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AUTONOMOUS VEHICLE: THE CONCEPT OF HIGH QUALITY OF SERVICE HIGHWAY

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ABSTRACT – Vehicle and Road Automation (VRA) is a support action funded by the European Union and coordinated by ERTICO that addresses the identified deployment needs from different perspectives: the deployment scenarios, the legal and regulatory needs and finally the standardization and certification requirements. In particular, the importance of the physical infrastructure and its link with the digital infrastructure has been emphasized. Indeed, to move safely, vehicles will need an accurate knowledge of the state of the road on which they are travelling. Automated vehicles are expecting from infrastructure that it fulfils some requirement in order to maximize safety. Generally speaking, the infrastructure must be "readable" by the vehicle. The objective of this paper is to investigate the concept of High Quality of Service Highway (HQoSH).

In this paper after defining infrastructure feature and their metrics we will show how the digital infrastructure can reflect the physical infrastructure state. It relies on data that has to be collected and analyzed by road networks operators. The classical approach consists in using road network operator services vehicles which periodically patrols along the itinerary. However, a more innovative solution consists in using the automated vehicles themselves as probe vehicles. Then infrastructure features must be provided to vehicles. Therefore, we will distinguish three class of variability in road features: static, temporary and dynamic and for each of them we will examine how the information can be provided to the vehicle. Finally, we will propose a scenario that will illustrate how HQoSH will contribute to optimize automated vehicle safety.

INTRODUCTION: HIGHWAY AUTOMATION AS A SYSTEM

Up to now, most of the works dedicated to autonomous vehicles are focused on the vehicle itself or on the digital infrastructure. Issues on safety and reliability are mainly seen from a vehicle standpoint. As a consequence of this vehicle centric vision, it appears that the world or OEMs and the world of road network operator have difficulties to communicate and exchange their respective expectation one from each other.

Fortunately this approach is evolving. Both OEM and road network operators start to understand that to move safely vehicles will need an accurate knowledge of the state of the road on which they are travelling. Indeed, automated vehicles are expecting from physical infrastructure that it fulfils some requirement in order to maximize safety.

Conversely, to comply with what is expected by the vehicles to ensure a given level of safety, road operators need to have accurate and real time knowledge of the state of the infrastructure. Probe vehicle (or FCD[1]) is a new approach to achieve this goal. FCD is complement to the classical approach based on patrol vehicles, road surface sensors and road side equipment.

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[1] Floating Car Data

In addition, the digital infrastructure which is a virtual representation of the physical infrastructure must reflect at any time its current state. This is made possible thanks to cooperative systems and local dynamic map (LDM).

Therefore, automated and probe vehicles, physical infrastructure, digital infrastructure, cooperative systems and local dynamic map are the key components of what we call “highway automation as a system”.

(Nicolas éventuellement pour compléter ?1/2 page)

INFRASTRUCTURE FEATURES AND METRICS

Automated vehicles are based on some key functions whose functioning must be ensured with a high level of reliability. It concerns mainly trajectory control but also the capability to anticipate and to manage simple or complex road situation with respect to Highway Code. Table 1 provides a non exhaustive list of such functions and the required information for a safe realization.

Function/manoeuvre	**Required information**
Lane keeping	Lane marking for lateral guidance
Curve overshooting prevention	Lane marking, road geometry, road skid resistance, road surface degradation, speed limit
Distance headway control	Distance to vehicle ahead and speed limit
Collision avoidance or mitigation	Near obstacle detection, far obstacle location
Collision avoidance on traffic jam queue	Traffic information, traffic jam queue location
Speed control	Legal speed limit, road geometry, visibility, road skid resistance, weather conditions
Safe overtaking	Road geometry, visibility, oncoming vehicles
Safe crossroads crossing	Crossroad geometry, approaching vehicles, traffic lights status
Safe roundabout crossing	Roundabout geometry, approaching vehicles
Vehicle stability	Road geometry, road skid resistance, road surface degradation, speed limit

Table 1 – Automated vehicles key functions

Features

Automated vehicle is no more an abstract concept for an unclearly defined future horizon. Five levels of automation has been defined making consensus worldwide. Lowest level automated vehicles (level 1 and 2) are on the market right now and in the near future level 3 automated vehicles will circulates on our road networks. Gradually, as the levels of automation will increase, expectations with respect to the infrastructure will be increasingly demanding, meaning that infrastructure has to provide an increasing level of quality of service (QoS). This QoS itself relies on some infrastructure features which are contributing to enhance or alter vehicle safety.

Some of these features affect road readability, other impact vehicle dynamics or their ability to anticipate some potentially critical situation (Table 2). All of them play a role in achieving a safe realization of the functions described in Table 1.

Infrastructure Features	**Role/Impact**
Lane marking readability	Vehicle guidance for lateral control
Road curvature and cant	Vehicle stability, curve overshooting prevention
Road slope	Collision avoidance during overtaking manoeuvre.
Road skid resistance	Vehicle stability in straight-right and curve situation
Ruts, potholes, ruptures, cracks	Vehicle stability in all situation
Geometric visibility	Collision avoidance during overtaking manoeuvre
Traffic light status readability	Safe crossroad crossing
Road sign readability	Driving with respect to highway code (e.g. speed limit)
Weather condition	Vehicle stability, vehicle headway, safe overtaking

Table 2 – Infrastructure features

Class of variability

It should be noted that an important characteristics of the above mentioned features is their dependence on time. Indeed, each of them can evolve more or less quickly over the time. As an example we have to consider at least three types of speed limits: 1) static speed limit materialized by road sign on the road side, 2) dynamic speed limits materialized by variable message signs (VMS) used for traffic regulation which can change over more or less long period (from a few hours up to many days) and 3) temporary speed limits materialized by removable road signs used to lower the speed throughout a work road or accident zone for instance. More generally, according to their rate of change, all infrastructures features could be classified into various class of variability such as static, dynamic, temporary. This will impact data representation of the digital infrastructure as shown in the sequel (see section on local dynamic map).

Feature metrics

Depending on the automation level, vehicles will expect from infrastructure a given level of QoS. For example, the presence of ruts or potholes on road where low speed automated vehicles are driving (less than 50 km/h) will be negligible on safety. Conversely, such road surface degradation can drastically affect safety when the same vehicles are driving autonomously on motorway at speed up to 130 km/h. Therefore it becomes necessary to introduce a road feature metrics such as to quantify the QoS level provided by the infrastructure. Indeed, depending on the QoS level, vehicle will decide if it can move into an autonomous or a manual mode.

(*La suite par Nicolas*)

DIGITAL ARCHITECTURE

As above mentioned the physical infrastructure is characterized by various features, their class of variability and their metrics. Consequently, an automated vehicle will move safely on a given road under the condition that these features will have characteristics of which values are enclosed within some limits. This is what we call a “secured itinerary” or a “High QoS road”

(HQoSR). Therefore, a vehicle arriving at the beginning of such a road will warn the driver that he can switch the vehicle driving mode from manual to automatic. Conversely, as soon as the "safe road" conditions are no more fulfilled, the vehicle must warn de driver to switch from automatic to manual. This is made possible thanks to a digital infrastructure which is a numeric representation of the physical infrastructure. This means that the infrastructure must provide in real time the vehicle with information that describes its current state. To achieve this goal many solution are possible depending of the features class of variability:

- Static features can be recorded under the form of attributes into digital map,
- Dynamic characteristics could be transmitted from traffic management centres to the vehicles using I2V[2] communication. Latency time seems not to be critical allowing then to rely on 2,5G or 3G media for instance.
- Finally temporary road characteristics could be transmitted to vehicle using both I2V and V2V[3] short range communication. Some information could be time-critical thus requiring low latency time communication media which will rely on IEEE 802.11p protocol.

(Jacques, ½ page max.)

AUTOMATED VEHICLES AND PROBE VEHICLES

Information on the current road status has to be collected and analyzed by road network operator before to be sent to the vehicles. The classical approach consists in using road network operator vehicles which periodically patrols along the itinerary or sensors located under the road surface or into road side units (RSU). However a more innovative solution consists in using the automated vehicles themselves as probe vehicles. Indeed recent vehicles (and especially future automated vehicles) are equipped with many sensors that allow to measure road characteristics: lane marking quality, road surface condition, road pavement degradation, visibility distance, weather conditions etc.

In this case, the sensor accuracy is improved by the use of Big Data analysis, the more data on a specific point is gathered and the more accurate is the measurement. However it implies to implement a whole secured data chain from the probe vehicles to a data centre using communication technologies and data storage. Probe vehicles can also be used to detect faults in autonomous vehicle sensors by comparing results to other the probe vehicles and searching for outliers.

Furthermore, the database structure, containing all data from probe vehicles, should be designed as dynamic where new infrastructure features can be added if needed by autonomous vehicles.

The main issue with probe vehicles analysis will be the way data are processed. Algorithms used should be calibrated and validated with test vehicles and test roads. This can be done by simulation means but should also be done in real conditions.

(Olivier, peux-tu développer davantage ?, ½ page en tout)

INFORMATION EXCHANGE : THE LOCAL DYNAMIC MAP

(Dominique 1 page)

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[2] I2V : infrastructure to vehicle communication.

[3] V2V : direct vehicle to vehicle communication.

Context and issues

Currently, the solutions proposed by laboratories (universities, institutes, and manufacturers) are based on embedded expensive devices and often working in controlled road situations (no snow, no rain, with good markings state, roads with low curvature ...). Among the first prototypes built for autonomous driving, we can mention those of Google, Audi, Tesla, PSA, Renault and more recently VeDeCoM. Within IFSTTAR (LIVIC laboratory), this type of researches was also developed in the projects ANR ABV, FP7 Have-It [4] and FP7 eFuture. These studies and the results obtained allowed doing some interesting findings regarding the use, the maturity and the capability to deploy this type of automated driving applications. This also allowed us to estimate the impact and the level of performance that we could expect. The conclusion is clear; the level of development is still far from the necessary performances needed for a large-scale deployment.

The first observation, and probably the most important, is that these active and safe embedded systems must guarantee a high level of reliability and a great robustness. Moreover, these systems must work in an extended set of conditions including degraded conditions. Unfortunately, to be closer to that goal (reliable and robust systems), the sensors to embed and the sources of information to handle on these prototypes must be numerous, from different types, and often they are very expensive. This complementarity and redundancy of information must guarantee an enough level of certainty, accuracy, confidence, and reliability. In case of degraded weather conditions and road infrastructure (road without readable markings), and in case of risky, hazardous and complex situations, the existing prototypes are not now able to operate optimally. In these degraded situations, the commonly used solution is to return control to the driver. However, we must keep in mind that this type of operating mode changing requires anticipating these risk situations and demand the use of an extended dynamic perception of the environment (a time range of 7 to 10 seconds). To achieve this aim, it is imperative to make the best use of distant information provided by either the infrastructure or neighboring vehicles. In these two situations, the deployment of communication means is necessary. It is important to quote that this step of autonomous driving break can also induce a stress and risk period for the driver.

The second observation relates to road infrastructure. Indeed, with many tests (some of them in IFSTTAR), on the issues of both the autonomous driving and the mobility of the future, we find that the road infrastructure presents on the French network is not enough efficient and adapted in order to guarantee the continuous use of active applications with a very high level of reliable and robustness. So, it seems relevant and necessary to study the problem and to propose solutions to adapt and / or to modify the existing infrastructure and make it more cooperative (generation of information) and intelligent (adapting information according to the situation). This type of research is a key topic of the European (H2020) and French (NFI, IFSTTAR unifying project R5G) Strategic Guidelines.

In this context and with using of these findings, it is clear that the future of autonomous mobility systems go through a balance between management and transmission of information from the infrastructure and vehicles. It is for these reasons that we propose in IFSTTAR innovative solutions, based on new distributed, interactive and cooperative approaches between vehicles and infrastructure, robust to degraded conditions for the building of Local and Extended Dynamic Perception Maps (LDPM and EDPM).

Environment Features class (Road and Infrastructure) and level of information

To address these constraints of information robustness and reliability in all road conditions and in all weather conditions, several complementary systems are possible without impacting "unassisted" road users for an efficient multi-modal mobility.

Embedded local level: The first level of information sources concerns embedded exteroceptive and proprioceptive sensors. These sensors allow building a local dynamic representation of the environment is made up of estimate of the road key components attributes: the obstacles, the road, the ego-vehicle, the environment, and the driver. These estimates obtained from both the processing and the fusion of raw data are typically used to respond to local situations. With this modeling, we are able to know the dynamic state of obstacles moving around the ego-vehicle and to know the position of the different traffic lanes. Knowledge of the "environment" key component allows knowing the status of both the vertical road signs and the weather conditions (visibility distance, presence of wet road, fog density ...). However, this knowledge is still limited by the range of onboard sensors and their availability is related to the quality of the environment (weather conditions, obstacles and road signs visibility, wear condition and road marking visibility). In case of partial or full lack of this information, the application quality can be sharply deteriorated and the level of functionality of the applications could also be questioned. In the case of informative applications, the impact on the safety is limited but in case of active applications, the consequences can be critical.

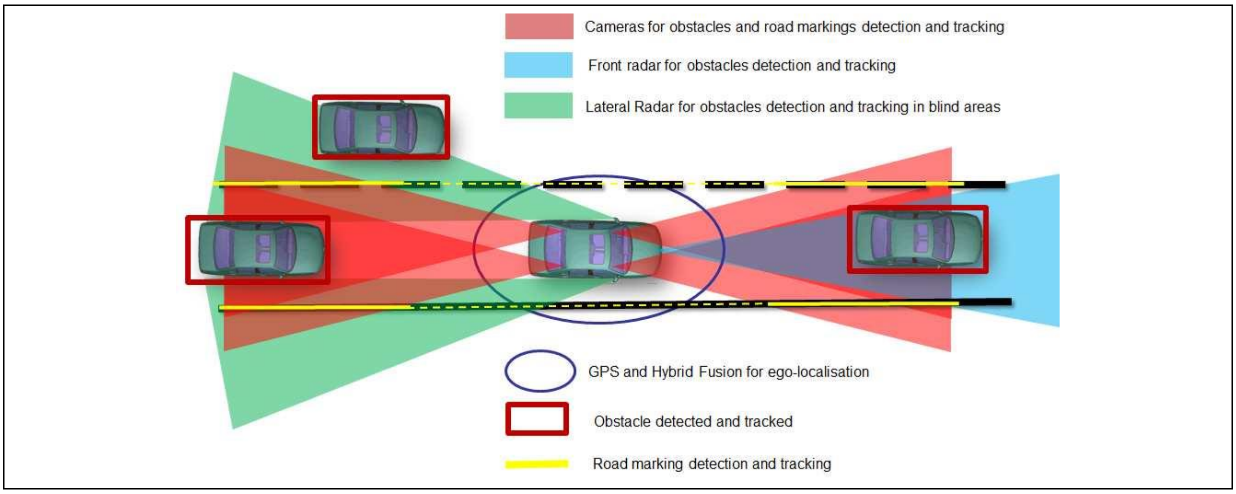

Figure xx: Local Dynamic Maps from embedded sensors

Long range communicating level: The second level of information concern objects and connected means that enable access to distant information (out of range of the embedded sensors). Among the available information, e-Horizon gives the ability to anticipate the arrival in a singular road situation such as an intersection, a high-curvature bend, a change in the traffic lanes configuration (narrowing, widening, increasing and decreasing the number of lanes ...). More dynamic information can be added to this information such as a work area presence, the current state of the intersection road sign, the risk level, the state of the pavement and the road markings, the traffic state, the weather conditions by area. All this information is available and transmitted by management centers present on the infrastructure. These management centers get their information from road users or probes vehicles. In this first "distant" or "long range" level, the issue is focused on the information sampling time and their levels of quality (accuracy, certainty, confidence)[5].

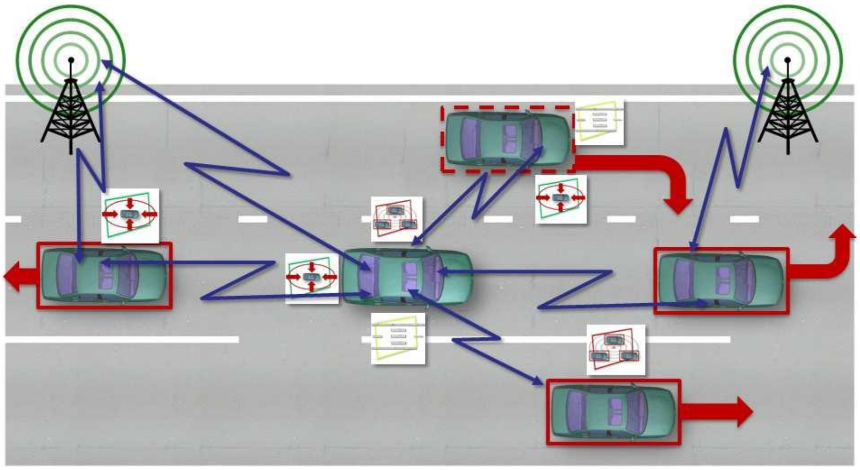

Figure xx: Extended Dynamic Maps with long range communication of key components information

Local intelligent and communicative level: The third level of information is intermediate. It is local but connected level. In this level, we find the short range media and the specific beacons and primitives integrated in the infrastructure. For instance, we can mention the electromagnetic systems like transponder devices. In this type of system, we often have a transmitter with a modulated wave, a repeater or re transmitter, and a receiver. In general, the active source is implemented on the vehicle and the transponder is integrated into the road surface and especially in a strategic position (lane border). The processing of the emitted/received waves will allow, in a very short-range (lane width), accurately to estimate the lateral distance between the vehicle and the road border. This process is, in theory, invariant to weather conditions and road surface damages. Moreover, it is easily possible to deploy this type of device over large areas because its cost of production and implementation is very low. Another interesting aspect is that this device can also be implemented and allows generating information in areas without visible and usable road markings. Depending on the technology used, this type of solution can transmit modulated and richer information to characterize, for example, speed limits, or approaches to specific and singular areas (city entrance, intersection approach, turning approach, round about ...) redundant to the geographic maps (Google Map, Open Street Map ...).

Local and Extended Dynamic Perception Maps

Thus, to ensure reliability and robustness of driving automation in any conditions, the estimate of the key components attributes of the road scene and the cooperative fusion of the information produced by the three levels of information presented above is essential.

For active driving assistance applications (lane keeping, lane departure avoidance, interdistance regulation, collision mitigation and avoidance, lane change assistance, adaptive co-piloting ...) it is therefore important to know how to process and to merge the 3 levels of information in order to build local and extended dynamic perception maps used by applications. In these perception maps, 5 key components of the road scene are characterized by all the information (not exhaustive) presented in the table below:

Obstacles	Roadway	Ego-vehicle	Environment	Driver
Dynamics: position, speed,	**Road markings**: type and attributes	**Dynamics**: position, speed,	**Weather conditions**: rain,	**Driver state**: alertness, vigilance,

heading … **Quality level**: confidence, accuracy, certainty … **Type**: vulnerable, non-vulnerable, contingencies … **Specific features** : Segments, length, width, height, colour …	(a,b,c for polynomial representation) … **Lanes**: number, position of the ego-vehicle, type (exit, merge, entrance ramp...) … **Navigable space** **Road geometry**: slope, bank, curvature, width, roughness … **Floor capabilities**: adhesion, tire-friction coefficient, type of coating, wear level, cracks …	heading … **Capabilities**: tire grip, braking, acceleration, ABS, ESP … **Map-matching**: link with the infrastructure … **Features**: communications, sensors equipment, perceptive area, range … **State**: indicators state, light state, gearbox …	fog, snow, low sun, visibility distance … **Traffic condition**: density, capacity … **Signs**: prohibition, danger, duty, indication, informative … **Road infrastructure**	monotony, stress … **experience and category**: young driver, experienced, elderly **Driver behavior:** gaze direction **driver actions**: gear, brake and acceleration pedals, indicators, lights

More specifically, if we want to implement an application of traffic lane tracking ensuring a high level of robustness to specific punctual degradation and breakdown (loss of road marking, degraded pavement, loss of ego-localization ...), we will have to merge information from 3 levels of knowledge. The first information concerns the positioning of the ego-vehicle and the identification of the traffic lanes [1][2]. For the positioning of the ego-vehicle, there exist many data fusion algorithms using embedded sensors proprioceptive (GPS, accelerometers, gyroscope, odometer). Unfortunately, some particular road configurations lead to GPS outage or degradation. What happens in that case? Is the positioning obtained with only dead reckoning (prediction stage) enough accurate to ensure an efficient lane keeping and lane tracking? A solution is to use a detection, a tracking, and an identification of the road markings and traffic lanes with an optical processing [7][8] in order to get redundant information allowing to update the ego-vehicle state estimation and compensate the GPS outage during a relatively short time (some seconds). Unfortunately, the quality of this approach is dependent on the quality of two sources of data: the accuracy of the map and the level of quality of road markings. Indeed, without road markings or with degraded road markings, the detection stage becomes very difficult or impossible.

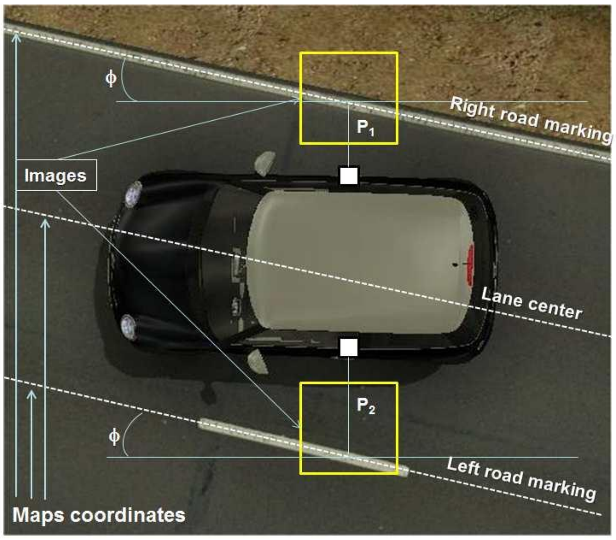

Figure xx: Ego-positioning enhanced with road marking detection and accurate MapMatching processes.

Therefore, in case of performance degradation of both the first hybrid fusion approach based on a classical filter (EKF, UKF, or IMM)[3][6] and the second approach using optical processing and accurate map, we need to find a new alternative source of information that is not impacted by the same causes of degradation. To reach this goal, infrastructure adaptation is essential. The solution is to add electromagnetic passive systems on the infrastructure encoding several types of information (speed, distance from a road singularity or an intersection ...) and to estimate the lateral distance between the ego-vehicle and the road (or lane) border. Then the use of an adaptive and dedicated fusion strategy will ensure a reliable and robust continuous lateral estimation even if, momentary, a loss of road marking, GPS, and potentially transponder appears. By reliability, we mean that this system has to provide always results included in an operating domain ensuring data usability and reliability. The robustness represents the capability of the system to not be significantly impacted or even to be invariant, to outliers and to noisy data (appearance of punctual failures or disturbances).

This example shows perfectly the need to know and to manage the information obtained from multiple sources of information coming from the vehicle and the infrastructure. It also shows the need to guarantee the quality of this information and the reliability and robustness of the algorithms using them. Finally, this simple use case shows that the use of information coming from onboard sensors, their processing and from distant system (with communication means) is sometime not sufficient. A strong reflection on the use and the adaptation of the road infrastructure as additional source of information and its informative capacity is essential to ensure a high level of quality and safety for active driver assistance applications.

FITH GENERATION ROAD (R5G) AS A GLOBAL SOLUTION

(Nicolas, 1 page)

DRIVING SAFELY WITH AN AUTONOMOUS VEHICLE: A SCENARIO

A typical driving scenario could be described as follows.

- A vehicle is arriving at the beginning of a secured itinerary.
- It receives information which describes the level of service provided by the infrastructure at this place.
- Therefore, the vehicle decides the level of automation it can support and notifies the driver.
- The driver accepts or rejects the proposed level (in the sequel, we assume he has accepted).
- In normal condition, the selected automated mode will be kept until the end of the safe itinerary.
- In abnormal condition (e.g. bad skid resistance condition) the vehicle receives the relevant information and evaluates if the new (lower) level of service complies with the current level of automation. If not, it asks the driver to switch back to the manual mode or to select a lower automation mode which complies with the current level of service.

- Finally, the vehicle reach the end of the high quality of service road and the driver is required to switch back to the manual mode.

All these modes change must be notified to the driver with a sufficient margin time to give him the opportunity to regain control safely. However, once this time margin is elapsed and without driver reaction, the vehicle must be able to manage autonomously a “minimal risk manoeuvre” [reference à HAVE-IT] such as stopping on the road shoulder.

(Jacques,1/2 page)

DISCUSSION

(Olivier,3/4 page à 1 page)

Automated transportation systems can be designed in several ways. Depending on the selected high level architecture, the effect on users trust and expectations will be radically different. Existing and proposed architectures vary globally from:

- Supervised: The whole automated transportation system is controlled by a supervisor, like an omniscient god managing all decisions taken by automated vehicles. This architecture supposes to have a reliable communication network. This category can be decomposed in three:
    - Distributed: Computations are done on several datacentres enabling a more reliable system [10].
    - Centralized: Computations are only performed on a single datacentre responsible for all traffic management.
    - Hybrid: A central computer manages all distributed datacentres [9].
- Fully autonomous: Each individual can make its own driving decision and can realize its own driving commands

In this paper, the proposed architecture is hybrid with probe autonomous vehicles gathering and sharing data to central server building a Global Dynamic Map from all received Local Dynamic Maps. The infrastructure plays the role of several distributed sensors and communication systems feeding the central database used by autonomous vehicles.

This kind of architecture, practical and efficient on a technical point of view may raise several issues.

On the matter of privacy, drivers would be travelling in a world surrounded of sensors. Sensors will be in their own car, on the road they are driving on and data will be processed in an unknown location. To trust the system, an important effort should be taken on the privacy regulation to protect users from any hacked usage of their private data. In France, the CNIL is responsible for protecting people and should be informed of such projects but this should be generalized.

On the responsibility side, a complex task will be to investigate the responsibility in case of accident. This is done in aeronautics for airplane crashes. Responsibility is often shared between the pilot, the air company, the airplane manufacturer and the air controllers. In the case of road automated transportation system, it is assumed that it would be the same. However, the fact that the probe vehicle is automatically estimating the level of service of the road may complicate this task as most of estimation algorithms will be provided as black boxes. Then, in case of accident, how to determinate who is the responsible? The probe vehicles which have made a wrong measurement (bias of all probes vehicles), the data centre which was not equipped with an efficient algorithm or the road itself for not being easy to read? Thus, probe vehicles estimation algorithm should be certified on calibrated experimental and simulated test road is order to give the possibility to simulate the accident conditions.

On a technical point of view, the standardization issue needs to be taken into account. If each road manager develops its own standard database it will raise compatibility issues. In any case, a community around data standardization for quality of service evaluation should be created around road managers, car manufacturers and data analysts in order to build a common norm. Furthermore, the hacking risk should be considered really high when modifying an entry on a database can make all vehicles to switch from autonomous to manual mode.

Finally, the cost of maintaining such data centres for quality of service should be balanced by the provision of a service reducing the cost of transportation. This can be done by extending the concept of quality of service to environment aspects such as air pollution or energy consumption.

CONCLUSION

(Jacques et tous, 1/4 à ½ page)

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(Tous, 3/4 page)

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