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Evaluation for Vehicle and Road Automation: needs and recommendations (Draft 1)

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Foreword

This work has been based on European and international discussions mostly within, on one side, the trilateral working group on automation between EU, US and Japan and, on the other, the i-mobility forum on automation.

The authors have recorded and used here such precious opinions even where they may differ from their owns.

To the international discussions a number of people have participated: Scott Smith, Jim Dale, Jane Lappin, Adriano Alessandrini, Adrian Zlocki, Maxime Flament

On the European side a number of people have participated to the Evaluation of Benefits discussions and contributed to them at least once: Nicholas Reed, Mariana Netto, Alvaro Arrue, Walter Hagleit, Markos Papageorgiu, Maarten Oonk, Andras Kovacs, Adriano Alessandrini, Stig Frazen, Ebru Dogan, Bastiaan Krosse.

Besides these expert discussions several other input have been crucial in this work

The work of Carlo Sessa and ISIS team in coordinating CityMobil2 work on socio economic long term consequences has been considered for this work. The work has been organised in collaboration with ERTICO – ITS Europe, POLIS and CTL and resulted in deliverable 27.2 of CityMobil2 which has been an input to this work.

The work of Scott Smith US DoT has been taken into account.

The results of the Adaptive project are also monitored.

Though not directly listed as authors all the people here mentioned have significantly contributed to shape this document.

Executive summary

The following main points are presented in D3.7.1 (Evaluation for Vehicle and Road Automation: needs and recommendations). This deliverable is a preliminary draft to illustrate the activity of VRA WP3.7. A final version (D3.7.2) will be submitted by the end of the project (end of 2016)

On-going R&D activities and state of the art:

- US-DOT work on evaluation of Schott Smith;
- CityMobil2 WP27 on long term impacts of road automation;
- ADAPTIVE work on safety, comfort and more of car automation;
- EURO FOT on level 1&2 automation (ADAS)

Need for further research:

- Define a (ore more than one) methodology to evaluate the benefits to “make crystal ball reading reliable”
- Evaluation of driver and other users behavior from objective data collected from sensors in the vehicles data logs so to learn to assess benefits “low cost” and keep benefit assessment up to date
- Evaluating effects on drivers used to level 3 technologies what will mean to go back to drive lower automation levels

Guidelines

- A handbook of methodologies to assess impacts would need to be drafted to help anybody to assess specific cases

Deployment issues

- Evaluation is concerned on what will change in the initial assessment depending on the market penetration of the new technologies and the way they are deployed. It is therefore necessary to foresee deployment scenarios as evaluation results are deployment dependent.

Conclusion and recommendations

- Evaluation is a crucial part of any research activity and road automation is not an exception. However the magnitude of the disruption potential road automation technology has on the society requires specifically focused evaluation actions to understand long term impacts of the different deployment scenarios before they are actually deployed.

1 Introduction

1.1 Purpose of Document

The deployment of vehicle and road automation on the European roads may lead to substantial paradigm shifts in the way we live and use mobility. Vehicle and Road Automation will have a great impact on many aspects of the society from safety to productivity passing by the environmental impact and in the longer term on land-use, quality of life, accessibility and even the fundamentals of European economy. Differently from D3.1 which identified the most probable deployment scenarios in which the different technologies and the modifications that they will cause to the mobility systems were investigated and placed on a time-scale; this deliverable aims to give a first attempt to what consequences automation will have. Such consequences will depend on a number of factors and choices and a wide range of effects is possible; the document tries to set the basis to define a comprehensive modelling framework and the different bits of modelling work which will be necessary to assess such consequences in a more quantitative and reliable way so to take important policy decisions based on such modelling outcomes.

1.2 VRA contractual references

VRA, Vehicle and Road Automation, is a Support Action submitted for the call FP7-ICT-2013-10. It stands for *Vehicle and Road Automation Network.*

The Grant Agreement number is 610737 and project duration is 42 months, effective from 01 July 2013 until 31 December 2016. It is a contract with the European Commission (EC), Directorate General Communications Networks, Content & Technology (DG CONNECT).

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1.3 Project Objectives

In the field of vehicle and road automation, VRA's main objectives are:

- To maintain an active network of experts and stakeholders
- To contribute to international collaboration
- To identify deployment needs
- To promote research and deployment initiatives

In practice, VRA will:

- Organise or support international meetings together with similar initiatives in US and JPN. (WP2.1)

- Support the iMobility Forum Automation WG and extend its role as a reference group for European activities on the topic eventually formulating common positions, especially at European level (WP2.2)
- Aggregate information on existing research or deployment activities in a shared wiki (WP2.3)
- Describe valid business models and deployment paths & scenarios and investigate the broad socio-economic implications of automation for the future societies (WP3.1)
- Clarify, report and setup a plan of actions on legal, liability, insurance and regulatory issues in different member states (WP3.2)
- Monitor and steer standardisation, compliance and certification for vehicle and road automation (WP3.3)
- Contribute to the discussion on relevant topics for the deployment of Vehicle and Road Automation: Connectivity (WP3.4), Human Factors (WP3.5), Digital Infrastructure (WP3.6), Evaluation of Benefits (WP3.7) and Decision and Control Algorithms (WP3.8).

1.4 Methodology description

A set of workshops or concertation meetings has been the method to get other stakeholders view and feedback. On-going R&D activities and state of the art have been considered.

1.5 Structure of Document

The document will be released in two versions over the project period. Each release will add or complement existing chapters.

The document consists of the following chapters:

- This introduction which sets the document objectives and guides the reader through it.
- Background and international framework: this chapter investigates literature on the matter and presents the Evaluation framework developed by the US DoT with the collaboration of the Trilateral Working Group on automation which might, with some continent specific adaptation, become the modelling reference for Europe as well.
- Potential benefits and dis-benefits of automation: this chapter aims to list extensively all the possible consequences of automation; not all will be present everywhere and with any technology but any evaluation work done on road automation deployment should take into account all such potential consequences.
- Expected impacts in the different evaluation categories: this chapter groups the impacts listed before in evaluation categories and tries to give, based on literature, a first attempt at impact expectations. Expectations however are influenced by a number of external factors and therefore span most diversely. Besides giving such expectations and the factors influencing them in each evaluation category the chapter attempts to define the time-scale for impact expectation and the “kind” of modelling necessary to quantify them.
- Conclusions and future work: this is the final chapter and recaps the findings and the expectations for the future of this activity.

2 Background and international framework

2.1 The multidimensional problem of evaluating road transport automation

Automating road vehicles (meaning here full automation, when vehicles drive themselves empty when needed) has a huge disruptive potential. The possibility of removing the burden of parking seeking (and pricing) sending the vehicle back home instead to be used by other friends or family members, on the private transport end of the line, and the possibility of having cheap direct taxi-like services from origin to destination, on the shared transport end of that same line, will affect our lifestyle and impact on a number of choices from where to live to mode choice to which new travelling reasons there will be. Such choices will in cascade affect length, number and mode of trips and again in cascade congestion, environmental impact and safety. Finally the use done of vehicles will affect the number of vehicles sold (and therefore manufactured) and the number of personnel employed to manage private vehicles and fleets deeply impacting on the state-of-the-art economy. Will it be all for the best? Maybe, and maybe not. Evaluating the potential impacts of full automation, and to a minor extent to partial intermediate automation levels, is therefore a necessary step for the governments at different levels (European, national, regional and local) to choose the policies to favour the take-up of those transport services which promises most of the benefits and prevent some of the negative impacts.

But evaluating the full potential of road automation is far from being easy. Automating vehicles can be done in very different ways, in different environments and with different goals. The problem has several dimensions.

- Geographic (on motorways or in cities and if in cities where in cities centres or peripheries how densely inhabited).
- Demographic (who are the users of the new transport concept which age will they have? This will influence accessibility and might create supplemental transport demand).
- Technological (which is the technology? For high speed – long range reduced angle sensors? For low speed - short range wide angle sensor? Will it know the infrastructure already will it be GNSS based or SLAM or others – this will affect the range of applicability and the kind of maps to provide).
- Of service supplied (will the vehicles be private or public? Individual or collective? Will they provide door to door service or be integrated with other transport systems?).
- Of interaction with the surrounding environment (will it need barriers? Will it need removing road side parking? Will it need adapting the infrastructure? How respectful of vulnerable road users? Which speed will it have to guarantee safety – a speed lower than manual vehicles?)
- Overall the vehicles need evaluation on its own or as part of the mobility? If so is not it essential to foresee different uses of such vehicles?

Limiting to urban transport and to fully automated vehicles the CityMobil2 project attempted to classify the different transport systems which might be implemented as in Figure 1 below.

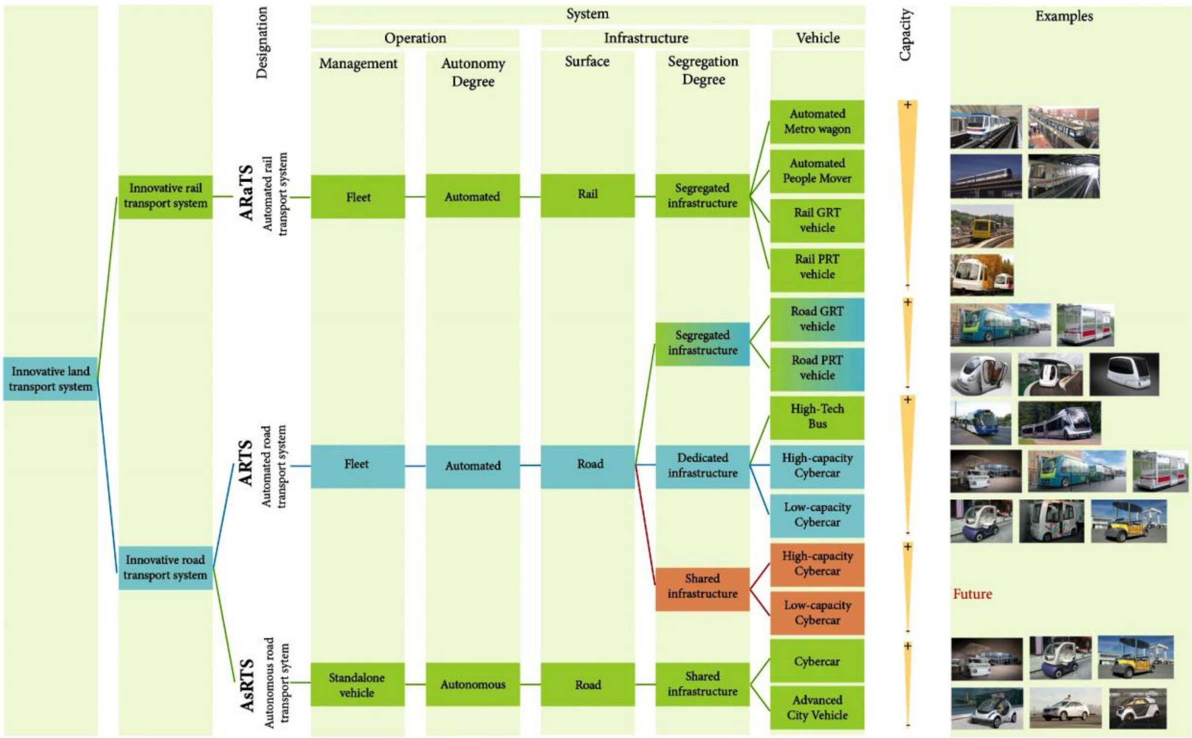

Figure 1: Automated transport systems classification according to CityMobi2 project source: CityMobil2 deliverable D15.1

Figure 1 classifies the transport systems first according to the operation level, to decide whether the vehicles are part of a fleet or standalone vehicles and whether they need some degree of control from a control system, in which case the vehicles are automated but not autonomous, or if they can take any decision and choice without any form of communication or cooperation, in which case they are autonomous. Second criterion of classification is whether there is any mechanical guidance needed from the infrastructure which will turn the automated transport system toward rail or whether the vehicles are purely road vehicles. This second criterion for classification is very useful because automation tend to blur the boundaries between road and rail making possible unprecedented synergies (why could not small automated public transport vehicles use the metro tunnels instead of the trains when in night hours it is no longer convenient to keep the metro running?). Third criterion is related to infrastructures. The infrastructure can be either fully segregated (accessible only to vehicles which are part of the system and protected against external intrusion) or dedicated (certified to be accessible by the vehicles of the automated transport systems and also to some other users who will need to follow specific rules) or shared (any road infrastructures shared by any road user). Depending on such criterion several different transport systems becomes possible (e.g. the difference between PRT and the Google autonomous cars is mostly there and in fleet supervision). This criterion might even be applied only temporarily giving birth to other new forms of transport like a shared car featuring advanced driver assist systems when in use with a driver on shared infrastructure which could become completely automated for relocation purposes when driving itself on dedicated infrastructures like bus lanes. The final criterion is the size of the vehicles which might even be varied by coupling more vehicles either immaterially (platooning) or with a mechanical connection (convoying).

The 13 possible combinations (and more) coming out of Figure 1 will then need to be applied in different urban forms to assess the impacts of full automation to public and shared transport in cities.

The CityMobil project (the first not CityMobil2) made a first attempt, through a land-use, demand and supply integrated modelling, at evaluating four (out of the 13) different innovative transport systems in different urban forms. It modelled High Tech Busses, PRTs, Advanced City Vehicles and CyberCars in four different conurbations: a small mono-centric city, Trondheim in Norway, a polycentric conurbation, Tyne and Wear region in UK, a midsized European Capital, Vienna in Austria and a large European capital, Madrid in Spain. The CityMobil consortium then classified the results obtained in a Passenger Application Matrix (an origin destination matrix in which origins and destinations are city centres, inner suburbs, outer suburbs, transport corridors, large facilities, …) and compared results obtained in each cell with those collected on the demonstration sites on five impacts including accessibility and financial viability. Though the work had just scratched the surface some first conclusions indicated how road automation in city centres of medium to large cities is mostly detrimental as conventional mass transits are best suited to serve the demand. PRTs can be the perfect solution for city centres of small cities as substitute to existing bus-based public transport. Corridors fed by CyberCars and served by High Tech Busses seem to be the best solutions in the outskirts of large cities as in polycentric cites where corridor of High Tech Busses connect the centres. None of the systems however have a great impact unless strong policies are implemented to accompany such systems.

The CityMobil2 Figure 1 and the description of the CityMobil modelling and evaluation work are just examples to show the complexity of the evaluation problem even when it is confined to passenger applications in urban areas of public transport services.

To get to the real extent of the automation impact it is necessary to add private mobility and the new hybrid forms of mobility which can be enabled by ICT applied to automation (like peer-to-peer car sharing) and the interurban dimension for passenger transport.

All this complexity for fully automated vehicle (level 4 and 5 according to SAE definition) evaluation, but some disruptive impact can be obtained already by partly automated vehicles (levels 2 and 3 of the SAE definitions).

Finally the impacts of automation on freight transport in cities and not has to be assessed.

2.2 Literature review

Several works in literature have been published recently on the expected impacts of road automation and, as the topic has a growing interest, activities on the matter multiply day after day.

A thorough review was made in CityMobil2 D27.2 with the specific objective of identifying studies of the impact of automation on the attitude toward sharing vehicles and on users and societal acceptance. The full review (worth reading) is in sections 2.4 and 2.5 of CityMobil2 D27.2. A summary of main findings follows.

One work has specifically analysed the potential of private cars to become shared (between family members and friends) when automated. Brandon Schoettle and Michael Sivak from the University of Michigan analysed the potential impact of self-driving vehicles on household vehicle demand and usage and found that significant reduction in average vehicle ownership per household could be obtained based on vehicle sharing inside the household up to 43% of average ownership rates.

Many other works analysed (including Fagnant and Kockelman 2014; Spieser et al. 2014; Zachariah, Gao, Kornhauser and Mufti 2013; Santi et al. 2014; Burns, Jordon and Scarborough 2013) are specifically focused on sharing fleets of automated vehicles either as part of the public transport network or replacing it. Some analyses the combined effect of ride-sharing (which is expected to be the only way to reduce the overall travelled mileage). Applications are studied in very different environments reaching very different results. None of the studies however foresee any effect on the land-use which having automated transport available might induce.

Building on this work, the **International Transport Forum "Urban Mobility System Upgrade" study** goes further by presenting detailed results of a full-scale simulation of shared self-driving transport for a mid-size European city (Lisbon). The ITF study eventually has provided key policy insights as follows:

- Self-driving vehicles could change public transport as we currently know it. For small and medium-sized cities it is conceivable that a shared fleet of self-driving vehicles could completely obviate the need for traditional public transport.
- The potential impact of self-driving shared fleets on urban mobility will be shaped by policy choices and deployment options. Transport policies can influence the type and size of the fleet, the mix between public transport and shared vehicles, and ultimately, the amount of car travel, congestion and emissions in the city.
- Active management is needed to lock in the benefits of freed space. Shared vehicle fleets free up significant amounts of space in a city. Prior experience indicates that this space must be proactively managed in order to ensure these benefits are fully reaped. Management strategies can include restricting access to this space by allocating it to specified commercial or recreational uses, such as delivery bays, bicycle tracks or enlarged footpaths. Freed-up space in off-street parking could be used for urban logistics purposes, such as distribution centres.
- Improvements in road safety are almost certain. Environmental benefits will depend instead on vehicle technology. The deployment of large-scale self-driving vehicle fleets will likely reduce both the number of crashes and crash severity, despite increases in overall levels of car travel. Environmental impacts remain tied to per kilometre emissions and thus will be dependent on the adoption of more fuel-efficient and less polluting technologies. It is likely that vehicles will be used more intensely. More intense use means shorter vehicle lifecycles and thus quicker adoption of new, cleaner technologies across the car fleet.
- New vehicle types and business models will be required. A drastic reduction in the number of cars needed would significantly impact car manufacturer business models. New services will develop under these conditions, but it is unclear who will manage them and how they will be monetised. The role of authorities, both regulatory and fiscal, will be important in guiding developments or potentially maintaining market barriers. Innovative maintenance programmes could be part of the monetisation package developed for these services.
- Public transport, taxi operations and urban transport governance will have to adapt. Shared self-driving car fleets will directly compete with urban taxi and public transport services, as currently organised. Such fleets might effectively become a new form of

low capacity, high quality public transport. This is likely to cause significant labour issues. Yet there is no reason why current public transport operators or taxi companies could not take an active role in delivering these services. Governance of transport services, including concession rules and arrangements, will have to adapt.

- Mixing fleets of shared self-driving vehicles and privately-owned cars will not deliver the same benefits as a full shared fleet - but it still remains attractive. In all fleet-mixing scenarios, overall vehicle travel will be higher. If only 50% of car travel is carried out by shared self-driving vehicles and the remainder by traditional cars, total vehicle travel will increase between 30% and 90%. This holds true irrespective of the availability of high-capacity public transport. Also, vehicle numbers will increase. Improved traffic flow of automated cars could mitigate congestion up to a point. However, the public policy case for self-driving fleets alone (without high-capacity public transport) may be difficult to make based solely on space and congestion benefits, due to the increase in overall travel volumes. Nonetheless, even in mixed scenarios, shared self-driving fleets could be a cost effective alternative to traditional forms of public transport, if the impacts of additional travel are mitigated. “All in” deployment of shared self-driving fleets may be easier in circumscribed areas such as business parks, campuses, islands, as well as in cities with low motorisation rates.

Another fundamental summary of the activities and demonstration projects which summarises the different uses of automation technologies and how they are being tested, demonstrated and evaluated is the White Paper prepared by Steven E. Shladover and Richard Bishop for the EU-US Symposium on Automated Vehicles named Road Transport Automation as a Public-Private Enterprise (not publicly available).

It starts giving a thorough description of automation technologies (and levels) and the role of the driver in each and then simplifies the difference citing Bryant Walker Smith in *Something Everywhere vs. Everything Somewhere*. Then it makes a state of the art and of the market and a list of non-technical open issues. The non-technical issues are concluded with a small section (5.6) on Benefits and impact quoted below.

The impacts of automated road transport will be diverse, complex and highly uncertain because it will affect so many aspects of transport system performance, especially at the higher levels of automation. Any prediction of impacts will have to be based on assumptions about many issues that remain highly uncertain and should therefore only be subjected to sensitivity analyses rather than definitive predictions. The following questions are sorted into those that are market-oriented and societally-oriented:

- Market-Oriented
    - Development trajectories of the automation technologies – what capabilities will become technically feasible in what years and how much will they cost?
    - Development of the market for automated transport systems – how much will customers be willing to pay for each capability?
    - How will the degree and extensiveness of infrastructure support affect market introduction of higher level automation systems?
    - What vehicle performance characteristics will customers desire?
- Societally-Oriented
    - How much cooperative infrastructure support will be available to facilitate the use of automation, and where will it be available?

- For vehicle performance characteristics that customers desire, how will that vehicle performance influence traffic flow capacity and stability?
- How much energy and emissions reductions will be achievable with the vehicle performance characteristics that customers desire?
- How safe will the automated transport systems actually be in practice, after accounting for their own internal failures?
- How will pedestrians and bicyclists interact with fully automated vehicles that have no human drivers?
- How will public preferences for housing evolve, and what impacts will that have on future urban form (trends in densification vs. sprawl)?
- How will employment patterns change, and what does that mean for commute trips to workplaces versus telecommuting?
- What is the elasticity of travel demand with respect to travel time when that travel time can be spent doing whatever the traveler wants to do rather than driving?
- How will the growth of online shopping affect urban goods movement needs?

Depending on the answers to questions such as these, the impacts of automation could vary greatly, ranging from large growth in VMT with concomitant adverse impacts on congestion, energy use and emissions, to new urban forms with reduced traffic impacts and improved quality of life.

2.3 The US DoT framework and the I-Mobility forum activities

The Department of Transport of the United States of America (US DoT) is attempting to harmonise the evaluation works in this field by defining an evaluation framework in which any research and demonstration project should fit its evaluation.

The Trilateral Working Group on Automation EU-US-Japan contributed to this American work and a newer version of the framework embedding the comments was developed and is presented below.

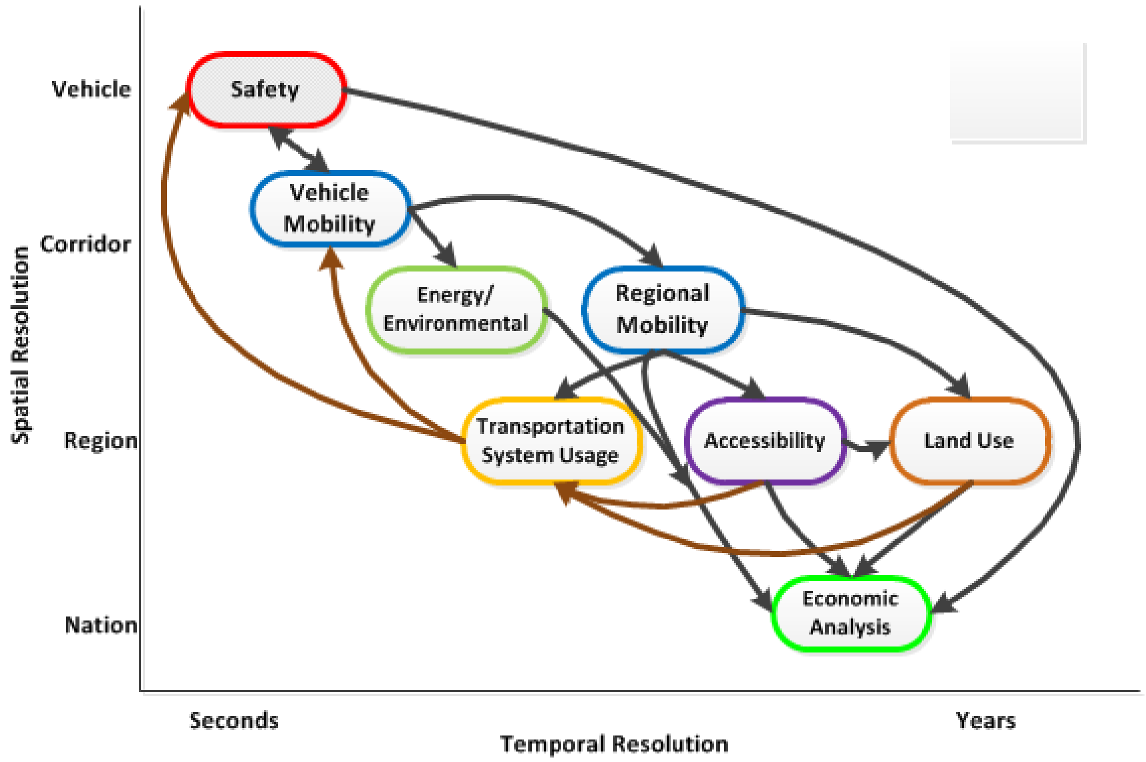

Figure 2: Automated transport evaluation framework[1]

Figure 2 depicts the proposed framework. On the horizontal axes there is the temporal resolution from the smallest (seconds) to the largest (years). Such resolution is the resolution which is necessary to give to any model to actually assess impacts. For example Safety (when safety means the likelihood of a vehicle to have an accident) requires to go into the details of the vehicle motion with timings of seconds and less. On the vertical axes the spatial resolution with the bottom part being the largest and the upper the more minute. Again safety (when safety means the likelihood of a vehicle to have an accident) needs to have a spatial resolution of less than a metre. Naturally road safety is much more than that. The likelihood of a vehicle to have an accident is only one factor in the safety equation; the second factor needs to account for the exposure. If an automated vehicle is half likely to have an accident per mile travelled than a manually driven one but it travels twice as many miles it will end up having worse safety scores. The framework does take into account this effect through a feedback arrow from the transportation system usage box placed in mid temporal resolution (the number of trips depend on daily and monthly decisions and in longer terms are influenced by land-use which is placed on the extreme right of Figure 2) and mid spatial resolution (region wide decisions affect the transportation system usage).

Following the framework from top left to bottom right; it starts with the already mentioned safety which should be modelled through micro-simulation models which take into account

[1] source:Scott Smith's presentation of Estimation of Benefits for Automated Vehicle Systems updated to the 15th of July 2015

the vehicle dynamic at highest rates. Safety has an influence on vehicle mobility and (once the feedbacks from the other impacts are applied on the economic analyses).

Vehicle Mobility is the impact of automation on the vehicle dynamic which will give the possibility to assess whether automated vehicles will have closer car following and more efficient intersection performance. Again this requires simulations which are very fast to judge vehicle interactions but in spatial terms a broader view. A corridor (or intersections) with all the vehicles on it rather than the single vehicle need to be considered. This is the first brick in assessing the automated vehicle (and therefore infrastructure) performance and has consequences on energy/environmental impacts and on the regional mobility because can make a mode more or less attractive. It receives a feedback once more from the transportation system usage as increased performances will impact on the demand and change the number of vehicles on the same link of the network (or intersection) and therefore the vehicle mobility.

Regional mobility is the direct consequences of the Vehicle Mobility in terms of Increased lane and intersection capacity this will need to be measured over an hourly rate and on a spatial resolution that ranges from corridors to region. Being this a direct measure of the transport system performances it has a direct impact on Transportation system usage, Accessibility (meaning providing transport for people so far excluded like elderly and impaired) and Land Use.

Energy/Environmental depends from the vehicle motion, stability of the flow and headway. As such is directly influenced by the Vehicle Mobility (as defined above). Figure 2 misses to indicate a feedback loop from the Transportation System Usage as, like for safety, VMT is a key factor in the equation. The main output of this impact is on the Socio-Economic Analysis.

Transportation System Usage is the demand related box and the central one in the framework. It receives in input (through the Regional Mobility) all previous ones as well as Accessibility and Land Use and provide feedback to everybody and (even if in Figure 2 the link is missing) to the final economic analysis as demand and in general transport patterns do have positive and negative impacts on the Economic Analysis.

Accessibility accounts for the increased options for non-drivers and therefore is influenced by the Regional Mobility. It has direct consequences on Land Use and Economic Analysis and provide feedback to the Transportation System Usage by affecting transport demand. It is spatially at regional level (as Transportation System Usage and Land Use) but temporally on the long term horizon second only to the land use impacts which requires years.

Land Use is at the same time input and output of automation evaluation. The current land use (whether the land is used with more density or more sprawl) influences both Economic Analysis and the Transportation System Usage and is the impact with the longest time horizon.

The Economic Analysis is the only impact at nation level spatially and has a broad temporal resolution going from hours to years. Even if in Figure 2 does not show any feedback loop because this is supposed to be the end of the process it has, through policies, potential feedbacks on each steps.

3 Potential benefits and dis-benefits of automation

Automation, as already said several times, can be organised in levels. Literature (and previous deliverables of this project) gave a full description of levels of automation. Here, rather than repeating the automation levels, a simpler classification was adopted. Either the driver is in the loop (even only for control or liability purposes) or she is not. If she is not than the car can drive empty.

In the following of this section the list of impacts defined in the meetings of the i-mobility forum on automation is reported and a first attempt to define which are achievable already with the driver in the loop and which not is done. Also for each impact whether it is a personal or societal impactor both.

3.1 The list of impacts and their dependence on the levels

Comfort: Automation should at least bring "smoother" driving for the better feeling of people on board; but in the highest automation levels it should also allow to spend better the time on board doing other tasks and not spending time controlling the vehicles; valet parking functions might also add comfort at the beginning and at the end of the journey.

Road Safety: Main goal of automation is to have safer road transport. Safety here is not intended just as "vehicle" safety (as it is in Scott Smith's Figure 2) but as road transport safety thus already influenced by the demand and VMT impacts.

Road capacity: if shorter headway are safely kept thanks to automation the capacity of the single lane will increase. There are also positions that stated how full automation without cooperation between vehicle and opportune amendments to the road code might lead to higher gaps between vehicles with negative impact on road capacity. In a way or another capacity will be impacted by automation.

Environment: Automation will impact on the environment for three main reasons:
if shorter gaps are kept vehicle drag will be reduced decreasing fuel consumption;
if congestion is relieved thanks to automation vehicles will consume less in less congested roads;
if the driver is removed cars can be driven in a more eco-friendly manner.

Transport Patterns: travel time, waiting time, commercial speed, … will all be affected by road vehicle automation; by automation itself, as the automated vehicles will move differently from a manually driven ones, and by the by-products of the impacts on demand, built environment, … which will all impact on the transport system performances. This impact combines Vehicle and Regional Mobility impacts of Scott Smith's Figure 2.

Fines reduction: automation will help obeying the road code reducing exposures to bad behaviours.

Accessibility: full automation will make “cars” available for those parts of the population which have not access to it otherwise (impaired mobility users, elderly, …).

Lifestyle change: Automation might lead (in the most advanced scenarios) to consider differently modal choice, housing choice, shopping habitudes and behaviour in general which will lead to a completely different lifestyle. This might be further enhanced by the fact that fleet sizes can be reduced (an household might need one car instead of two and new forms of shared mobility arise)

Impact on built environment: full automation might change the need for parking at facilities (shopping centres, airports, train stations, …) or in residential areas changing completely the rules with which the built environment is designed.

Impacts on infrastructures: infrastructures, road infrastructures first but not only, might require adaptation if a significant share of road traffic will be made of automated vehicles.

Impact on demand: the increased accessibility, the new shared mobility and transits services that will be made possible and the (possibly) decreasing cost of the trip will generate more trips affecting the overall transport demand.

Productivity: not having to drive and being able to go faster anywhere will affect the productivity of the individuals.

Costs: automation will affect fuel consumption, insurance costs, damage repair costs, tyre consumption and many other ownership costs for the vehicles.

Economy: Impacts on jobs, GDPs industrial production, tertiary services,… will all be impacts on the economy of automation.

Land Use: Impacts on how automation will change the way the land is used today; on one had it could encourage urban sprawl, on the other it could encourage dense urban cities.

Security: Either personal security (in shared modes with no driver) or cyber security are both potential impacts of automation.

3.2 *Impacts classification in direct and indirect socioeconomic impacts*

The impacts listed were then classified in direct (personal) and indirect (socioeconomic. Other wording “personal” and “societal” respectively for direct and indirect impacts was also used. Furthermore an attempt to identify which of the listed impacts are expected just for full automation (no driver in the loop in short AUTO) and which can be seen already with advanced driver assistance systems (driver in the loop in short ADAS).

3.2.1 *Direct (personal)*

Comfort (both ADAS and AUTO)

Road Safety (both ADAS and AUTO)

Road Capacity (both ADAS and AUTO)

Transport Patterns (some) (mostly for AUTO)

Fines (both ADAS and AUTO)

Accessibility (only for AUTO)

Productivity (both ADAS and AUTO)

Lifestyle change (only for AUTO)

Costs (both ADAS and AUTO)

Personal Security (only for AUTO and in shared modes)

Cyber Security (both ADAS and AUTO)

3.2.2 *Indirect socio-economic (societal)*

Road Safety (both ADAS and AUTO)

Road Capacity (both ADAS and AUTO)

Environment (both ADAS and AUTO)

Transport Patterns (some) (mostly for AUTO)

Fines reduction (both ADAS and AUTO)

Accessibility (only for AUTO)

Lifestyle change (only for AUTO)

Impact on Built environment (only for AUTO)

Impact on Infrastructures (only for AUTO)

Impact on Demand (only for AUTO)

Productivity (both ADAS and AUTO)

Economy (mostly for AUTO)

Land Use (only for AUTO)

Cyber Security (both ADAS and AUTO)

3.3 Classifying impacts in evaluation categories

The list of potential impacts identified in 3.1 and classified in direct, indirect and whether they are expected already with the driver in the loop or not in 3.2 is quite extensive and covers all the possible aspects. However to make such impacts measurable they have been grouped in evaluation categories. Such categories (inspired by the MAESTRO EC Project classification) are arbitrary and different clustering can be made.

First impact category is *Safety and security* which includes impacts on Road Safety and Security at different levels.

Transport Patterns is a category in itself it already include typical transport impacts (travel time and its variability, waiting time, number of trips, …).

Energy and Environment evaluation category does include the impacts on the environment and (by arbitrary choice) those on land use; considering the consumption of land an environmental impact. It could have included (and indeed in the CityMobil2 La Rochelle workshop on the long term effects of automation it did) the impacts on the built environment which here was left to be clustered on the infrastructural impacts.

Social and lifestyle impacts include Comfort, Accessibility and Lifestyle Change.

The *Infrastructural* evaluation category includes Road Capacity, Impact on the built environment (also classifiable in Environment and in Land use) and Impact on infrastructures.

Finally the *Economic* evaluation category includes the financial impacts like Costs and Fines reduction; those on Productivity and all the other impacts on the Economy.

4 Evaluating the impacts in the different categories

Though as mentioned several times automation impacts can be the most diverse depending on the implementation conditions, this section describes the general feelings of experts toward the different impact categories and defines necessary modelling studies to have a first quantitative impact forecast.

4.1 Safety and security

Safety is the main motivation for most people to embrace road vehicle automation. As such, experts tend to concur that a full deployment of automated road vehicles will only happen when automation will guarantee a much higher safety than manually driven vehicles.

Indeed literature studies on the impacts on safety of the early ADAS systems show that safety is increased by driver assist functions keeping the driver in control of the vehicle.

However for a fully automated vehicle sharing the current road infrastructure with other vehicles manually driven miracles cannot be expected. The Google cars tested in California still have crashes and ADAS equipped cars do too.

Extracting from the SafetyNet (a European project which investigated in-depth road accidents) database the data of the accidents recorded on a straight road it is possible to classify and count the manoeuvres each vehicle involved in the accident did. Accidents can happen:

- when the vehicle (always the grey one in the sketches) is either rear-ended (first sketch in the upper left corner of Figure 3) which occurred 18.8% of the recorded occurrences in the database;
- when the vehicle rear-ends the vehicle in front (second sketch from the left in the upper row of Figure 3) which occurred 16.9% of the times of the recorded occurrences in the database;
- when the vehicle is hit in its lane from vehicles coming from different directions (an illegal counter flow vehicle, a vehicle from the side lane which loses control, … - third sketch); or hits/is hit by an animal on its lane (fourth sketch first row); or hits/is hit by an object in the lane (fifth and last sketch on the first row of Figure 3) which all together happens 24.3% of the times;
- when the vehicle does an intentional lane change to overtake (first sketch second row) or not (second sketch second row of Figure 3) which together account for 5.5% of the occurrences;
- when the vehicle loses control hitting another vehicle (first sketch third row) or leaves the carriageway either on the right (second sketch third row) or on the left (third sketch third row of Figure 3) which all together occurred 34.5% of the times of the recorded occurrences in the database.

Even if the database does not have statistical significance the numbers are a good examples to attempt a quantification of the potential safety benefits of automation.

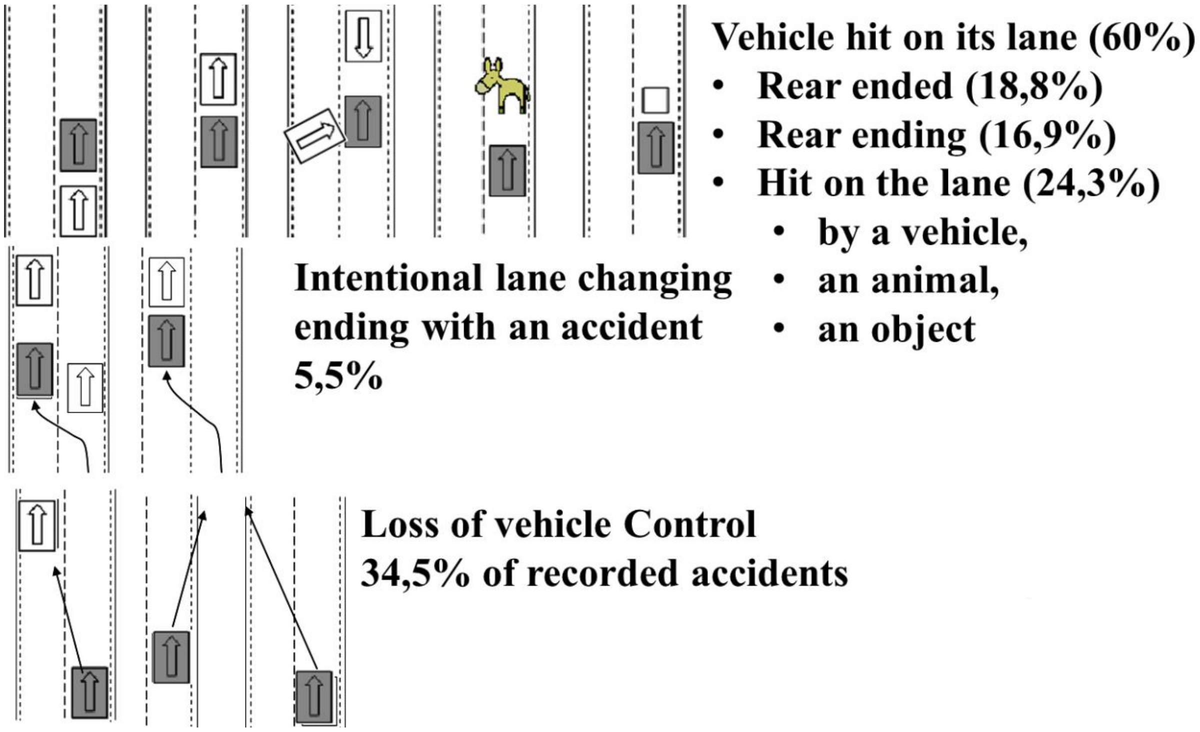

Figure 3: Accident dynamics and vehicle-maneuver-percentages on a straight road[2]

Starting from the second row of Figure 3 automation technology can prove absolutely safe in lane changing thus saving 5.5% of accident igniting manoeuvres.

Progressing to the third row of Figure 3 if the automation technology never loses control of the vehicle (not even if an animal jumps in front of it) it will save 34.5% of accident igniting manoeuvres.

On the first sketch of the first row of Figure 3, if the automation technology demonstrates that it can cut in half rear-ending (reducing them to zero would mean increase safety distance with problems in traffic and depletion of road capacity) it would save 8.5% of accident igniting manoeuvres.

On the second sketch of the fists row of Figure 3, if the technology demonstrated to be able to reduce of a third rear-ended (increasing distance from the vehicle in front and decreasing speed each time it is too closely followed and avoiding sudden manoeuvres – so far automation has not been convincing on this) it would save 6.2% of accident igniting manoeuvres.

Finally on the last three sketches of the first row of Figure 3 the automation technology is not expected to be able to produce benefits. On the contrary preventing all loss of control it might mean to hit more often objects or animals in the lane. Even if only a 20% increase is expected 4.8% more accident igniting manoeuvres are expected.

[2] Source: Davide Usami (…) elaborations on 1000 accidents of the SafetyNet (…) database

Summing all the percentages together 50% of the accident igniting manoeuvres can be reasonably expected to be saved by automated vehicles on motorway-like stretches. Naturally this is true if there is only one automated vehicle in a flow of manually driven ones. The more vehicles become automated the less other igniting manoeuvres will exist leaving only external causes and decreasing further the accident risk.

This positive effect will be counterbalanced by an eventual increase of VMT which will increase the overall number of accidents.

In simulation and study terms evaluating safety effects of automation can be done by analysing (as done above) the manoeuvres igniting accidents and simulating the behaviour of the automated vehicle in such circumstances.

A completely different approach to safety is suggested by the CityMobil2 project which suggests an ex-ante study of the interaction of the vehicle with the infrastructure and the adoption of countermeasures (infrastructural, on the vehicle, on control system or on road-side sensing) to decrease the accident risk to an acceptable level. The level adopted for the CityMobil2 demonstration was rail-like meaning 100 times safer than cars but this is a parameter that can be tuned on the local exigencies.

Security issues exist in sharing vehicles (Alessandrini and Filippi 2004). The earliest experiences with fully automated public transport systems done in the European project CyberMove in the early years 2000 showed how people might be afraid of sharing small vehicles without an authority figure such as the driver. This issue has to be addressed by making the system more secure (adding CCTV and harassment buttons) and on the perception side by demonstrating security.

In simulation and assessment terms the only real evaluation option is to implement systems and ask people to try and to assess the security.

Beside personal security the huge thereat of automation is cyber-security. This is an issue to be evaluated. The robustness of the vehicles and the systems to external attempts of intrusion has to be demonstrated through opportune information technology procedures.

4.2 Transport Patterns

Of all the evaluation categories this is the one most depending on the implementation of the automated transport system. Automation in itself will not guarantee higher speeds, or better schedule keeping unless automation is used to make a transport systems with such characteristics.

The only possible approach to forecast transport patterns impacts and indicators is to simulate automation scenarios in different conurbations which would allow measuring whether similar trends are to be expected in all the scenarios or whether they will be scenario dependent.

The main complexity of such simulations is the integration of demand forecast with the supply and land use modelling. Demand will strongly depend on the way automation is implemented but also on the way it is accepted by the users.

The CyberMove project interviewed users in year 2003 after their rode on a 2GetThere ParkShuttle automated vehicle showcased on the quai de millionnaires in Antibes (France) and 85 to 97% of the interviewee (depending on the parking fee) replied that they would leave their car and use the system instead (Alessandrini et al. 2005). This is a clear overestimation due to the enthusiasm of having rode on a system so far considered only fantasy. CityMobil2 project targeted specifically this issue doing stated preference surveys before and after riding the system and, though overall automated busses confirm to be more attractive than manual ones, in the before survey older and less educated people were more sceptical (Alessandrini et Al. 2014) while in the after survey younger and more educated were less enthusiast and the other less sceptical (CityMobil2 consortium 2015). This seems to confirm that while automation per se can be seen as potentially attractive is the kind of system implemented (and the accompanying measures) which will make it a success or not and influence transport patterns results. As such simulations of such impacts need to be handled with extreme care.

4.3 Energy and Environment

At microscopic (single vehicle functioning) and mesoscopic (traffic flow) level, energy and environmental impact expected from road vehicle automation are perfectly systematised by professor Matthew Barth in Figure 4.

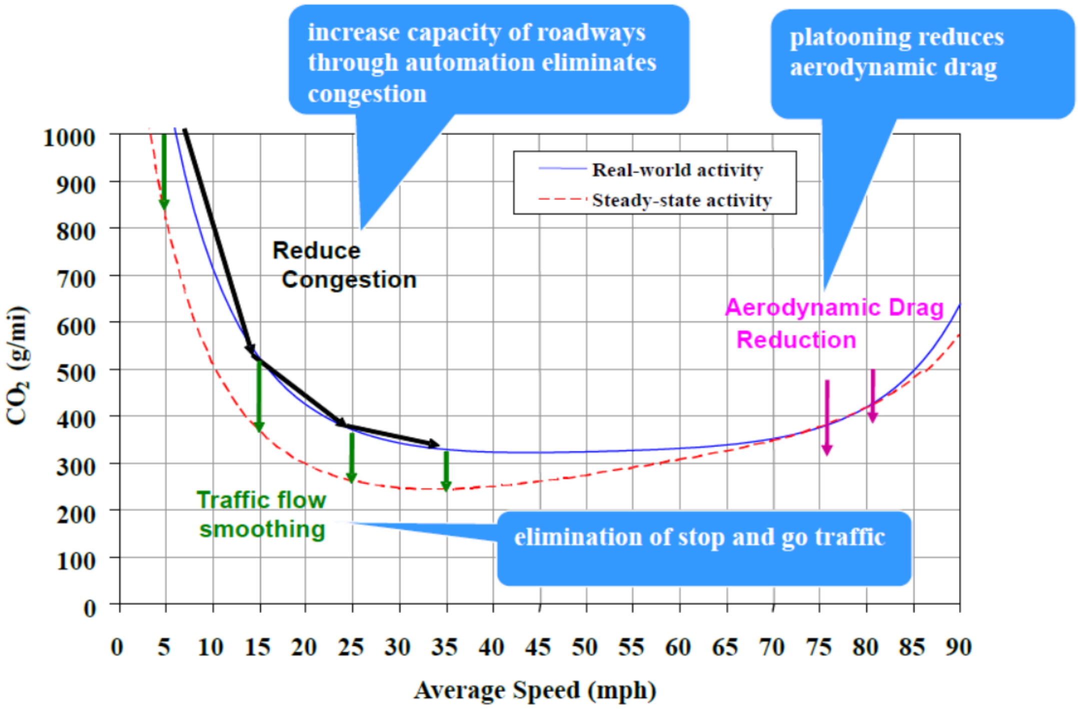

Figure 4: Three regimes on how to reduce on-road energy and emissions through automation[3]

First automation promises to smooth and homogenise vehicle behaviour eliminating (or strongly reducing) useless accelerations followed by decelerations up to eventually eliminate stop and go; second the platooning of vehicles will increase the road capacity so keeping the same flow traffic would become smoother increasing average speed which (below the 60

[3] Source: Matthew Barth 2012

km/h 35 miles per hour in Figure 4) means reducing average consumption; finally platooning again will reduce drag at high speed thus reducing consumption at higher speeds.

These three regimes are all synthesized in Figure 4 which starts from the traditional experimental curve which correlate average vehicle consumption with the average traffic flow speed. Consumption is very high at very low speed decreasing with speed increase and reaching a minimum around the 60 km/h to re-increase because of the aerodynamic drag at higher speeds.

On such a curve Barth shows the first phenomenon as lowering the curve itself because in the same traffic conditions an automated vehicle is supposed to be less likely to waste energy in useless accelerations; the second phenomenon is shown with arrows which move the average speed forward and therefore down in consumption and the third lowering the curve again in higher speed ranges.

While the second regime can be expected but not yet measured because it requires such a high percentage of automated vehicles in the flow to be able to influence it; the third regime has been measured by SARTRE EC project being in the range between 4% and 10%.

The first regime was experimentally measured by the CityMobil2 project which compared data of a manually driven electric minibus with the data collected on the automated minibuses in the Oristano demonstration of summer 2014 shown in Figure 5.

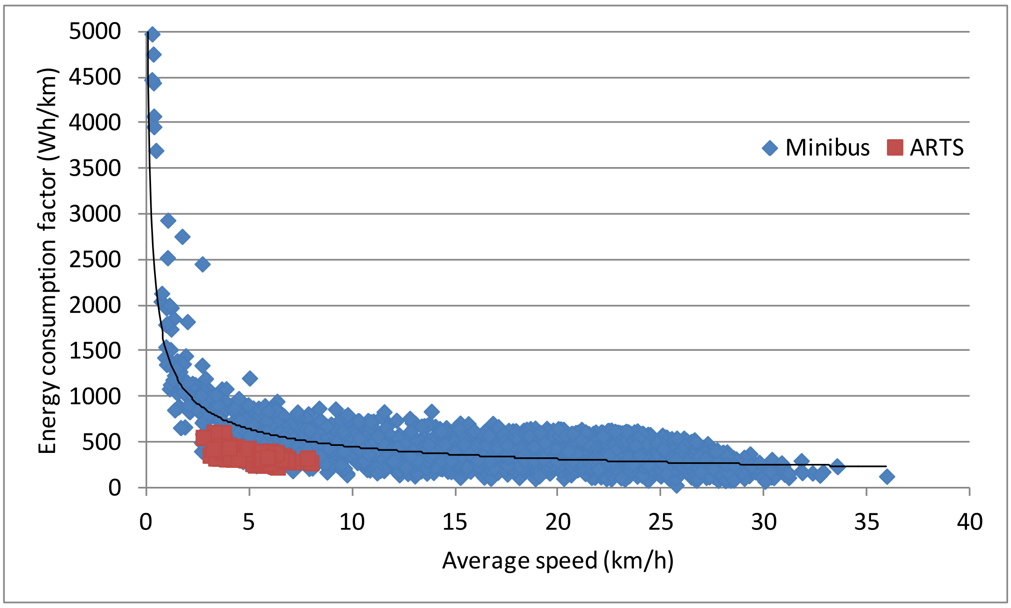

Figure 5: Energy consumption comparison ARTS vs. Minibus[4]

Figure 5 has the black curve (corresponding to Barth's light blue one) which is the fitting of the blue dots. Each blue dot is the energy consumed and the average speed of the minibus on a two minute portion of one of its journeys. The red dots (much more concentrated) are measured energy and speed of one trip of the ARTS vehicles in Oristano. Beside noticing

[4] Source: CityMobil2 Oristano Evaluation

that the average speed of the automated vehicles is much lower (limited by the specific application) the red dots are concentrated on the bottom part of the blue cloud; meaning that indeed at the same given average speed the automated vehicle consumes as the manual one in its best operating conditions. A fitting curve would therefore (as Barth predicted) be around 30% lower.

Naturally these three regimes do not take into any account the demand and the transport patterns resulting from them.

When measuring the energy consumption per passenger·kilometre the crucial factor is the occupancy rate. If a vehicle consumes 30% less energy but for other reasons the occupancy would be half then this would result in increased energy consumption.

As such Energy cannot be evaluated neglecting the implementation scenario and the other transport patterns.

Environmental impact (besides CO2 which depends directly on energy consumption) is a completely different matter. Automation might give the opportunity to electric drive-train to increase their market share with high contribution in reducing traffic related air pollution. Beside electrification smoother driving contributes significantly in pollutant emission reductions also from conventional drivetrains.

4.4 Social and lifestyle impacts

Comfort, Accessibility and Lifestyle Change have been included in this evaluation category.

While Accessibility has one or more directly measurable indicators, which can range from the time to destination it takes to impaired mobility or elderly people (and more in general people with no car availability) to the number of services reachable in a given time; Comfort can only be measured qualitatively by asking users to rate it. Lifestyle Change is even more difficult because it is definitely an impact but seldom (if ever) measured in evaluating transport related project. It has been inserted here because automation promises to have much deeper and broader impacts than any transport related innovation since the internal combustion engine.

Even the definition of Comfort can be interpreted in a very broad sense. Besides how comfortable being on board of the vehicle is, it could measure how comfortable is it to use a certain transport mode (an automated vehicle that picks the user up from her house doorsteps can be considered more comfortable than walking few hundred metres to a stop) or how much the time on-board can be re-used for other purposes (slight overlap with the productivity impact in the Economic category).

The expert opinions collected by CityMobil2 foresee high impacts in this category in any scenario and any way of implementing automation but how to prepare simulations to measure such impacts remain difficult to say.

4.5 Infrastructural

Automation will have, depending on the way it will be implemented, a number of very different impacts on the Road Capacity, the Built Environment (also classifiable in Environment and in Land use) and Infrastructures in general.

Automating private (and public) cars might change forms and dimensions of the car-parks (like in Figure 6 below) and free road side parking space to be destined to other uses.

Certain kinds of automation (CityMobil2 like for example) will require certifying and occasionally revising the road infrastructures; adopting platooning techniques will increase road capacity while non-connected autonomous vehicles might actually require higher safety distances and therefore reduce the throughput.

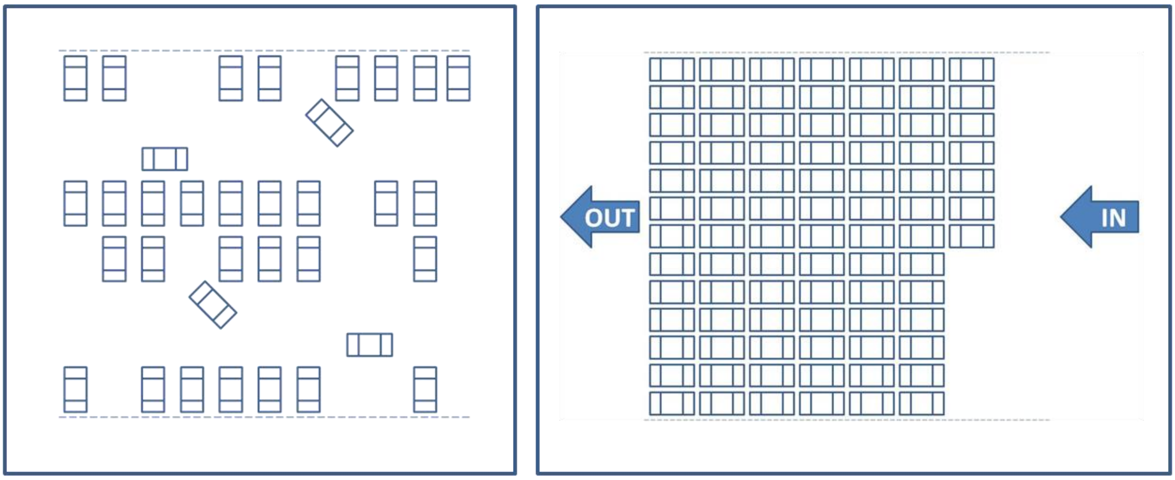

Figure 6: Possible car-park reorganization due to automation[5]

As such the impacts in this category will strongly depend on the considered scenario (whether interurban, urban and eventually which urban form) and on the kind of transport system implemented thanks to automation.

However the levels of simulations involved to measure impacts in this category are extremely clear.

To measure what will happen to road infrastructures a detailed simulation of the vehicle motion and vehicle to vehicle (and to other road users) interaction need to be done. This will allow defining which throughput each road segment will have after the automation implementation. These figures will be needed to define the effects on demand and transport patterns which will allow define the new parking needs and the different use which can be done of space and the Built Environment in general (e.g. an airport in the fully automated car scenario might need a huge kiss-and-fly are and much less parking lots and similar considerations will apply to malls and other attraction points).

4.6 Economic

Economic impacts range from the individual Costs an automated vehicle user will need to sustain to buy or use the vehicle to the reduction in Fines to pay for wrongdoing (this can have an impact on some city budget) to those on Productivity, because the time spent in the vehicle can be used to work, and all the other impacts on the Economy.

[5] Source: CityMobil2 Deliverable 27.1

While the direct and indirect costs can be measured alongside the other impacts by any regional-scale simulation the broader impact on the economy is more problematic.

Expert opinions, which were initially very negative on the impact full automation would have on the car market, tend to change for two reasons. First even should be true that automation will encourage sharing and thus reducing the number of circulating vehicles it will not reduce (on the contrary) the VMT thus requiring more frequent vehicle change with a balancing effect on the market. Second a number of new mobility related markets will be opened by sharing automated vehicles and car-makers are among the best placed enterprises to benefit of these new economy. The way to simulate these effects it through comprehensive regional modelling of different transport scenarios which will allow measuring the number of circulating vehicles and the miles travelled by each in each scenario and thus applying some proxy figures (e.g. the number of employees per car sold, the number of employees per VMT and the number of employees in fleet management per shared car) it will be possible to foresee the overall economic impact of the different scenario

5 Conclusions and future work

Mobility is becoming a major issue in our societies. Road transport, our primary means of transport, boosts our lifestyle but at the same time degrades the surroundings in which we live. Pollution, road accidents and traffic congestions are some of our greatest burdens either in urban areas or on main roads. In such environments traffic infrastructure and the possibilities for its extension are both limited and unsustainable.

Road automation can contribute to solve these problems if opportunely implemented. There are four different ways to implement road automation:

- automating cars, for urban and interurban private mobility
- automating urban road transport systems with the aim to solve the last mile problem of conventional public transport
- automating urban freight collection and distribution (including reverse logistics)
- automating interurban road transport for freights

These four ways share a common technological core, the automation of road vehicles, but propose very different applications and implementation plans and can have very different impacts.

A project to evaluate the drivers and the consequences of the implementation of each approach would clarify whether the EU need to adopt any policy to facilitate one of the most promising ones and discourage the others.

5.1 Challenges

Evaluating automated vehicles and transport systems is crucial to understand:

- which are their advantages compared to conventional systems;
- how would users react to them;
- which the drawbacks;
- whether they will it be more sustainable than conventional systems; and
- how much do they cost.

However automating vehicles can be done in very different ways, in different environments and with different goals. The problem is multidimensional:

- Geographic (on motorways on in cities and if in cities where in cities centres or peripheries how densely inhabited)
- Demographic (who are the users of the new transport concept which age will they have? This will influence accessibility and might create supplemental transport demand)
- Technological (which is the technology? For high speed – long range reduced angle sensors? For low speed - short range wide angle sensor? Will it know the infrastructure already will it be GNSS based or SLAM or others – this will affect the range of applicability and the kind of maps to provide)

- Of service supplied (will the vehicles be private or public? Individual or collective? Will they provide door to door service or be integrated with other transport systems?)
- Of interaction with the surrounding environment (will it need barriers? Will it need removing road side parking? Will it need adapting the infrastructure? How respectful of vulnerable road users? Which speed will it have to guarantee safety – a speed much lower than manual vehicles?)
- Overall the vehicles need evaluation on its own or as part of the mobility? If so is not it essential to foresee different uses of such vehicles?

5.2 Work to do

Technical evaluation of the vehicle performances can be done in an “almost objective” way once the key technical indicators to measure are selected; one approach can be to extend the CONVERGE evaluation guidelines defined by the homonym EC project of the late nineties on evaluation ICT for mobility.

On the other hand transport, energy-environment, safety-security, societal and economic evaluation is strictly dependent on the application scenarios studied. The MAESTRO methodology, from the homonym EC DGVII funded research project to establish guidelines to evaluate pilot and demonstration transport projects, can be adopted here on simulations and field-trials of a number of scenarios for the application of automated vehicle technology to urban and interurban mobility..

Annexes

Annex 1 – References

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