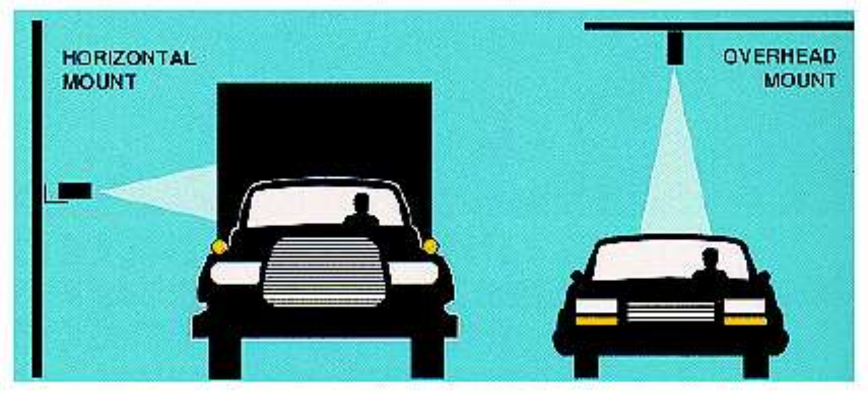
Magnetic sensors

- Detect the perturbation on the earth magnetic field caused by the presence of a vehicle
- Do not require installation in the pavement
- Several physical configurations are able to support diverse applications
  - Counting
  - Speed measurement
  - Vehicle classification



Ultrasound sensors

- Detects the reflected ultrasonic wave (25-50 kHz)
- Several physical configurations area able to support diverse applications
  - Counting
  - Speed measurement (Doppler effect)
  - Presence/Occupation



Microwave radars

- Detect echos from microwave bursts (1-30 GHz)
- Constant frequency Doppler radar
  - Evaluates speed from the difference between the emission frequency and the echo frequency
- Modulated frequency radar
  - Speed
  - Presence
  - Classificaton

TC-20 Doppler microwave radar. (Photograph courtesy of Microwave Sensors, Ann Arbor, MI)

TDN-30 Doppler microwave radar. (Photograph courtesy of Whelen Engineering Company, Chester, CT)

Video capture and processing (1)

- Image and video capture and processing by single cameras or arrays of cameras
- Most expensive technology
- Greater flexibility and potential – Programmed functionality
- Remote vision

(a) Autoscope 2004 (b) Autoscope Solo
(Photographs courtesy of Econolite Control Products, Anaheim, CA)

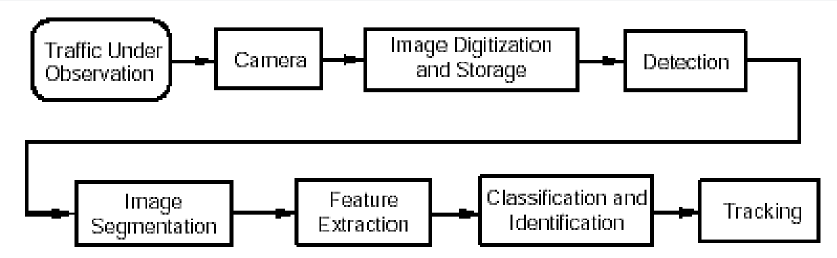
(c) Traficon VIP 3 (Photograph courtesy of Traficon, Heule, Belgium)
(d) Iteris Vantage processors (Photograph courtesy of Iteris, Anaheim, CA)

Video capture and processing (2)

- Diverse algorithms support many applications
  - Counting
  - Speed measurement
  - Vehicle classification
  - Vehicle identificaton, license plate recognition

    Ex: HI-TEC solutions

  - Legal enforcement
    - Access control to restricted zones
    - Unauthorised parking
    - Unauthorised circulation



Other sensors

Roadside:

- Passive Acoustic Arrays
- Infrared passive sensors
- Laser sensors

- Toll gantries

Global sensing:

- Celular networs
- Satellite positioning systems

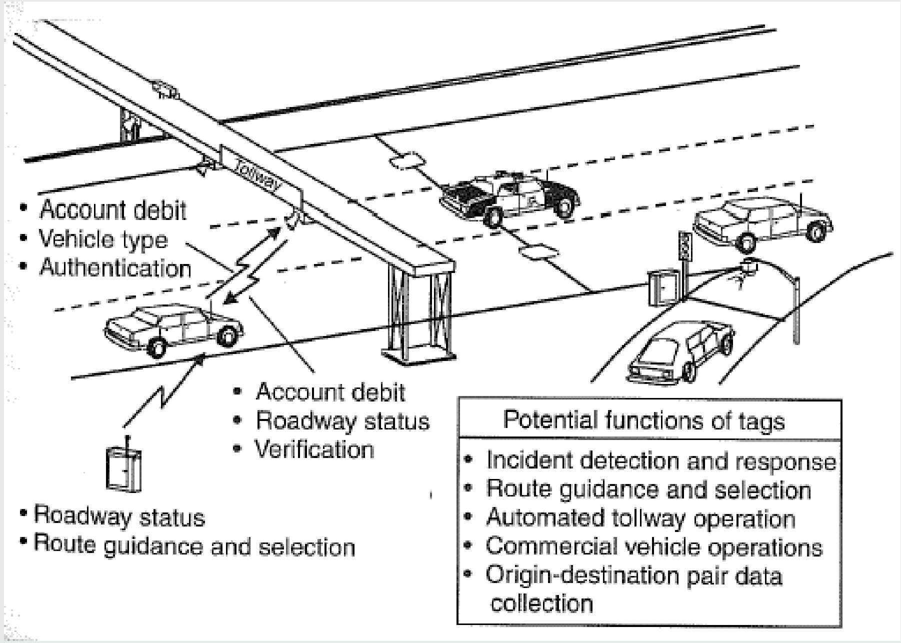
Require an identifier or some form of terminal equipment in the vehicle

Vehicle sensing technologies

Sensor technology	Count	Presence	Speed	Output data	Classification	Multiple lane, multiple detection zone data	Comms. bandwidth	Sensor purchase cost[a] (each in 1999 U.S. $)
Inductive loop	X	X	Xb	X	Xc		Low to moderate	Low[i] ($500–$800)
Magnetometer (two axis fluxgate)	X	X	Xb	X			Low	Moderate[i] ($900–$6,300)
Magnetic induction coil	X	Xd	Xb	X			Low	Low to moderate[i] ($385–$2,000)
Microwave radar	X	Xe	X	Xe	Xe	Xe	Moderate	Low to moderate ($700–$2,000)
Active infrared	X	X	Xf	X	X	X	Low to moderate	Moderate to high ($6,500–$3,300)
Passive infrared	X	X	Xf	X			Low to moderate	Low to moderate ($700–$1,200)
Ultrasonic	X	X		X			Low	Low to moderate (Pulse model: $600–$1,900)
Acoustic array	X	X	X	X		Xg	Low to moderate	Moderate ($3,100–$8,100)
Video image processor	X	X	X	X	X	X	Low to high[h]	Moderate to high ($5,000–$26,000)

Toll gantries

- Reuse existing infrastructures for road tolling



© Lawrence Klein – Sensor Technologies and Data Requirements for ITS. Artech House.

Global sensing

- Global positioning systems
  - GPS, Galileo (Europe), BeiDou (China), Navic (India), GLONASS (Russia)
- Wireless communication networks
  - Celular networks
  - WiFi spots

Positioning

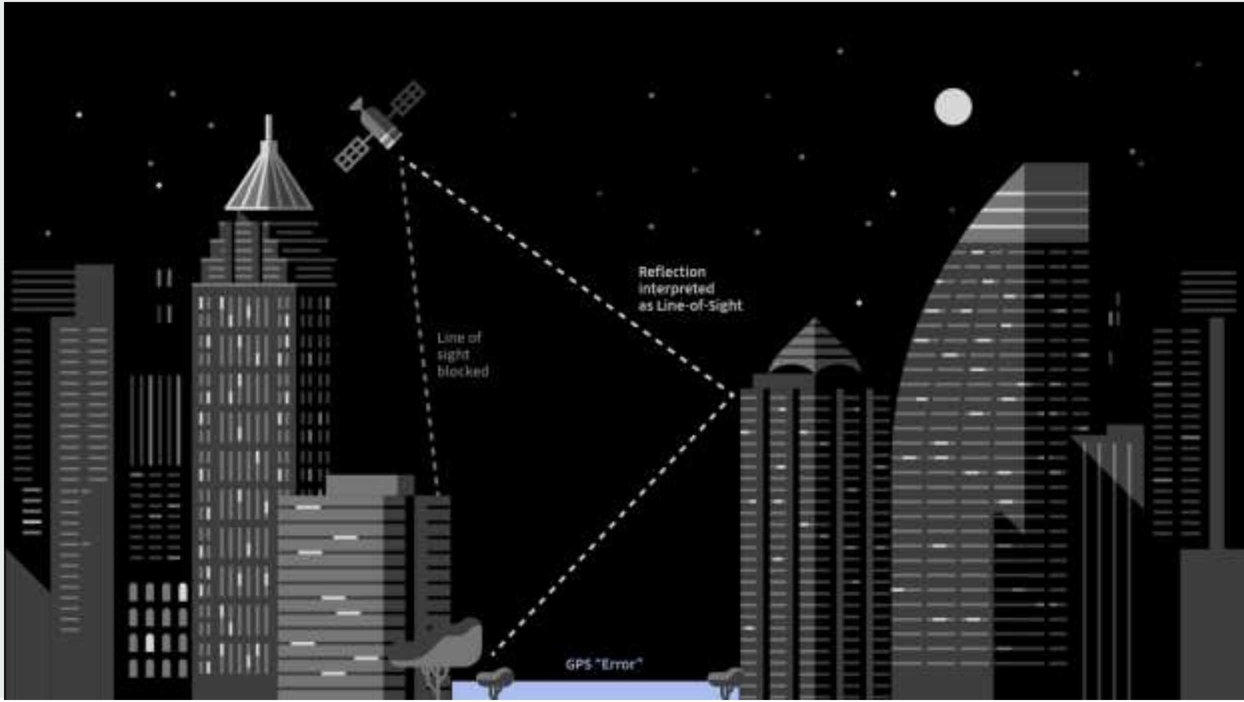
- Triangulation based on reference points
  - Measure the distance
  - Measure the angle
  - Example: Location of a ship in line of sight with two lighthouses
- Distance measurement
  - Transit time of a signal from a reference emitter
  - Signal strength (power) measurement – $E \approx k / d^2$

Problems

- Variations in the propagation media
- Obstacles in the horizon
  - Obstruction, atenuation, or reflection of the signal

Solutions

- Combine GPS with other navigation methods (e. g. dead reckoning)
- Enhance GPS information with 3D maps (e. g. Uber shadow maps)

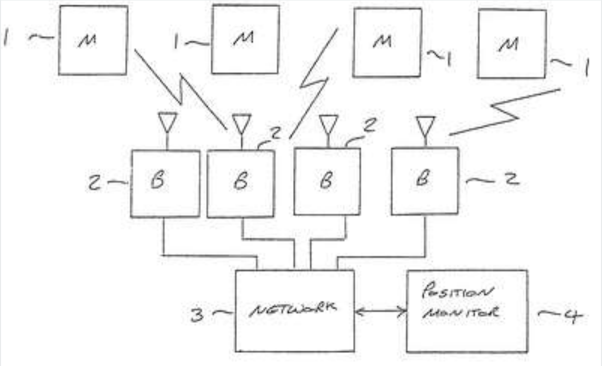


Celular networks (1)

- "*all automatic location identification*" FCC directive for emergency calls (Enhanced 911 – E911)

- The celular network derives the location of the terminal by triangulation from the base stations
  - Resolution dependent on the network grid
  - Weak resolution compared to other sensors
  - Measures traffic flows in near real time

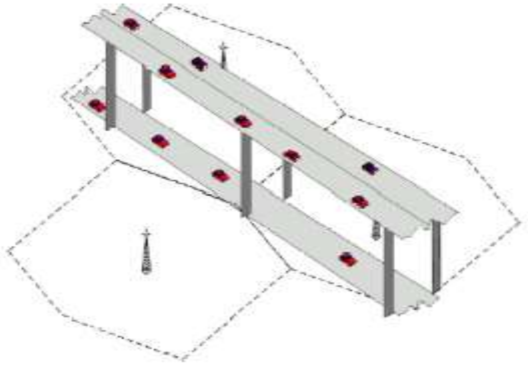
Percentage of calls	Location by the network	Location by the terminal
67%	100 m	50 m
95%	300 m	150 m

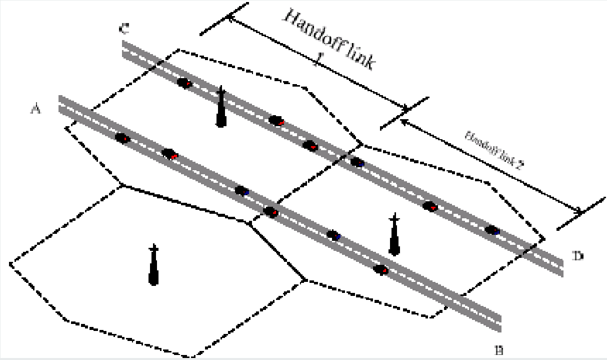


United States Patent 6973319, Inventors: Richard Ormson (Berkshire, GB), Assignee: NEC Corporation (Tokyo)

Celular networks (2)

- More reliable for long trips
- Distinction between terminals in vehicles and terminas on bicycles and pedestrians
- Some locations require inference from path
- Geo-location depends on the grid of the telecommunications operator
- Is tis possible to forecast traffic congestion and infer incidents from traffic patterns on the celular grid





Zhijun Qiu, Peng Cheng. 2006.

Application of ILDs (1/2)

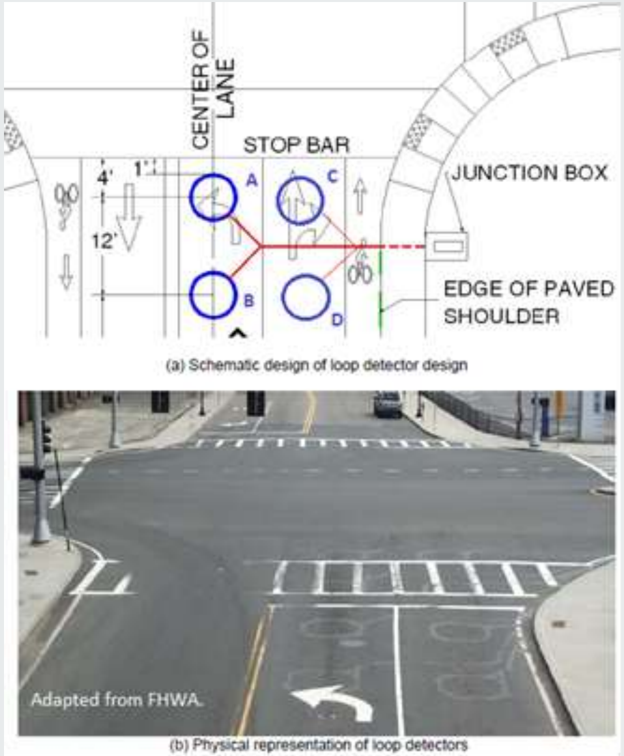
Group of vehicle sensors using inductive loop detectors A, B, C and D installed in a street with the layout depicted in the figure. Sensors in the same lane are 4 meters apart.

Each detector produces two types of events:

- ON when it starts to detect something over it,
- OFF when it ceases to detect something.

(A car passing over a detector generates two events: ON and, later, OFF.)

1. What was the speed (km/h) of the first vehicle passing on the right lane (over sensors C-D)?
2. How many vehicles turned left at the junction?
3. How many trucks passed the street at the left and right lanes? (A truck is vehicle longer than 6 m.)



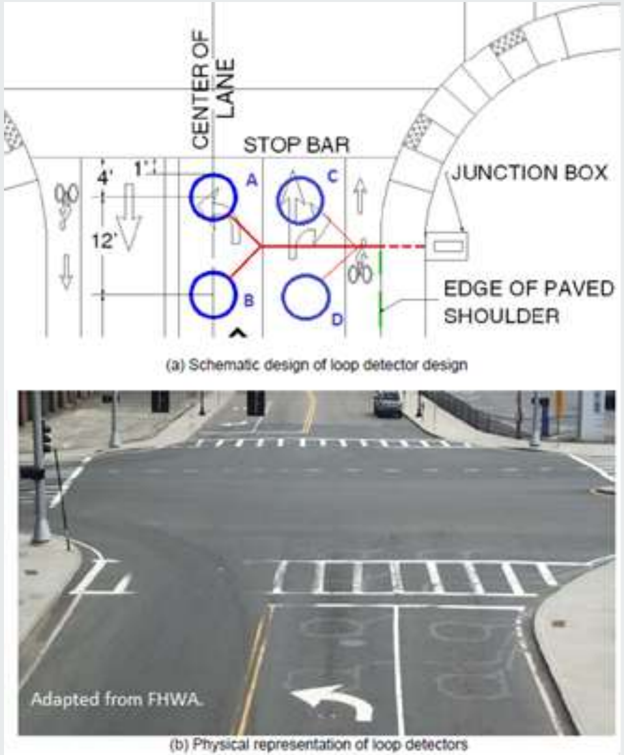
(a) Schematic design of loop detector design

(b) Physical representation of loop detectors

Application of ILDs (2/2)

1. What was the speed (km/h) of the first vehicle passing on the right lane (over sensors C-D)?
2. How many vehicles turned left at the junction?
3. How many trucks passed the street at the left and right lanes? (A truck is vehicle longer than 6 m.)

Time [ms]	Sensor	Event
10	D	ON
100	B	ON
410	C	ON
460	D	OFF
860	C	OFF
1000	D	ON
1300	A	ON
1300	B	OFF
1400	C	ON
1620	D	OFF
2020	C	OFF
2500	A	OFF



(a) Schematic design of loop detector design

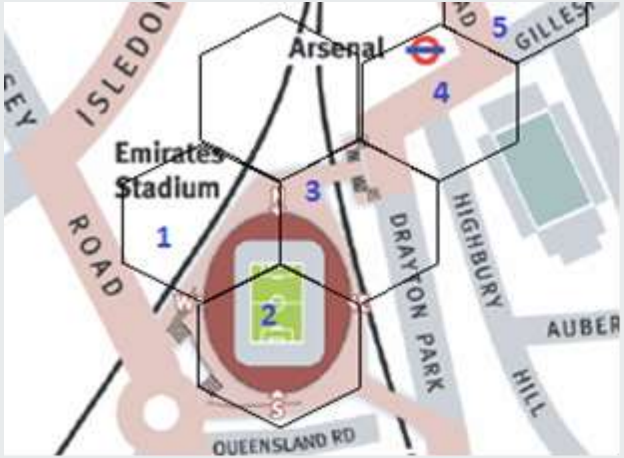
(b) Physical representation of loop detectors

Application of global sensing (1/2)

The area around a football stadium is covered by the cellular communications network sketched in the figure. About 40,000 people with mobile phones leaved the building at the end of the game and went back home by public transport or using their private cars. The enclosure of the stadium is covered by cells 1, 2, 3; the subway entry by cell 4.

1. Estimate the approximate percentage of spectators who used the subway.

Time	Cell				
	1	2	3	4	5
19:00	10.100	20.100	10.100	50	50
19:15	10.100	20.100	10.100	50	50
19:30	10.100	20.100	10.100	50	50
19:45	8.989	15.656	11.211	1.161	50
20:00	5.656	8.989	8.989	6.717	1.161
20:15	2.322	2.322	6.767	7.828	3.383
20:30	100	100	2.322	6.717	4.494
20:45	100	100	100	2.272	3.383
21:00	100	100	100	50	1.161
21:15	100	100	100	50	50



Application of global sensing (2/2)

You will need to consider some reasonable assumptions such as:

- during the period there are no other significant flows of people in the area
- all the people leaving cell 4 either entered the subway or moved to cell 5

Time	Cell				
	1	2	3	4	5
19:00	10.100	20.100	10.100	50	50
19:15	10.100	20.100	10.100	50	50
19:30	10.100	20.100	10.100	50	50
19:45	8.989	15.656	11.211	1.161	50
20:00	5.656	8.989	8.989	6.717	1.161
20:15	2.322	2.322	6.767	7.828	3.383
20:30	100	100	2.322	6.717	4.494
20:45	100	100	100	2.272	3.383
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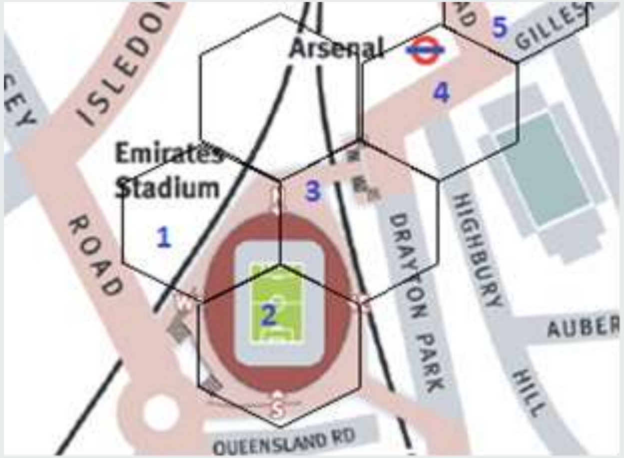
21:15	100	100	100	50	50



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02
Vehicle to Infrastructure Interaction (V2I)
Traffic Management Systems

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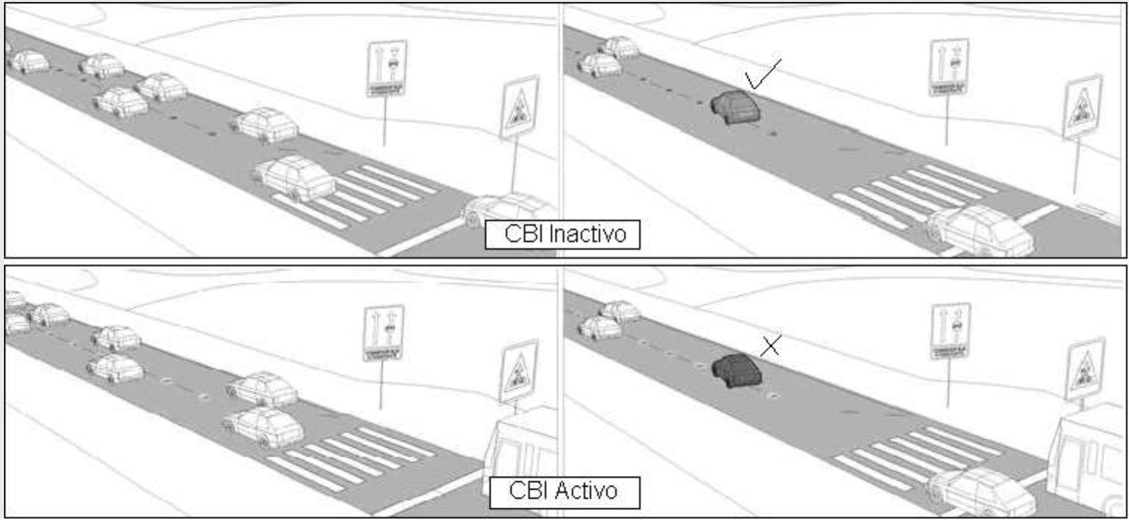
Intermitent bus lane(1)

Bus lane reserved whenever a public passenger bus approaches



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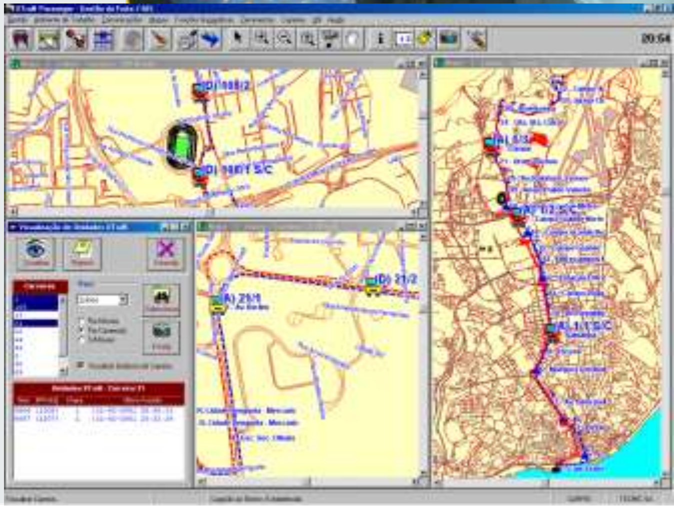
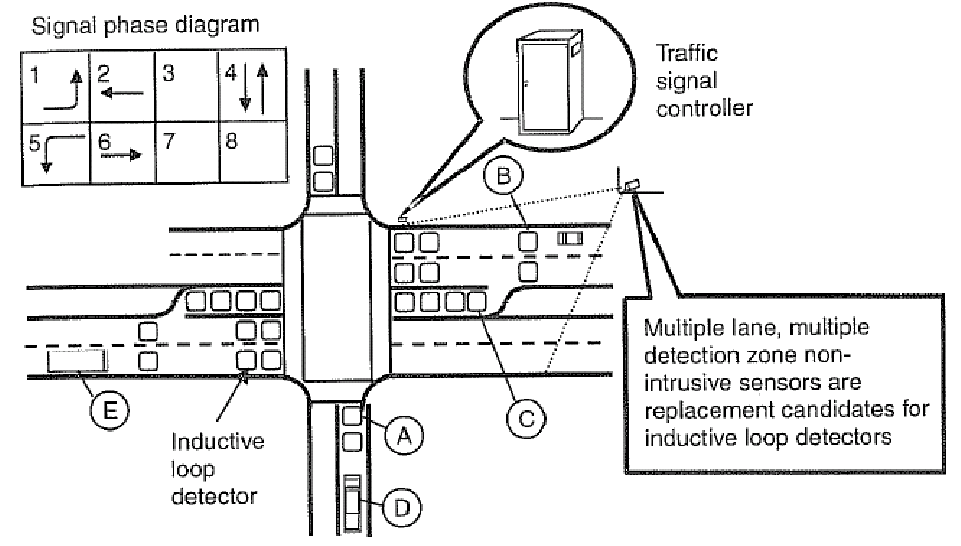
Intermitent bus lane (2)

1st instalation at
Cidade Universitária,
Campo Grande,
Lisbon



Intersections

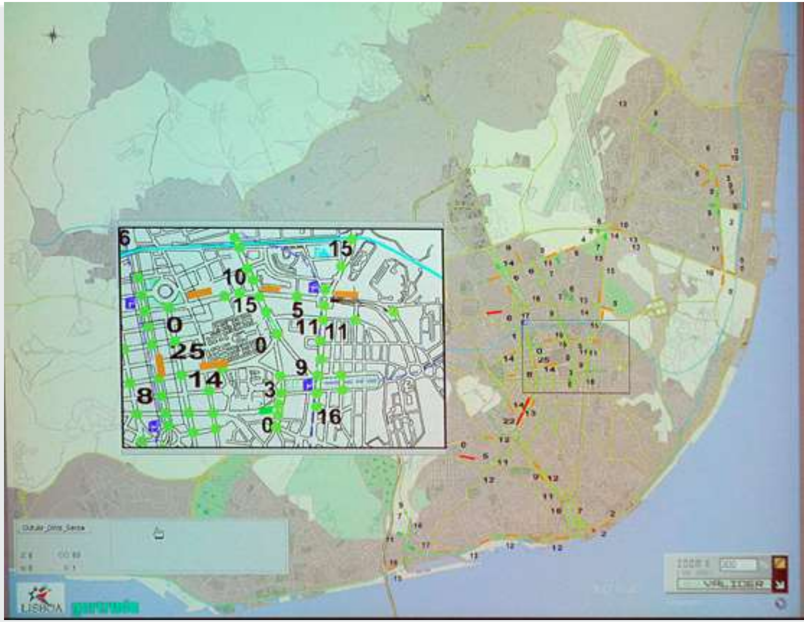
- Fixed time intervals
- Variable time intervals depending on traffic conditions
  - Priority to emergecy vehicles



Traffic management

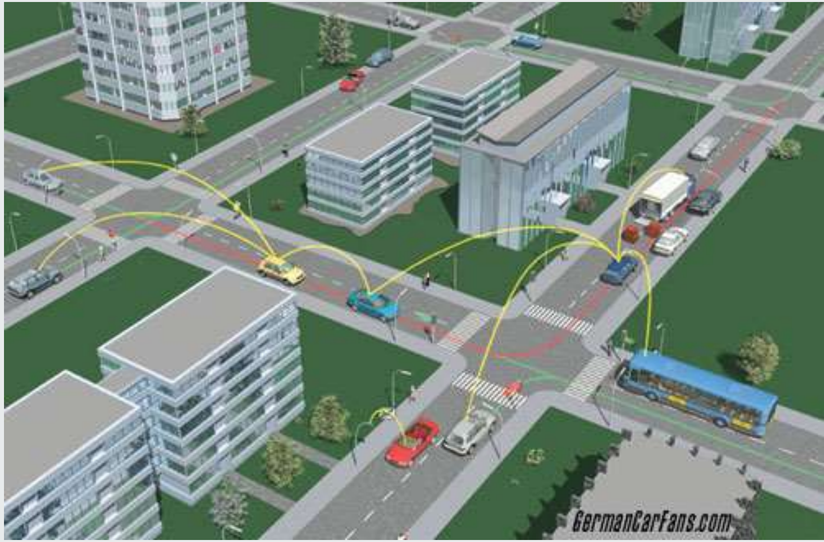
Captures and processes information from sensors and globally controls traffic lights

Lisbon Gertrude (*Gestion Electronique de Règulation en Temps Réel pour L'Urbanisme, les Déplacements et l'Environnement*)



Intelligent intersection

"BMW ConnectedDrive seeks to intelligently network the driver with his car and the surroundings, thus making road traffic safer, more efficient, and more comfortable"



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