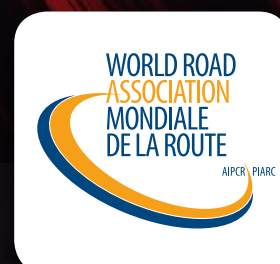


# COOPERATIVE VEHICLE HIGHWAY SYSTEMS

Technical Committee 2.1 *Road Network Operations*  
World Road Association



# STATEMENTS

*The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.*

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*World Road Association (PIARC)  
Tour Pascal B - 19<sup>e</sup> étage  
92055 La Défense cedex, FRANCE*

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# AUTHORS/ACKNOWLEDGMENTS

This report has been prepared by *Work Group 2.1.3* of the Technical Committee 2.1 *Road Network Operations*.

Main author is:

- Jacques Ehrlich (FR)

Contributors are:

- Jeremy Millar (AU)
- Satoshi Ueda (JP)

Reviewers are:

- Alexis Bacelar (FR)
- Sylvain Belloche (FR)
- Martial Chevreuil (FR)
- Valentina Galasso (IT)
- Richard Harris (UK)
- Jeremy Millar (AU)
- Ian Patey (UK)
- Serge Pelissier (FR)

Translators :

- Sylvain Belloche (FR)
- Jacques Ehrlich (FR)

The Work Group 2.1.3 was chaired by Jacques Ehrlich (FR).

## COOPERATIVE VEHICLE HIGHWAY SYSTEMS

We can consider that the most recent developments of the vehicles are:

- the massive deployment of sensors, actuators and computers allowing to develop a kind of “*vehicle and transport system intelligence*”;
- their ability to communicate among themselves or with the infrastructure through the concept of cooperative systems;
- the introduction of electric motor combined or not with thermal motor: hybrid vehicles or full electric vehicles.

All these changes are beneficial for both the car manufacturers, cycling manufacturers, road networks operators and transport users (drivers or simple users).

This report attempts to describe the key issues and the latest advances around these important developments.

After an introduction to the main issues, the report is organized into three parts:

- **Topic 1:** Newest evolutions and innovative services based on cooperative systems: in this section is described system architecture and the main technical principles in relation to the most recent standards. New services provided by these systems are also briefly described.
- **Topic 2:** Emergence of electric vehicles: in this chapter we describe the main technologies (vehicle architecture, batteries) and their limitation. The question of smart grid as the required road equipment to fulfil the user recharging demand in urban are also addressed. Finally, we attempt to provide some answer to question on link between road safety and electric vehicles. This section also briefly discusses the emergence and electric bicycles and the potential benefits to the transport system.
- **Topic 3:** Network monitoring based on cooperative system: the floating car data concept: in this section we introduce the concept of probe vehicle and we describe its main contribution to road network operation. Innovative application already deployed or that could be deployed in a near future are also proposed in this chapter.

Finally, this report concludes with a summary of best practices and recommendations.



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## 1. INTRODUCTION

The emergence of information and communication technology has had a profound impact on vehicle and roadside systems.

On the vehicle side, embedded electronics account for more than 30% of the cost of a vehicle. They are equipped with a multitude of sensors and actuators and various computers (ECU) and internal digital networks for interconnection (CAN bus, FlexRay bus, etc.). Over the last 20 years, the introduction of these technologies has stimulated a boom of information and driving assistance systems with the main objective to improve road safety, driving comfort, but also for the car manufacturer to remain competitive within a highly competitive market. These systems have the potential to also significantly improve road efficiency and access.

On the infrastructure side, roads are equipped with many detection and information devices allowing road operators to gain knowledge of the network condition and to provide information, recommendations and instructions to users and operators. The aim is to improve road safety (information on accidents or incidents), road mobility (information on congestion, speed recommendations and route guidance) to promote multi-modality and to facilitate commercial transactions (electronic toll, e-commerce) etc.

However, the development and implementation of these technologies has been undertaken independently. Although mediums and protocols for information exchange between vehicles have existed (RDS-TMC) for more than twenty years, their technological limitations imposed fairly strict limits on the development of innovative applications.

The concept of cooperative systems was introduced around 10 years ago (2000s), where vehicles, infrastructure, users, and road operators can interact using telecommunications. This has been made possible by the emergence of new communication technologies (e.g. 3G, 4G, DSRC, WAVE etc) and GPS deployment.

### 1.1 MAIN ISSUES

#### 1.1.1 Road safety improvement

In the field of road safety, the key word is anticipation. Advanced driving assistance systems (ADAS) and accident prevention systems are designed to mitigate driver error (responsible for over 80% of accidents).

These errors occur due to factors such as poor perception, poor decision-making and inappropriate driver action. Errors occur most often during one of the following steps:

1. an environmental detection step in which the driver makes use of perceptive capacities;
2. an analysis and decision making step based on the experience and cognitive capacities of the driver and finally;
3. an action step during which the driver operates vehicle controls (brake and accelerator pedals, steering wheel) to control its trajectory in order to follow the decision taken during the previous steps.

Driving assistance systems attempt to overcome the various failures that can occur during these different steps. There is a greater probability of avoiding an accident when the driving assistance intervention occurs early in the sequence of actions in the perception step.

Before the introduction of cooperative systems vehicle perception capacity was limited by the range of its perception sensors including cameras, radar and lidar, namely a few hundred meters.

Cooperative systems can extend this range, therefore offering a greater ability to anticipate and consequently a greater opportunity of avoiding the accident. This range will also extend to other road users such as cyclists and pedestrians further increasing the road safety benefits.

### 1.1.2 Mobility improvement

Improving mobility requires an accurate and real-time knowledge of the network. The state of the network is mainly described by the speed, traffic flow and journey times on the various roads (or road segments).

Before the 2000s, the characterization of network state was mainly provided by sensors on infrastructure (on the road side on under pavement), mainly induction loops for speed flow and congestion, and cameras for incident detection and verification.

Such equipment requires significant investment on infrastructure and ongoing operational and maintenance costs. For example, the Paris ring road and the majority of motorways in England have stations for measuring speed and flows every 500 m. A number of Freeways (Motorways) in Australia have vehicle detection stations (studs) for the same function.

The emergence of cooperative systems has introduced the concept of “*probe vehicles*”. Many modern vehicles have sensors which measure their speed and their own travel time on a road segment. This data can be transmitted to a traffic management centre or traffic information providers where they are aggregated and processed to provide information such as travel time or a map of congestion, accidents and incidents

### 1.1.3 Road network operation improvement

Network operation encompasses many aspects. These include the optimization of use for the avoidance and minimization of congestion, and the viability of maintenance which consists in the early detection of any deterioration of its state (ruts, areas of temporary loss of adhesion, poor visibility condition etc).

Classically, the road operator makes decisions based on knowledge of the network state (see [section 1.1.2](#)). Countermeasures may lead to interventions or maintenance teams or recommendations to drivers. Recommendations to users are typically displayed on variable message signs (VMS).

In the near future, the introduction of cooperative systems and probe vehicles will enable the use of vehicles as mobile sensors to detect road damages, adverse environmental conditions etc. For example, when a majority of vehicles trigger their ESP<sup>1</sup> on a curve, this is a sign of speed that is

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<sup>1</sup> ESP = Electronic Stability Program: a driving assistance system to prevent loss of trajectory control.

inappropriate to the infrastructure characteristics; this could be due to a number of factors including: temporary or permanent degradation of road surface adhesion or an inappropriate speed limit etc. Cooperative systems will enable road operators to provide recommendations to drivers via messages directly displayed within vehicles or on Smartphones applications instead of the traditional variable message sign located on infrastructure. This is the principle of the so-called “*in-vehicle signage*”.

## 1.2 TECHNOLOGICAL TARGETS

### 1.2.1 Non cooperative vehicles

First generation of driving assistance system is based only on the intrinsic capabilities of vehicles ie. their own sensors excluding any usage of infrastructure or neighbouring vehicles sensors.

Vehicles are equipped with two kinds of sensor: proprioceptive, exteroceptive. Proprioceptive sensors are used to measure the state of the vehicle itself. These are odometers (distance measurement), gyroscopes (yaw rate measurement), accelerometers, or complete inertial navigation system (INS). Proprioceptive sensors are used to calculate the vehicle dynamics including the detection limit state before loss of control. For example, the ESP system uses odometers on each wheel, a gyros and a sensor for measuring steering wheel angle.

Exteroceptive sensors are based on measurements made on the environment (distance to the vehicle ahead, distance to roadside line crossing etc.). These are onboard cameras, radar and laser scanners (LIDAR). As mentioned above the range of these sensors is limited to a few hundred meters limiting the ability to anticipate. Emergency braking driving assistance is an example of a system based on a camera that detects and estimates the time to collision (TTC) to the vehicle ahead. Autonomous (or adaptive) cruise control (ACC) is another example of driving assistance based on exteroceptive sensors, which aims to maintain a safe distance to the vehicle ahead.

### 1.2.2 Cooperative vehicles vs. autonomous vehicles

There is sometimes confusion between cooperatives vehicles and autonomous vehicles. Cooperatives vehicles refer to vehicles that have the capability to communicate with other mobiles or infrastructures entities such as other vehicles, motorcycles, bicycles, pedestrians, traffic management centres, road side units etc.

Autonomous vehicles refer to vehicles that have the capability to drive without active intervention from a driver or with only a partial driver intervention<sup>2</sup>.

Cooperative vehicles and autonomous vehicles are completely different concepts. However, depending on the automation level, autonomous vehicles will partially rely on cooperatives vehicles due to the fact that in some circumstances or manoeuvres such as platooning, intersection crossing, overtaking etc. autonomous vehicles will require information from other cooperative entities.

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<sup>2</sup> There is currently a consensus to define different levels of automation from non-automation (level 0) to Full Driving Automation (level 4).

In the sequel, we address only the issue of cooperative systems (including vehicles) excluding autonomous vehicles.

### 1.2.3 Cooperative vehicles

Cooperative systems are systems in which different entities exchange information by means of wired or wireless<sup>3</sup>. These entities are mainly: vehicles, roadside equipment, traffic management centres and onboard or outboard nomadic systems or interactive kiosk terminals. An early (but effective) form of cooperative system is a one-way information exchange (from management centres to vehicles) carried by the RDS-TMC radio. It informs drivers about travel times, congestion and accidents.

In their advanced form (but not yet marketed) cooperative systems allow bidirectional communication between vehicles (in a range of about 500m), between vehicles and roadside beacons (RSU), between RSU and traffic management centre. Cooperative systems support both the downlink from management centres to vehicles and the uplink vehicles and vehicles to the management centres. There is also the emergence of bidirectional communications between vehicles and smart phone systems. This will have the benefit of vehicles communicating with other road users such as pedestrians and cyclists.

The benefits of cooperative systems were partly discussed in § 1.1. They allow better anticipation of road hazards and also more precise and real-time knowledge of the infrastructure state.

A very good example of the ability to anticipate provided by cooperative systems is the detection of vehicle obstacles (IHW). A major cause of accidents on highways is collision with a stationary vehicle on the road. Initially, there may be a minor incident (failure) that turns into a serious accident involving several vehicles. The reason is that the vehicles upstream are not aware of the presence of a vehicle obstacle and do not have time to slow down or to avoid it. Cooperative systems can provide the ability to avoid such accidents. The stationary vehicle emits a warning message to vehicles located upstream in a range of 500m to 1km. Then, drivers are alerted and can slow down and avoid the incident. Thus, cooperative systems can extend the perceptive capacity of vehicles beyond the range of exteroceptive sensors.

It should be mentioned that IHW can also be implemented using infrastructure equipment: as an example the MIDAS (Motorway Incident Detection and Automatic Signalling) used in the UK for c. 20 years provides this capability using inductive loops and matrix signals.

The GPS receiver (see § 4.4.1.5), which plays a major role in these systems can be regarded as a “*cooperative sensor*” which enables the calculation and determination of position.

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<sup>3</sup> Wired communication between traffic management centre and wireless communication between vehicles or vehicles and Road Side Unit.

## 2. NEWEST EVOLUTIONS AND INNOVATIVE SERVICES BASED ON COOPERATIVE SYSTEMS

Cooperative systems are the subject of significant research and development worldwide. At European level, the DRIVE-C2X project involving various initiatives of European countries demonstrates the use of the latest technology and the most innovative applications.

The American Connected Vehicle Safety Pilot is a research program that demonstrates the readiness of DSRC-based connected vehicle safety applications for nationwide deployment. The vision of the Connected Vehicle Safety Pilot program is to test connected vehicle safety applications in real-world driving scenarios in order to determine their effectiveness at reducing crashes and to ensure that the devices are safe and do not unnecessarily distract motorists or cause unintended consequences.

In Australia, Austroads have established a Cooperative ITS Steering Committee and appointed a Project Director for the Austroads' Cooperative ITS Project. There is a significant body of work being undertaken through these channels to ensure an appropriate policy and regulatory framework is in place to enable successful deployment of C-ITS in both Australia and New Zealand.

Additionally, the Intelematics Company have developed the Toyota Connected Vehicle program. The state of the art platform provides motorists with access to a range of traveller information and assistance services through an interactive dashboard and supporting web, Smartphone and agents assisted interface. Innovative architecture allows upgrades and entirely new applications to be seamlessly uploaded to the vehicle head unit, allowing programs to evolve and adapt as the market for connected vehicle services matures.

System architecture and technologies have now reached a sufficient level of maturity to allow the development of standards for interoperability and to provide the level of stability required for deployment to be considered.

### 2.1 SYSTEM ARCHITECTURE (FOR COOPERATIVE SYSTEMS)

The overall architecture is based on different entities: traffic management centres, - roadside unit (RSU), vehicles, nomadic systems (Smartphones) and interactive kiosk terminals.

This architecture can offer different data paths to convey information from a source to a destination. The path followed depends on the particular nature of the communicating entities, the maximum latency time expected, the data throughput and the range (see § 1.2.2). For example, to transmit itinerary or speed recommendations from traffic management centre to vehicle, information will follow a path from the centre to a road side unit, and then from a road side unit to the vehicles that are located in its transmission range. Another simpler link consists in transmitting the information directly from TMC to Smartphones.

Conversely a stationary vehicle can transmit a warning message to the vehicles upstream thanks to direct vehicle to vehicle communication and simultaneously send a message to a traffic management centre by the relay of a road side unit located in its transmission range or directly from vehicle to TMC by means of mobile phone sending an SMS (eCall). Then the traffic

management centre will bring assistance to the motorists involved in the incident and simultaneously disseminate this information to vehicles located far upstream of the incident (tens of km) thanks to a network of road side units located along the road or directly from TMC to Smartphones.

## 2.2 KEY TECHNOLOGIES

Key technologies are the essential technologies for the realization of cooperative systems. Among them, the following technologies may be mentioned: communication medias and protocols, GPS technologies, architecture of each communicating entity (or ITS station), local dynamic map and technologies to ensure communication security and privacy and end-user application.

### 2.2.1 Medias, protocols and messages management

These key technologies aim to transmit messages between the communicating entities involved into cooperative systems: vehicles, road side unit, centres and personal nomadic devices (e.g. Smartphone).

Various communication medias are used for exchanges between entities:

- between vehicles: short range communication “*WAVE*<sup>4</sup>” or IEEE 802.11p;
- between vehicles and RSU: same as above;
- between UBR and center management: technologies based on cell phones in the third and fourth generation (3G and 4G).

When using these communication media, data exchanges rely on internet Ipv6 protocols including that which provides several routing capabilities: from point to point (unicast), broadcasting to groups of vehicles (multicast) that are located in the same vicinity (Geocast). This protocol supports multihop that is to say that a vehicle can operate as a relay to transmit information to other vehicles and thus potentially increase the transmission range.

But the existence of media and protocols is not in itself sufficient. The data itself must be structured and harmonized (concept of data dictionary) following standards depending on the application. For example, data exchange between traffic management centres and road side unit is based on the DATEX2 standard. Other messaging systems are used such as CAM, DENM, SPAT, EVSCN, RIM [1] to encode information dedicated respectively to vehicle state characterization, road events, traffic lights status, electric charging station status and recommended itinerary.

### 2.2.2 Communicating entity architecture (ITS station)

The key technologies are the electronic devices, namely the ITS stations, that support media, protocol and messaging described in the previous section.

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<sup>4</sup> WAVE = wireless access in vehicular environments

ITS stations are communicating platforms embedded in vehicles or road side units or implemented in management centres or nomadic systems. Each communicating entity (or ITS station) is based on an architecture consisting of a number of functional building blocks or layers (below is described the European architecture only):

- the media access layer provides the interfaces to the various communication channels (WAVE, 3G, 4G, WIFI etc.);
- the protocol layer provides support for IPv4 and IPv6 protocols and supports various transmission modes (unicast, multicast, Geocast);
- the facility layer provides a common set of services required by the application layer, such as location-based services, access to vehicle internal digital network (CAN bus), messaging services, local dynamic map, digital mapping services (including map matching), access user interface (HMI<sup>5</sup>);
- the application layer supports services for end-users whether they are drivers, passengers, road operators etc.;
- in addition it should be mentioned the management layer which control the overall operation of the ITS station and security and privacy layer [1].

Physically an ITS station consists of several subsystems: an ECU<sup>6</sup> (a microcomputer) that supports application software and facilities, a modem that supports media access, protocols, management, security and privacy layers and finally a user interface that can be either located directly on the dashboard of the vehicle or on a nomadic device (tablets, Smartphones).

### 2.2.3 Local dynamic map and GPS localization

This key technology aims to locate on the road network all communicating entities and events whether they are static or moving.

Dynamic local map (LDM) is a central concept in cooperative systems. It is a database of information, objects or events within the environment of each ITS station. Information is located on a digital map. Conceptually we can consider the LDM as a four layer GIS. The higher we go along the layer, the more evolving are the referenced event. The lowest layer (layer 1) contains information stable over time (buildings, road layout and natural obstacles). In contrast, at the upper level (layer 4) we will find short lifetime events detected by neighbour vehicles (mobile obstacles, traffic jams, traffic lights etc). Accidents and incidents are referenced at layer 3. The LDM is updated continuously by the data received from neighbouring vehicles or roadside units and its coverage area changes with the vehicle movement.

The driving assistance systems applications may at any time get the information they need from the LDM. In addition, the LDM provides a notification mechanism: thus, an application can “*subscribe*” to a specific event. In case of occurrence of this event, the application will be automatically notified and will handle the event in a very short time. Further information on the LDM are provided in the case study [1].

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<sup>5</sup> HMI=human-machine interface

<sup>6</sup> ECU = electronic control unit



### 2.2.4 Technologies for security and privacy

Security is characterized by the following issues:

- integrity : during transmission, data should not be altered accidentally or voluntarily;
- confidentiality: the message should be readable by the authorized recipients only;
- authentication: verifying the identity of an entity such as to allow access of the entity to the system;
- non-repudiation: it is the guarantee that no entity (sender or recipient) can deny a given transaction;
- privacy is an important factor for public acceptance and successful deployment of cooperative system. It means that the driver is able to keep and control the information related to the vehicle (e.g. identity of the driver, the driving behavior, the past and present location of the vehicle etc.) from other parties. Privacy is based on usage of pseudonyms that cannot be linked to long term ID user or other pseudonyms. On vehicle demand, pseudonyms are delivered by agreed authorities.

More information can be found in the European PRESERVE project (<http://www.preserve-project.eu/deliverables>).

## 2.3 STAKEHOLDERS AND VALUE CHAIN

Value chain description is a very complex task as this chain depends on the one hand on the organization at the level of each State and on the other hand on the services that are provided to the end-user. The European project SAFESPPOT and more specifically the sub-project BLADE has provided a description of stakeholder organization under the form of interaction diagram<sup>7</sup> [2]. Therefore, we limit our discussion to quote here the main stakeholders of cooperative systems without specifying their role and position in the value chain. These are the national and supranational (EU) public authorities, the central bodies, the road operators, the car makers, the map makers, the vehicles and infrastructure equipment suppliers (HS & SW), the certifier, the content provider the value added service provider and the telecom operator. A detailed description of these stakeholders and their role can be found in [3].

## 2.4 INNOVATIVE SERVICES (USE CASES)

Here, the goal is not to provide an exhaustive list of applications based on cooperative systems but rather to describe some use cases that seem the most innovative and promising to improve significantly road safety, mobility and road network operation.

The following descriptions come partially from SCOREF project specification [4].

### 2.4.1 Road safety services

**Prevention of collision on vehicles stopped on the road:** the objective is to alert vehicles located upstream of slow or stopped vehicle such as to avoid a collision. To achieve this goal it is required that the recipient vehicles can estimate the longitudinal alignment with the stopped

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<sup>7</sup> B&SM = Business and Service Model Road Side Unit.



vehicle. Therefore, accurate positioning on its lane is essential. If the collision risk is proven, then an alert is provided to the driver such as he can react accordingly; conversely a message is provided to the driver under the form of simple traffic information to stimulate his driving wariness.

**Prevention of collision on wrong way vehicles:** The goal is to alert drivers of vehicles located upstream of a wrong way vehicle to avoid a frontal collision. The wrong-direction can be detected by the vehicle itself or by the roadside equipment or other vehicles (driving in the right direction). In any cases an alert is sent to the wrong way driver to encourage him to deal with this situation and to the vehicles that could encounter him such as their drivers can react accordingly.

**Prevention of collision of vehicle with cyclists or pedestrian:** The goal is to alert drivers of vehicles to the presence of pedestrian or cyclists when turning, approaching or passing to avoid a collision. This is achieved by a nomadic device (smart phone) alerting the drivers via the in vehicle systems of the pedestrian or cyclists location so they can react in time to stop, slow down or allow adequate passing width.

#### 2.4.2 Mobility services

**Traffic information and recommended route:** The objective is to provide information on a recommended route to vehicles via the transmission of a specific message (RIM = Recommended Itinerary Message). The message emitted by a traffic management centre to a roadside unit (RSU) contains the traffic information and a list of waypoints of the detour to follow. Then the UBR broadcasts this information to vehicles. On reception vehicles verify the relevance of information in relation to their own position, their route and final destination, and then display on the vehicle's HMI the route to follow. In a more advanced form, the recommendations can be customized for each driver and take into account travel time criteria, kilometric additional cost, fuel consumption and CO<sub>2</sub> emissions.

**Car sharing:** A customer expresses the need for a mobility service. He records his request using an application on a Smartphone, for example. The customer has previously given its mobility profile (eg. doesn't have a vehicle, accepts short carpooling, taxi and public transit offers). Then he receives available offer, information on potential hazards on public transport and possibly carpooling or taxi offer. Roadside units turn the demand for mobility to vehicles nearby. A driver becomes aware of the client's request on his vehicle's HMI. He can satisfy customer demand and makes him an offer. After user-validation and verification by a central server, client and driver terminals pass through a conductor accompaniment mode to meet demand / supply. The cost of the trip is shared; the driver drops the client to the requested location. After completion of the journey, client and driver can rate each other.

**Mobility as a service:** Twenty-three key organisations in Finland (<http://maas.fi/>) have partnered to cooperate in the establishment of the first Mobility-as-a-Service operator in traffic. Mobility as a Service (MaaS) refers to combining all forms of personal transport together into seamless trip chains, with bookings and payments managed collectively for all legs of the trip. The term Mobility as a Service (MaaS) stands for buying mobility services based on consumer needs instead of buying the means of mobility.

### 2.4.3 Network operation services

See *section 4*: “Network monitoring based on cooperative system: the floating car data concept.”

### 2.4.4 Day-1 use cases

Day-1 uses case refers to a set of twenty ITS applications that have been prioritized for deployment by the US DOT [5] and which are summarized on the *table* below.

Day-1 Use Case	
1 Emergency Brake Warning	11 Electronic Payment: Toll Roads
2 Traffic Signal Violation Warning	12 Traveller Information
3 Stop Sign Violation Warning	13 Ramp Metering
4 Curve Speed Warning	14 Signal Timing Optimization
5 Display Local Signage	15 Pothole Detection
6 Present OEM Off-Board Navigation	16 Winter Maintenance
7 Present OEM Reroute Information	17 Corridor Management Planning Assistance
8 Present Traffic Information	18 Corridor Management Load Balancing
9 Electronic Payments: Parking / General	19 Weather Information: Traveller Notification
10 Electronic Payments: Gasol	20 Weather Information: Improved Forecasting

The Day-1 applications were selected based on several factors including high-priority safety, mobility, and commerce needs; ability to be implemented during the timeframe of initial Vehicle Infrastructure Integration (VII) deployment; compatibility with low penetration of VII-equipped vehicles; and ability to test the system and inform decision making.

## 3. EMERGENCE OF ELECTRIC VEHICLES

As reduced oil consumption, environmental protection and sustainable development have become major challenges to our modern societies, whether they be developed or emerging, new vehicle engine designs, especially electric vehicles, offer considerable promise.

The emergence of the electric vehicle has generated many concerns in both the technical realm (state of technology for the vehicle, batteries and charging infrastructure, etc.) and the non-technical realm (environmental footprint, economic model, profitability, etc.).

Given the considerable importance of this topic and the sometimes heated debate it raises, the corresponding literature is quite extensive. With this backdrop, our objective herein is twofold:

1. produce an incisive overview of the topic by referring, as needed, interested readers to bibliographic materials that offer more detail;
2. attempt to determine the potential consequences of implementing electric vehicles for the topic under study, namely: managing road networks and the connected vehicle.

### 3.1 GLOSSARY/DEFINITIONS

Among the electric vehicles now on the market, a distinction must be drawn between hybrid electric vehicles (HEV) on the one hand and pure electric vehicles (EV) on the other.

Hybrid vehicles are characterized by their hybridization rate, i.e. the percentages of functionalities provided by electricity and thermal sources, as well as by the vehicle configuration, which relates to the coupling mechanisms inherent in the two engine types.

### 3.1.1 Level of hybridization

- **Micro-hybrid:** Use of a starter-alternator that allows shutting off the heat engine while idling and at very low speeds (less than 10 km/h);
- **Mid-hybrid:** A system very close to that of the micro-hybrid yet with the additional features of braking energy recovery and an acceleration enhancement;
- **Full-hybrid:** In addition to the functions mentioned above, the electric motor is capable of propelling the vehicle over a certain distance.

### 3.1.2 Hybrid vehicle configuration

- **Parallel hybrid:** process that assists heat engine operations by superimposing in the design an electric motor of variable power (10 to 50 kW), drawing its energy from a traction battery recharged during the deceleration phases. Examples include the Honda Insight;
- **series hybrid:** the lone traction engine is electric; it is fed through a battery recharged by a heat engine coupled to an alternator + rectifier (use of an electric generating set for the sake of simplification). Via Motors' VTrux pick-up trucks operate based on this principle;
- **series-parallel hybrid:** according to Wikipedia, this configuration is: "*a complex combination of both the series and parallel solutions. Joint motion of the heat and electric motors relies on considerable overlap with an epicyclic gear train that enables the motors to rotate at different speeds. For example, the Toyota Prius, Yaris HSD and Auris HSD, Nissan Altima Hybrid, Lexus Rx400h, GS450h and LS600h have all been designed with variants of this operating principle (i.e. the Hybrid Synergy Drive system).*";
- **plug-in / rechargeable hybrid (PHEV):** these vehicles, although part of the hybrid category, are rechargeable and thus come equipped with charging capacity and a charger. The configuration may be in series or parallel. PHEV are produced either via an after-sale transformation of HEV vehicles or as an initial assembly, as illustrated by: the BYD F3DM (China), Chevrolet Volt (USA) and its European Opel Volt Ampera version, the Toyota Prius Plug-in Hybrid, and Volvo's V60 Plug-in Hybrid.

### 3.1.3 Electric vehicle (EV)

(Pure) electric vehicles are fitted with an electric motor fed by onboard batteries, which are mainly recharged by connecting the vehicle to the electricity grid (on the household power supply or else at a public charging station). Examples include: BMW i3, Chevrolet Spark EV, Fiat 500e, Ford Focus Electric, Mercedes B-Class Electric Drive, Nissan LEAF, Toyota RAV4 EV, Citroën C-Zero, Renault Kangoo ZE, and Zoe.

### 3.1.4 Power and Energy

**Electric Power:** The unit of production is expressed in W (watts), kW or MW, etc. As a reminder, electric power is measured as the product:  $P=U.I$

and is not to be confused with:

**Electrical energy:** whose units are expressed in Wh, kWh, etc. Electrical energy is given by the formula:  $W=U.I.t=P.t$

## 3.2 CURRENT CONDITIONS AND TRENDS IN THE ELECTRIC VEHICLE MARKET

(Source: Breezcar, <http://www.breezcar.com>)

*”Every year, the worldwide electric vehicle market doubles in size. As 2014 got underway, nearly 405,000 models of 100% electric vehicles and rechargeable hybrids were in circulation in the busiest market environments, led by the United States, Japan and China.*

*The study released end of March by the Baden-Württemberg Solar Energy and Hydrogen Research Center (Zentrum für Sonnenergie- und Wasserstoff Forschung Baden-Württemberg, or ZSW) reported new figures on growth of the global electric vehicle market. This study also indicated the 7 most dynamic national markets (figures published in January 2014).”*

COUNTRY	# VEHICLES IN CIRCULATION
USA	174 000
Japan	68 000
China	45 000
France	40 000
Netherlands	30 000
Norway	19 000
Germany	17 500

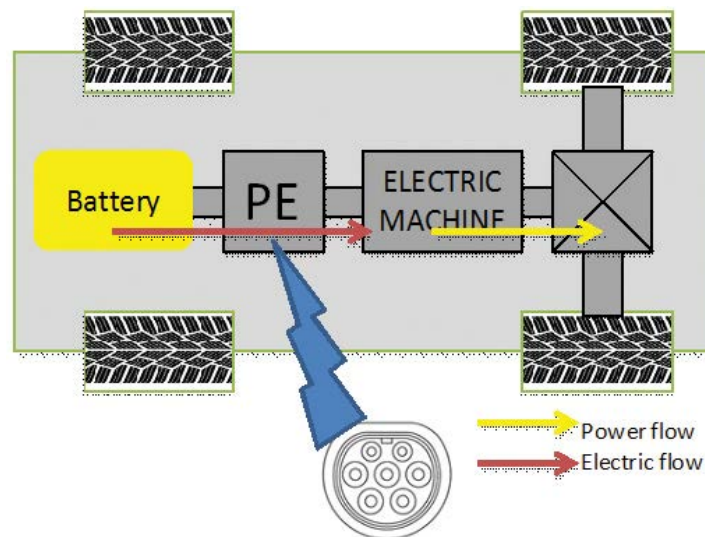
Considerable caution is needed however when forecasting market trends and simplistic linear extrapolations must be avoided. The French market has shown relative stagnation or even slight regression during 2014 despite a fairly generous purchase subsidy (€6,300 bonus). The primary obstacles appear to be: heavy, expensive and still rather inefficient batteries (topping out at 150 km of autonomy), an underdeveloped charging infrastructure (5,600 stations in France), and hindrances in standardizing charging outlets. Amid this context, France’s “pure electric” percentage in 2013 stood at 23% (13,954 vehicles sold) vs. 77% hybrids (46,785 sold). The rechargeable hybrid market is in its infancy and for the time being lacks a reliable source given the number of sales, yet this segment only represents a very small percentage of the total electric vehicle fleet.

### 3.3 KEY TECHNOLOGIES

#### 3.3.1 Vehicles<sup>8</sup>

##### 3.3.1.1 Pure electric vehicles (EV)

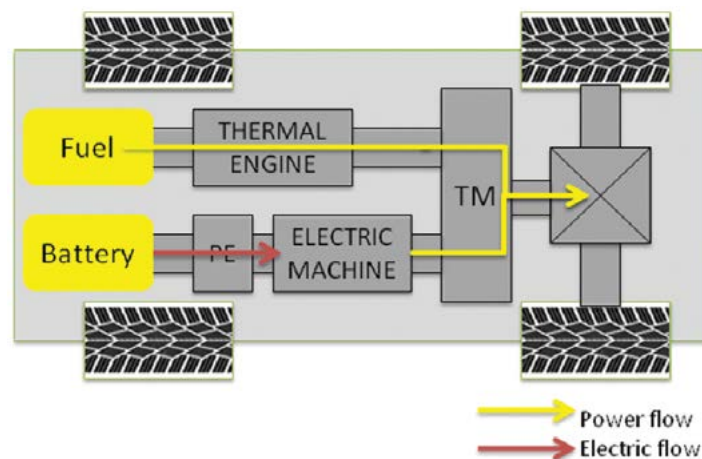
*Illustration 1* describes the configuration of a pure electric vehicle. Engine torque is generated by the electric motor on its own, which in turn is supplied by a rechargeable battery that's either plugged into the grid or powered by braking energy (i.e. regenerative braking).



*Illustration 1 - Pure electric vehicle (EV) – PE =Power Electronics*

##### 3.3.1.2 Series hybrid (series HEV)

*Illustration 2* displays the configuration of a series hybrid vehicle. According to this type of vehicle, propulsion is exclusively provided by an electric motor drawing its energy from a battery charged either by a generator hooked up to an internal combustion engine or by recovering braking energy (i.e. regenerative braking). Let's note that a vehicle running on a fuel cell matches this configuration, with the fuel cell replacing the electric generating set. It should be noted that on this illustration “Thermal generator” is a thermal engine coupled with an electric generator.

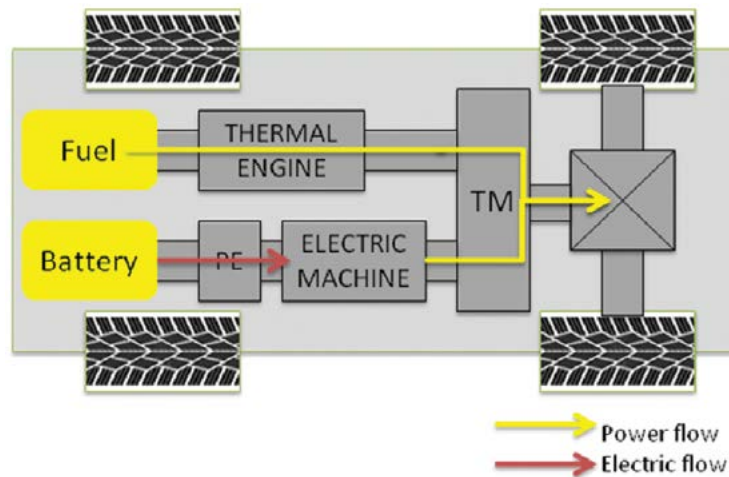


*Illustration 2 - - Hybrid Serie Vehicle architecture (serie HEV), TM = Torque Management*

<sup>8</sup> *Illustration 1, illustration 2, illustration 3, illustration 4* modified from [14] Road Side Unit.

### 3.3.1.3 Parallel hybrid (parallel HEV)

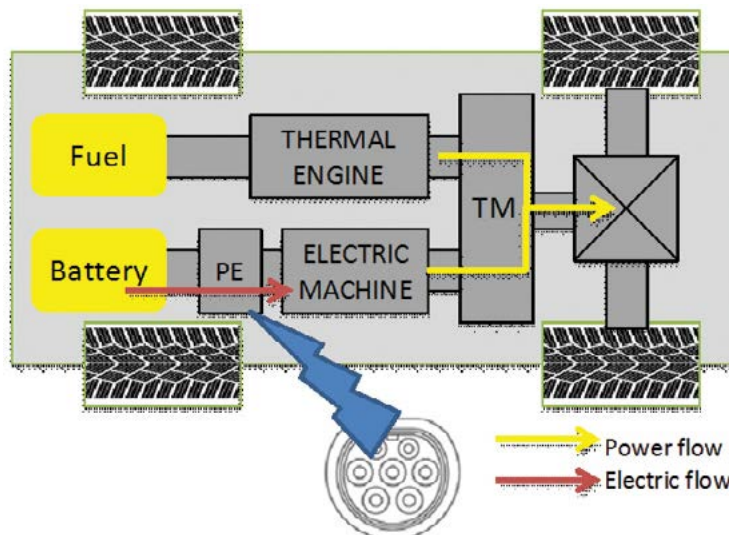
*Illustration 3* shows the configuration of a parallel hybrid vehicle. By means of mechanical coupling, the torque transmitted to the wheels consists of a combination of individual torques stemming from the electric motor and heat engine. Moreover, the battery is recharged by both the heat engine and the regenerative braking circuit.



*Illustration 3 - Hybrid-parallel vehicle (parallel HEV)*

### 3.3.1.4 Rechargeable hybrid (PHEV)

A rechargeable hybrid vehicle operates like a regular hybrid yet also offers the possibility for its batteries to be recharged by connection to the electricity grid (*illustration 4*).



*Illustration 4 - Plug-in Hybrid-parallel Electric Vehicle (PHEV parallel)*



### 3.3.2 Batteries

An important characteristic of electric vehicle batteries is their specific energy; expressed in Wh/kg, this quantity of energy is capable of being stored by the battery as a function of its mass. Other criteria may be taken into account in order to compare various battery technologies; such criteria include: life cycle, specific power (in W/kg), cost and ease of recycling, behaviour under extreme temperatures, and voltage per element.

*Table 1* lists the comparative characteristics of a selection of battery technologies.

Battery type	Specific Energy (Wh/kg)	Voltage (V)	Peak power (W/kg)	Time life (# of discharge)	Self discharge (% per month)
Lead Acid	30-50	2	700 <sup>9</sup>	400-800	5
Nickel-Metal Hydride (Ni-MH)	60-110	1,2	900	800-1000	>30
Nickel-Cadmium (NI-Cd)	45-80	1,2	1000	1500-2000	>20
Lithium-Ion (Li-Ion)	90-180	2,7-4	1500-5000	500-1000	2
Sodium metal Chloride (Na-NiCl)	120	2,6	200	800	10 % per day

*Table 1 - Batteries comparison (modified from Wikipedia<sup>10</sup>)*

The Li-ion technology is the most promising available today; it features a high specific energy, good performance at high temperature, a low self-discharge rate and a nominal voltage per cell three times greater than that of most other technologies, which serves to reduce the number of cells required to produce high voltages. Nonetheless, this technology carries a disadvantage in terms of safety, as witnessed by the need for example of an electronic monitoring device to control the voltage of each battery cell, with several hundred cells potentially being involved.

### 3.3.3 Charging systems

#### 3.3.3.1 Type of charge and average recharging time

Three types of charge can be distinguished: normal, accelerated and fast. These require charging powers of 3, 24 and 43 kW, respectively.

The recharging time depends on both battery capacity and charging power.

For a battery with an average capacity of 20 kWh, which offers autonomy on the order of 120-150 km, 6 to 8 hours would be necessary for a recharge at 3 kW, 1 to 2 hours for a recharge at 24 kW, and 20 to 30 minutes at 43 kW.

#### 3.3.3.2 Charging mode

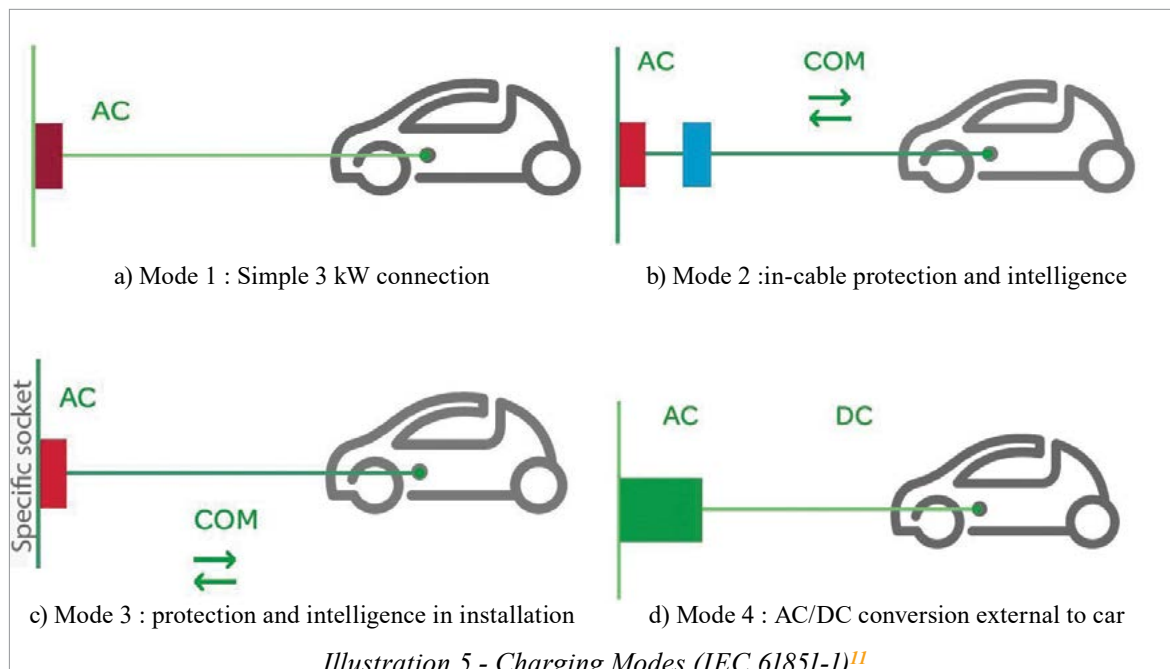
Four charging modes are available (in Europe):

<sup>9</sup> In discharge only

<sup>10</sup> [http://fr.wikipedia.org/wiki/Accumulateur\\_%C3%A9lectrique](http://fr.wikipedia.org/wiki/Accumulateur_%C3%A9lectrique)

- according to Mode 1 (*illustration 5a*), the vehicle is simply connected to the electricity grid using a standardized 16A socket. Charging power is limited to 3 kW;
- Mode 2 (*illustration 5b*) closely resembles Mode 1 though with one difference: the cable contains a box to communicate with the recharge device that allows for “*intelligent*” charge management;
- in Mode 3 (*illustration 5c*), both the protection and intelligent charge management features have been integrated into the recharge device. This mode requires a special outlet and makes it possible to generate a charging power of up to 43 kW;
- Mode 4 (*illustration 5d*) immediately delivers a direct current and accommodates a continuous quick recharge at a power capable of reaching 50 kW.

It can already be projected that Mode 3 will be the one imposed in the future since it offers the best charge protection and optimization functionalities, especially when taking the operations of other electrical equipment into consideration.



<sup>11</sup> « Model,2,3,4 » par Schneider Electric — <http://www.schneider-electric.com/documents/product-services/en/product-launch/electric-vehicle/the-charging-infrastructure-essential-for-the-safety-of-people-and-equipment.pdf>. Sous licence Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons - <http://commons.wikimedia.org/wiki/File:Mode4.JPG#mediaviewer/File:Mode4.JPG>



Several types of outlets are available depending on the selected charging mode. For Modes 1 and 2, the standard 16A socket is specified. For Mode 3, three types of outlets exist, but ultimately the second type (see *illustration 6*) has been mandated as the standard across Europe: it is compatible with both single- and triple-phase power supplies, in handling currents of up to 70 A under 500 V.



*Illustration 6 - Type 2 Socket*

### 3.4 MAIN CHALLENGES

#### 3.4.1 EV consumption and impact

This section will examine the impacts from an energy standpoint. *Section 3.4.3* will assess impacts from the vantage point of power.

As indicated above, the complete recharge of a vehicle for 120-150 km of autonomy requires an energy quantity of approx. 20 to 25 kWh. On this basis, it is estimated that the energy needed per vehicle is on the order of 2 MWh/year. In France, if the year 2020 objective of 2 million EV is met, then the estimated energy required to recharge this fleet would equal 4 TWh, i.e. roughly 1% of all energy consumed (500 TWh).

However, even if EV autonomy is reduced, 90% of daily trips (primarily urban) are still observed to be shorter than 40 km, and moreover private passenger (i.e. non-professional) cars are idle more than 90% of the time.

This observation tends to favor slow charging at night, which in most cases turns the recharge step into a complementary charge consisting of recovering about  $\frac{1}{4}$  of the capacity consumed during the day and lasting less than 2 hours at night.

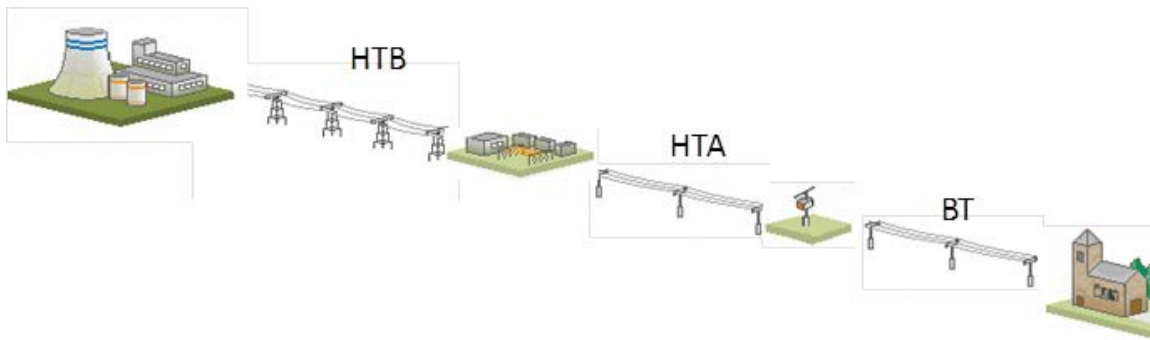
Accordingly, charging stations need to be installed not only on the street (basically to serve the needs of car-sharing systems) but also at individual residences (condo/apartment parking lots), though this widespread installation is not expected to happen anytime soon.

This basic design is obviously not automatically applicable to either utility vehicles or big rigs.

### 3.4.2 Electricity distribution network (today)

In France<sup>12</sup> (*illustration 7*), the electricity produced by power plants is first carried over long distances on high-voltage (HTB) lines managed by the RTE Electricity Transport Network; it is subsequently transformed into (HTA) voltage electricity (typically at 20,000 volts) to be transported by the distribution network managed by ERDF. This transformation process takes place at the station prior to transmission.

Once routed through the distribution network, the high-voltage (HTA) electricity directly supplies industrial clients. For other client categories, it is converted to low voltage (BT) at transformer stations prior to delivery.



*Illustration 7 - Electricity Delivery Network In France<sup>13</sup>*

A similar set-up is found in the United States. An EHV (Extra High Voltage) network for the long-distance transmission, an HV (High Voltage) network for distribution and an LV (Low Voltage) network for delivery to industrial uses, municipalities and rural areas.

<sup>12</sup> [http://www.erdf.fr/How\\_the\\_electricity\\_network\\_operates](http://www.erdf.fr/How_the_electricity_network_operates), [http://www.erdf.fr/fonctionnement\\_du\\_reseau](http://www.erdf.fr/fonctionnement_du_reseau)

<sup>13</sup> From [14]

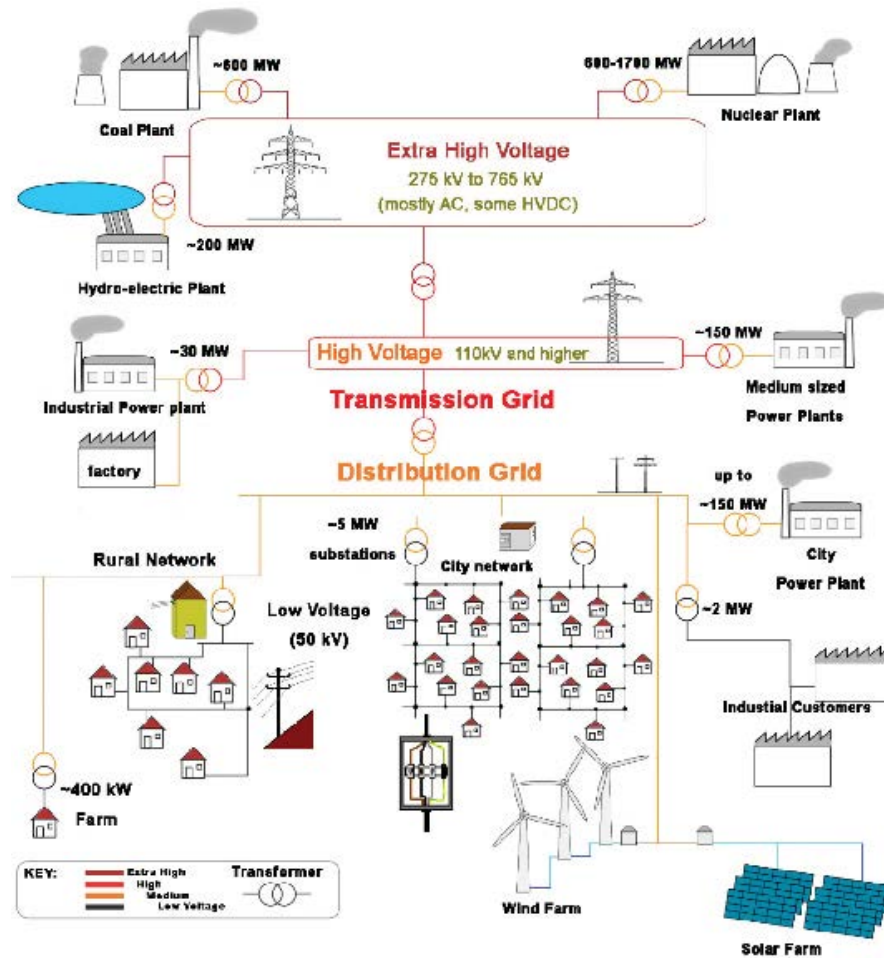


Illustration 8 - Electricity delivery network in USA<sup>14</sup>

### 3.4.3 Demand management

As indicated in [section 3.4.1](#) above, the energy required to charge all EVs in circulation by year 2020 has been estimated at approx. 4 TWh. Current studies show that if the recharge step is poorly managed, then electricity distributors might be faced with very high peak power demands. The focus here is no longer on energy (measured in Wh) but rather on power (units of W). France's total installed power capacity today amounts to some 100 GW.

The curve in [illustration 9](#) provides an example of daily winter consumption in France. A peak can be noticed at 7:00 pm, with power on the order of 85 GW. In the absence of intelligent charge management, the additional power needed for electric vehicles by year 2020 is estimated at 6 GW for the 2 million vehicles being slowly recharged (i.e. at 3 kW).

Even if the network has on the whole been correctly sized to accommodate this additional load, a more refined analysis would have to determine how this load is being divided from one locality to the next.

Under the hypothesis of a quick recharge at 22 kW, the additional 44 GW required would be well beyond the capacity of France's current network.

<sup>14</sup> From [16]

Managing consumption peaks constitutes the real challenge in designing smart infrastructure. While such management efforts are not specifically tied to the rollout of electric vehicles, still their emergence has no doubt contributed to accelerating policy guidelines and decisions in this field. The constant increase in consumption, coupled with the necessity of integrating new energy sources (e.g. wind, solar) into a “*systems*” approach, is also responsible for pushing development of an intelligent system for managing both production and consumption.

Generally speaking, public authorities much like energy distributors are seeking “*smoother*” consumption patterns (with or without electric vehicles) so as to avoid crisis situations tied to exceptional peak conditions (e.g. a harsh winter).

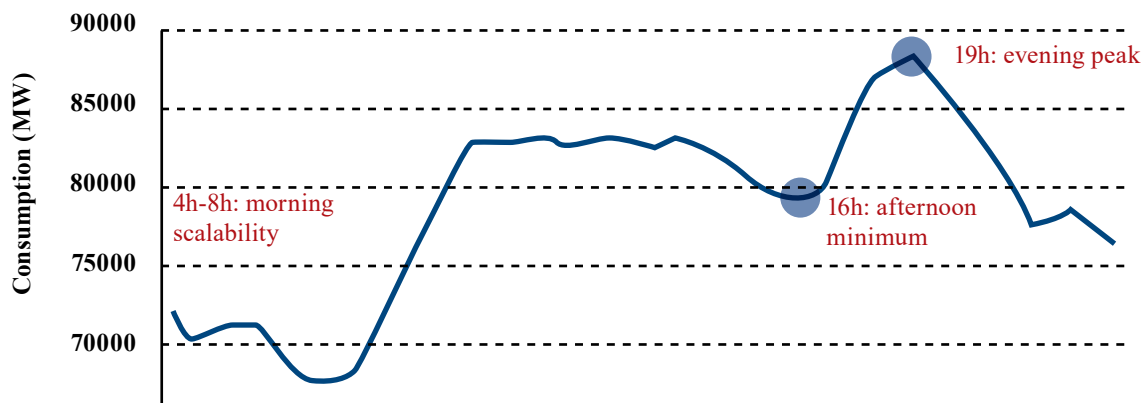


Illustration 9 – An Example Of Daily Power Consumption In Winter In France<sup>15</sup>

### 3.5 SMART GRID

The smart grid will be primarily intended to improve the way consumption is handled while at the same time incorporating renewable and decentralized means of energy production (photovoltaic and small wind turbines).

The goal consists of adjusting, in real time, electricity production and distribution (i.e. supply and demand) through prioritizing consumption needs (quantity and location) according to their urgency, for the purpose of: maximizing power plant efficiency; offsetting the need to constantly build new lines; minimizing line losses; optimizing the (random) insertion of decentralized production, especially of renewable sources; and mitigating or eliminating altogether problems related to the intermittence of certain sources (solar, wind, tidal power and, to a lesser extent, hydroelectricity).

The Smart Grid concept encompasses more than optimizing consumption management since it includes the notion of a network return cycle: during certain time intervals, vehicle batteries may be used as distributed storage facilities (i.e. the V2G, or Vehicle-to-Grid, concept).

<sup>15</sup> Source : [15]

### 3.5.1 Smart grid architecture

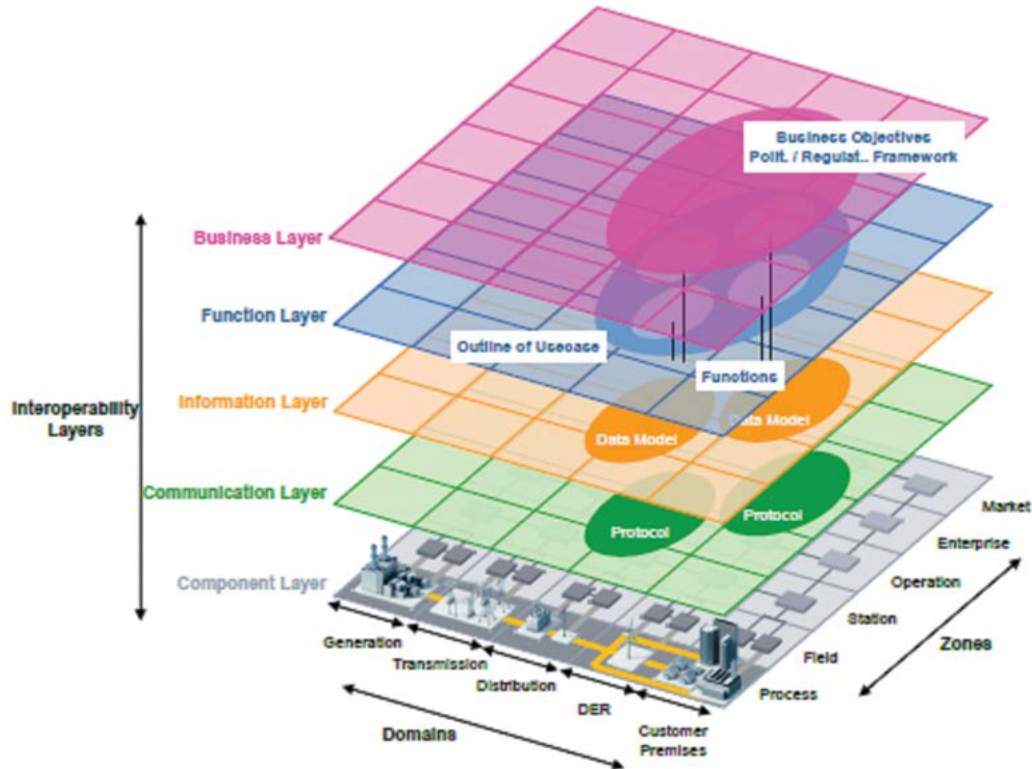
The electrical energy system is undergoing a paradigm shift sparked by the evolution from a conventional, centralized, top-down vision of the production chain, composed of Generation-Transmission-Distribution, in favor of a more decentralized system in which the participating entities dynamically alter their roles while cooperating.

The European Smart Grid conceptual model not only describes a physical network, but also encompasses the interactions taking place among actors involved in the system.

*Illustration 10* illustrates the architecture developed at the European scale. A detailed description is quite complex and lies beyond the scope of the present study. Interested readers are referred to [3].

This conceptual model comprises 3 dimensions:

- A “*field*” dimension that spans the entire energy distribution chain, from production through supply to the end user;
- A “*geographic zone*” dimension that describes an energy management process hierarchy;
- An interoperability dimension (i.e. the capacity to exchange information among various entities) involving technical aspects (component interface) or non-technical aspects (business interface).



*Illustration 10 - European smart grid architecture framework*

This model should be viewed as a framework designed to accommodate energy distribution applications or services, which are referred to as use cases. Implementation of a use case begins with its “*projection*” (or mapping) onto the 3-dimensional model (*illustration 11*). This model thus enables treating not just the technical aspects associated with a use case implementation, but the economic, regulatory and informational aspects as well.

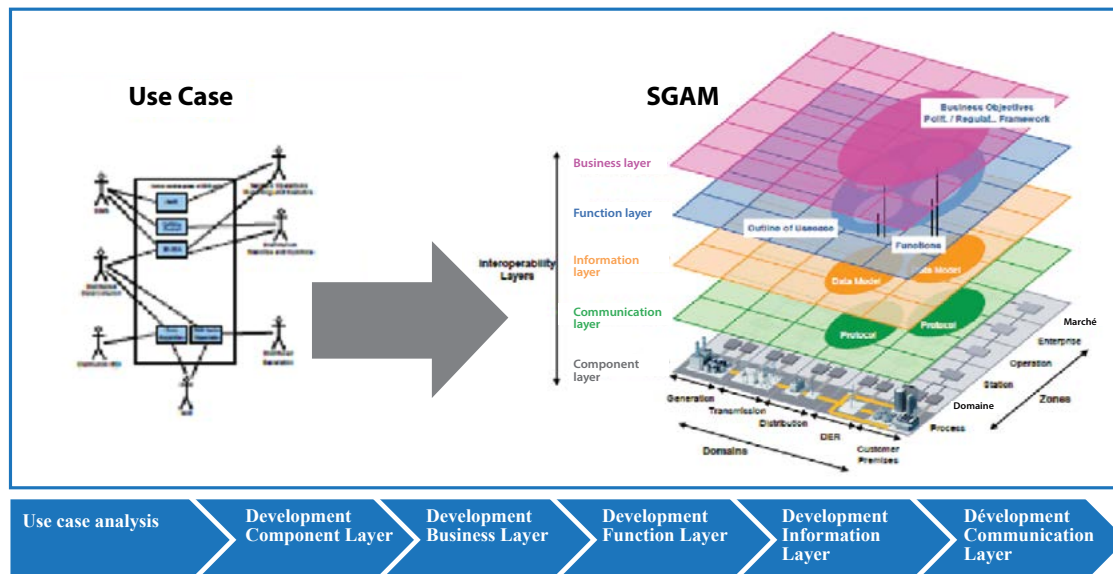


Illustration 11 - Use case mapping process to architecture framework

### 3.5.2 Role of cooperative systems

Communication is a fundamental element of Smart Grids for its role in connecting dedicated energy “*production*” entities, i.e. links in the production chain, in addition to entities helping manage the energy optimization process and its actors (whether individuals or corporate concerns) with the greatest impact on the value chain.

The scope of required communication (long, medium or short range) is associated with a specific set of standardized communication protocols and channels.

As regards electric vehicles, which lie all the way at the end of the distribution chain, communication takes place via the cable hookup and recharge plug. Both these devices connect the vehicle to the charging station (hence to the Smart Grid) and transport the energy required to complete the charge plus the messages exchanged between vehicle and infrastructure as part of the load optimization protocol.

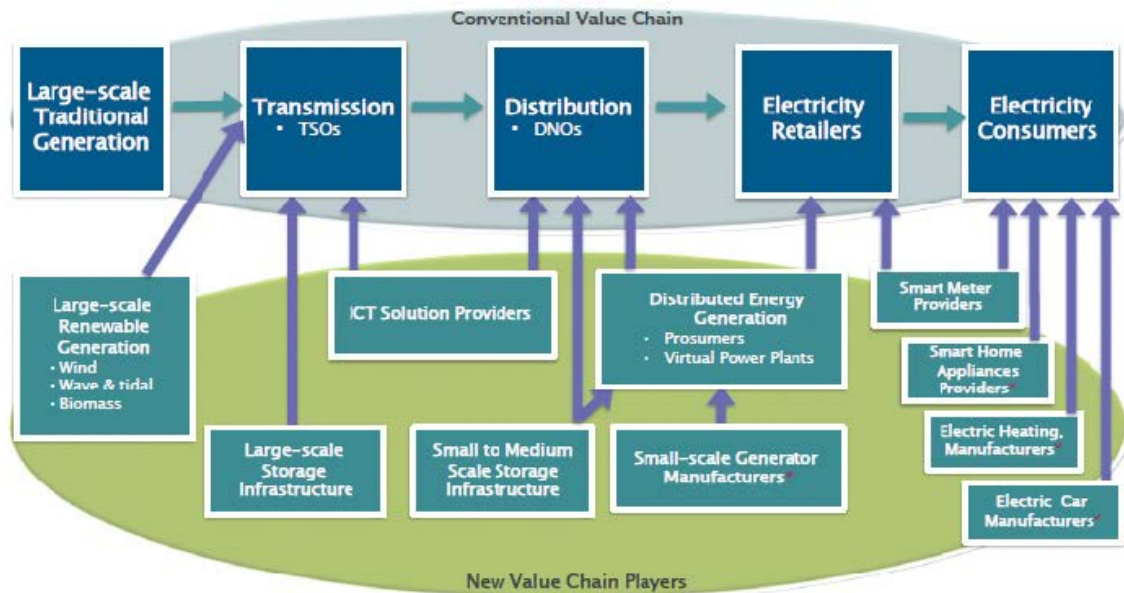
### 3.5.3 Chain of actors and value chain

A good understanding of the value chain proves essential to effectively developing economic activity around the Smart Grid; this condition enables both industrial and economic actors to position themselves within the production process or the smart infrastructure management process.



No single standardized representation can be found of the value chain. Each country develops its own vision, or even several visions. *Illustration 12* presents a futuristic British vision of the value chain associated with the Smart Grid [4].

This orientation also relies on components from the distribution chain.



*Illustration 12 - UK vision of the value chain*

### 3.6 IMPACT OF THE EMERGENCE EV ON ROAD NETWORK OPERATION

For the road network operator, the impact of EVs is apparent from two points of view:

- Road safety: do EVs create any specific accident scenarios?
- Infrastructure layout.

#### 3.6.1 EVs and road safety

To the best of our knowledge, no statistics have yet to be released that enable identifying specific accident trends tied to the introduction of electric vehicles, most likely due to a lack of sufficient historical time series data and a total EV fleet still too small to generate a robust statistical analysis.

From a road safety perspective, the electric vehicle can mainly be characterized by its quietness and acceleration/deceleration capabilities distinct from those of equivalent heat engine cars.

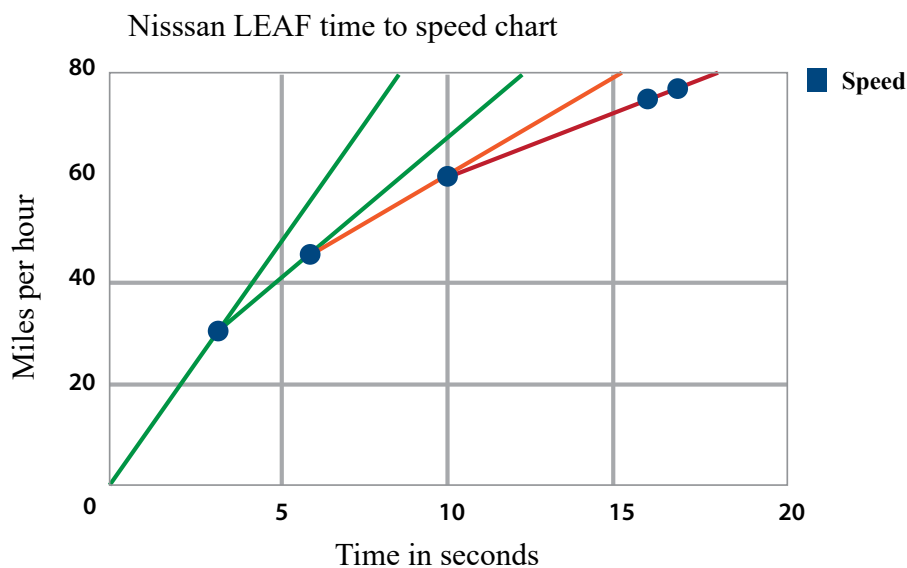
The absence of any natural noise emitted by EVs causes an accident risk primarily in urban environments with pedestrians crossing the street. The majority of electric vehicle manufacturers have already resolved this problem by generating artificial noises specifically intended to alert pedestrians of an oncoming EV.

As regards the acceleration and deceleration features, at this point one can simply state that differences exist, but it remains unclear as to whether such differences act to raise or lower the likelihood of vehicle accidents.

By way of example, *illustration 13-a* demonstrates an acceleration from 0 to 102 km/h (0-60 mph) in 10 seconds with a NISSAN LEAF (source: automaker), which slightly beats the equivalent heat engine vehicle (0-100 km/h in 13 sec). But even more significant here is the information shown in *illustration 13-b* (source: automaker) of a very high acceleration capacity during the first few seconds after startup followed by a threshold (hence a linear speed increase), which offers a certain amount of driving comfort due to the elimination of jerks (i.e. the 4th derivative of distance).

This “controlled” acceleration is typically calibrated in order to avoid sliding, which in turn could become a source of risk for vulnerable users in urban situations involving pedestrian crossings. Here again, only historical trends and an in-depth analysis of accidents will lead in the future to determining whether or not EVs in an urban context create a specific source of additional accidents.

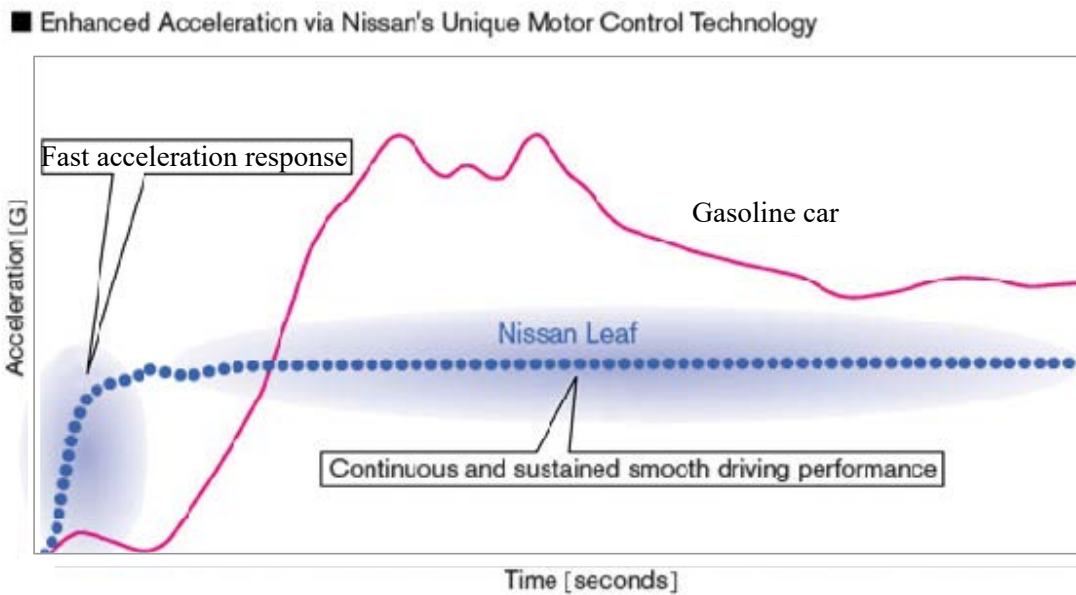
Moreover, when singling out EV impacts, two considerations would seem to suggest risk reduction: regenerative braking introduces smoother braking (less abrupt decelerations), and for motorcyclists a greater difficulty to “soup up” an engine compared to the case of a heat engine (which is the cause of many accidents among riders of low-powered mopeds).



a) Speed vs. time of a Nissan Leaf

*Illustration 13 – Speed and acceleration of a Nissan LEAF*





b) Acceleration vs. time of a Nissan Leaf

*Illustration 13 – Speed and acceleration of a Nissan LEAF*

### 3.7 INFRASTRUCTURE DEVELOPMENT

Is it appropriate to speak of specific infrastructure improvements tied to the emergence of EVs?

Here again, caution is required since future trends must be disaggregated between what in fact is strictly correlated with EVs and what can be ascribed to society's natural evolution that the emergence of EVs has merely facilitated.

#### 3.7.1 Trends strictly tied to the emergence of EVs: Charging stations

In France, the “*Green Book*” master plan on charging infrastructure made available to the public for “*carbon-free*” vehicles, published by the government in 2011, recommends sizing a network adapted to users' needs, with an emphasis on intelligent charging (modulation of current supplied depending on various criteria, e.g. energy and environmental) and in promoting nighttime charging where the vehicle is parked most of the time (i.e. at an individual's residence, at the workplace for professional vehicles). No recommendations were issued regarding the type of energy contract reached, but metropolitan areas like Paris or Nice have opted for contracts that include “*green energy*” certificates (source: Wikipedia, [http://fr.wikipedia.org/wiki/Station\\_de\\_recharge](http://fr.wikipedia.org/wiki/Station_de_recharge)).

##### 3.7.1.1 The case of a 500,000-population metropolitan area

This report [5] indicates that for a metropolitan area of 500,000 inhabitants and a vehicle fleet of around 275,000 for all uses combined (i.e. individual and professional), the national plan's objectives call for some 3,300 rechargeable vehicles in year 2015 and approx. 15,000 by 2020. An analysis of parking patterns would provide an accurate identification of primary parking locations (private space vs. public zone) for all vehicles circulating within the area, along with an estimation of the numbers of vehicles.

For the metropolitan area under study, around 80% of the primary parking spaces are located on private property (single-family or multi-family dwellings, company premises) vs. roughly 20% in public places (parking lots or on the street).

The report goes on to propose an approach for calibrating the number of charging stations, by drawing the distinction between the primary site, where 90% of charging at 3 kVA takes place, and the selected secondary station, where the other 10% of charging occurs (either slow or fast).

For the primary charging stations, the report stipulates one station per vehicle (i.e. 3,300 for the metropolitan area with 500,000 population serving as our reference), distributed as follows: 60% in individuals' private parking lots, 20% in private company lots, 5% in public lots, and the remaining 15% on the street.

For secondary stations, a total of 250 are allocated, including 70 operating at accelerated power, split as follows: 16% in public lots, 46% on the street, 34% on private property (hotels, supermarkets, etc.), and the last 4% as quick charging stations (location not specified).

The cost of setting up a charging station had been estimated in 2011 at €5,000, €8,000 and €55,000 for powers of 3 kVA, 22 kVA and 43 kVA, respectively, including equipment, engineering, facilities and connections. Operating expenses comprise the energy subscription (between €30 and €995 depending on the power rating) and maintenance and repair costs, estimated at 10% per year of the total equipment expenditure for normal and accelerated charging, and at 5% for the fast charge.

### 3.7.2 A natural evolution merely accelerated by the emergence of EVs

The objective is to adapt infrastructure to meet mobility challenges raised over the 2030-2040 time frame.

An appropriate response would focus on rolling out cooperative systems, delegated driving (see [section 1.2](#)) and the “*Smart Grid*” ([section 1.3.5.1](#)). The infrastructure is no longer simply a driving space but instead becomes a space for exchanging information and energy. The European FOR (Forever Open Road) project and its French counterpart “*R5G*” (5th-Generation Road)[6] are aimed at anticipating this evolution. Interested readers are referred to the case study appended to this report , as well as to the article [7].

## 3.8 END USER SERVICES

### 3.8.1 Services provided for battery charging

Most of electric car makers provide information on location and availability of EV charging stations. For example, in France, Renault-Nissan proposes the Chargemap (<https://fr.chargemap.com/>) service that provides on internet or Smartphone a list of available charging stations. The service is partially based on user community as users can interact with the service. Other services worldwide exist in countries where electric vehicles are deployed: Plugshare (USA) (<http://www.plugshare.com/>), Chargepoint (<http://www.chargepoint.com/>), Zap-Map (UK) (<https://www.zap-map.com/>), e-Stations (Australia) (<http://e-station.com.au/>). In addition, operators of electric car pooling have integrated in their system the information on availability of parking and charging stations.

### 3.8.2 Electric car sharing, Self-driving vehicles and Mobility as a services

Electric cars offer several advantages in relation to car sharing policies: Electric cars require less maintenance and are more durable than ordinary cars. Recharging is simpler and charge stations can be offered at a multitude of locations in dense grids. In addition, electric cars find their primary use in urban areas (due to driving distance restrictions) and are therefore often designed for urban usage. They are relatively small and light in order to offer power economy.

All in all, electric cars have been found to be suitable for temporary usage in urban areas through different types of car sharing policies. Most important is the AutoLib system in Paris involving 3000 electric cars for temporary usage [8].

Moreover, the current evolution of self driving vehicles (i.e. vehicles with the capacity to drive without driver interaction and even without driver presence) shall be seen in the light of the advantages of electric vehicles. The first stage of self-driving includes the ability of the vehicle to find and connect to a charge station and parking place when needed, and to self-drive to a pick-up point independently of driver when called into service by a user. Current development indicates commercial availability of this functionality around 2025-2030. The combination of self-driving and electric vehicles with car-sharing policies brings totally new possibilities to urban mobility. It will allow for users without driving license to benefit from the advantages of individual transport and for transport service providers to offer door-to-door mobility through combinations of public and individual means of transport. This possibility is often referred to as Mobility as a service [9]

### 3.8.3 Electric bus

Refer to case studies [10], [11]

### 3.8.4 Electric bicycle

Active transport and specifically cycling has been recognised globally as part of the solution to developing a sustainable and accessible transport system and specifically mitigating congestion. The uptake of electric bicycles in Italy and Germany now exceeds regular bicycles and countries such as Austria, the USA, Canada and the Netherlands. Electric bicycle offer a low-emission and more environmental sensitive solution. They also require less physical effort to operate than the traditional bicycle. This allows rider to travel greater distances. Various studies have also shown people typically drive their car less when they have an electric bicycle. Unlike electric cars, electric bicycle does not require an extensive network of charging stations and can be self-propelled if required thus ensuring personal mobility at all times. The e-bike also has the ability to expedite vehicle to cycle connectivity as the technology integrates with nomadic devices and other communications systems.

## 4. NETWORK MONITORING BASED ON COOPERATIVE SYSTEM: THE FLOATING CAR DATA CONCEPT

Infrastructure monitoring is a major issue for road network operation. The objective is to collect accurate and up to date information in order to understand the state of the road network: speed, travel time, congestion, accidents, hazards, origin and destination (O/D), environmental condition, weather condition, road condition (surface and pavement), visibility etc.

### 4.1 DEFINITION/CONCEPT

Infrastructure monitoring based on cooperative system is a concept that can be defined as a system (set of hardware and software resources) that allows the collection, aggregating and analysis of data in order to characterize the state of road network. System components include: probe vehicles (also known as floating vehicle data (FVD)), road side assets, communication networks and back office centers.

The principle is to aggregate data from different sources (probe vehicles) in a given location (a region, a city, a road segment). It is then possible to build data and information whose robustness mainly depends on the number of vehicles involved. An example is travel time estimation. Traditional methods require measurement points (magnetic loops, CCTV) located on infrastructure to estimate travel time between these points. In the cooperative approach, travel time is provided by the probe vehicles themselves by transmitting their travel time) along a road segment; or by transmitting their location at defined time interval which the system can then use to calculate travel times, speed, etc. Then data aggregation from several vehicles driving along the same segment allows the calculation of estimated average travel time on this segment. It is then possible to provide the total travel time estimation along an journey by summing the travel times of the different segments of a journey. This information can be communicated to the drivers or the road network operators using conventional channels like VMS, RDS-TMC or more sophisticated medias like in-vehicle platform or Smartphones.

### 4.2 A NEW PARADIGM

Traditionally, road network monitoring relies on vehicle from equipment installed on the infrastructure such as inductive loops for speed and traffic flow measurement, cameras for incident or hazard detection, weather stations for meteorological conditions assessment on a given location etc. In this approach the infrastructure plays the major role in term of event detector.

The evolution of V2X communication technologies, in-vehicle sensors and onboard electronics allow the paradigm to be progressively changed. In the middle term it will be possible to substantially reduce the number of sensors on the infrastructure as they will be replaced by probe vehicles.

This innovative approach offers potential in term of accuracy of real-time information, and thanks to the diversity of sensors that are embedded in modern vehicles, the same vehicles can provide a wide range of information such as travel time, speed, obstacles, visibility distance, distance headway etc. From this evolution we can expect a significant reduction in investment and maintenance costs of infrastructure.

### 4.3 SYSTEM ARCHITECTURE

*Illustration 14* shows the architecture of a system based on floating car data. On the left bottom side, the probe vehicle collects data and information from its own sensors which is transmitted to a back office center to aggregate and analyze the data. Results (traffic information, alert, recommendation etc) are transmitted back to the vehicles (right bottom side). Depending on the communication technologies, links between vehicles and back office can be direct (3G, 4G) or relayed by road side equipment using DSRC (US-JP) or WAVE (Europe) technologies.

The question of relaying the information by road side unit remains today an open issue without common agreement. Each solution offers advantages and drawbacks that are presented below.

#### 4.3.1 Direct upward/downward link

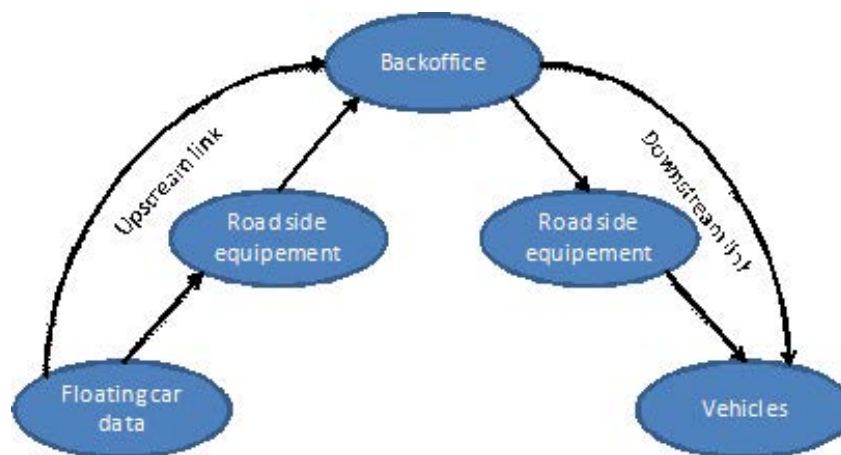
Direct upward or downward link without road side unit relay, relies on cellular communication.

##### Advantages :

- relies on existing communication infrastructure (including emerging countries) in continuous improvement (2G, 2,5G, 3G, 4G);
- extended countries coverage especially in developed countries;
- no investment on infrastructure for road network operators.

##### Drawbacks:

- recurrent cost for the end-user (subscription);
- limited level of performance that don't allow to process events that require low latency time (less than a second).



*Illustration 14 - system architecture*

#### 4.3.2 Indirect upward or downward link

Indirect upward or downward link relayed by road side unit relies on DSRC (USA, JPN) or WAVE (Europe) for vehicle to road side communication and on ADSL for road side to back office data transfer.

**Advantages:**

- cost for end-user is limited to the initial investment on the vehicle (V2X communication platform). However, there is no recurrent cost for communication;
- High performance level that allows to process events requiring very low latency time.

**Drawbacks:**

- heavy investments on infrastructure for the road network operator (road side unit) hardly conceivable for emerging countries;
- full country coverage is not economically viable and also due to unavailability of energy especially on rural road.

Finally, several factors suggest that it is the direct communication between vehicles and back office centers that will prevail:

- the continuous improvement of cellular communication (emergence of 4G technology) will allow to process emergency events;
- recurrent costs (subscriptions) are decreasing due to the competition between operators;
- versatile platforms like Smartphone will support a wide variety of low cost services which is not necessarily the case with DSCR or WAVE platform fitted on new vehicles;
- moreover, Smartphones have a short life cycle (3-5 years) as opposed to integrated platforms (10 -15 years) which gives them a very good adaptability to changes.

## 4.4 KEY TECHNOLOGIES

The concept of floating car data has emerged from the evolution of communication technology and electronics in vehicles. The evolution of V2V and V2I communications has already been widely presented in the first part of this document. We will focus more on developments of other technologies and their integration into an architecture for deploying services based on probe vehicles.

### 4.4.1 Probe vehicle

For about twenty years, the provision of electronics in vehicles has grown considerably. Today it represents more than 30% of the total cost of a light vehicle. Its primary function is to provide the driver with a driving assistance for accident prevention, improving mobility, helping in navigation and for improving comfort (infotainment) etc. The main components of the electronics include: electronic control unit (ECU), sensors, actuators and a digital networks interconnection between computers (mainly the CAN bus).

#### 4.4.1.1 Electronic control unit (computer)

Their number may vary from a few units to several tens. They support distributed processing and are located in various parts of the vehicle.

#### 4.4.1.2 Digital communications networks

This is the internal network to the vehicle which allows interconnecting electronic control units together to share some information. For example, the “*speed*” data may be used by the engine control computer but also by those who control the windscreen wipers rhythm. Most used networks (also called “*bus*”) are CAN and FlexRay bus

#### 4.4.1.3 Sensors

Two sensors types are identified:

1. proprioceptive sensors that provide information about the vehicle dynamics (speed, acceleration along three axis, distance etc) and,
2. exteroceptive sensors that provide information about the external environment of the vehicle (obstacles, position of other vehicles, position of the vehicle on the road etc.).

Moreover most of the driver controls (wipers, turn signal, brakes and accelerator pedal are equipped with sensors to know at any time the condition of their use (e.g. the percentage of depression of the accelerator pedal.)

#### 4.4.1.4 Actuators

They act primarily on devices that control the vehicle trajectory: steering angle of the wheels, brakes and accelerator. ESP and ABS controller can also be considered as an actuator.

#### 4.4.1.5 GPS Receiver

Often likened to a sensor, GPS delivers an absolute position in a geodetic datum. Associated with a digital map this position is processed to a geo location on this map. GPS plays a major role in the concept of probe vehicle since all information delivered by the sensors is only meaningful if they are geo localized. In addition, this sensor is distinguished by its operation being dependent on the reception of signals from a constellation of satellites at an altitude of 20,000 km.

### 4.4.2 Road side units

The primary function of roadside equipment is relaying communications between vehicles and back office centres. This aspect has been largely developed in [section 1.2](#) and in the case study [1].

In addition, roadside equipment can also support sensing function. Unlike probe vehicle, collected data provide information about a local situation. Therefore, these devices are usually located in places where there are recurrent problems: congestion, queue, crossroads, fog or ice etc. Already marketed equipment include: incident detection cameras, speed and traffic flow measuring stations (based on cameras or magnetic loop), ice detection systems etc. In the framework of the European project SAFESPOT other types of events were studied: incursion of animals on the road, fog detection. The case study [12] describes the ongoing research on the joint use of probe vehicles, roadside weather station and information provided by Meteo-France to assess the risk of fog occurrence.



## 4.5 APPLICATION OF PROBE VEHICLES TO ROAD NETWORK MONITORING

There are still no official classification of applications based on probes vehicles. The most advanced work is supported by the USDOT and by the MLIT in Japan that work together in a taskforce to share information and to foster the development and deployment of probe vehicle with a harmonized point of view.

In its final report, “*US-Japan Collaborative Research on Probe Data: Assessment Report*” the taskforce propose a list of priority applications (Chapter 7). On the USA side applications are classified according to three categories: 1) mobility, 2) reducing the environmental impact, 3) management of meteorological situations. On the Japanese side, 17 applications are classified according to three levels (1, 2 or 3) depending on to their degree of maturity: 1) currently in use, 2) can be deployed in the near future or 3) possible in the future.

In Europe, work is less advanced. It is conducted (in conjunction with the US-JPN taskforce) in the Probe Data Work Group led by ERTICO.

In addition, there is some national initiatives like for example The National Traffic Operations Centre (NTOC) operated by the English Highways Agency uses FVD to enrich traffic data from traditional sources – over 600,000 probe vehicles are used – the service has been running since 2013 and covers the whole of the English Strategic Road Network

We develop below applications that seem most significant from the point of view of road network monitoring. We propose a classification into the following categories: mobility, road safety, weather condition, environmental, road diagnosis, knowledge survey.

For each application a maturity index is proposed: 1) deployed now in an experimental setting (e.g. Field Operational Test) or in a real situation, 2) possible deployment in the short term (<5 years), 3) deployment in the medium term (> 5 years).

The maturity index comes from a survey addressed mainly inside the TC21 (14 answers)

All applications are based on data transmitted from vehicles to a back office centre where they are aggregated. The term aggregation cannot be reduced to a simple average but includes process of varying complexity and the use of statistical models.

### 4.5.1 Mobility application

See [13] case study as an example of commercial deployment in Europe and especially in France.

Application	Maturity
Travel time estimation on a route by aggregating the times achieved by the probes vehicles on road segments	1
Detection and characterization of congestion (position, length, average speed congestion) by aggregating low speed or zero speed in a given area.	1
Information on the availability of a route: in emergency situations (natural disaster, etc.), vehicle sensors help to characterize the availability of a route to provide first aid or any other emergency services	2 <sup>16</sup>

<sup>16</sup> Tested following tsunami that occurred on March 11, 2011



#### 4.5.2 Road Safety Application

See case studies [1] and [14] as examples of experimentation.

Application	Maturity
Dynamic harmonization of speeds and headways: the objective is to provide speed and distance headway recommendations in response to situations of congestion, incidents or adverse traffic situations.	2, 3
A possible extension of this application is a direct action on cruise control (CC) and adaptive cruise control (ACC) for speed and headway control.	3
Queue alert: vehicles which detect that they are located in a queue (or traffic jam) transmit alerts to upstream vehicles so they can reduce their speed to avoid an accident (collision).	2
Stationary Vehicles alert: a vehicle stopped in the road transmits alerts to prevent upstream vehicles to avoid an accident. Alerts can also be transmitted by witness vehicles.	2, 3
Detection of potentially hazardous areas: recurrent abnormal behavior of vehicles approaching a curve such as longitudinal, transversal acceleration yaw rate, speeds outside of normal values could be interpreted as warning signs for the road network operator. Then a thorough analysis of the situation could make it possible to conclude that the geometry of the road is intrinsically dangerous or that speed limit is unsuited and thus allow the road network operator to apply necessary countermeasures.	2,3

#### 4.5.3 Weather condition monitoring

Embedded electronic provides many driving parameters: windshield wipers operation, lights and fog lights status etc. Moreover, the recurrent trigger of ESP, ABS or ASR can be a warning sign of a slippery roads due to ice. In addition, in the near future, high-end vehicles will be equipped with cameras to measure the distance of visibility in the fog which will enrich the information on weather conditions.

Application	Maturity
Rain detection: observation in a given area of vehicles that operates simultaneously their windscreen wipers can be interpreted as warning signs of rain.	2
Ice detection: observation on a given area of vehicles that repetitively and unexpectedly trigger their ESP/ABS or ASR is information that can be interpreted as the warning signs of ice.	2, 3
Fog detection: the presence in a given area that vehicles turn on their headlights and fog lights simultaneously is an information that can characterize the presence of fog	2
Distance of visibility in the fog: thanks to computer-vision techniques using on-board cameras it is possible to estimate the distance of visibility in fog in front of the vehicle. Then the aggregation of information from multiple vehicles allows to calculate an estimate of the distance of visibility on a given area or itinerary. This information could also be merged with information automatically downloaded from weather stations located in some airfields (e.g. METAR messages).	3

#### 4.5.4 Road distress monitoring

Application	Maturity
Road surface diagnosis: the information to detect zones of reduced skid resistance are the same as those mentioned above for the detection of ice. Recurring triggering of ABS, ESP and ASR systems on a given location are indicators that could be interpreted to detect area with reduced skid resistance. However, their fusion with meteorological data is necessary to discriminate the causes: rain, snow, ice or degradation of the road pavement or combination of both causes.	3
Detection of degradation of the road surface: the presence in a given location of vehicles subject to oversized vertical accelerations may indicate road surface degradation like ruts, potholes, ruptures, cracks causing vertical movements of the car body. The probe vehicle must be equipped with sensors sensitive enough to detect these movements. Recent studies shows that sensors (accelerometers) integrated into some Smartphones have the required sensitivity.	3
Road geometry unsuited to speed limits: see the <i>section "Detection of potentially hazardous areas"</i> . The same information can be used to diagnose an inappropriate speed limit or dangerous road geometry (radius of curvature, cant).	3

#### 4.5.5 Advanced knowledge survey

Application	Maturity
Survey on O/D: : Tracking itineraries of vehicles cohort on specified areas help to get better knowledge of the flow (O/D) and refine predictive models of traffic. The Anonymization of the information is a crucial issue but techniques are now available to preserve privacy <sup>17</sup> .	2
Environmental assessment: the ability of newer vehicles to measure their own emissions (CO2 or other GHG sensor) and calculate their own fuel consumption should provide global environmental assessments across a network, a city or geographic area.	3

#### 4.5.6 Environmental application

Most mobility applications described in *section 4.5.1* have an impact on reducing fuel consumption and emissions of greenhouse gases in so far as that they help to improve the traffic.

Application	Maturity
Eco driving recommendations: from information from probe vehicles as mentioned above, recommendations can be provided to improve both driving safety ( <i>section 4.5.1</i> ) and fuel consumption. These eco driving advises concern mainly gear ratios, speed profiles (acceleration, deceleration) etc.	2, 3

### 4.6 INFORMATION ACCURACY

The issue of information accuracy based on the aggregation of data from probe vehicles is very complex and up to now there no comprehensive answers. Each case requires specific studies taking into account the context: urban, suburban, highway, day, night, traffic type, but also the type of information expected (travel time, speed, distance visibility etc.)

To this date, the majority of studies focus on applications related to traffic: profiles of speeds, travel time, traffic density.

Various studies show that this accuracy depends mainly on the vehicle location accuracy, the probe vehicle data frequency and the proportion of probe vehicles in the traffic flow. Concerning location, it appears that accuracy provided by GSM may be too low and GPS location is recommended<sup>18</sup>. Concerning probe vehicle proportion figures should be used with caution. Some studies [15] mention a rate of 1 to 5%, other studies [16] suggest that the collection of data from 2 to 20 vehicles per 15 minutes on a road segment (length not specified) is enough to estimate a travel time with a relative error of 10%. Several studies underline possible bias due to the type of drivers or the type of probe vehicles (fleet of taxis, trucks etc.). For more information, read the following paper [17], [18].

### 4.7 LEGAL ASPECTS

#### 4.7.1 Privacy

Security and privacy issues must be considered in the general framework of cooperative systems. Methods and techniques used are the same as those described in *section 2.2.4*.

<sup>17</sup> See European project PRESERVE <http://www.preserve-project.eu/>

<sup>18</sup> Most Smartphones include a GPS chipset

#### 4.7.2 Information property

Although the legal framework for the data ownership from probe vehicles has not yet been clarified so far, it seems that it is the vehicle owner who owns the data produced by the vehicle. Consequently, he should be able to claim several rights:

- the right to access to their own data;
- the right to control the use made with the data by third parties (involved in the value chain) namely the car manufacturers (for remote maintenance, for example), the service providers, the communication operators, the road network operators etc;
- the right to compensation as soon as he authorizes its data usage for commercial purposes, such compensation may take the form of a service access with preferential terms.

### 4.8 STANDARDISATION

Intelligent Transport Systems (ITS) support the movement of people and goods in various aspects. Essential to ITS is information and telecommunication technologies. International standardization of ITS is carried out by ISO, IEC, JTC and ITU. In particular, ISO/TC 204 is a technical committee specialized on ITS standardisation activities. See more details on ISO/TC2014 in appendix (*section 9*).

The following standards are relevant for probe vehicles :

#### 4.8.1 ISO/TS 25114:2010: Intelligent transport systems - Probe data reporting management (PDRM)

- ISO/TS 25114:2010 provides a common framework for defining probe data reporting management (PDRM) messages to facilitate the specification and design of probe vehicle systems and gives concrete definitions of PDRM messages;
- ISO/TS 25114:2010 also specifies reference architecture for probe vehicle systems and probe data which incorporates PDRM, based on the reference architecture for ISO 22837, and basic data framework for PDRM instructions, which defines specifically necessary conditions for PDRM instructions, and notations of these instructions (in XML).

#### 4.8.2 ISO 22837:2010 Vehicle probe data for wide area communications.

It specifies the following.

- Reference architecture for probe vehicle systems and probe data;
- basic data framework for probe data elements and probe data;
- core data element definitions, which are basic descriptive elements intended to appear in every probe message, i.e. the location and the time at which the probe data was sensed;
- initial set of probe data elements, which are commonly used in typical probe data enabled application domains, such as traffic, weather, and safety;
- example probe messages, which define how probe data elements are combined to convey information to probe processing centres.

#### 4.8.3 ISO 24100:2010 Intelligent transport systems - Basic principles for personal data protection in probe vehicle information services

- ISO 24100:2010 states the basic rules to be observed by service providers who handle personal data in probe vehicle information services. This International Standard is aimed at protecting the personal data as well as the intrinsic rights and interests of probe data senders, i.e., owners and drivers of vehicles fitted with in-vehicle probe systems.

### 5. BEST PRACTICES, RECOMMENDATIONS

#### 5.1 COOPERATIVE SYSTEMS

The data transmission principle between vehicle and infrastructure is now quite old. The RDS-TMC system that allows data transmission from traffic management centres to vehicles using the FM radio transmission channel may be the first form of the later so-called “*cooperative systems*”.

Since then, many projects on direct or indirect bidirectional communications between vehicles and / or between vehicles and infrastructure have been set up. Their objectives are multiple: demonstration of the technical feasibility of communication solutions, development of new applications, assessment of users’ acceptability and of their impact on road safety, elaboration or advancement of standards and demonstration of systems interoperability at least at the scale of a continent. Most of these projects have led to medium scale experiments involving dozens of vehicles on experimental areas whose size is the one of a district or a small town and on a few tens kilometre routes.

The conclusions of most of these projects raise the same issue: what is the business model that ensures profitability and sustainability of cooperative systems based services? This issue has not found a clear answer yet. As a result, to that date (2015), cooperative systems are not fully deployed yet, or at least not in an expected form.

However, Japan has exceptionally achieved nationwide deployment of Cooperative-ITS called “*ETC2.0*” (formally called “*ITS Spot Service*”). The RSUs of DSRC were installed nationwide in 2011, and as of April 2015, more than 600 thousand users had installed ETC 2.0 onboard units, with which they can enjoy multi ITS applications such as mobility applications, safety applications, probe-base applications and ETC. In addition, the road authorities and operators have started to utilize collected huge amount of anonymized probe data for some applications listed in the [section 4.5](#) in order to improve road network operation. This Public-Private-Partnership approach contributing the rapid and wide deployment of ETC 2.0 could serve as a useful reference for the countries planning to introduce and deploy Cooperative-ITS (See Case Study X).

This model is much more difficult to find than in most developed countries and particularly in Europe there has been a withdrawal of the States. Thus, the development of the communication infrastructure for mobile applications is no longer of the States prerogative. Then, the model has to find its own economic equilibrium.

Another obstacle to the deployment of these systems is their dependence to in-vehicles technology. Although it is possible to equip vehicles with aftermarket communication platforms it is clear

that retrofitting remains an unusual operation. Therefore, cooperative systems will be probably deployed only on a renovated fleet. This inevitably introduces significant delays since the renewal of the whole fleet takes from 15 to 20 years.

These difficulties are even more heightened in developing countries where fleets are often old or even obsolete and where it is almost unthinkable to deploy infrastructure dedicated to mobile applications (roadside units networks) given the needed investments and maintenance budgets.

Meanwhile a revolution emerged with the development of social and community networks based on cellular networks (2G, 3G, 4G) for mobile applications. Freeing standards, building on existing infrastructure (the cellular networks one), community applications are growing beyond all expectations. Waze bought by Google in 2014 for approximately \$ 1.1 billion dollars is the archetype of the success of this type of application. Early 2014, according to Wikipedia, Waze was used by about 70 million people worldwide.

### 5.1.1 Best practices

A 2-speed deployment is indeed occurring; a slow one based on costly infrastructure and whose business model is still to be found and a swift “*low cost*” model one based on simple architectures operated fully or partially by user communities and with services whose quality is probably somewhat degraded but nevertheless sufficient to meet user expectations.

These two models are not necessarily in opposition: they can be complementary, for example the low cost one can be the transition stage to more complex and more expensive systems, but with a higher level of service.

These two models can be designed by two different kinds of architectures whose characteristics can be summarized as follows:

High Cost Architecture	Low Cost Architecture
<p>The architecture allows direct communication between vehicles.</p> <p>The vehicle-infrastructure communication is done either directly or via a roadside units network.</p> <p>All communicating entities (vehicles, roadside units, centres) have a “ITS platform” compliant to ETSI standard.</p>	<p>The architecture does not allow direct communication between vehicles.</p> <p>The vehicle-infrastructure communication is done directly via cellular communication networks.</p> <p>All communicating entities are ordinary mobile phones or Smartphones.</p>
<b>Key Technologies:</b>	
from the vehicle side:	
<ul style="list-style-type: none"> <li>sensors, actuators;</li> <li>embedded computers;</li> <li>internal digital networks (CAN bus);</li> <li>communication platform;</li> <li>human Machine Interface (specific dashboard).</li> </ul>	<ul style="list-style-type: none"> <li>Smartphone.</li> </ul>
From the infrastructure side:	
<ul style="list-style-type: none"> <li>roadside Units;</li> <li>variable message signs.</li> </ul>	<ul style="list-style-type: none"> <li>existing communication infrastructure (2, 3, 4G).</li> </ul>
From the centre side (backoffice)	
<ul style="list-style-type: none"> <li>calculators;</li> <li>human Resources.</li> </ul>	<ul style="list-style-type: none"> <li>calculators or cloud computing;</li> <li>human Resources.</li> </ul>
<b>Drawbacks</b>	
<ul style="list-style-type: none"> <li>expensive architecture for drivers because it requires a specific communication platform. In addition, only most recent vehicles will be equipped;</li> <li>expensive architecture for road operators as it requires the deployment of a dedicated infrastructure (roadside units).</li> </ul>	<ul style="list-style-type: none"> <li>limited performance due to the response time of communication media (3G mainly today): this excludes applications requiring answers in a very short time;</li> <li>applications based on proprietary protocols may affect interoperability;</li> <li>integration in a comprehensive framework for the sharing of resources or information raises difficulties or is impossible.</li> </ul>
<b>Benefits</b>	
<ul style="list-style-type: none"> <li>meets in force or emerging standards;</li> <li>interoperability is ensured at least at the scale of a continent;</li> <li>can be integrated into an architecture framework to share resources or information;</li> <li>high performance especially in terms of latency time for information exchange;</li> <li>high level of service allowing support for emergency situations (eg alert on vehicle at a standstill on the road).</li> </ul>	<ul style="list-style-type: none"> <li>inexpensive for drivers;</li> <li>inexpensive for road operators;</li> <li>rapid deployment since it is based on widespread technologies even in developing countries;</li> <li>possible deployment in developing countries since it does not require major investment or fleet renewal;</li> <li>business model achieved thanks to the contribution of user communities.</li> </ul>

### 5.1.2 Recommendations

The recommendations are in line with the following observation: low-cost applications are deployed more quickly than high-cost applications for the reasons given above. Moreover, with the emergence of 4G communication technology, high-level service applications that were impossible to deploy might now arise.

#### **We recommend:**

1. to ensure synergies “*high cost - low cost.*” Low cost architectures open a full-scale field experiment that enables to know which applications are offering the best cost / benefit ratio. This allows then a feedback for future deployments based on high cost architectures. Conversely, high cost architectures allow to prototype new applications that are today unthinkable on low cost architectures;
2. to foster the deployment of cooperative applications in developing countries: low cost architectures are well suited to these deployments because they rely on existing networks and do not require the renewal of the fleet or the installation of roadside equipment;
3. to foster large-scale experiments: this is not to prove concepts or to test feasibility anymore but rather to demonstrate the utility, usability and acceptability of services based on cooperative systems. In addition large-scale experiments contribute to the initiation of an industrial sector for cooperative systems and consequently to the diminution of equipment costs. The European project SCOOP is an example of such a large scale experiment both from the number of considered vehicles point of view and from the perimeter of experimental areas;
4. to ensure the integration of applications into an architecture framework so as to share and reuse resources, whether hardware or software;
5. to develop a dual conception of information exchange in which vehicles and infrastructure do contribute at the same levels: this is developed in the conclusion of this report.

## 5.2 ELECTRIC VEHICLES

The development of electric and hybrid vehicles contributes positively to the reduction of CO<sub>2</sub> emissions and greenhouse gases. The fact remains that the future of electric vehicles and more specifically of fully electric vehicles is difficult to identify. It is important to remain cautious in the foresight on the vehicle fleet evolution in the short term (2020) and in the long term (2050).

In France, 5663 electric vehicles were sold in 2012, 8779 in 2013, 10560 in 2014 and 4603 for the first 4 months of 2015, which means a total of 29,605 over the period 2012-2015. At the European level, sales concentrate on Norway (rank 1), France (rank 2) and Germany (rank 3). These figures show that the objectives set by the BLUE Map (19) scenario (approximately 500,000 electric vehicles in Europe in 2020) will probably not be achieved.

Key locks are vehicles cost and autonomy, as well as availability of charging stations.

- The issue of cost is now partly solved in most developing countries with substantial State aids in the form of subsidies to purchase a vehicle;
- likewise proactive actions have been done by States to install charging stations;
- however, the issue of autonomy is the main lock. Today a full electric vehicle is limited to 120 to 150 km. As a result, electric vehicles are mainly urban vehicles that fit in car sharing



systems, in company or administration fleets where they are used as commercial vehicles for the realization of urban tours, but they are also seldom used as a second vehicle in households.

This also raises the issue of the deployment of this kind of vehicle in developing countries: only in transition and high-growth rate countries like China who also faces major environmental problems seem the most suitable candidates for the deployment of electric vehicles (starting, in China with powered two-wheel vehicles).

### 5.2.1 Recommendations

From the road safety point of view, with tens of thousands vehicle fleet only for countries whose size is averaging European ones it is difficult to identify a specific kind of accident for electric vehicles due to the small sample size submitted to the analysis.

Furthermore, the smart grid is an important issue so as to widespread the deployment of electric vehicles. However, current research extends beyond the strict framework of a rational use of existing energy sources available today: nuclear, thermal, hydraulic, wind, solar etc. The concept of the 5<sup>th</sup> generation Road or of the Forever Open Road (FOR) includes the idea of a road that is producing its own energy but also a road that can be providing the energy needed for electric vehicles.

#### We recommend :

1. to foster all research operations that analyze in details the electric vehicle use and driving behaviors with a special attention to possible bias introduced by their specific uses (captive fleet, shared vehicles) and by social and occupational categories of their owners;
2. to foster all research operations that develop the concept of “*while traveling*” recharging. The FABRIC European project is an example of such an operation. It aims at developing a technology that allows the recharging of a vehicle while driving on charging spots that transmit energy without contact.

## 5.3 PROBE VEHICLES

Probes vehicles (or floating car data) allow considering extremely promising applications for road network management. Wherever the vehicle density is sufficient, they offer an alternative to conventional methods for network monitoring based on infrastructure sensors by substituting in-vehicle sensors.

### 5.3.1 Best practices

Today can be considered as the beginning of the exploration of the possibilities given by probe vehicles. Indeed, main applications deal with traffic monitoring, travel time estimation, congestion and incident detection.

The development of in-vehicle sensors allows considering infrastructure diagnosis applications at a 5 to 10-year horizon: rain and ice detection, inappropriate speed limits, road surface degradation, visibility distance estimation etc.

As for cooperative systems, low cost application development can be considered to be relying not

on vehicle sensors (since therefore necessarily newer vehicles) but on sensors embedded in Smartphones (accelerometers, GPS, cameras).

### 5.3.2 Recommendations

The main open questions deal with:

- the performance of low-cost systems;
- information accuracy and its link to the probe vehicles' penetration rate;
- legal aspects.

#### **We recommend :**

1. to foster research operations whose aim is to characterize the performance of low cost sensors, especially those incorporated in nomadic systems like Smartphones. This also includes addressing issues such as the integration of these systems in vehicles to ensure the quality of measurements;
2. to foster research operations so as to develop a scientific framework to estimate the accuracy of results. This framework should take into account the quality of raw data provided by sensors, the frequency of sampling, the penetration rate of equipped vehicles, the data transmission frequency towards the back office centres, the kind of data aggregation-fusion algorithms whatever data is exchanged between vehicles or is coming from another source (eg roadside weather station data);
3. to foster field operational tests to validate theoretical works by comparisons between information obtained by conventional methods of data collection and processing and information based on probe vehicles;
4. to explore parts of legal aspects, especially those dealing with data ownership and compensation models that can be offered to those who provide data.

## 6. CONCLUSION

The development of cooperative systems and probes vehicles are the foundation of what may be called the “*information system tied to the road.*” This system should aim at meeting reciprocal expectations: firstly, infrastructure expectations towards vehicles and secondly vehicle expectations towards infrastructure. This duality is justified through the emergence of future vehicles: autonomous vehicles and associated traffic management system.

An automated highway system cannot be well functioning without a detailed knowledge of the network status. The vehicles themselves will contribute to the knowledge of this status through the concept of probe vehicle.

Conversely, to move safely, vehicles will need an accurate knowledge of the state of the road on which they are travelling: this concept of the high level of service road (or secure road) provides the vehicle with guiding functions (thanks to high quality lane markings), a description of its geometry (slope, curvature, cant), its adhesion etc. This set of information will be included in digital maps or transmitted directly to vehicles from the management centers.

Future work of the Road Network Operations Technical Committee could be aiming at developing this concept in all its dimensions.

## 7. GLOSSARY

ABS	Antiblockiersystem (from German)
ACC	Automatic cruise control (cruise control that control distance headway)
ADAS	Advanced Driving Assistance System
ADSL	Asymmetric digital subscriber line
ASR	Acceleration Slip Regulation
AUTOLIB	Car sharing system in France
CAM	Cooperative Awareness Message
CAN bus	Control Area Network (network for in-vehicle communication between ECU)
CC	Cruise control (speed regulator)
CCTV	Close Circuit Television
DENM	Decentralized Environmental Notification Message
DRIVE-C2W	European project on cooperative systems
DSRC	Dedicated Short Range Communication
ECU	Electronic control unit (in-vehicle micro computer systems)
ESP	Electronic Stability Program (a system to prevent loss of trajectory control)
ETC	Electronic Toll Collection
EV	Electric Vehicle
FCD	Floating Car Data (equivalent to Probe Vehicle, Probe Data, Probe Data Vehicle)
FLEXRAY	High performance and reliability network for in-vehicle communication between ECU
GIS	Geographic Information System
GPS	Global Positioning system
HEV	Hybrid Electric Vehicle
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IHW	Incident Hazard Warning (warning system for prevention of collision)
ISO	International Organization for Standardization
LDM	Local Dynamic Map
LIDAR	Laser detection and ranging (a laser scanner to detect obstacles)
MaaS	Mobility as a Service
METAR	METEorological Airport Report
MLIT	Ministry of Land, Infrastructure, Transport and Tourism in Japan
PDRM	Probe Data Reporting Management
PHEV	Plug-in Hybrid Electric Vehicle
RDS-TMC	Radio Data System and Traffic Message Channel
RIM	Recommended Itinerary Message
SAFESPOT	European project on cooperative systems
SCORE@F	French project on cooperative systems (French part of DRIVE C2X European project)
SPAT	Signal Phase and Timing
TMC	Traffic management centers
TTC	Time to collision
USDOT	Ministry of Transport in USA
V2I	Communication between vehicle and infrastructure
V2V	Communication between vehicles
V2X	Communication from vehicle to other entities (vehicles, infrastructure)
VMS	Variable message sign
WAVE	Wireless Access in Vehicular Environment (European standard for short range communication)
XML	Extensible Markup Language

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## 9. APPENDIX 1 – ISO/TC204

### 9.1 OVERVIEW

Intelligent Transport Systems (ITS) support the movement of people and goods in various aspects. Essential to ITS is information and telecommunication technologies. International standardization of ITS is carried out by ISO, IEC, JTC and ITU. In particular, ISO/TC 204 is a technical committee specialized on ITS standardization activities.

National standards bodies represent ISO in their countries. Participating countries take part in TC meetings and play active roles with a voting requirement and nominate experts for items of their interests. Observing countries follow as observers with the right to submit comments and take part in TC meetings.

TC204 was set up in 1992 and started activities from 1993. TC204 has 26 Participating and 27 Observing countries and holds 12 active WGs for wide technical & application areas of ITS (*illustration 15*).

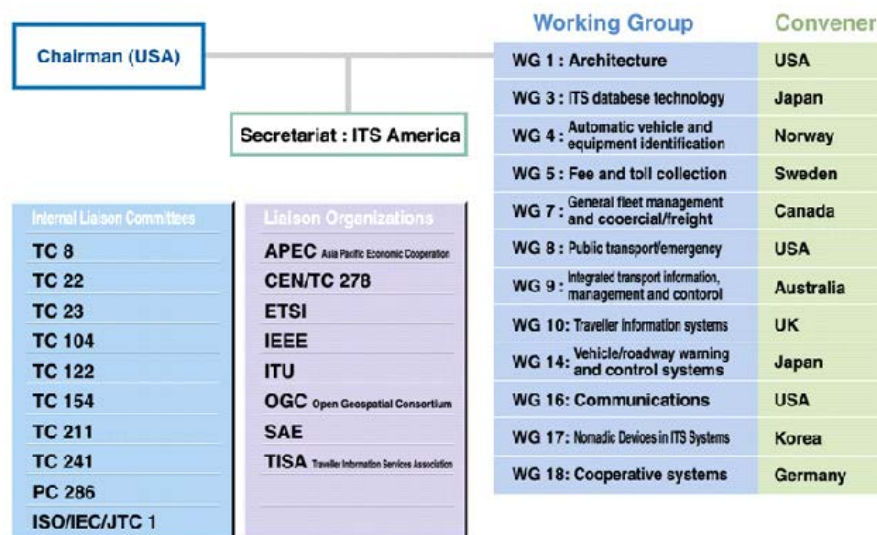


Illustration 15 - Organization of ISO/TC204

The scope of ISO/TC204 covers of standardization of information, communication and control systems in the field of urban and rural surface transportation, including intermodal and multimodal aspects thereof, traveler information, traffic management, public transport, commercial transport, emergency services and commercial services in ITS field. Under study at ISO/TC 204 are standardization proposals for (1) system architecture, (2) interfaces (message sets, etc.), (3) frameworks (data dictionaries and message templates), (4) system performance requirements, and (5) test methods.

## 9.2 ACTIVITIES OF WORKGROUPS

### 9.2.1 WG1

WG1 is preparing standards related to information and methods to be shared within the ITS sector including common use of terms, sharing of concepts and methodologies to describe documents and data in ITS.

### 9.2.2 WG3

WG3 has been involved in standardization of exchanging format between geographic information providers and compact stored format allowing high-speed search, and has made efforts for developing specifications for functional requirements, data models and data elements for geographic information.

### 9.2.3 WG4

WG 4 is in charge of standardization of items necessary for interoperability between systems regarding AVI/AEI, an automatic identification system for vehicles and equipment through electronic onboard equipment or simple media tags. First, it discussed standardization themes on surface transportation like trucks, and then added an intermodal AVI/AEI system as a theme.

### 9.2.4 WG5

ISO/TC204/WG5 is responsible for global standardization of the Electronic Fee Collection (EFC) application, whilst other international standardization groups develop technology-related standards (such as positioning and communication protocols). Most EFC standards are developed as joint work items with CEN (TC 278/WG1).

### 9.2.5 WG7

The current WG7 is a merger of WG6 (General Fleet Management) and WG7 (Commercial/Freight). WG7 is in charge of standardization in the field of the former WG6 and WG7.

### 9.2.6 WG8

WG 8 is working on the standardization of public transport. Public transport includes buses, trains, trams and emergency vehicles.

### 9.2.7 WG9

WG 9 is working on standardization for traffic management (traffic information and control, etc.). Specifically, it is working on the systematization of information and standardization of communication systems between traffic management centers, between centers and roadside modules, and between roadside modules, in order to exchange data efficiently and to provide information for outside organizations.



### 9.2.8 WG10

Traveller information systems, subject to standardization by WG 10, constitute a core part of ITS. This working group has work items designed to study data dictionaries and message sets to provide information for drivers through various communication media, such as FM broadcasting, DSRC, cellular phones and digital broadcasting. Recently, many activities have been seen in integration of user services and XML standardization of TPEG (Transport Protocol Experts Group).

### 9.2.9 WG14

The scope of WG 14 is broad. “*Warnings and controls for autonomous/infrastructure systems*”, including vehicle control, external information sensing, communications, and interface with users.

### 9.2.10 WG16

WG16 is involved in standardizing two systems; Communications Access for Land Mobiles (CALM) ITS systems, and probe information systems. CALM refers to a set of ISO standards for ITS based on the ITS communications and station architecture (ISO 21217). CALM is suitable for the use in C-ITS.

### 9.2.11 WG17

WG17 is in charge of developing standards targeting ITS services using nomadic devices such as smart phones and portable navigation devices which are rapidly disseminating worldwide. Standardizations of vehicle gateway, guidance protocol for safety assistance system, traveler’s information provision service are promoted.

### 9.2.12 WG18

WG18 is aimed for promoting international standardization of cooperative ITS in the cooperation with European CEN/TC278/WG16. The cooperative ITS integrates communications of vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-infrastructure (I2I) with ITS services and applications simultaneously on the communications system, and enables sharing of data between different applications. Development works of WG18 also cooperate with other existing WGs of TC204 and maintains liaisons with other SDOs (especially CEN, ETSI, IEEE, SAE).

### 9.3 MAPPING WITH PIARC SERVICES

For reference, a table of PIARC Road Network Operations (Cooperative vehicle highway systems) is inserted in this section. It shows service mapping with ISO TC204/WG18 (including other WG e.g. WG14).

The following *table* shows how services described in *section 4.5* of this report are mapped into the different WG of ISO/TC2014

TABLE 1 - PIARC RNO SERVICES AND ISO TC204/WG18 ACTIVITIES						
PIARC RNO*			ISO TC204			
Category	No	Application	Related WG	Related WG18 DT	Related WG18 item	Service Group (Based on ISO 14813-1**)
Road safety services	1	Prevention of collision on vehicles stopped on the road	WG3 WG14 WG16 WG18	DT3 DT5 DT8.2 DT8.3	TS 18750 TS 17425 TR 20025 TS 19324	C.3 Automated Vehicle Operation C.4 Collision mitigation / avoidance
	2	Prevention of collision on wrong way vehicles	WG3 WG14 WG16 WG18	DT3 DT5 DT8.2 DT8.3	TS 18750 TS 17425 TR 20025 TS 19324	
	3	Prevention of collision of vehicle with cyclists or pedestrian	WG3 WG14 WG16 WG18	DT3 DT5 DT8.2 DT8.3	TS 18750 TS 17425 TR 20025 TS 19324	
Mobility Services	4	Traffic information and recommended route	WG3 WG10 WG16 WG18	DT3 DT5 DT7 DT8.2 DT8.3	TS 18750 TS 17425 TS 17426 TR 20025 TS 19324	A.2 Real-time Transport Status Information A.3 Real-time In-vehicle display A.4 Real-time route guidance and information A.5 Multi-modal trip planning A.6 Travel services information
	5	Car pooling	WG10 WG17	-	-	E.3 Demand responsive and shared transport

**TABLE 1 - PIARC RNO SERVICES AND ISO TC204/WG18 ACTIVITIES**

PIARC RNO*		ISO TC204					Service Group (Based on ISO 14813-1**)	
Category	No	Application	Related WG	Related WG18 DT	Related WG18 item			
Network operation services	Mobility application	6	Travel time estimation	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025	B.2 Transport management and control	
		7	Detection and characterization of congestion	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		
		8	Information on the availability of a route	WG3 WG9 WG16 WG18	DT3 DT5 DT6 DT7 DT8.2	TS 18750 TS 17425 TS 17429 TS 17426 TR 20025		
	Road Safety Application	9	Dynamic harmonization of speeds and headways	WG3 WG14 WG18	DT3 DT5 DT7 DT8.2 DT8.3	TS 18750 TS 17425 TS 17426 TR 20025 TS 19321		
		10	Queue alert	WG3 WG14 WG18	DT3 DT5 DT8.2 DT8.3	TS 18750 TS 17425 TR 20025 TS 19321		
		11	Stationary Vehicles alert	WG3 WG14 WG18	DT3 DT5 DT8.2 DT8.3	TS 18750 TS 17425 TR 20025 TS 19321		
		12	Detection of potentially hazardous areas	WG3 WG9 WG14 WG18	DT3 DT8.2	TS 18750 TR 20025		
		13	Rain detection	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		
	Weather condition monitoring	14	Ice detection	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		I.2 Weather monitoring
		15	Fog detection	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		
		16	Distance of visibility in the fog	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		
		17	Road surface diagnosis	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025		
Road distress monitoring	18	Detection of degradation of the road surface	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025	B.5 Road transport infrastructure maintenance management		
	19	Road geometry unsuited to speed limits	WG3 WG16 WG18	DT3 DT8.2	TS 18750 TR 20025			
	20	Survey on O/D	WG3 WG16	-	-		Probably falls underneath B.4 Demand management, although it does not appear to be specifically called out	
Advanced knowledge survey	21	Environmental assessment	WG16 WG18	DT3 DT8.2	TS 18750 TR 20025	I.3 Environmental conditions monitoring		
	Environmental application	22	Eco driving recommendations	WG16 WG18	DT3 DT8.2	TS 18750 TR 20025	Perhaps a new service group under Vehicle Services	



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*World Road Association (PIARC)  
Tour Pascal - 19<sup>e</sup> étage  
92055 La Défense cedex, FRANCE*

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