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

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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

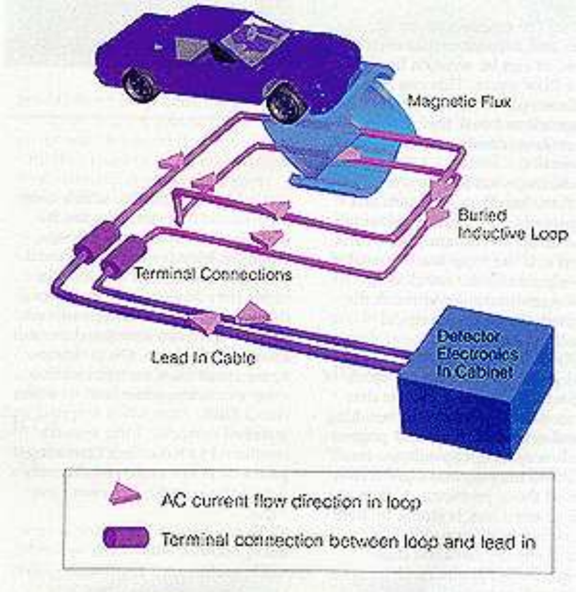

Figure 1 — Car passing over inductive loop buried in pavement.

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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

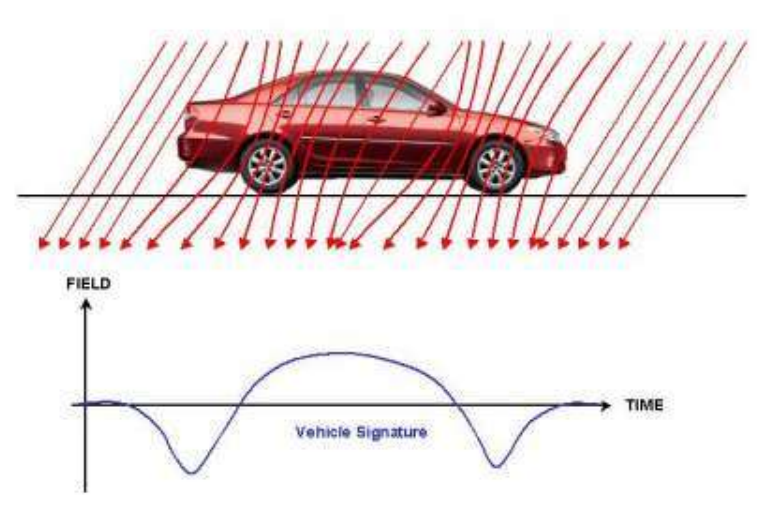
speed = d / [time(ILD1, ON) – time(ILD2, ON)]

Vehicle classification:

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

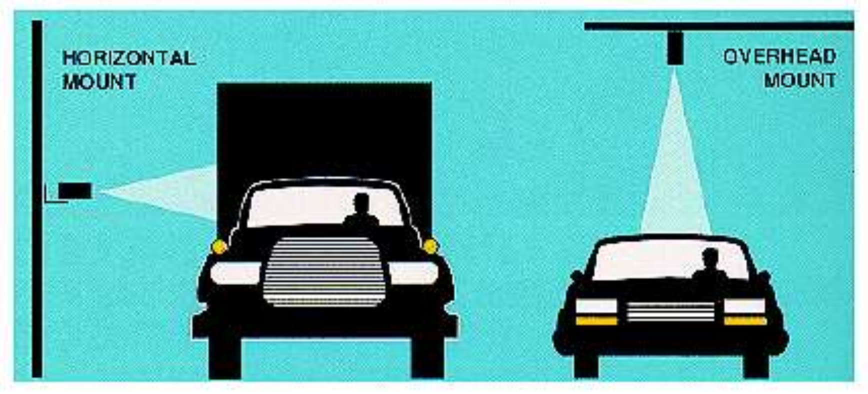
Magnetic sensors

- 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)

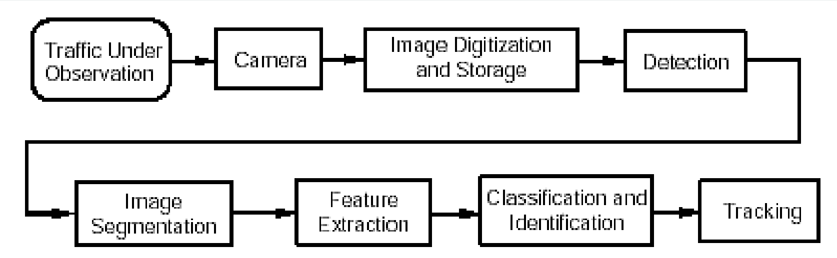
(d) Iteris Vantage processors (Photograph courtesy of Iteris, Anaheim, CA)

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

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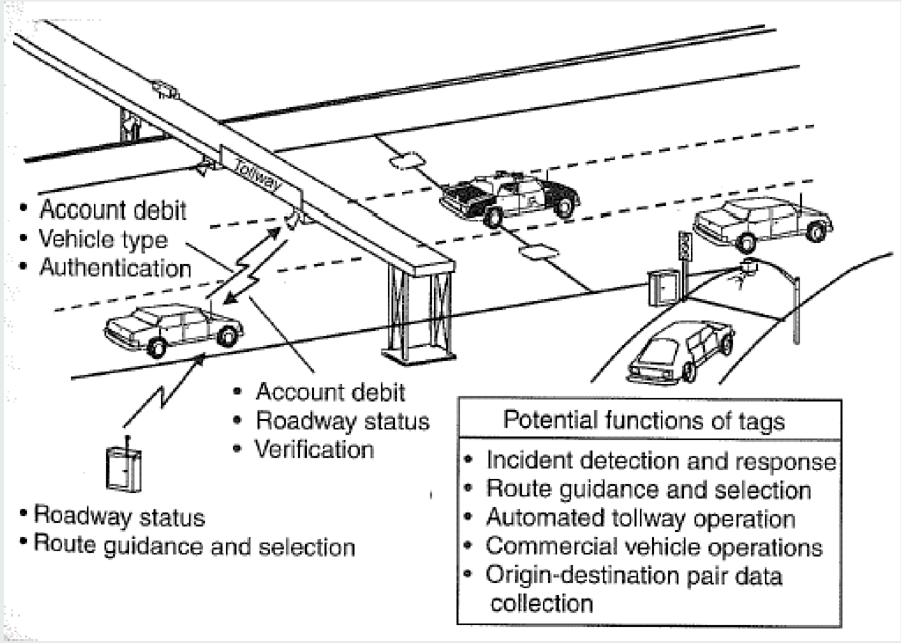
Vehicle sensing technologies

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

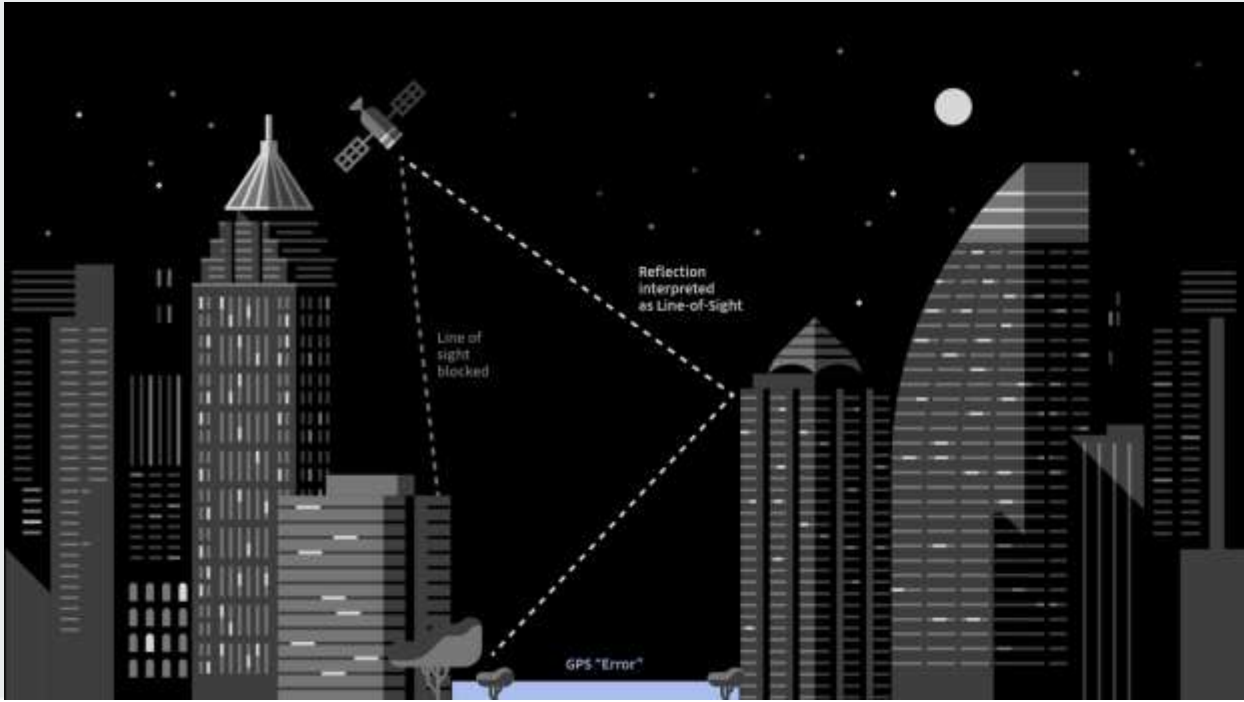
- Triangulation based on reference points
  - Measure the distance
  - Measure the angle
  - Example: Location of a ship in line of sight with two lighthouses
- Distance measurement
  - Transit time of a signal from a reference emitter
  - Signal strength (power) measurement – $E \approx k / d^2$

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)

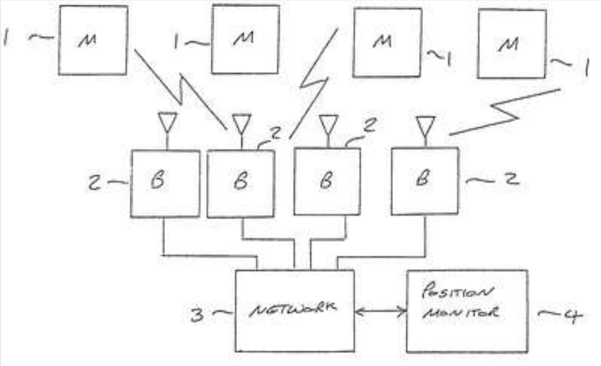


Celular networks (1)

- "*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

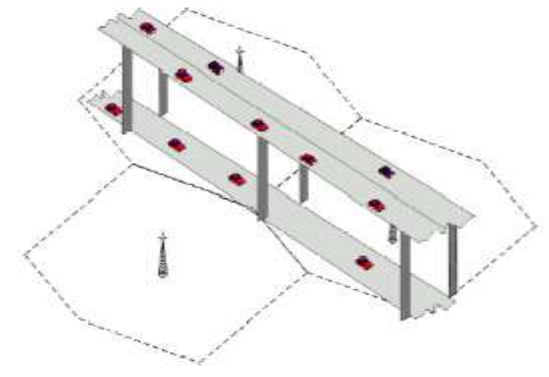
Percentage of calls	Location by the network	Location by the terminal
67%	100 m	50 m
95%	300 m	150 m

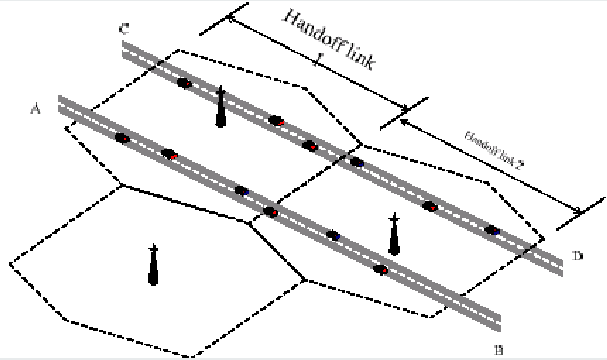


United States Patent 6973319, Inventors: Richard Ormson (Berkshire, GB), Assignee: NEC Corporation (Tokyo)

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)

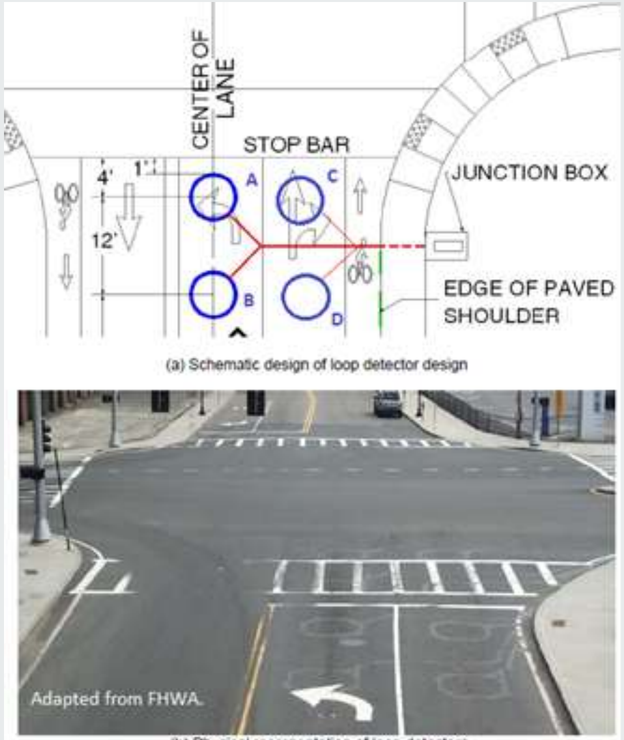
Group of vehicle sensors using inductive loop detectors A, B, C and D installed in a street with the layout depicted in the figure. Sensors in the same lane are 4 meters apart.

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.)



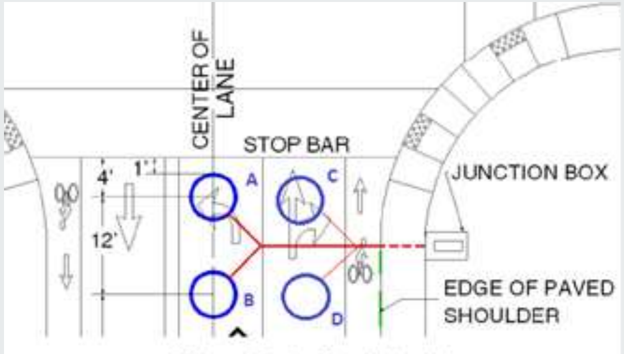
(a) Schematic design of loop detector design

(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

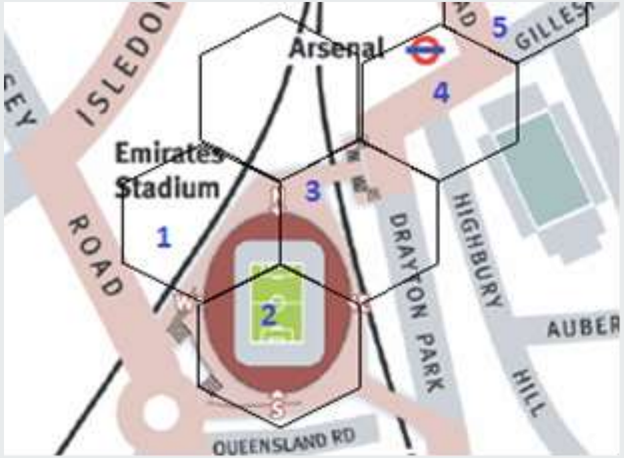
(b) Physical representation of loop detectors

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

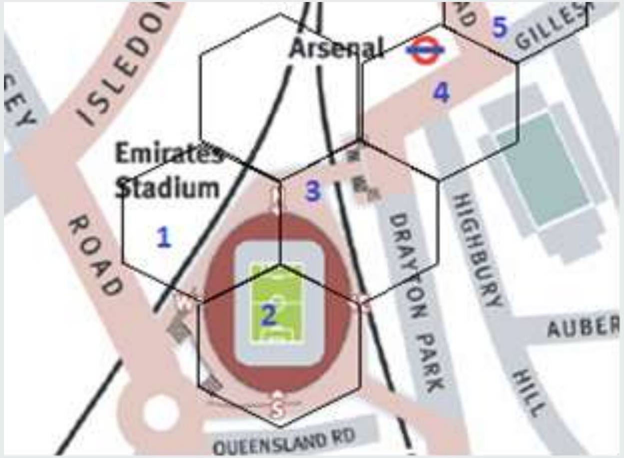


Application of global sensing (2/2)

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
21:00	100	100	100	50	1.161
21:15	100	100	100	50	50



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02
Vehicle to Infrastructure Interaction (V2I)
Traffic Management Systems

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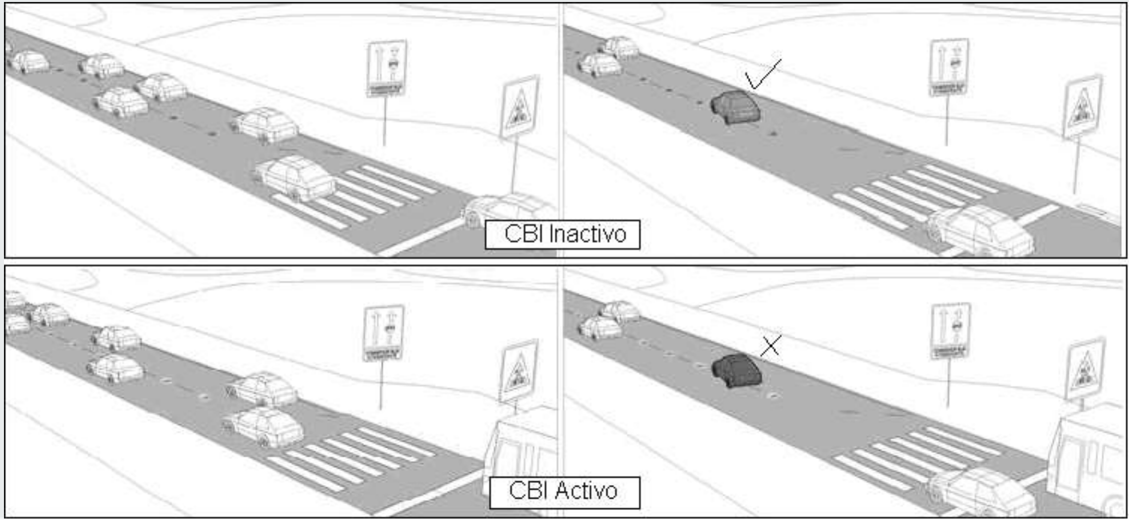
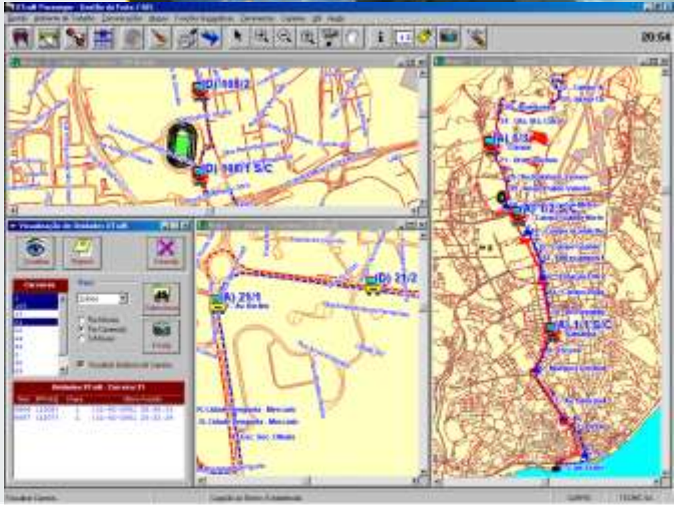
Intermitent bus lane(1)

Bus lane reserved whenever a public passenger bus approaches



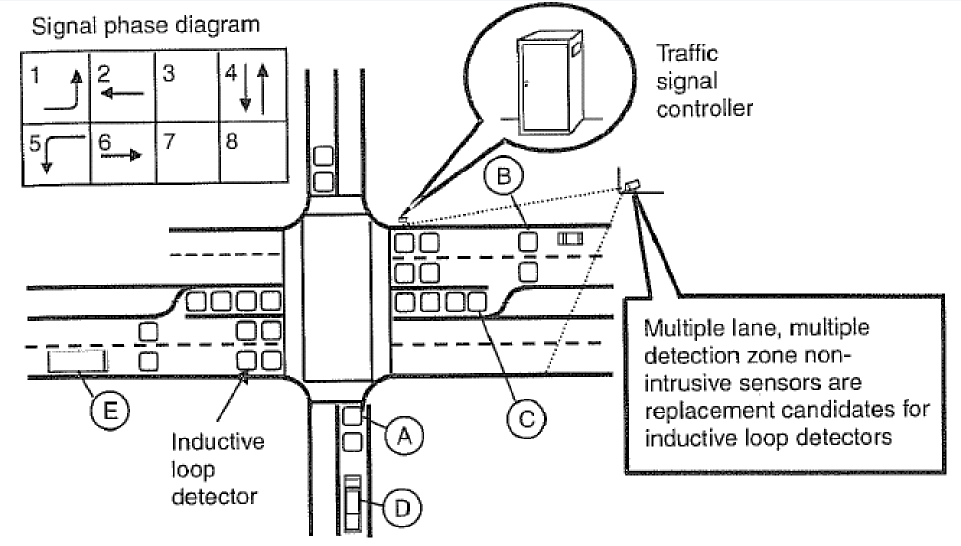
Intermitent bus lane (2)

1st instalation at
Cidade Universitária,
Campo Grande,
Lisbon



Intersections

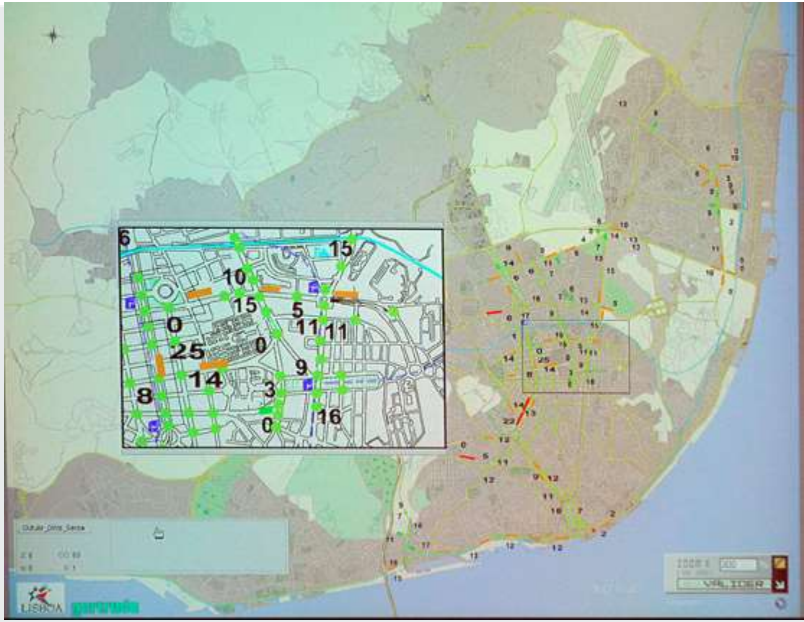
- Fixed time intervals
- Variable time intervals depending on traffic conditions
  - Priority to emergecy vehicles



Traffic management

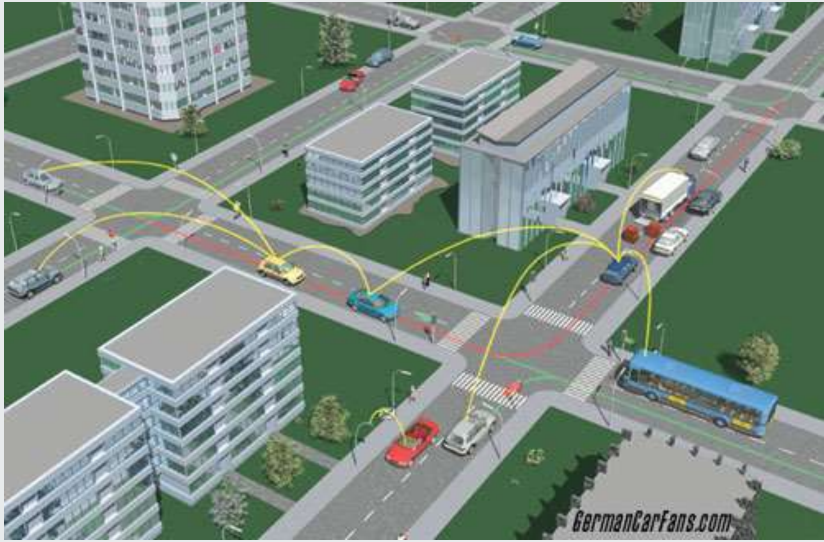
Captures and processes information from sensors and globally controls traffic lights

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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References

- Sensor Technologies and Data Requirements for ITS. Lawrence A. Klein. Artech House. 2001.
- Traffic Detector Handbook: Third Edition – Volume I. Federal Highway Administration, US Dep. of Transportation, October 2006.

03
Human-Infrastructure Interaction

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Plan

- Basic requirements for personal identification
- Smart cards as security elements
- Standards and interoperability frameworks
- Smarphones vs smart cards

- People work, live and enjoy cities
- The seamless flow of people to/from workplaces, to access services, and to entertainment and leisure activities is a feature of dense urban spaces
- Most technological developments of personal devices target urban communities

Basic requirements

- Identification

  Identity check in public services or to reserve services and control accesses, login in IT services or communities
- Access rights validation

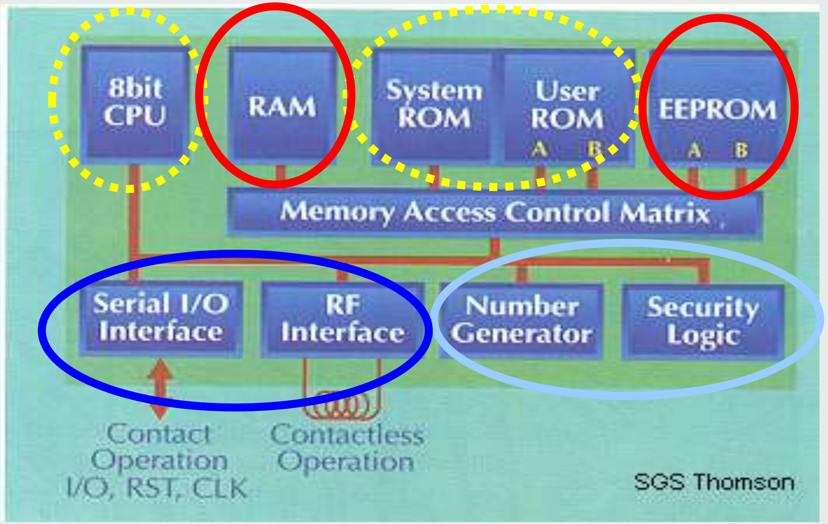
  Verification of the rigths to access or use a service
- Payment

  Pay a service
- Non-functional requirements
  - Transaction speed
  - Security & Privacy
  - Autonomy

Main personal device technologies

- Smart cards and tags
- Smartphones

Main blocks of a chip card



Functionality

Memory

Security

Interface

Smart card interfaces

- Contact

  Mechanical connections

  Transaction time ≈ seconds

- Contactless

  Electromagnetic coupling

proximity	~ 60 cm	m
	magnetic induction	*radiofrequency*
passive cards	active cards	RF sensors
tags, stickers		

Transaction time ≈ mseconds

The smart card as a security element (1)

- The most important applications use smart cards as personal secure elements which are able to store reserved information and to check internally security keys
- The security properties are achieved by the electrical and logical construction of the card and by the deployment process
  - Electrical: Chip protection to reverse engineering
  - Logical: Memory hierarchy with strict access rules
  - Deployment process: Formal protocols to generate security keys involving the relevant organizations (manufacturer, managing organization, merchants, etc.)
- Small transaction time + strong security device $\Rightarrow$ decentralized security

The smart card as a security element (2)

- Application examples
  - Government: ID card/citizen card, drivers license, passport
  - Banking: EMV for debit/credit cards
  - Telecommunications: SIM cards, pre-paid cards
  - Transportation: Calypso, Mifare cards with pre-paid and season tockets
  - Corporations: Identification and access control to premisses and facilities

Structure of commands

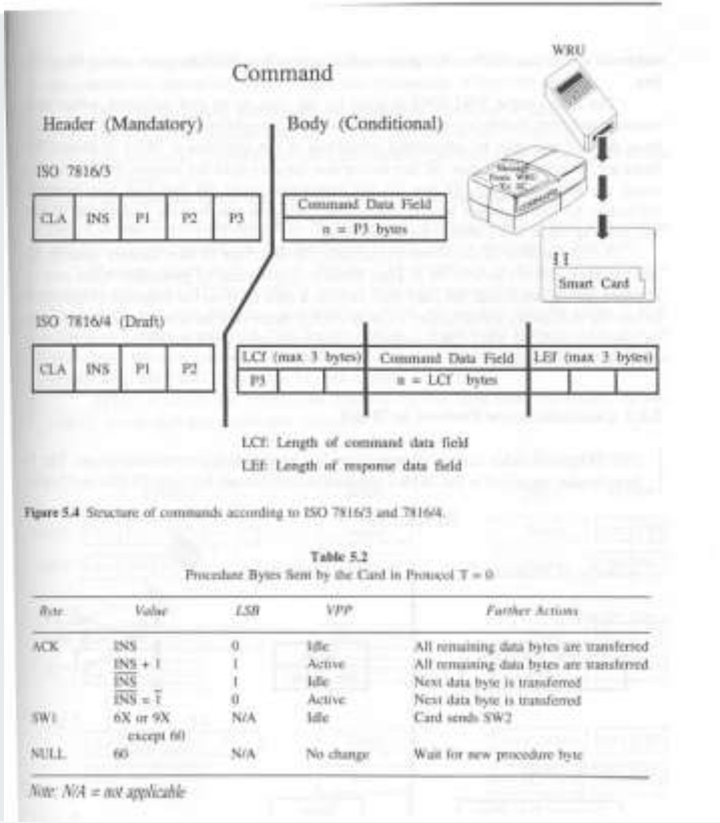


Figure 5.4 Structure of commands according to ISO 7816/3 and 7816/4.

Table 5.2
Procedure Bytes Sent by the Card in Protocol T = 0

Byte	*Value*	*LSB*	*VPP*	*Further Actions*
ACK	INS	0	Idle	All remaining data bytes are transferred
	INS + 1	1	Active	All remaining data bytes are transferred
	$\overline{INS}$	1	Idle	Next data byte is transferred
	$\overline{INS} + \overline{1}$	0	Active	Next data byte is transferred
SW1	6X or 9X except 60	N/A	Idle	Card sends SW2
NULL	60	N/A	No change	Wait for new procedure byte

Note: N/A = not applicable

© Smart Cards. José L. Zoreda, José M. Otón. Artech House, 1994.

Strict hierarchical memory structure (ISO 7816-4)

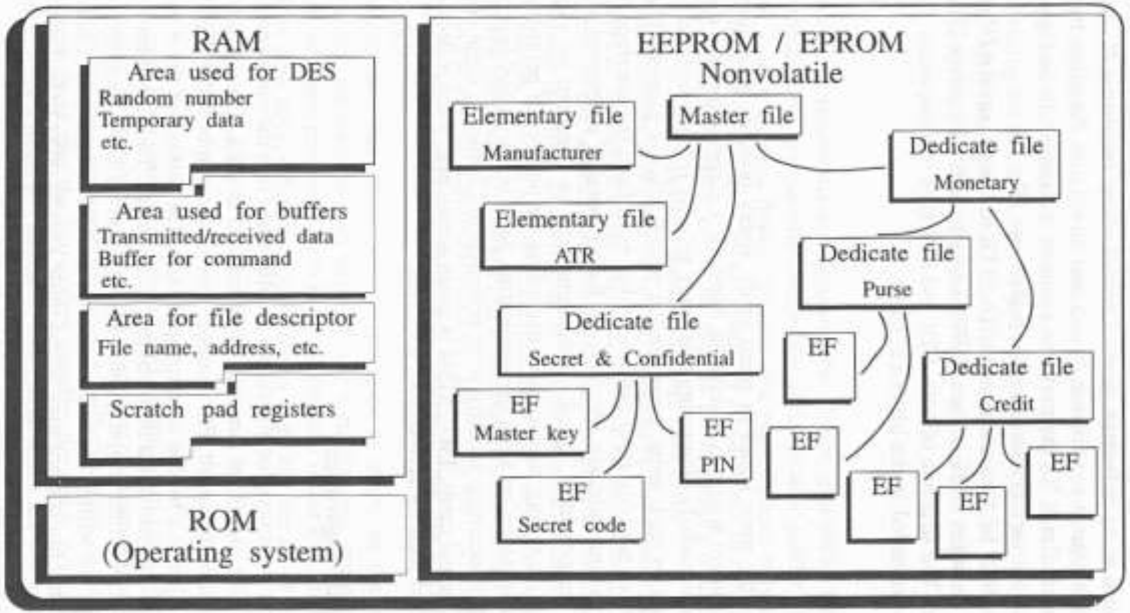


Figure 5.8 Hierarchical memory structure proposed by ISO 7816/4. ROM and RAM areas remain unmodified.

Mandatory access control to memory regions

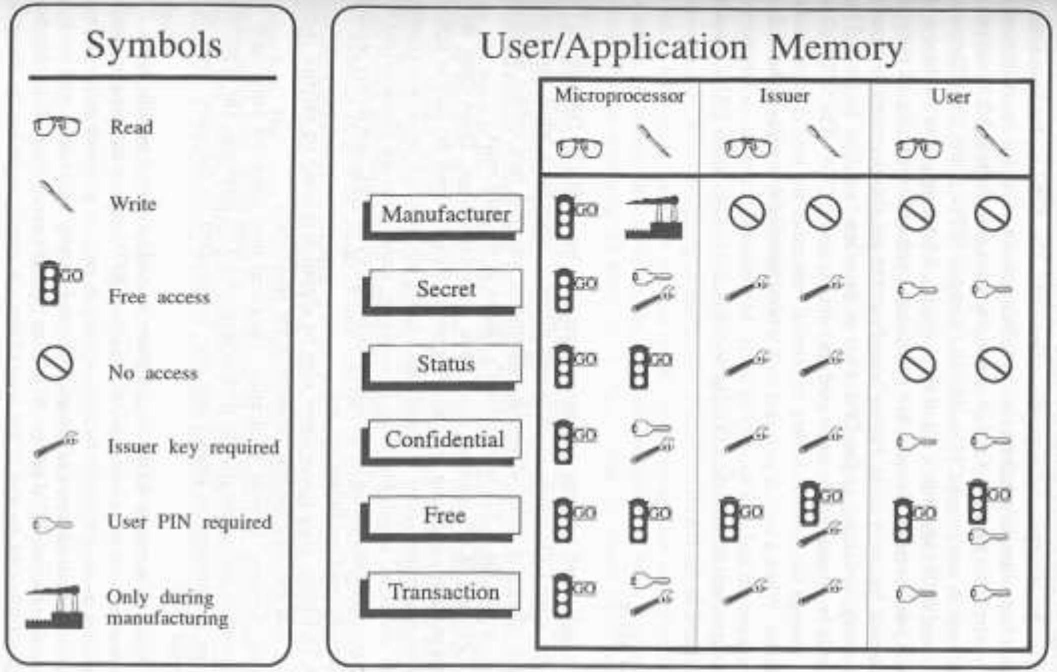


Figure 4.3 Typical zones of user/application memory.

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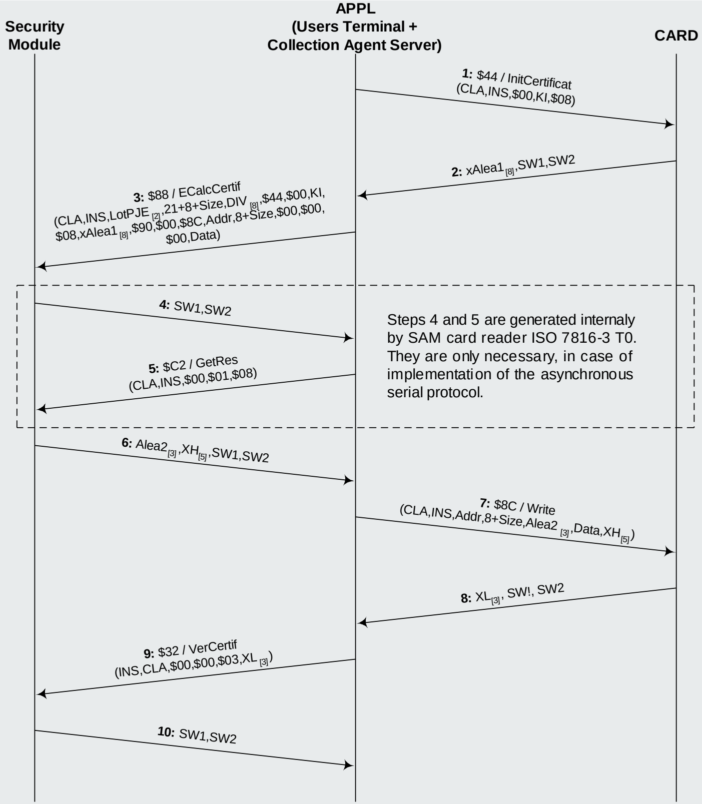
Decentralised security
Mutual authentication

- Sometimes it is required the mutual authenticaton of the card and the terminal

- Terminal addresses the card
- Card replies and sends a piece of a certificate
- Terminal sends certificate to a Security Module (SAM – Security Application Module)
- SAM replies with the other part of the certificate
- Certificate is encapsulated in the message to write
- Mutual verification between card and terminal



Smart card standards (1)

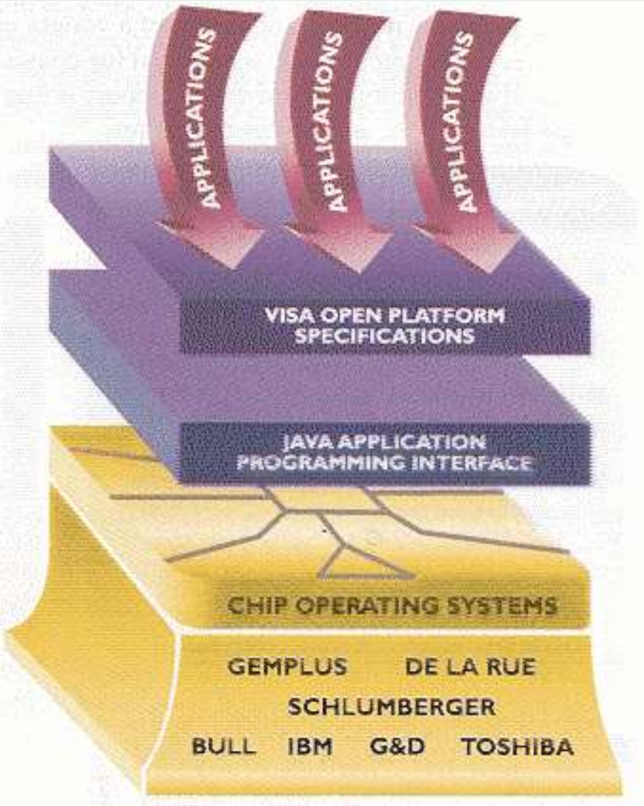
- Define levels of abstraction within the card

Application

Application interface (API)

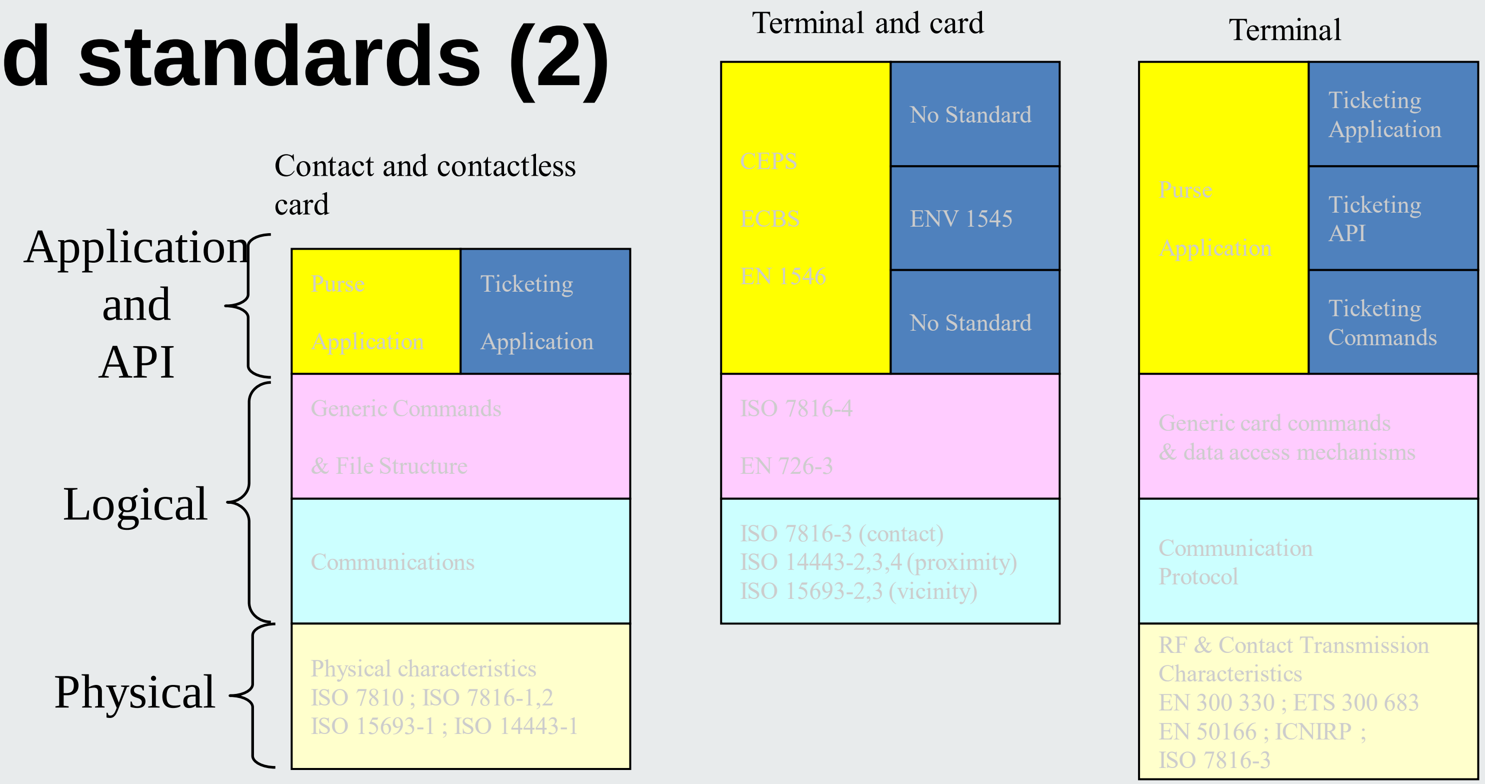
Logical

Physical



Smart card standards (2)

Define layers of abstration in the card and the terminals (e.g. Bank & Transports)

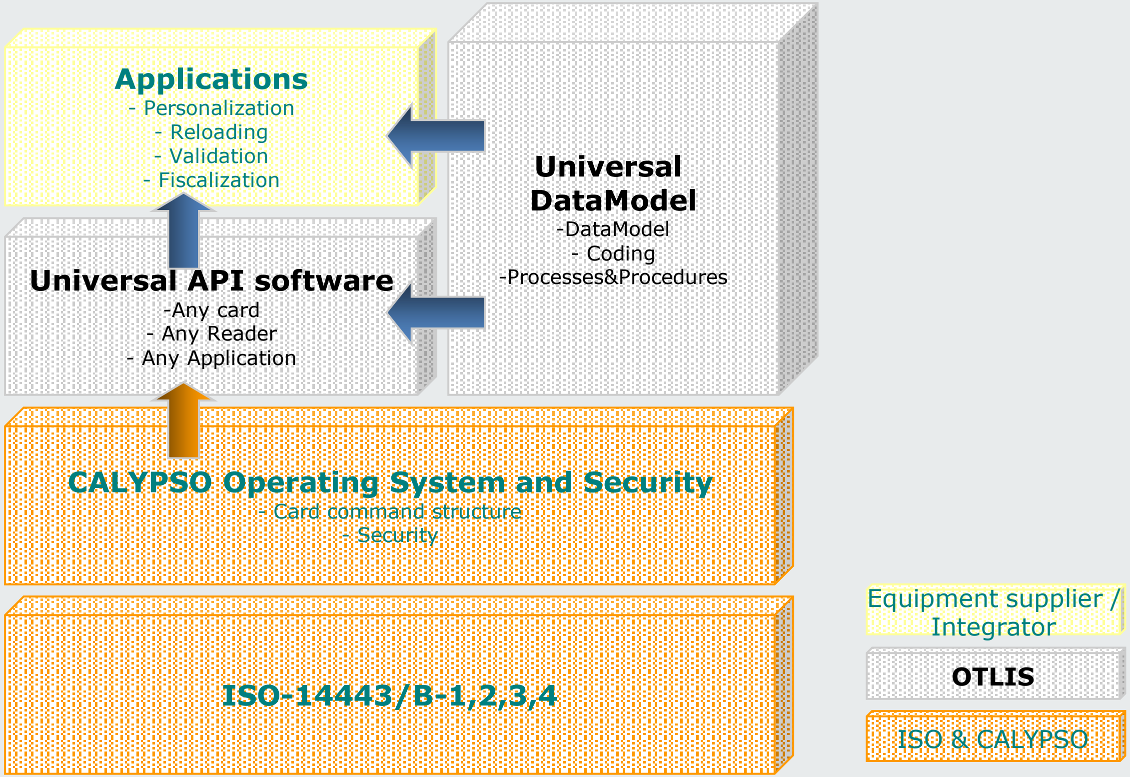


Application level standards (Card and Terminal)

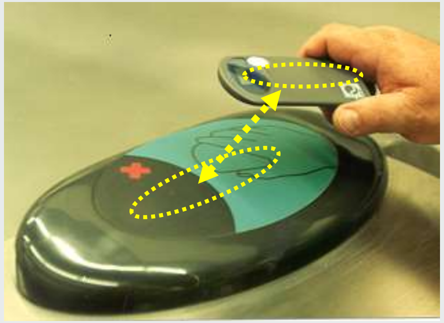
- Application
  - VisaCash, EN1546, ECBS-TCD, CEPS (e-purse)
  - Visa Smart Debit, Visa Smart Credit, EMV'96 (debit/credit)
- Terminal
  - OCF (OpenCard Framework) & PC/SC
  - Visa Open Platform (VisaCash, Visa Smart Credit, Visa Smart Debit, Java WORA™)

Interoperability frameworks

- Required to enable the smart card system to run across several service operators and with several technology providers
- Consider 3 layers
  - **Technology platform**: The card and its operating system standard (e. g. ISO & Calypso)
  - **Service level platform**: Common APIs and the data model of the federated service operators (e. g. OTLIS)
  - **Application level**



Evolution of RF/ID Portable Devices



RFID Smart-Parking

EMV Contactless Smartcard

2001 | 2003 | 2007 | 2008 | 2008/9..

Contactless Microprocessor Smartcard

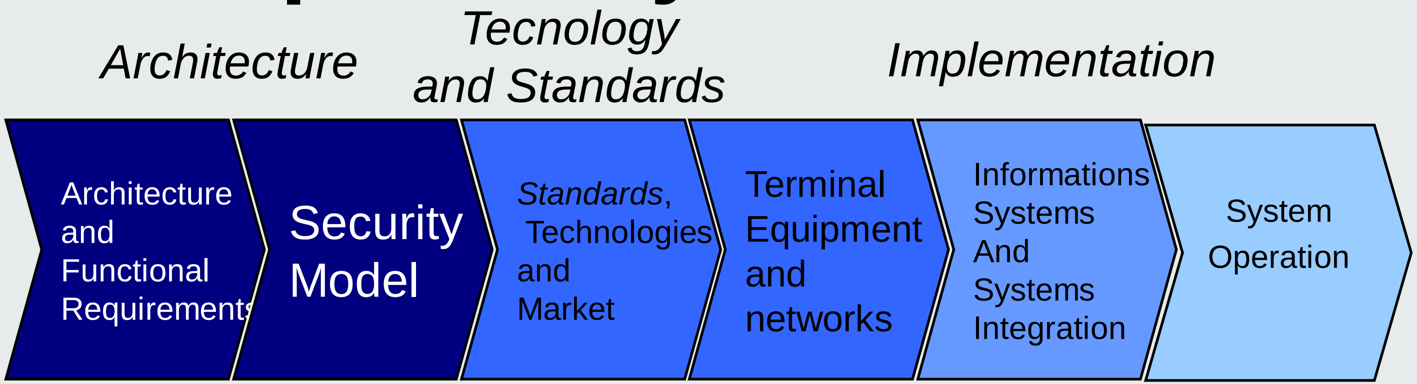
Contactless Paper Smart-ticket & Memory Card

Contactless Multi-application Smartcard

RFID USB Smart-Token

NFC Mobile Phone

Development cycle



Why smartphones are being slow to replace cards in these smart cities applications?

- Compared to smart cards smartphones are full fledged computers
- But they do not provide a security element comparable to the smart card
  - SIM card distribution is controlled by telecommunications operators which take advantage to control the provision of services over their networks
  - That is the same reason why there not so many cross sectorial application of cards (banks + telcos, telcos + transports, etc.)
- Perhaps wait for more devices with dual chip capability, or for service operators to value user convenience vs risk

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Or no cards, no smartphones, just image processing

- Shenzhen traffic police [webpage]
  (24 April 2018, translated by Google, non accessible in 2021)

For next lecture

- Imagine how traffic/mobility (vehicle and people flows) can/will be managed in the future

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06
Future Road Environments
C-ITS Applications

Alessio Ciavarella, Alberto Cunha

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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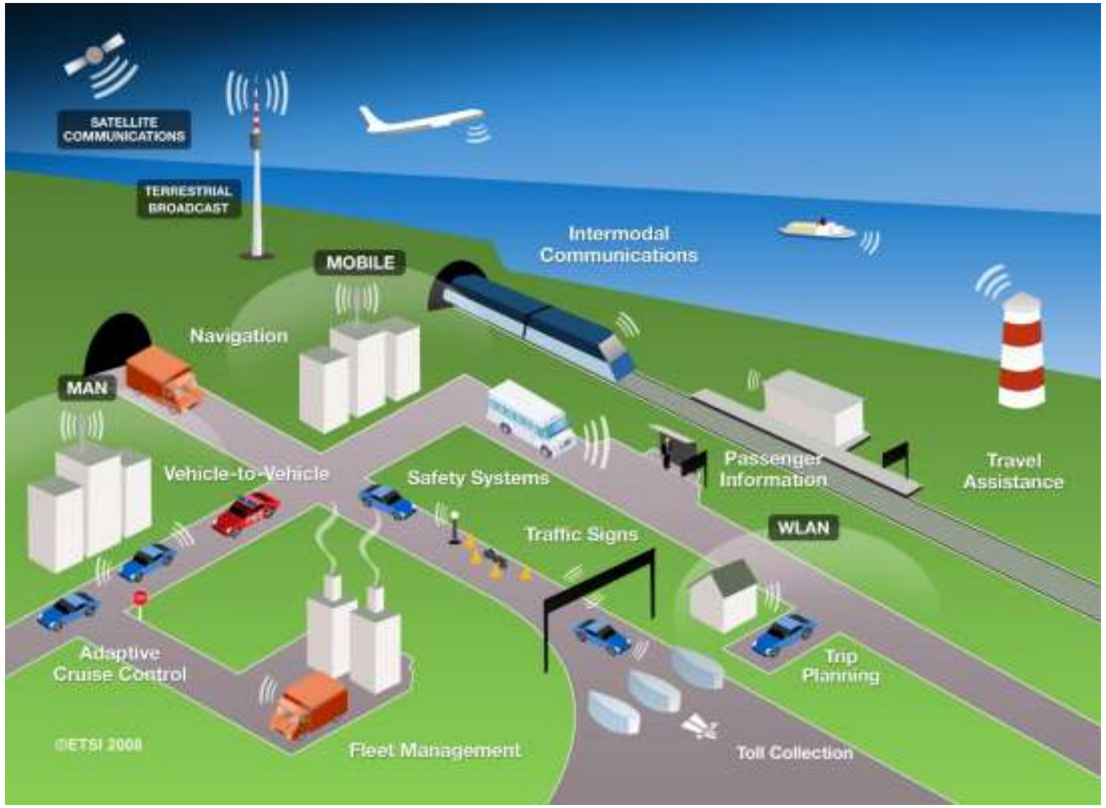
Overview

- Introduction to Cooperative Intelligent Transport System (C-ITS)
- C-ITS issues and challenges

Cooperative-Intelligent Transport System (C-ITS)

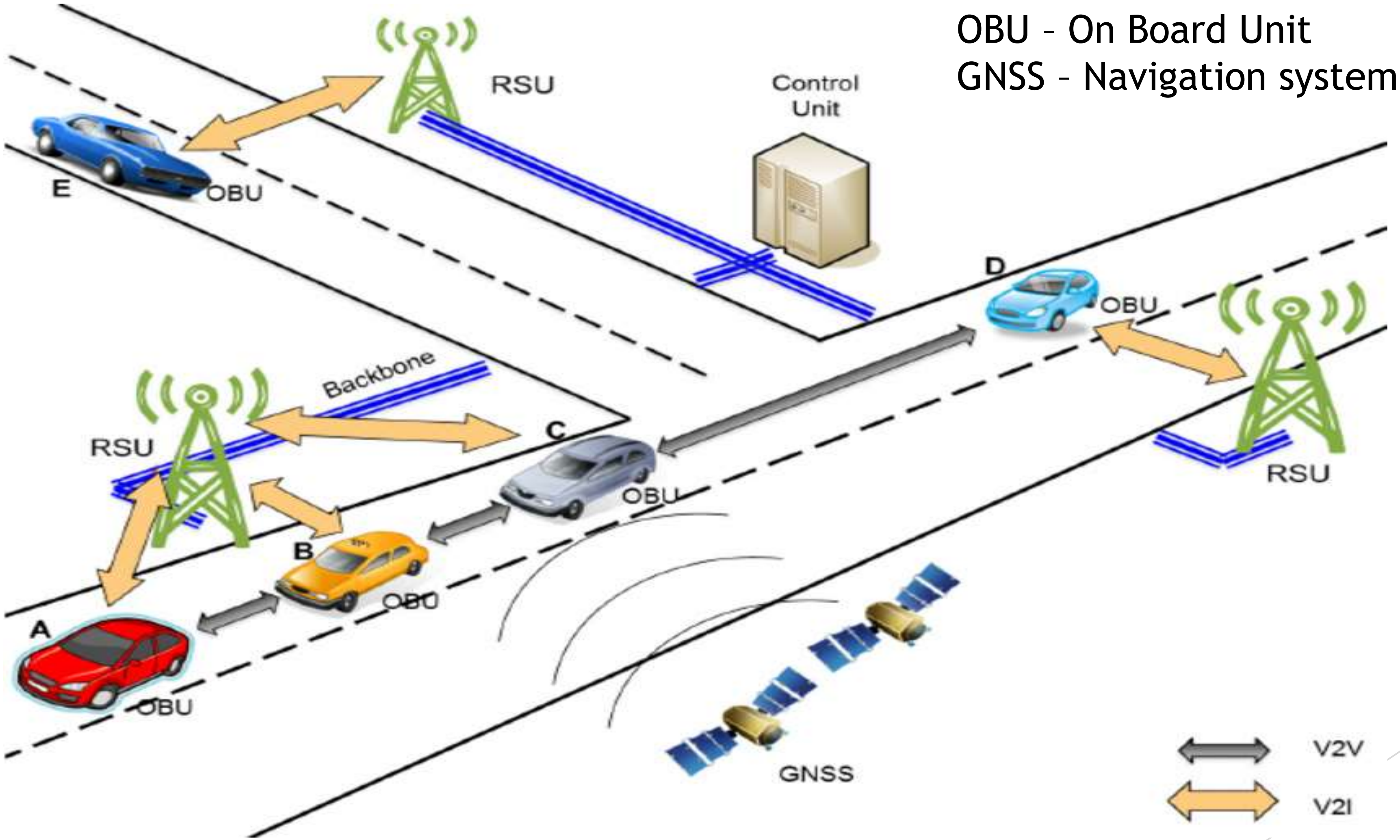
A system that connects and integrates different transport systems and the infrastructure through the use of Information and Communication Technologies.



The objectives are:

- Improvement of road safety
- Reduction of traffic jam
- Reduction of pollution
- Creation of the basis for future autonomous driving vehicles

C-ITS infrastructure



RSU – Road Side Unit
OBU – On Board Unit
GNSS – Navigation system

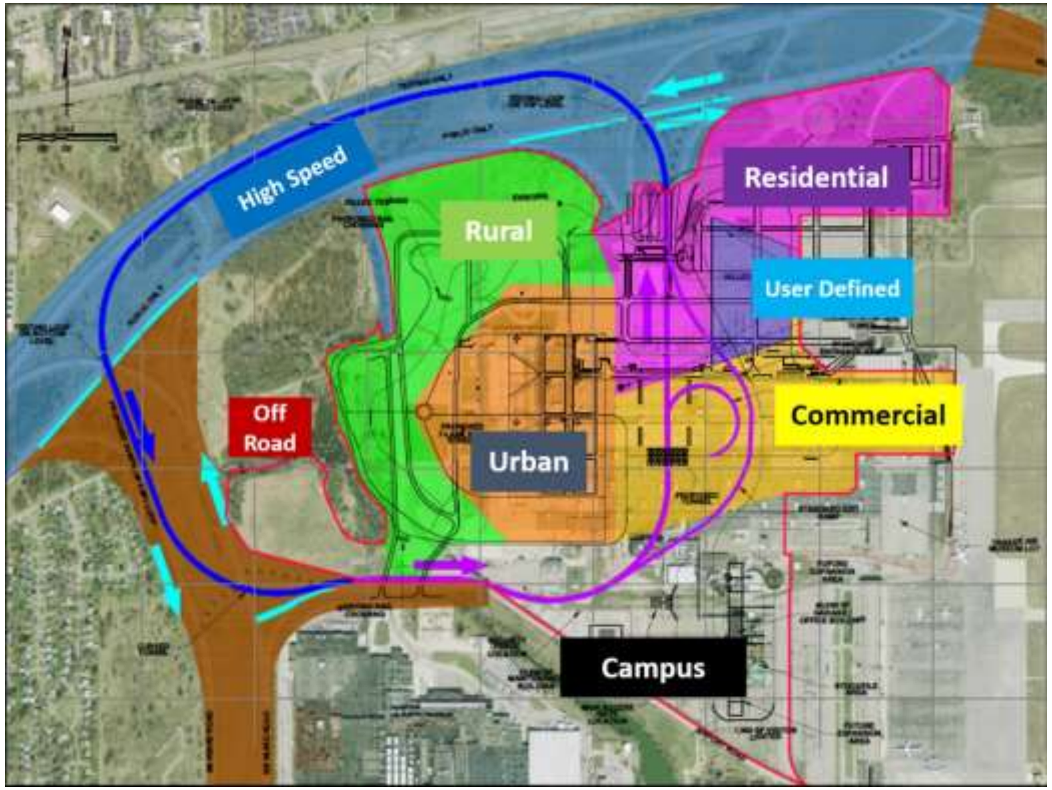
C-ITS issues and challenges

C-ITS systems have two main issues:

- many applications are related with road safety where people could be exposed to possible failures and misbehaviours
- are characterized by a complex infrastructure involving both network and car equipment. Therefore having a working system in real cities requires remarkable resources in terms of money and time

For these reasons they need to be developed and tested in a proper and controlled environment with reasonable resources.

Dedicated testing site installation



American Center for Mobility
www.acmwillowrun.org

One possible solution might be the realization of a specific site to make all the necessary tests.
But this solution still needs:

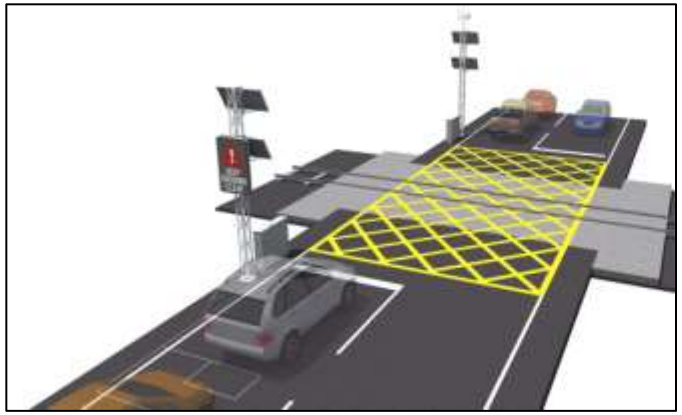
- infrastructure (roads, railways, …)
- equipment (chips, antennas,…)
- vehicles (cars, buses, …)
- real users substituted by dummies (drivers, pedestrians, cyclists, …)

Use cases - Crossings

- **Pedestrian/bicycle crossing**

- Meeting point of different road users (drivers, pedestrians, cyclists)
- Implement and test V2I and V2P communication
- Evaluate methods to improve crossing safety

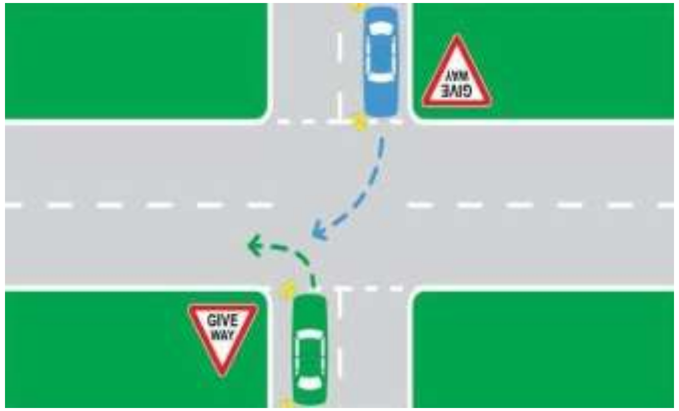
- **Level crossing**



- Evaluate interaction among different means of transport (cars, trains)
- Implement and test V2I communication
- Improve the working logic and safety of the level crossing (e.g. approaching of emergency vehicle)

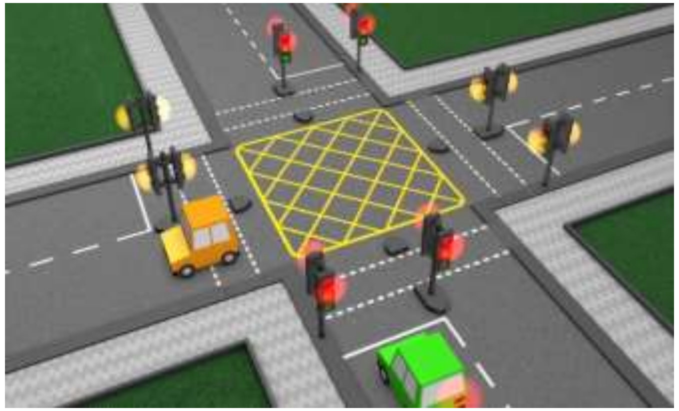
Use cases - Intersections

- **Intersection with modified priority**



- Traditional road signals may be substituted by "intelligent" ones
- Evaluate different systems to control the intersection (e.g. centralized or distributed)
- Test specific algorithms for decreasing traffic congestion

- **Traffic light**



- Traditional traffic signals may be substituted by "intelligent" ones using V2X technologies
- Improve the traffic light logic according to traffic conditions
- Implement GLOSA systems (Green Light Optimal Speed Advisory)

Use cases – Hazard situations

Many road hazards might be encountered while driving along roads (ice, animals, obstacles, etc.). When these situations occur the vehicles that are involved can warn the others in order to let them take the appropriate countermeasures.

The evaluation of these use cases permits to:

- emulate various road hazards
- implement and evaluate the V2V message exchange
- evaluate the possible countermeasures that shall be taken by the vehicle

Use cases – Active Road Signs

Nowadays, road signs are still passive entities that lay on the road side to:

- impose a prohibition (e.g. speed limit)
- notify a warning (e.g. dangerous curve)
- change intersection priority (e.g. give way)

The aim of this use case it to:

- explore the possibility of making the traditional road signs active entities able to communicate with approaching vehicles
- define a message format to support this kind of application
- Simulate the actions taken by the vehicles

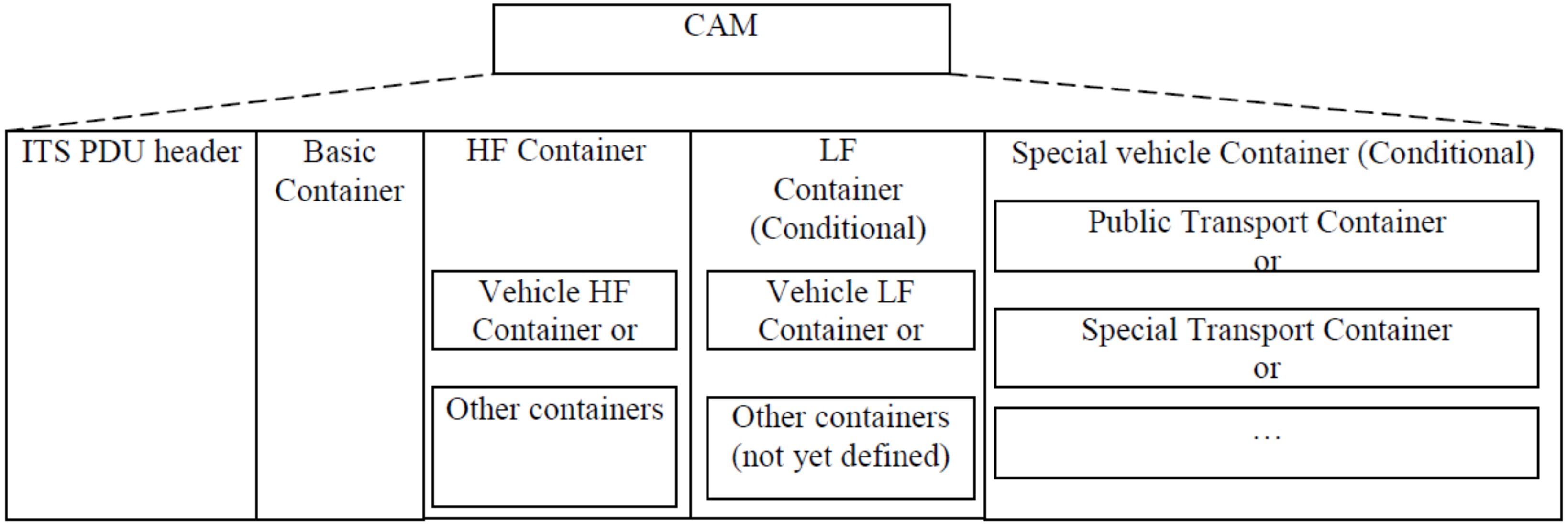
Message definition

The V2X communication involves the use of well-defined messages:

- CAM – Cooperative Awareness Message
- DENM - Decentralized Environmental Notification Message

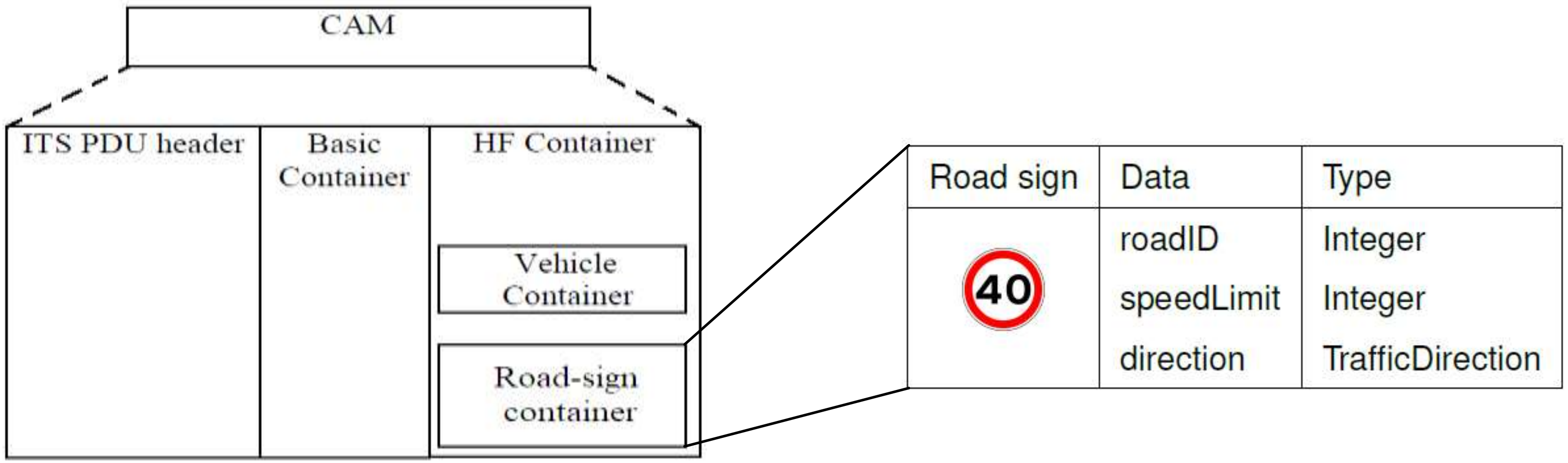
defined by the ETSI (European Standard Telecommunication Institute).

Cooperative Awareness Message



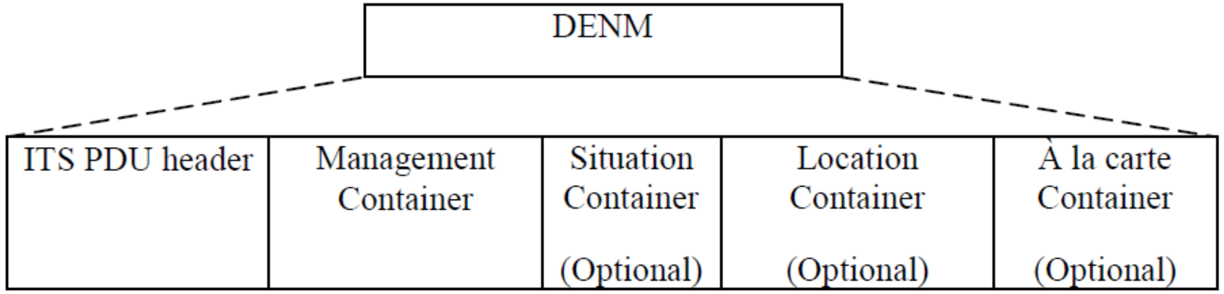
- Periodically generated (< 50 ms)
- Create and maintain awareness among C-ITS stations (RSU, vehicles, …)
- Support cooperative performance (e.g. estimate the collision risk)
- Contains status and attribute information of the originating C-ITS station (type, location, speed, …)

Custom CAM message



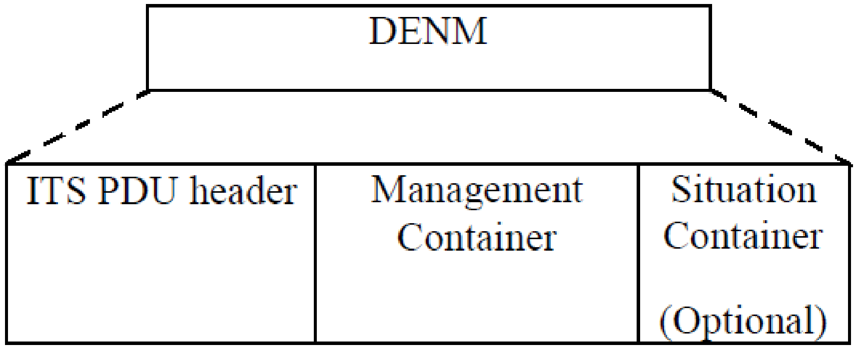
- Periodically generated (< 50 ms)
- Create and maintain awareness among C-ITS stations (RSUs, vehicles, …)
- Contains status and attribute information of the originating C-ITS station (type, location, speed, …)
- the **road-sign container** contains the data generated by “Active Road Signs”

Decentralized Environmental Notification Msg



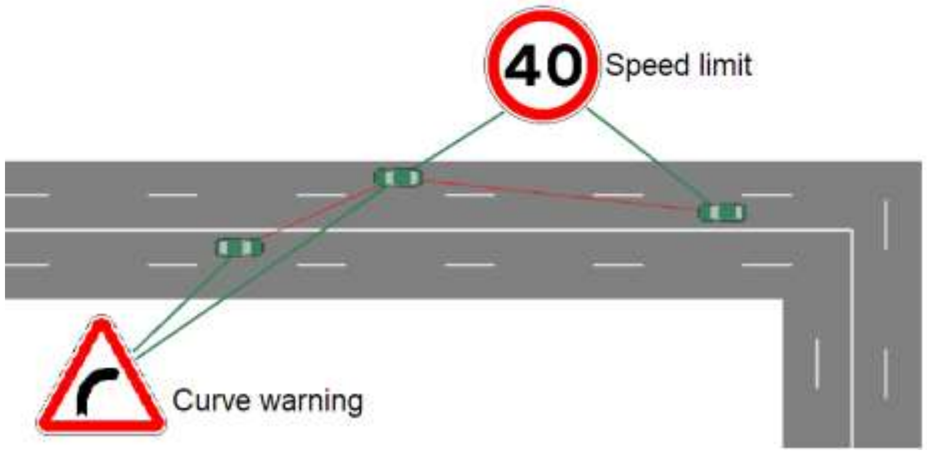
- Generated only in case of an hazardous event (asynchronous)
- May be repeated for a certain duration or untill its cancellation
- Contains information about the originating C-ITS
- Contains information about the event (type, location, …)

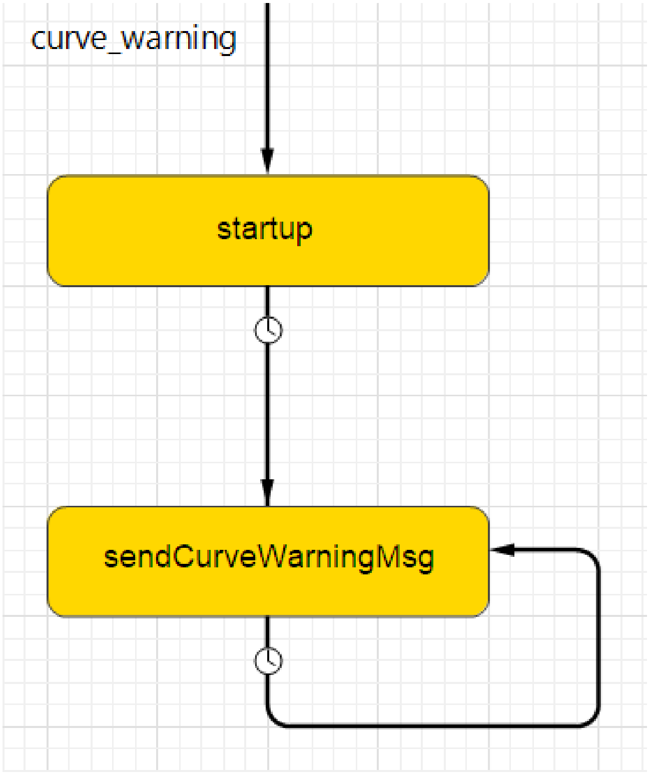
Custom DENM message



- Generated only in case of an hazardous event (asynchronous)
- May be repeated for a certain duration or till its cancellation
- Contains information about the originating C-ITS station
- Contains information about the event (type, location, …)

An example – The Active Road Sign agent

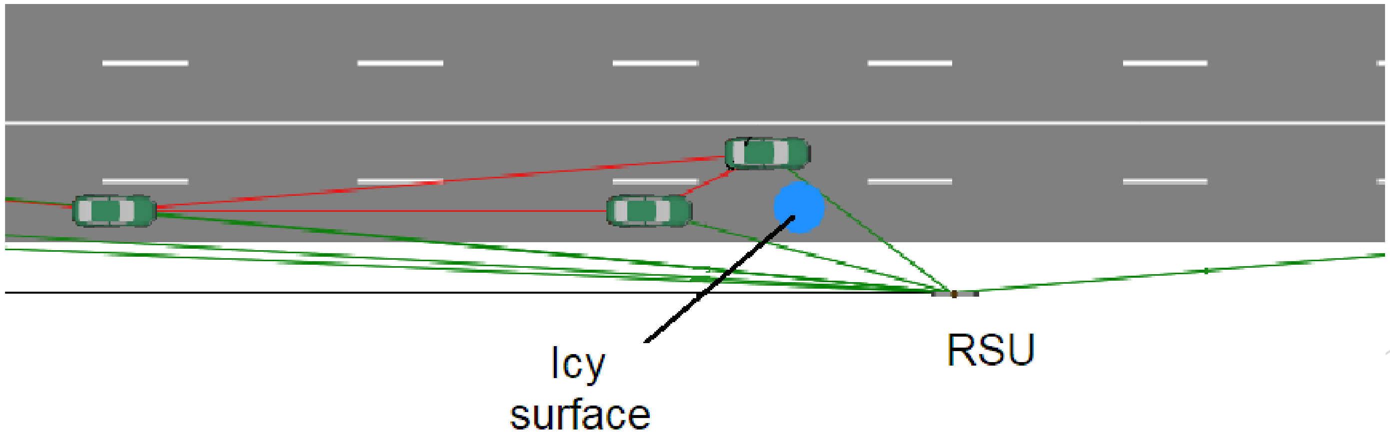




- Cars receive the message from the road sign
- Ignore non relevant messages
- Adapt their speed according to the received message

Icy road scenario evaluation results

Requirements	Result
Possibility of placing an hazard anywhere on the road	Yes
Possibility for cars to detect the hazard	Yes
Possibility to send warning message to close RSU in order to guarantee message delivery	Yes
Possibility for cars to get to the standard speed once that the hazard has been overtaken	Yes
Possibility for cars to change their path to avoid the hazard	No



04 (future 02+03)
Present and Future Mobility Management

Alberto Ramos da Cunha
alberto.cunha@ist.utl.pt

- Imagine how traffic/mobility (vehicle and people flows) can/will be managed in the future

Present Traffic Management

- Sensors
  - Inductive loops, video cameras with image processing, or controlled by human operators
- Actuators
  - Traffic lights, variable signals
- Communications
  - Mostly wired network
- Control
  - One owner
  - Centralized control with some forms of local management
  - Good quality (but probably poor) data (ex. accurate vehicle counters)

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

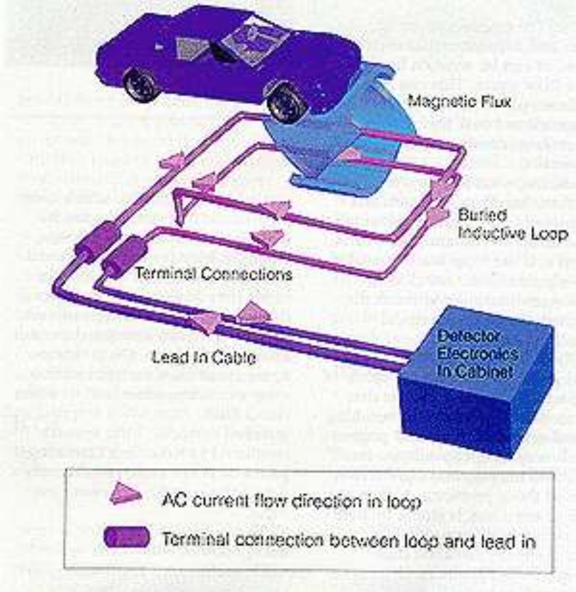
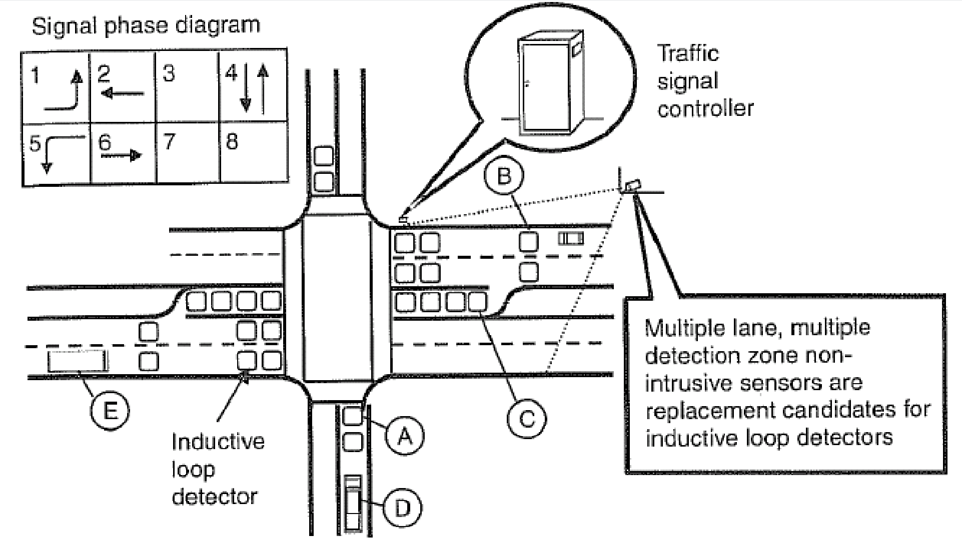


Figure 1 — Car passing over inductive loop buried in pavement.

Intersections

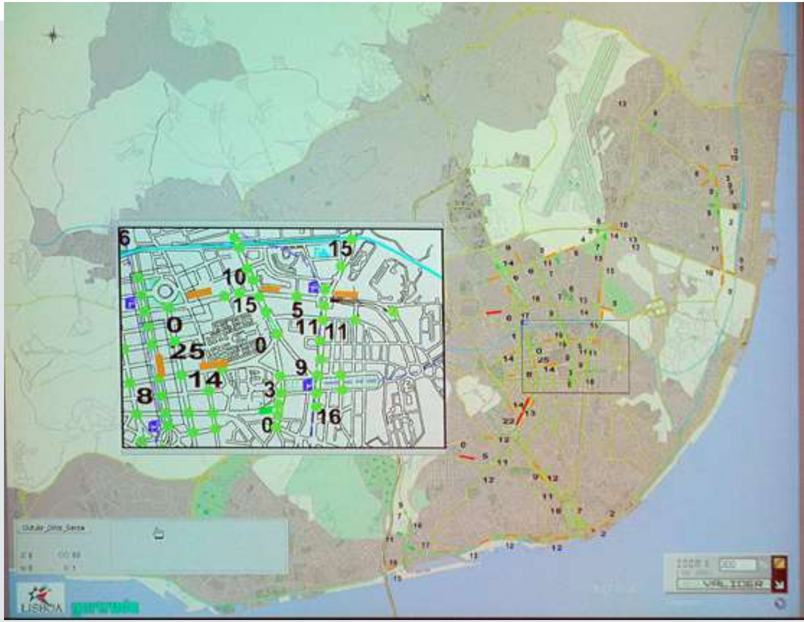
- Fixed time intervals
- Variable time intervals depending on traffic conditions
  - Priority to emergecy vehicles



Traffic management

Captura e funde os dados dos vários sensores e comanda os semáforos à escala global

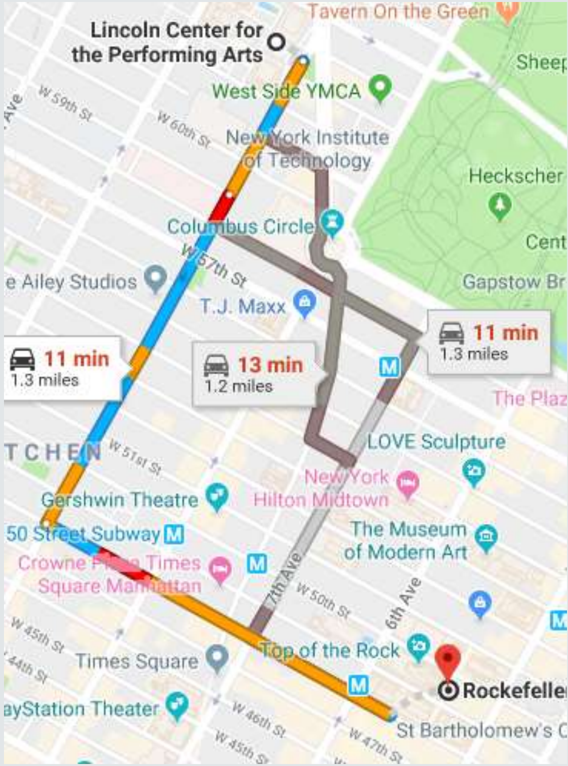
Lisbon Gertrude (*Gestion Electronique de Règulation en Temps Réel pour L'Urbanisme, les Déplacements et l'Environnement*)



Future Traffic Management

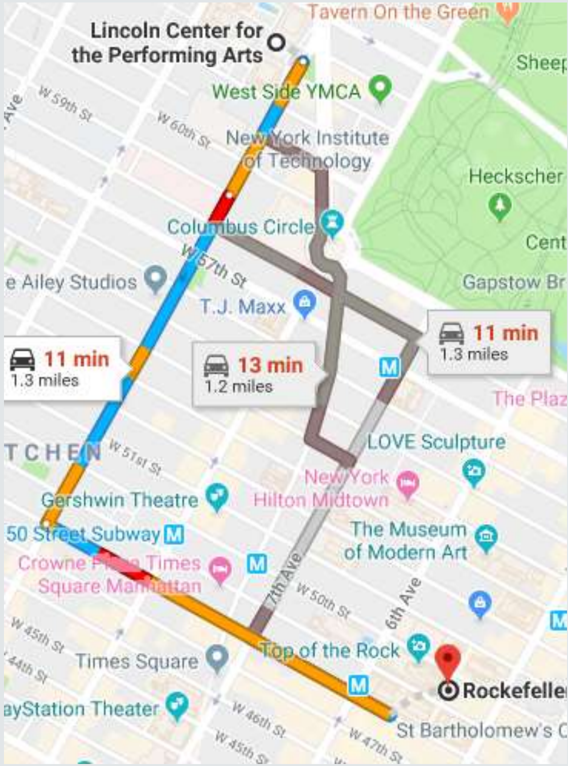
(incremental enginners view)

- Sensors
  - Automatic vehicle location (GPS, beacons), and
  - Detection (video cameras, electronic license plates)
  - Crowd-sourced
- Actuators
  - Automatic control of autonomous vehicles, traffic lights, variable signals
- Communications
  - Vehicular networks, WiFi, celular (fixed and wireless or celular networks)
- Control
  - Cooperatively distributed
  - Rich data from several sources/owners (ex. Google Maps)
  - Variable data quality (lots of information – number and types of vehicles, vehicle IDs, driver profiles and behavior patterns, etc.)



Future Traffic Management
("Google-like" view)

- Sensors
  - Pre-installed onboard or smartphone, video cameras
  - Crowd-sourced + tagged humans
- Actuators
  - Automatic control of autonomous vehicles
  - Biopulses
- Communications
  - Vehicular networks, WiFi, celular (fixed and wireless or celular networks)
- Control
  - We will do it



Future Traffic Management

(“Google-like” view)