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UDC 681.32

CITYMOBIL2 – CHALLENGES AND OPPORTUNITIES OF FULLY AUTOMATED MOBILITY

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Abstract

Main benefits of road automation will be obtained when cars will drive themselves with or without passengers on-board and on any kind of roads, especially urban areas. This will allow the creation of new transport services, forms of shared mobility, which will enable seamless mobility from door to door without the need of owning a vehicle. To enable this vision vehicles will not just need to become "autonomous" when automated, they will need to become part of an Automated Road Transport System (ARTS).

The CityMobil2 EC project mission is progressing toward this vision defining and demonstrating the legal and technical frameworks necessary to enable ARTSs on the roads. After a thorough revision of the literature allowing to state that automation will give its best when it will be full-automation and vehicles will be allowed to circulate in urban environments, the paper identifies where these transport systems perform at their best, with medium size vehicle as on-demand transport services feeding conventional mass transits in the suburbs of large cities, on radial corridors as complementary mass transits with large busses and platoons of them and as main public transport for small cities with personal vehicles; then defines the infrastructural requirements to insert safely automated vehicles and transport systems in urban areas. Finally it defines the vehicle technical requirements to do so.

1. Introduction

CityMobil2 is a European project which deals with automating mobility. The CityMobil2 vision can somehow clash with other based on the automation of the single vehicle which is supposed to bring all kinds of benefits without requiring neither communication nor the involvement of the infrastructure. The first section of this paper is dedicate to analysing the claims and quantifies the expected benefits of automation demonstrating that only driverless communicating vehicles which are capable of driving themselves out of the motorway can really provide the promised breakthrough.

Established that automating mobility is much more than just automating vehicles, not all automation forms are useful whenever and wherever; each environment has a best performing system and sometimes, though sustainable in the long term, the implementation of automated road transport system might require legislative intervention to make possible and sustain the start-up of new transport concepts. Building on the results of its predecessor CityMobil project, CityMobil2 uses a geographical classification to identify the transport tasks better suitable to each transport system based on road vehicle automation. CityMobil2 has 12 cities studying how best integrate (and where in the city) automated road transport systems.5 of them will become real life demonstrators.

Where does this vehicle have to run then? How safely (and legally) insert them on urban roads? CityMobil2 defined where these system should run and how adapting roads to make them as safe as rail transport though as flexible as cars. Section 1.3 reports on these findings of the project.

Final section of the paper, before conclusions, reports on the development of a list of technical requirement for automated vehicles to be part of an automated road transport system.

2. Vehicle automation levels and their benefits

NHTSA (National Highway Traffic Safety Administration) and SAE have recently classified automated road vehicles in levels on the basis of how many and which ones of their functionalities are automated.

NHTSA has defined 5 levels of automation [1], from Level 0 (no automation) to level 4 (full self-driving automation) where *[…]the driver […] is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles*. SAE is currently defining 6 levels of automation (they will be reported in standard SAE J3016, currently work in progress) [2], from level 0 (non-automated) to level 5 (full automation) where the vehicle automatically manages *[…] all aspects of the dynamic driving task under all roadway and environmental conditions […]*.

The potential benefits of automating road vehicles are: increased road capacity, increased safety, lower environmental impact, opportunity for new business models. However different levels of automations bring to different levels of achievable benefits. In this section the achievable benefits coming from different levels of automation will be discussed and analyzed.

Both SAE and NHTSA fail to include in their definitions of automation levels cooperative systems; V2V (vehicle to vehicle) and V2I (vehicle to infrastructure) communications can be crucial to claim some of the benefits.

Safety. Piao and McDonald argue in [3] that only cooperative systems allow to reach safety and efficiency benefits. For example ACC (Adaptive Cruise Control) allows to maintain a desired time gap from the preceding vehicle but for driving comfort convenience the braking capacity is limited and the driver has to take over the control when a higher level of braking is needed. Such situations can bring to not negligible safety issues. Many studies addressed this topic; among them [4, 5, 6 and 7], agree that Advanced Driver Assistance Systems (ADAS) while increasing safety one side might decrease it on several others:

- some drivers might fail to intervene effectively in automation failure scenarios; ADAS seemed to make drivers less likely to reclaim control in an emergency-braking, the measured brake time was 3 times higher and the brake reaction time 2 seconds higher than the corresponding ones in a fully manual scenarios;

• it is conceivable that newly qualified drivers with basic training could immediately use a vehicle equipped with ADAS; this may improve their performance in the short-term, but since novice drivers do not possess the knowledge or experience to react in a critical situation, there will be no over-learned reactions to emergency situation and errors may occur.

Level 4 (according to NHTSA) and levels 4 and 5 (according to SAE) on the other hand will need to embed recovery strategies and fail-safe and safe-life protected failure modes not having the possibility to rely on the driver presence in case of automation failure strengthening safety.

Capacity. Many studies have been carried out to investigate the effects of ADAS on road capacity. In short road capacity is mainly a matter of time gap between 2 adjacent vehicles. In [8] the effects of both autonomous and cooperative ACC on highway capacity have been evaluated in a simulation of a single-lane highway. They represent the typical results that can be obtained in terms of road capacity using ACC. Setting an average time gap of 1.4 s they found the greatest impact is from 20% to 60% of ACC penetration in the flow but, even in this best case, the estimated capacity increase with ACC remain quite modest, at best less than 10%. This means going from the 2100 v/h of the reference scenario to the 2250 v/h of the best scenario. Moreover, increasing ACC penetration above 60% leads to modest loss of capacity. The conclusion is that sensor-based (autonomous) ACC can only have little or no impact on highway capacity even under the most favourable conditions.

Time gap between vehicles can be reduced using communication-based (or cooperative) systems. Reducing the time gap under 1.4 s leads both to user acceptance and safety issues if driver intervention is still expected in emergency situations. These issues can be solved non contemplating driver intervention at all through CACC or platooning. According to [8] CACC set with a time gap of 0.5 s can potentially double the capacity of a highway lane at a high market penetration. In this paper it is worth to consider that such a result can be reached only at a 100% market penetration: even just a single vehicle not communicating with the other vehicles and/or with the infrastructure would create a non-negligible safety concerns.

Furthermore there is a legal issue to consider on this regard. Road code indicates the brick-wall-stop as the criterion to calculate the safety distance from the preceding vehicle. Setting an average deceleration of 5 m/s^2 and a reaction time of 1 s this criterion returns a maximum lane capacity of 1500 v/h at 25 km/h that decreases increasing the speed: 1300 v/h at 50 km/h, 1125 v/h at 70 km/h and so on. Basing on this criterion a lane capacity of 2100 v/h is already illegal and, in a certain way, the introduction of partial automation tends to force drivers to go against the law reducing even more the time gap between the vehicles. Platooning will only be possible if amendments to the road code are made as explained in appendix 1 to [13].

Environment. A recent study [9] comparing an automated highway system (AHS) and ADAS in terms of environmental impact, technical feasibility and economic affordability found that AHS are the most promising technology for increasing capacity and reducing CO2 emissions.

An in-depth overview of many ICT-based solutions and their contribution to CO2 reduction is reported in [10]. Among the most promising technologies of road automation platooning is the one guaranteeing the greatest CO2 reduction, approximately between 5 and 7.5%. At second place it can be found ACC, with an addressed CO2 reduction slightly above 2.5%. Benefits of platooning in terms of CO2 reductions are addressed in many other studies. Among those in [11] a 15% reduction is reported for three trucks driving at 80 km/h with a gap of 4 m. In [12] a fuel save between 7 and 15% is reported for three cars with a gap of 8 m following two heavy trucks at 85 km/h.

A vehicle consumes less energy in a smooth driving at constant speed rather than in stop and go conditions and it consumes less energy at high speed closely following another vehicle because it has less aerodynamic drag. Therefore from the environmental point of view the major contributors of automation to fuel consumption, keeping the total driving mileage constant, are reducing congestion and smoothing driving conditions and platooning to reduce aerodynamic drag at high speed.

As explained in 1.1.2 before full automation (and the necessary legal amendments) there is little contribution to be expected in reducing congestion and allowing platooning.

Lifestyle and business model. Automation, the full automation which allow to send empty vehicles to relocate themselves where needed most, allows implementing shared mobility and transit systems much more flexible and comfortable than conventional ones especially in those areas traditionally badly served by public transport.

The eventual increase of public transport (and shared mobility) share that might result because of automation implies economic changes too, the greatest being represented by the overall business model of the road transportation system. There will be the real chance to substitute the one person-one vehicle business model with other business models. Such a topic deserves an in depth argumentation that, however, goes beyond the aims of this section. On this regard part of the work going on in the CityMobil2 project is focused on assessing the socio-economic impact of automated road transport systems. Findings from this work will help to define the economic scenario of the future and to set the proper path to make it real and convenient.

3. Which automated transport in which part of the city

A new mobility based on automated road vehicles providing door-to-door seamless mobility (on-demand and/or scheduled) with the aim of replacing private cars and, in some contexts, even traditional public transport is the subject of several subsequent research projects funded by the European Commission.

ARTS, Automated Road Transport Systems, as lately defined by the CityMobil2 project, range from large buses to be used on corridors to small individual vehicle to dual mode city cars and have been tested in several European Research Projects and some of them are now operating in different cities and contexts. Such ARTS can be summarized in the following four following categories.

- Personal Rapid Transit (PRT): automatic individual transport systems that use 4-place vehicles running in dedicated lanes[1]. PRTs work like taxis, carrying passengers from origin to destination without intermediate stops [14-17].
- CyberCars (CC): automated road vehicles ranging from 4 to 20 passengers. Such vehicles work in a network as a collective taxi, in which the passengers can have different origins and destinations. The lane used by the network can be segregated or not [15-19].

[1] The traditional PRT concept is to keep the entire network dedicated and segregated to the point that most PRT networks are conceived on elevated monorails; however the same concept might apply using road lanes non-necessarily fully segregated and this concept has been exploited here.

• High Tech Buses (HTB): vehicles for mass transport using an infrastructure which can be either exclusive for the buses or shared with other road users. They can use various types of automated systems, either for guidance or for driver assistance or for full automation and platooning [15-16].

• Dual-Mode Vehicles (DMV): city vehicles with zero or ultra-low emission and driver assistance systems, parking assistance, collision avoidance, also supporting full automated driving in certain circumstances (e.g. platooning for relocation, [16-17].

According to the service required, the four ARTS perform best in different contexts inside and outside the cities.

An approach to evaluate where the ARTS perform best has been developed in the framework of the EU project CityMobil (2006-2011) [20], where the four ARTS were tested in 13 European cities through large scale demonstrators, showcases, and city studies. They were evaluated by collecting indicators of social, environmental, economic, legal and technological impacts of the ARTS [20].

A Passenger Application Matrix (PAM), consisting in a two-dimension symmetrical matrix where the results of the evaluations of the ARTS are grouped according to their origins and destinations (respectively rows and columns of the PAM), was developed to consolidate and cross-compare results of different demonstration, study or simulation.

Ten possible origins and ten possible destinations are in the PAM.
They are:

- City centre,
- Inner suburbs,
- Outer suburbs,
- Suburban centre,
- Major transport nodes (e.g. airport, central station),
- Major parking lots,
- Major educational or service facilities (e.g. university campus, hospital),
- Major shopping facilities,
- Major leisure facilities (e.g. amusement parks),
- Corridor.

The cells of the PAM represent all the possible OD pairs, as reported in figure 1,where the final PAM of the CityMobil project is reported, filled with the results of the evaluations made (the grey cells are those with evaluations available, whereas the white cells have no evaluations within CityMobil).

The PAM identifies which automated transport is best suitable to each cell and helps evaluate pros and cons of the implementation of the different technologies in each particular environment.

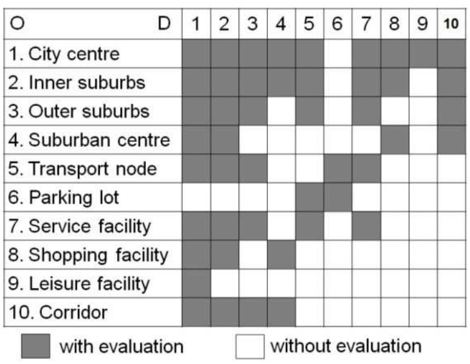

Figure 1 – The Passenger Application Matrix

An example of the evaluations in the cells is reported in figure 2, where an extract of the CityMobil PAM, concerning the city centre and inner suburbs rows and columns, is showed.

Looking at the city centre to city centre cell, three ARTS were tested in seven European cities: Cybercars in four cities, Personal Rapid Transit in five cities, and Dual-Mode Vehicles in two cities. For each of them different indicators were measured. The main outcomes on the ARTS after comparing the evaluations, extensively reported in [21-22], are:

• The dual-mode vehicles are considered by the users as easy to use, useful and safe, in order to substitute the conventional cars.

• People are willing to pay more than conventional public transport to use the innovative service provided through the ARTS and well disposed to substitute the private car with such new technology.

• PRT resulted to be more convenient than the other ARTSs in terms of performance and emissions reduction, but applicable only in small to medium size cities while conventional mass transits are the best option for the centres of large cities.

• As final result, in the city centre of small/medium cities both Dual-Mode vehicles and PRT can be applied, being well-accepted by the users and providing good improvement to the city mobility.

D O	City centre	Inner suburbs
City centre	CC (Gateshead, Madrid, Trondheim, Wien) PRT (Gateshead, Madrid, Trondheim, Wien, Uppsala) DMV (La Rochelle, Orta San Giulio)	CC (Gateshead, Trondheim) PRT (Gateshead, Trondheim, Uppsala) HTB (Gateshead, Madrid, Trondheim, Wien)
Inner suburbs	CC (Gateshead, Trondheim) PRT (Gateshead, Trondheim, Uppsala) HTB (Gateshead, Madrid, Trondheim, Wien)	CC (Gateshead, Madrid, Trondheim, Wien) PRT (Gateshead, Trondheim, Daventry, Uppsala) HTB (Gateshead, Madrid, Trondheim, Wien)

Figure 2 – An extract of the Passenger Application Matrix

This is an example on how to use the PAM; the other main results which can be found in [21-22], are:

• with medium size vehicle as on-demand transport services feeding conventional mass transits in the suburbs of large cities,

• on radial corridors as complementary mass transits with large busses and platoons of them and

• as main public transport for small cities with personal vehicles.

CityMobil2 [23] will contribute to populating the PAM with the results of its 12 ARTSs studies and 5 demonstrators in European cities.

4. How to integrate automated road transport systems in urban areas

ARTS have the main purpose of providing passenger transportation services in urban areas, but deploying an ARTS in public urban roads must be done, first and foremost, safeguarding both the ARTS' users and the road users in the surrounding environment [25]. Of all road users, special attention must be given to Vulnerable

Road Users (VRU). In fact, pedestrians' road fatality in urban areas is above 70%, both in Europe and in the US [26 and 27], with the elderly representing the highest fatality rates [28 and 29]. Since elderly-related incidents have greater impact and likelihood of occurrence [30], elderly safety should define the baseline for the safe integration of ARTS in urban areas. Thus, the focus in the definition of the ARTS' safety requirements in CityMobil2 has been shifted, from a driver-vehicle-centric approach, to a comprehensive, road-safety approach. Other objectives, like the improvement of traffic conditions or users' comfort, were subordinated to safety. Though seemingly conservative, this approach aims might finally help to make road transport as safe as rail one.

Up to date, the most relevant legal experience of an ARTS using at-grade infrastructure was the CityMobil Rome, Italy. In order to grant the construction and testing clearance2 to the system, the Ministry of Infrastructure and Transport (MIT) demanded, besides an extensive series of tests of all the safety-related subsystems, that the ARTS' vehicle track be entirely segregated with physical barriers [31].

5. Conclusions

After examining the quantification of potential benefits of partial automation available in literature, the paper highlighted how most of the promised benefits will be delivered by automation when it will be "full" and on urban roads. The new automated road transport systems, that can become extensively applicable, will make seamless mobility from door to door possible without the need of owning a vehicle and deeply impacting the economy and the society.

The paper then reported the main findings of the CityMobil project, which highlighted how Automated Road Transport Systems suitable for different trips might range from individual to ridesharing to collective mobility depending on the city area. It finally showed how the infrastructure first and the vehicles and communication system then should be made to make ARTS fully safe, even in non protected environments.

Main conclusions of this paper are:

- a legal and public intervention is needed to understand that inserting automated transport on roads is much more than automating a vehicle, but requires to revamp the law, the roads, and even the communication infrastructure; much less road and much more rail finally bring road safety to acceptable levels;
- automated vehicles would not need to be autonomous, they would need to be constantly connected and a supervising system (much like the air traffic control) should be established;
- further research and standardisation is needed in the communication field to allow large scale applications of these new transport systems.

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UDC 007:681:510.2

HIGH CAPACITY ROBOTIC URBAN CLUSTER-PIPELINE PASSENGERS TRANSPORT

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A project of intelligent transport system is discussed in the article. The system is based on mass transportation of passengers by means of mobile autonomous robots. The robots are assembled in caravans on cluster basis. This new type of public transport system is aimed to increase mobility and flexibility of public conveyance. It also ensures significant economic benefits - since efficiency is almost equal to metro transportation but at the same time the cost of manufacturing and maintenance is much lower. The project is at the stage of conceptual design. Ongoing research is related to computer simulation of the system in different conditions and intensity of passenger traffic.

Keywords*: traffic, adaptive control, passenger traffic, rate of vehicle utilization, intelligent transportation system.*

1. Introduction

The increase in motorization and transport mobility of the population has led to increase of the city streets transport flow, causing revaluation of principles of traffic management, as well as an incentive to develop new forms of public transport. Statistical data of traffic on the main streets of the United States and Europe show that