

Final publishable summary report

Executive Summary

The 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 in 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 mission was progressing toward this vision defining and demonstrating the legal and technical frameworks necessary to enable ARTS on the roads.

CityMobil2 is an EC funded project, which aims at fostering the implementation of ARTS in European cities. ARTS are road transport systems based on fully automated (no driver seat—no steering wheel) vehicles, which have a prior knowledge of the infrastructure they use, and which is certified with them. ARTS vehicles are not autonomous but constantly supervised and managed by a supervisory system under the control of a human operator.

The CityMobil2 general objectives include the organization of groundbreaking demonstrations of ARTS in 7 European cities; the study of long term socio-economic impact of automating mobility; and the definition of a legal framework which will finally allow ARTS on urban roads.

CityMobil2 work plan was organised in two phases. In the first phase, the study phase, 12 cities studied ARTS insertion in their sites and prepared proposals to host a demonstration. At the same time the research team prepared the technical specifications for the ARTS fleets to be used in the Project demonstrations. The five ARTS manufacturer partners in the consortium prepared their bids on the basis of such specifications. Two fleets of 6 10-passenger vehicles each were selected.

During the second phase, the demonstration phase, two procured fleets (from project partners Robosoft and EasyMile respectively) were brought in the 7 selected cities for variable periods to supply real transport services.

The selected demonstrations are

- Oristano, in Sardinia (Italy), July and August 2014
- La Rochelle, France, from October 2014 to April 2015
- Lausanne, Switzerland, from October 2014 to April 2015
- Vantaa, Finland, in July and August 2015
- Trikala (Greece)— from August 2015 to February 2016
- Sophia Antipolis (France) from March to May 2016 and
- San Sebastian (Spain) in from April to July 2016.

CityMobil2’s workpackages 18, 25, 26, and 27 respectively: studied the impact of these systems on passengers and other road users and assessed their reactions and how to improve the technology and its urban integration to satisfy the “human factor”; evaluated the demonstrations and cross-compared results; defined a certification methodology and proposed a legal framework; and forecasted long term impacts.

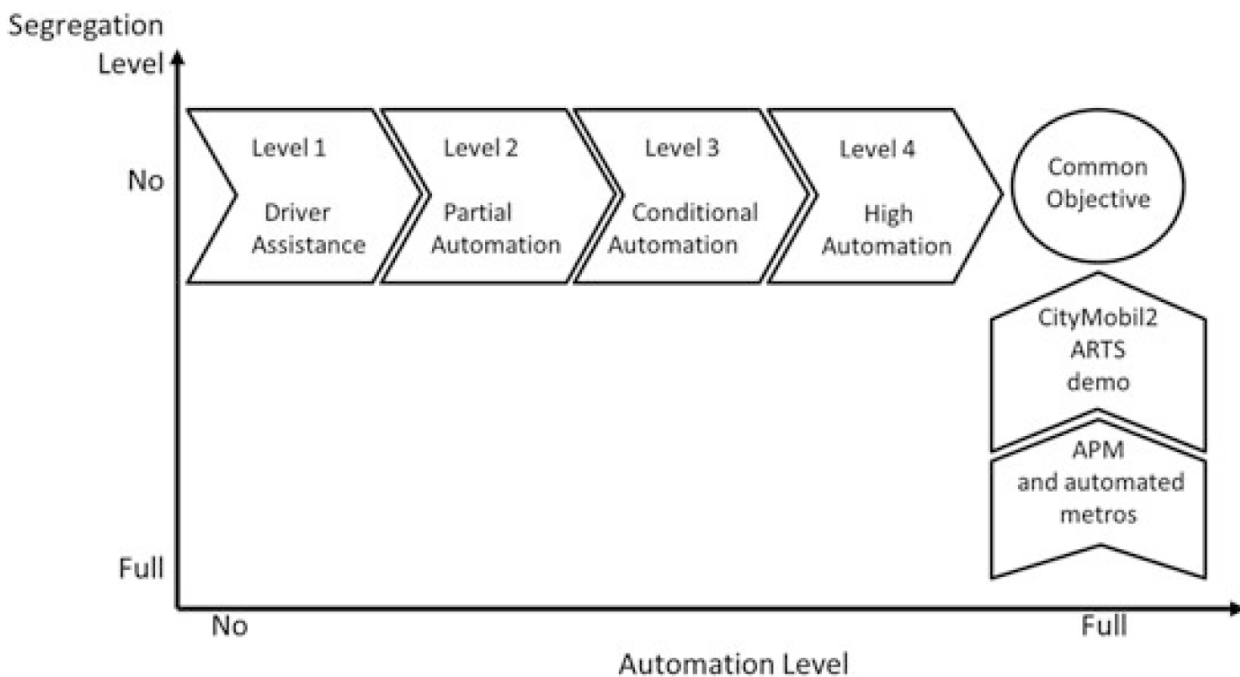
Summary description of the project context and the main objectives (4 pages)

CityMobil2 is a European project which deals with automating mobility. The CityMobil2 vision can somehow clash with others 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

Building on the results of its predecessor CityMobil project, CityMobil2 used a geographical classification to identify the transport tasks better suitable to transport system based on road vehicle automation. CityMobil2 has 12 cities studying how to best integrate (and where in the city) automated road transport systems. 7 of them became real life demonstrators.

Where does this vehicle have to run then? How can they be safely (and legally) introduced on urban roads? CityMobil2 defined where these system should run and how to adapt roads to make them as safe as rail transport though as flexible as cars.

Road vehicle automation technology brought two different (not necessarily competing) concepts: on one hand the “Autonomous vehicle” which is a conventional road vehicle with increasingly Advanced Driver Assistance Systems (ADAS) and which, one day, will allow the driver to distract (e.g. texting), to sleep or even to be absent; on the other hand, the cybercar, a vehicle which is part of an ARTS, it does not have a driver and can drive itself on a preapproved road network, offering last mile transport mostly to supplement mass transit.



The figure above shows a chart with the degree of automation versus the degree of segregation, showing that the future for both concepts is full automation everywhere, but while autonomous vehicles will remove the driver only in the long term, ARTS, having no driver from the start, needs to move out from the segregation.

The key differences between the two concepts are:

- infrastructures where they can operate:

- autonomous vehicles are conceived for any road without any prior knowledge of the infrastructure nor any interaction with it,
- cybervehicles can move only on well-known road infrastructures which are adapted to make the system safer than road transport and certified alongside the vehicles; cybervehicles, infrastructure and the supervisory system altogether form an ARTS; and
- degree of automation,
 - autonomous vehicles can drive themselves in most of the circumstances but when automation fails the driver is expected to take over,
 - cybervehicles simply have no driver; should automation fail, a failsafe system will stop the vehicle safely and notify the other vehicles and the (human) operator of the problem

Automated transport systems were in operation even before CityMobil2 (e.g. the Rivium Parkshuttle, the Masdar and the Heathrow PRT) but they required partly or completely segregated infrastructures and are certified as if they were automated railways. CityMobil2 demonstrated that similar technologies can operate on the roads with slight modifications and with the right certification procedure.

In general, the automated vehicles performed well. Particular outcomes were:

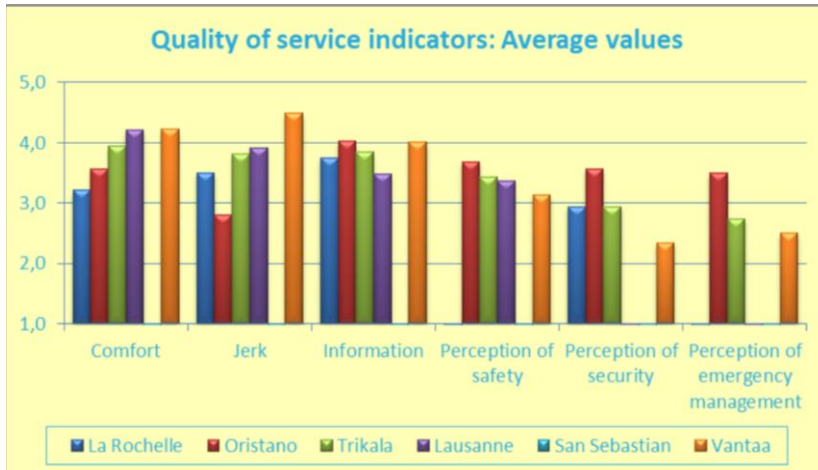
- Traffic conditions in urban areas are complicated because of large numbers of cyclists and pedestrians. The vehicles were run at low speeds to ensure the safety of the demonstration (about 10km/h). The safety of vehicles at higher speeds needs to be proved in the future studies.
- The reliability and robustness of the automation technology needs to be improved. Some technical failures were reported in the demonstration, although the continued development of the vehicles during the project has led to significant improvements.
- The effects of weather on ARTS performances were more significant than anticipated with, for example, the dust resulting from high temperatures and dry weather creating problems for the correct perception of obstacles by lasers located low on the vehicles. In addition, heavy rain and hail were often detected as an obstacle by LIDAR sensors.
- The central management system developed for Lausanne was particularly useful in the development of system to support the vehicle operations.
- During the demonstrations, substantial data was collected about vehicle performance which is valuable for further improvements of the vehicles, especially in localisation and obstacle detection. A strong base of operating knowledge and of technologies generated by a comprehensive approach to evaluation has been developed which places the manufacturers

User Trips

The results of use frequency show that, in all cities, most people used the ARTS once and, in all cities, they appear to make occasional trips rather than a systematic ones (commuters) with the exception of Trikala, where there was a significant percentage of users who made the trip between 2 and 4 days a week (42%). This is consistent with the results relating to the users' trip purpose. Most users in all cities made their trip to test the ARTS except in Trikala. This finding can be explained by the experimental character of the ARTS service as implemented in the cities. In Trikala there were higher percentages of trips made for health, bureaucracy and education than the other cities and the usefulness of the service was the highest rated among the cities.

Quality of Service

Over 1 500 ARTS users were interviewed to assess their perception of the ARTS service. ARTS users were rather satisfied with the performance of the ARTS vehicles with higher than average ratings on comfort, information availability and safety. The factor mapping of user acceptance and quality of service showed that there is room for improvement, although the later demonstrations with the more advanced vehicles showed an improvement in user views of service quality. ARTS users were willing to pay for ARTS services, but not at a price higher than that of the conventional equivalent.

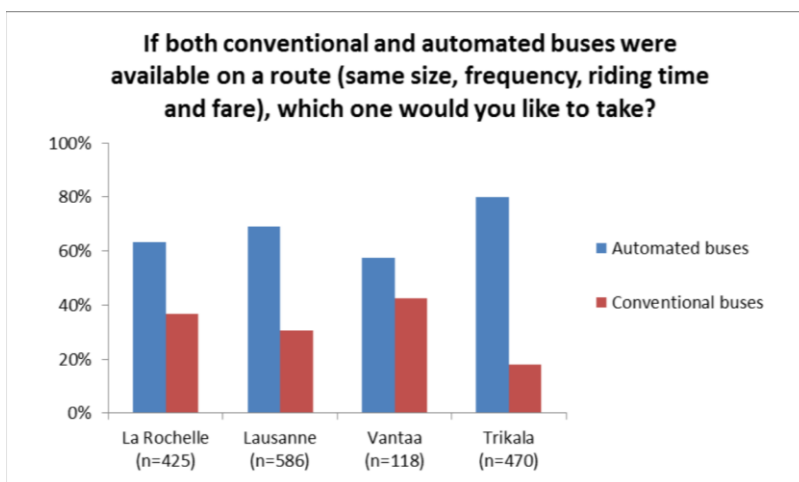


Positive attitudes from the public

In four of the seven ARTS demonstrations, the opinions of over 2 000 local residents were sought. Overall, public attitudes were positive towards the implementation of automated vehicles in urban areas. Most people surveyed were positive about the safety benefits of automated vehicles, believing that automated vehicles would be either safer than or as safe as human-driven vehicles.

For the ARTS demonstrated, the most attractive outcome was their potential to reduce fares (no driver costs). Passenger security was one of the issues of most concern especially for night-time services. The most supportive role for the ARTS vehicles was viewed as a complement to public transport as feeders/distributors.

The public supports the future applications of automated vehicles to replace buses on existing routes, as automated taxis or for car-sharing and car pooling.



Main S & T results and foregrounds. The length of this part cannot exceed 25 pages.

The Main foreground was achieved in the following sectors:

1. How to Integrate Automated Road Transport Systems in Urban Areas
2. How certifying ARTS for legal and safety purposes
3. How other road users interact with ARTS
4. Which long term impacts to expect

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. 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, with the elderly representing the highest fatality rates. Since elderly-related incidents have greater impact and likelihood of occurrence, safety regarding the elderly 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 that of rail.

One ADAS example well explains why the safe way to insert automated vehicles on urban roads is to consider them as a set alongside with infrastructures and supervision systems, rather than autonomously. One ADAS application allows a car to self-steer to avoid a pedestrian suddenly jumping in the carriageway from between cars parked on the road side; the car does not slow down but checks whether the other lane is unoccupied and automatically steers into it. This technology, though extraordinary, has questionable safety benefits. Any false positive detection would start a maneuver which would confuse the driver. In complex environments, a second line of parked cars would probably exist on the other side of the road, possibly hiding other road users, so that any such maneuver might lead to hitting another pedestrian coming from the opposite end of the road. Finally, the behavioral adaptation of the driver to such technology will make her more prone to distraction, causing more threatening situations. The CityMobil2 technical prescriptions [5] in this situation are: for ARTS vehicles, in case of obstacles occluding the sensor view, not to make any evasive maneuver but slow down before reaching the zone in which the risk exists of an unseen pedestrian suddenly jumping in the carriageway. ARTS infrastructure will tend to avoid the presence of road side parking or any other impeding obstacle on the road-side, and if these cannot be avoided, the ARTS vehicle's speed shall be adapted to the sensors' visibility.

The kernel of the CityMobil2 approach is to mitigate risks directly at the system's design stage by analyzing interactions between the ARTS, infrastructure, other road users and the surrounding environment [3].

ARTS vehicles can share the road with other road users but to ensure safety, clear definitions have been given by the project on which infrastructures to share and which rules to apply for this. CityMobil2 has therefore defined three levels lane-sharing for ARTS:

- ***segregated*** – in which ARTS vehicles are the only ones allowed and the lane is physically protected against external intrusions;
- ***dedicated*** – in which the lane used by the ARTS is clearly marked to be used preferentially by the ARTS vehicles, though other users can access it, but need to respect certain rules; and

- **shared** – in which ARTS, manual vehicles and other road users share the same lane without any precaution.

Segregated lanes are not simply reserved to ARTS vehicles, they are protected against external intrusion allowing high speed operation (just like motorways). In dedicated lanes, even if the ARTS vehicle has priority, pedestrians and bikers can cross them and move on them and other vehicles can be allowed if they respect few basic rules (no overtaking, no parking, no stopping, no reducing the distance from the ARTS vehicle below safety distance). CityMobil2 does not envisage shared lanes in the project's demonstrations. However, they can be foreseen in the future.

CityMobil2 has in its demonstrations dedicated lanes accessible to pedestrians and bikers in pedestrian areas, collector streets and urban streets (as defined by the Highway Capacity Manual of Transportation Research Board [6]), dedicated lanes accessible to other motor vehicles on collector streets, while in arterial roads, ARTS lanes need to be segregated because of the high speed of the other vehicles (above 50 km/h) and of the ARTS vehicles themselves (40 km/h). At the moment CityMobil2 does not foresee ARTS vehicles on highways or freeways.

On this basis, the CityMobil2 legal framework proposal is to divide the road infrastructure in two independent (but connected) infrastructures. ARTS have dedicated or segregated lanes, which may intersect with lanes for manually driven vehicles (always with traffic lights and road-side sensors that control respect of lights) and access for manually driven vehicles to some of the ARTS lanes, while ARTS cannot access "normal" lanes. Pedestrians and cyclists crossing at given intersections are always possible, while on certain lanes they can even share the way with ARTS.

To achieve the implementation of this framework, CityMobil2 proposes two separate EC Directives: one to regulate the technical procedure for certification of ARTS (infrastructure, vehicles and all subsystems) and one to regulate the civil liability of ARTS' manufacturers, operators, and manually driven vehicles using ARTS dedicated lanes.

The principles of the Technical Directive are:

- to achieve vehicle and infrastructure certification through a risk assessment (as in the rail technical standard EN50126);
- to take advantage of the modularity of the "Type approval" on motor vehicles Directives; and
- to be based on modular "Use Case" approach
 - a specific interaction situations between ARTS, infrastructure, road users and surrounding environment is a use case
 - and a certified use case doesn't require another certification if the same conditions repeat in another location.

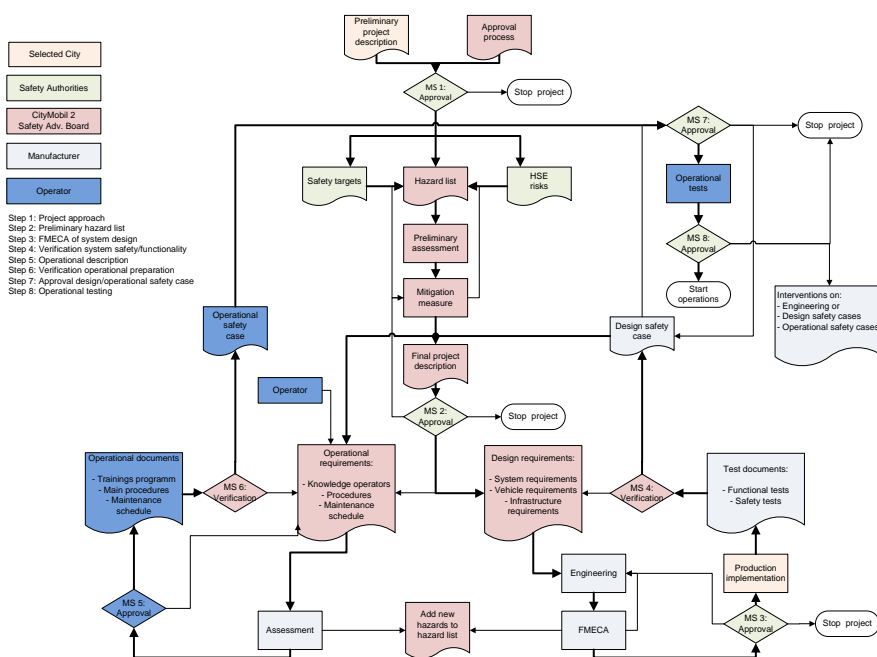
How certifying ARTS for legal and safety purposes

The Risk Assessment procedure is organized in the following 8 steps:

- Step 1: Project approach
- Step 2: Preliminary hazard risks
- Step 3: FMECA and system design

- Step 4: Verification of system safety/functionality
- Step 5: Operational description
- Step 6: Verification of operational preparation
- Step 7: Approval design/operational safety cases
- Step 8: Operational testing

Each step corresponds to a verification phase in the workflow shown in figure 2. Five actors are involved in the process: the city authorities who manage the infrastructure; the safety (or certification) authorities, normally the national ministry; a safety board from the project; the ARTS manufacturer; and the ARTS operator. Each one has tasks to accomplish. In figure below each of these actors have a color and tasks of each actor are correspondingly color coded. For example it is the role of the safety authority to give the safety targets at the beginning and provide a list of health and safety risks they want to be considered (light green tasks in figure below).



Risk Assessment procedure workflow
Source: CityMobil2 2014

First the procedure requires that the involved authorities agree that the proposed procedure is acceptable to issue a certification for the described project (step 1). Then the procedure foresees the compilation of a preliminary hazard list and proposal of mitigation measures, changing the project description until it is agreed that risks are mitigated and the final description approved (step 2). An example of this process for one section of the Oristano demonstrator is provided in the next section.

The ARTS needs then to be designed according to the specificities of the site and the agreed mitigation measures; changing the vehicle and sensor design could affect the mitigation measures. The system engineering need to pass a FMECA (Failure Mode, Effects, and Criticality Analysis) which will demonstrate that even in case of subsystem failure, the system will still react respecting

the prescribed safety targets (step 3). Two examples of the kind of measures which can be imposed by this analysis are:

- the braking system needs to be self-engaged, the vehicle control system will use an actuator to dis-engage the braking system to allow the vehicle to move. This is necessary because in case of an electric blackout the vehicle will still come to a safe stop without any intelligence or external command;
- the obstacle detection sensors need to be used on several layers of intelligence, the lower level will require that, should anything be detected in a critically safe area around the vehicle, an emergency brake is triggered directly without any superior intelligence intervention, to avoid that, should the higher level software fail, the vehicle hits anything.

Step 4 will verify that the functional safety outcome of the FMECA will indeed work.

Step 5 will consider operational requirements for the first time. Weather conditions, as well as hours of operation, lighting conditions will come into play here. Tests will be made to guarantee that the systems reaches the same safety level for which they are engineered in all operational conditions.

Step 6 includes operational procedures; the manuals for the operators, their training program, the maintenance schedule and all the other conditions which might affect in time the effectiveness of the system safety will need to be considered as well as emergency procedures in case of failure.

Step 7 will define the operational safety cases on the basis of the approved procedures and devise tests on those cases.

Step 8 will be the final tests (dry runs) before the final approval to public opening.

Such procedure is applied to any section of the ARTS route several times depending on the different external conditions (e.g. number of pedestrian on the section, ...). Each of these cases are “use cases”; assuming the safety target that the safety authorities establish are homogeneous, the certification of one use case which repeats under the same conditions in a different site should be pre-certified.

Hazard identification and mitigation measures in Oristano

To give an example of the second step of the risk assessment procedure explained above, one section of the Oristano demonstrator has been taken.

The Figure below shows the selected section on the map and in photo (as if taken from on board the vehicle). The vehicle is the blue square on the right hand side of figure 3. In Oristano demonstrator the route is shared with pedestrian and bikers. The vehicle detects an area of 30 meters at 180 degrees in front. Such detection distance is enough to guarantee a safe stop at 45 km/h speed and 2.6 m/s² deceleration.

However three fixed obstacles are in the 30 meters area in front of the vehicles: two buildings (one close on the right hand side and one further away on the left and side) and one bench on the right hand side; the bench impedes the view of the safety sensor because it is a laser at 25 centimeters height from the ground.

Being the bench at 4.5 meters from the vehicle, and considering an emergency deceleration of 3.5 m/s² (which incidentally would cause standing passengers in the vehicle to fall), the maximum allowed speed for the vehicle to guarantee a safe deceleration would be 34 km/h if pedestrian (moving

at a maximum of 6 km/h speed) were the only other allowed road users and 8 km/h if bikers (moving at a maximum of 25 km/h) were also allowed.

Another possible mitigation measure would be to have a barrier (either a bumper or a gate to open) preventing the bike to “shoot” out from behind the wall and the bench at 25 km/h. Lowering the maximum speed of the bike to 10 km/h the ARTS vehicle speed would need to be reduced only to 25 km/h.



Hazard identification and mitigation measures in Oristano
This example shows how mitigation measures are not only to be taken on board but could be more effectively embedded in the infrastructures.

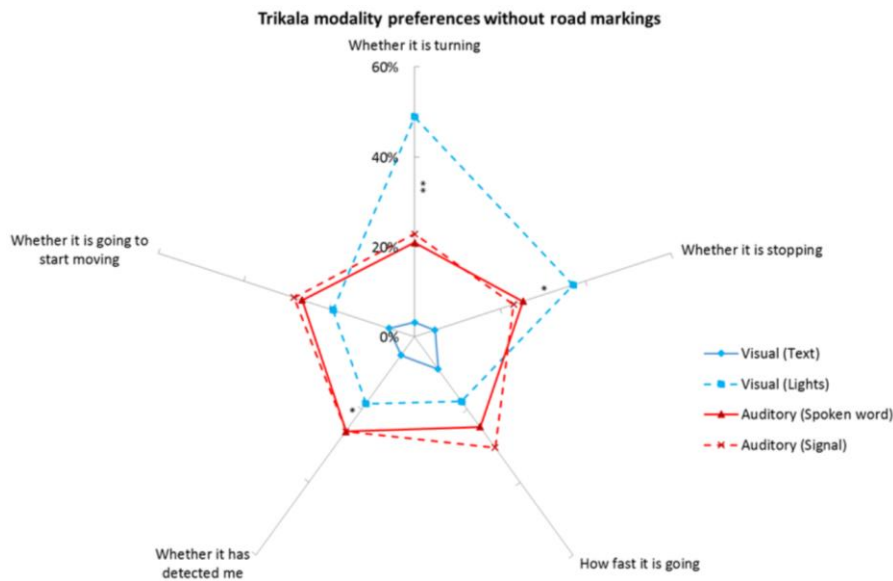
A more efficient sensor might avoid considering the bench as an obstacle but the wall behind the bench will always hide a biker and unless the biker is forced to slow down or a road-side sensor alerts the automated vehicle, it would either be unsafe or forced to slow down, decreasing its performance as a transport system.

How other road users interact with ARTS

Structured questionnaires were the primary means used to assess the comprehension and attitudes of other road users' (e.g. cyclists and pedestrians) towards automated driverless vehicles. The questionnaire was developed using a highly validated social-psychological model - The Unified Theory of Acceptance and Use of Technology. Key results from the survey in La Rochelle, Lausanne and Trikala include:

- Regarding safety, the effect of road markings was significant, with overall lower perceptions of safety in an environment where there were no road markings compared to an environment with road markings.
- Concerning priority, where there were no road markings, about two thirds of participants believed that they had priority to cross the ARTS vehicle's path. However, this went down to about one third in the presence of road markings.
- With regard to information about the behaviour and intention of the automated road vehicle, respondents reported greater importance of receiving information about the vehicle in the absence of road markings compared to when there are markings. There was no significant difference in terms of location, gender, or age categories on ratings of importance.
- Regarding preferences for type (modality) of information, there is a significant difference across the three locations between the ratings given to each information modality (i.e. visual

text, visual lights, spoken words, and auditory signals) for all types of vehicle behaviour, irrespective of whether there are road markings.



Which long term impacts to expect

On 30-31st March 2015, more than 100 experts from Europe, the US, Japan and Singapore met in La Rochelle (France) in a workshop organized by the European project CityMobil2. The workshop focused on the expected impacts of road vehicle automation take up in different typologies of urban environments - compact cities, sprawled cities, connected cities and rural areas - and for two different scenarios: automation of private cars and diffusion of shared self-driving vehicles. The experts had to assess the potential impacts of automation on the economy, transport, the environment and society.

The pros and cons of two “caricature” scenarios – automation with and without a paradigm shift to shared mobility – were debated and a number of potential impacts were identified in terms of: job disruption and creation; personal trips costs; public budget effects; insurance costs; accessibility to remote areas; road capacity and its use; journey comfort and convenience; energy and emissions; land saving for new public space uses; social impacts in terms of safety, personal security, health and active travel (trade-offs in automated rides vs. walking or cycling) and different perception/value of time spent travelling in automated vehicles.

Preliminary analyses undertaken to prepare for the workshop included a review of recent urban self-driving transport scenario studies, an online DELPHI survey, and a qualitative evaluation of the socio-economic impacts of different urban road automated transport scenarios.

In this paper we summarize the key results of:

- ▶ The online survey focusing on road transport automation in different urban contexts.
- ▶ The qualitative appraisal of the expected impacts of driverless urban transport scenarios and the results of the 1st Day session discussing the impacts.

- ▶ The 2nd Day session on the stakeholders' perspectives concerning the preferred scenario, and which business model changes and policies would be needed to enable the transition to the preferred scenario of urban transport automation.

Results of the online survey

The aim of the on-line survey was to evaluate 8 options of urban transport automation, contrasting 2 extreme scenarios (automated private car ownership vs. automated car-fleet sharing) in four different urban typologies:

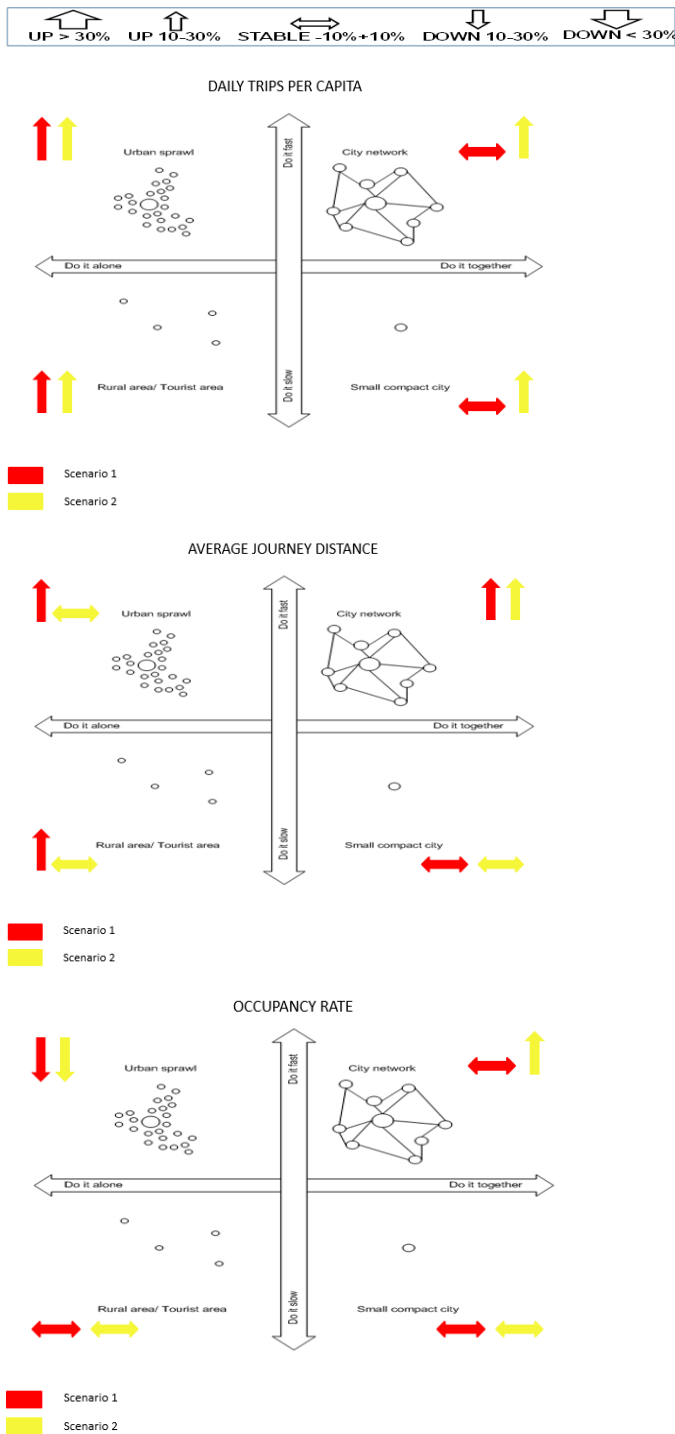
- ▶ *Urban Sprawl*: Large cities with a city core surrounded by low density suburbs, with the prevalence of fast trips mostly done alone to/from the city centre and – to a limited extent - of tangential trips. Car ownership is high, the daily trips per capita in a working day are high, the average distance is high and the occupancy rate is low.
- ▶ *City Network*: Polycentric regions/city networks with the prevalence of fast trips mostly done together. Car ownership is low, while all other benchmark values - daily trips per capita, average distance occupancy rate - are high.
- ▶ *Small Compact City*: The prevalence of short distance/slow trips, done together or by foot and bicycle, characterize small compact cities. The occupancy rate is high, while all the other benchmark values – car ownership, daily trips per capita, average distance – are low.
- ▶ *Rural/Tourist Areas*: Low density areas with the prevalence of slow trips mostly done alone. Car ownership is low, the daily trips per capita are low, the average distance is high and the occupancy rate is low.

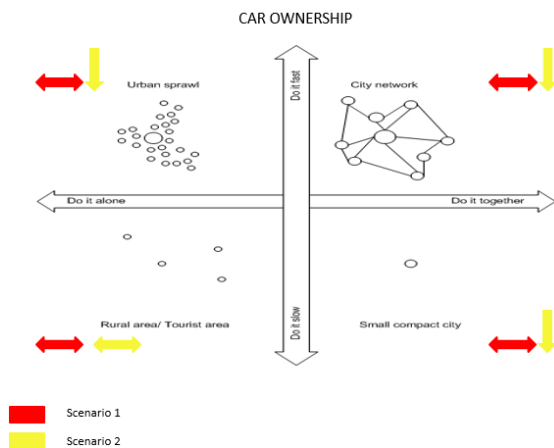
A key assumption underpinning this approach is that – besides some general technological and social drivers - urban transport automation challenges, opportunities and impacts will be different in low and high density city contexts, and depending on the available transport infrastructure (in particular the existence of high capacity links). The survey was concentrated only on the direct impact on transport patterns in each urban form, not on second order land use impacts of automation on the urban forms themselves – for instance the extent to which automation may provide a further impulse to urban sprawl facilitating longer journeys is beyond the scope of our study.

For each urban form, respondents to the online survey had to consider two contrasted and somehow “extreme” scenarios:

- ▶ *Scenario 1: Automated car ownership-centred mobility*. A private automated mobility scenario is the result of a technology revolution without a significant change in the conventional private transport behaviour. Most of the people will continue to own and drive their cars. Self-driving vehicle sharing will develop to a limited extent, within the same household – reducing in some contexts the need to purchase a second car – or more broadly by means of peer-to-peer car sharing schemes. In any event, the autonomous vehicles will continue to be mostly in private ownership.
- ▶ *Scenario 2: Automated car fleets-centred mobility*. This scenario envisages a shift from privately owned individual vehicles to collective purchase and operation of fleets of self-driving vehicles – that may be owned by private or public service operators – and are available for simultaneous (ride-sharing) or sequential use (car sharing) on demand, complementing and integrating existing mass transits.

89 participants answered to the survey. The majority of respondents was interested to evaluate automation scenarios only in the urban sprawl context, considering the other contexts less relevant or because they were less confident in assessing likely self-driving scenarios for other urban forms. The car ownership centered scenarios was also slightly more popular than the shared self-driving vehicles, collecting more answers. Figure 1 summarizes the main results concerning the expected changes of four key variables characterizing urban mobility – daily trips per capita, average journey distance, occupancy rate and car ownership – for the 8 options considered (2 scenarios x 4 urban forms):





Survey results

The arrows (red for scenario 1 and yellow for scenario 2) represent for each key variable both the direction (increase, decrease or stability) and the intensity (bigger arrows for > 30% change in the base variable, smaller arrows for a change between 10% and 30%) of the likely change, according to the most frequent responses to the survey (modal values).

The most frequent answers have been more conservative than our impact assumptions presented in the online questionnaire. According to the majority of respondents urban transport automation will cause the key variables to change within the range 10%-30% at most – or to stay the same - not changing radically (more than 30%) in one direction or the other. This is because – in the opinion of many - autonomous vehicles, are only one of many factors that will affect transport demands and costs in the next few decades, and not necessarily the most important. More in detail, the key insights and conclusions for the single variables characterizing urban mobility are as follows:

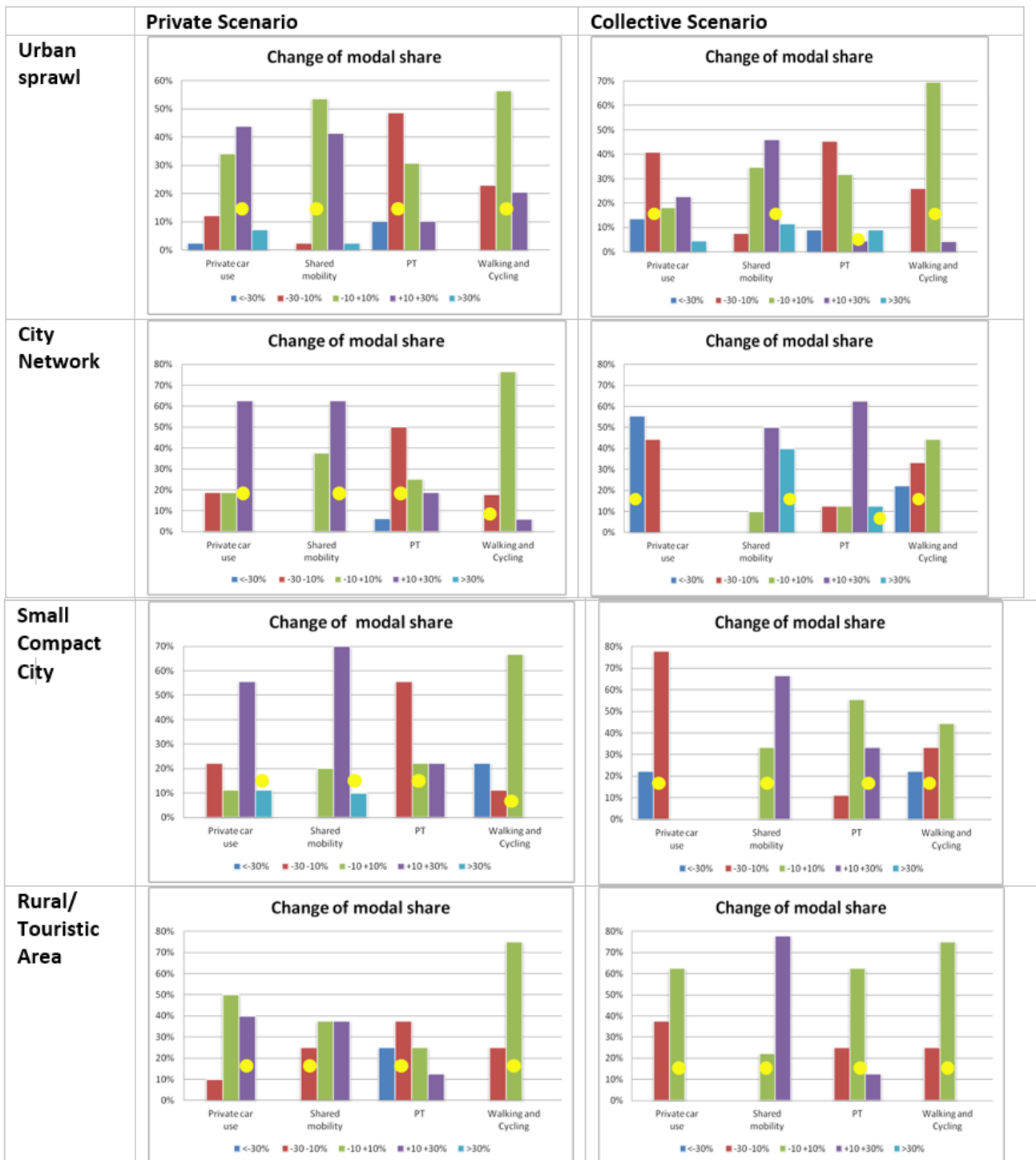
- ▶ *Daily trips per capita* will increase in the urban sprawl and rural areas settings, as the self-driving car availability will augment the flexibility and opportunity to combine daily travel schedules for different members of the household. In the more compact forms – city network and small compact city – daily trips are expected to increase only in the automated car-fleet scenario, thanks to the availability of more capillary services. The impact pathway presented in the survey assumes that the cars are more often available because of their capability of self-driving, and this alone will induce more daily trips per capita (increasing more than 30%). Most of the respondents to the survey were more prudent, guessing for a more moderate increase, as car availability is not the only factor affecting car use, especially in potentially congested urban contexts or where a good high capacity public transport is available. The number of impaired mobility people trips should increase, but it also depends on the availability of the facilities at the end of the journey and on the easiness in getting in and out of a car. By the same token, the impact on aged people propensity to travel may be important, but insofar as the aging population do not easily understand and adopt new technologies may be scared by these developments.
- ▶ The *average journey distance* will increase in the private automated scenarios for all urban forms, except in the small compact city, where short distance trips are prevailing and self-driving will not change substantially the range of accessibility choices. On the contrary, the average journey distance will not increase in all car-fleet automated scenarios, except in the city network, where the offer of coordinated car sharing and ride sharing options is likely to increase the longer trips between the different cities of the network. The impact pathway presented in the survey assumes that the car use for longer trips is encouraged because the trips become more comfortable and the passengers are free to choose what to do while the car

is driving itself. Average distance may increase between 10 and 30% as a result. Most of the respondents to the survey agreed on this assumption. However, a consistent minority were more skeptical due to the higher autonomous vehicle costs, which may reduce both the penetration of these vehicles in the market and their extensive operation and use by households members. In addition, the length of the trip is primarily affected by the current city size and form, a factor that influences travel needs and cannot be changed in short times. Both factors – low driverless cars penetration and rigid land use patterns – may cause average distance not to increase, at least in the short term. The average commuting time may also remain constant, as automated modes will not automatically be faster – indeed speed limitations for the autonomous driving are in the cards. The picture can obviously change in the long term, as the greater travel comfort can induce further urban sprawl and longer commuting trips.

- ▶ The *occupancy rate* will decrease in the urban sprawl context, as an effect of the empty trips to relocate the self-driving cars to the next users – i.e. another member of the household in the private automated scenario or another user in the car-fleet scenario. This effect is not considered significant instead in other urban contexts (small compact cities, rural/tourist areas), with the exception of the car-fleet scenario in the city network, where fleet based car sharing and ride sharing services are assumed to optimize the journeys and bring an increased occupancy rate (between 10% and 30% more). The impact pathway presented in the survey assumes that empty trips will increase substantially (causing an average occupancy rate increase of 30% or more) in the private automated mobility scenario, to allow different members of the household to use the same car during different hours of the day. Automation will not deliver the same effect in the car fleet scenarios, because fleet owners will be motivated to minimize empty running, e.g. through dynamic pricing. Most of the respondents to the survey consider the assumption for the private automated mobility scenario too pessimistic. Occupancy rates – some respondents claimed – are already low especially in the urban sprawl context (around 1.3), it is difficult to reduce them further. In addition, the operating costs of “dead-heading” empty private vehicles will become something households examine, pushing for a more efficient use of the car. Empty trips could be reduced as well by the sharing of self-driving cars between members of the same household or through ride sharing with neighbors or work colleagues. In a nutshell, a decrease of occupancy rate is expected, but more moderate – below 30% - in the private automated mobility scenarios, and not expected at all in the automated car fleet scenarios. In the city network automated car fleet scenario – as mentioned – the occupancy rate will increase, as most of the respondents to the survey agree.
- ▶ Finally, according to the majority of respondents, *car ownership* is poorly affected in the private automation scenario – whatever the urban form. On the contrary, it is obviously likely to decrease in the car-fleet sharing scenarios, but the latter not in the rural area context, where the car will remain a key asset to hold (with more opportunities however for ride sharing or peer-to-peer sharing). However, some respondents to the survey highlight that car ownership could decrease substantially also in the private automated mobility scenarios, because self-driving cars may serve the mobility need of more than one family member in the same day, and the ownership of second or third cars could drop for this reason. If the autonomous vehicles are more expensive than the conventional ones, new vehicles purchase will be also limited, with a detrimental effect on car ownership. On the other hand, in the automated car fleet based scenario -- according to some respondents car ownership will decline if car and/or ride sharing will effectively happen - in particular in the city network context where a radical decrease of car ownership is assumed (more than 30% of decrease). However, for this to happen it will require new business to start up, which will need payback to cover for car

purchase, depreciation, maintenance, insurance and fuel, and based in the right places. Thus, the cost could be high to the consumer, which may mean that the adoption takes longer and thus car ownership would not change so rapidly.

As it concerns the changes of modal share, between *private car use*, *shared transport*, *public transport* and *walking & cycling*, the results of the survey are shown for the two scenarios in the figure below:



Survey results for the model share scenario

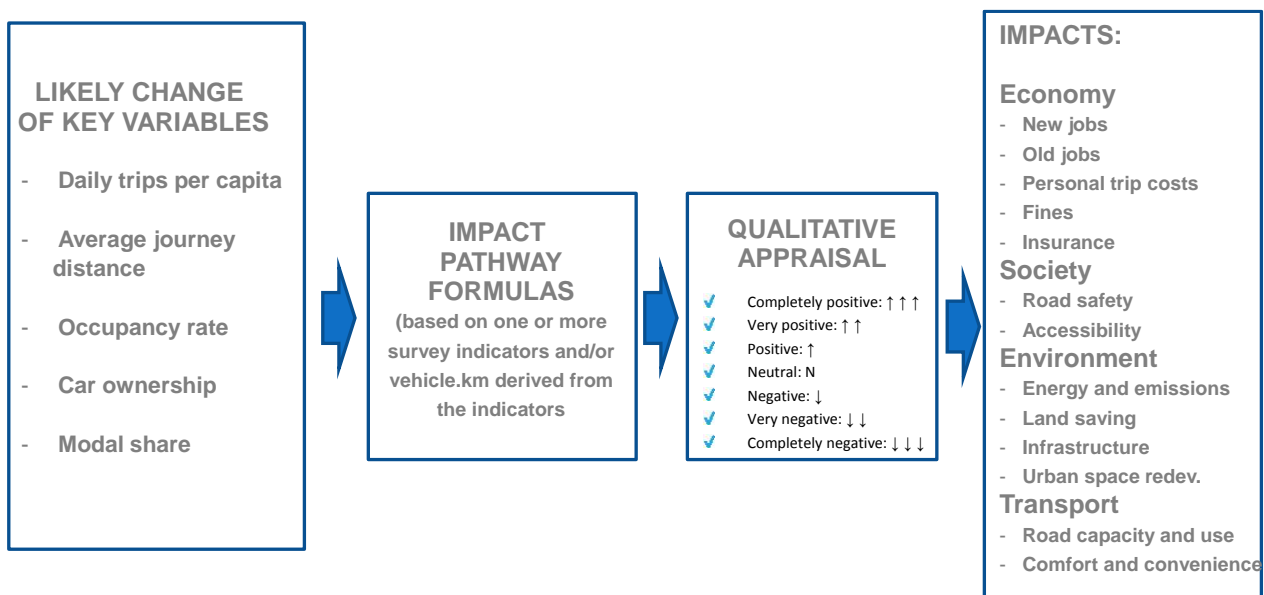
Not surprisingly, in the private automated scenario the private car use is expected to increase for all urban contexts, as a consequence of the greater comfort of using and travelling with a self-driving car. The only exception is observed in the rural area context, where the majority of respondents think private car use will remain the same. A reduction of the public transport share is expected, almost mirroring the increase of the private car use, while most of the respondents think that walking and cycling shares will remain stable, as automated transport should not attract those that enjoy walking or cycling.

The impact pathway presented in the survey assumes for modal shares in the private automated scenario an increase of private car use. This primarily because thanks to new self-driving capabilities cars can be used by people that cannot drive (children and elderly people with reduced driving capabilities). In addition, the pathway assumes stable share of car/ride sharing especially in the urban sprawl context, a reduction of public transport ridership, and a slight negative trend from walking and cycling, mainly due to the trips made with new automated vehicles when the conditions for walking or cycling are not comfortable (e.g. bad weather). Further comments from the respondents to the survey pointed towards a possible increase of shared transport also in this scenario. Shared mobility will be higher if cars become available to younger people who currently travel by public transport, and the acquisition of private – and expensive – automated vehicles will probably encourage their owners to propose more ride sharing to others to amortize the purchase costs. Some peer-to-peer car sharing will be also encouraged – although less than ride sharing - as connected and automated features of the new cars will reassure owners and let them share their cars more easily, reducing the risks of accidents, thefts, etc., and ensuring that the cars come back to the owners when needed. Finally, some respondents questioned the expected reduction of the public transport share. This depends by what will happen with the costs of the different options for the user: self-driving, shared transport, public transport. Insofar as the prices of automated vehicles will be higher, this will reduce private car usage by raising public transport and shared mobility. In addition, if the circulation of self-driving private vehicles in the urban areas will be more easily controlled and managed, this may have a positive effect also on the reliability of public transport in the same areas, increasing its use. In the car-fleet centered scenario, there is a potential complementarity between public transport and self-driving shared transport modes in the city network context, as both shares are expected to increase while private car use is likely to decrease radically. The same effect is not expected in the small compact city and in the rural area contexts, where shared transport will increase but the public transport share is likely to remain the same. On the contrary, in the urban sprawl context the new self-driving shared transport mode can be a potential substitute for public transport, with shared mobility eroding not only the private car use but also the public transport share. The impact pathway presented in the survey assumes for modal shares in the automated car fleet based scenario that the car use decreases because efficient public transport becomes available where it was not before the automation (last-mile public transport), increasing the share of seamless public transport intermodal trips. Shared mobility is also increased a lot as the availability of fleets of shareable self-driving cars is the main feature of this scenario, while soft modes are not affected. Most of the respondents agreed with these assumptions. Although not mentioned in the scenario, driverless taxis will be a form of shared mobility, and they will increase substantially. Public transport might see even a rise of high capacity arterials (e.g. metro rides) since publicly run and maintained automated vehicles might serve as feeders thus offering for the first time – especially in sprawled areas – a competitive public transport option. However, one comment “out of the chore” highlighted that shared mobility services would not hold the same characteristics (e.g. response time) in central/high demand and in peripheral/low demand areas, and the same applies to conventional public transport services. Although it is true indeed that shared vehicles could offer a solution for the last mile problem, this would not

dramatically change the level of service between central and peripheral zones, and the households living in peripheral locations might choose to still own and use a private vehicle. Finally, a potential positive side-effect on walking and cycling has been also mentioned, as the new free space due to less need of parking space for the self-driving cars (which are expected to circulate more continuously during their lifetime) may lead to reconversion of parking lot space to more attractive pedestrian zones. This means that more people might prefer to walk due to enhanced safety, walking space and less pollution.

Qualitative appraisal of expected impacts and highlights from the 1s Day session

The number of trips per capita, the average travelled distance and the occupancy rate of each transport mode are the key variables to determine the number of vehicle-kilometers travelled each day. This, together with the modal share of the different modes, allows to know whether in each scenario the number of vehicle-kilometer travelled overall increases or decreases with respect to the “do nothing” scenario and how much. Most of society and environment impacts of transport depends on the vehicle-kilometer travelled. Even if an automated vehicle can be less polluting or less prone to accidents than a manually driven one, the overall impact might still be negative if the increase in the number of vehicle-kilometer (exposure) is more than the reduction of accident risk or emission per vehicle-kilometer, producing a rebound effect. Similarly, the economic impacts are dependent on the car ownership rate and the vehicle-kilometers travelled because these variables influence the number of vehicles sold and the economy related to fleet maintenance and management. The key variables considered in the online survey have then be used to give a qualitative evaluation of 13 long-term socio-economic impacts belonging to 4 evaluation categories on the basis of the survey indicator results, as illustrated in the scheme below:



Evaluation of survey results

A first qualitative appraisal of impacts has been presented at the La Rochelle workshop. The results of the discussions are summarized below for the four categories of impacts.

Economy

The *economic impacts* computed with the qualitative methodology included *new jobs, employment, personal trip costs, fines, and the impacts on insurance costs and services*. According to the computations, all economic impacts will be positive in the private automated scenario, in particular in the urban sprawl context but also, with slight differences of intensity, in the other urban contexts (city network, small compact city, rural area). This is caused primarily by the significant increase of

total mileage expected when autonomous vehicles will be diffused, making travel more comfortable and accessible to categories of users – elderly, disabled - that today are excluded. Impacts will be positive also in the shared transport scenario, with the only exception of employment in old jobs, where the effect is considered neutral, because traditional jobs in the car manufacturing, repair, maintenance etc. will not increase due to the reduction of cars sold on the market. However, according to most of the survey respondents the impact on employment may be less favorable for the private automated scenario, in all urban contexts, because of job losses in maintenance and control services needed per km travelled, not compensated by the increase of total mileage. Moreover, other economic impacts include:

- ▶ The impact of travel comfort on personal productivity, during and after the trip
- ▶ The impact of safety on human capital health and productive value
- ▶ The impact of accessibility enabling economic development, in particular of more remote suburban areas where self-driving cars contribute to improve accessibility
- ▶ The impact of fines not only on household budgets, but also on public budgets that will suffer a loss.
- ▶ The same for parking fees: their reduction is a benefit in terms of personnel trip costs, but would have an heavy negative impact on the local authorities budget, as parking charges are an important source of revenue

Society

The *social impacts* computed with the qualitative methodology include *safety and accessibility for disabled and elderly people*. According to the computations, these social impacts will be positive in the collective automated scenario, for all urban contexts, while in the private automated scenario the impact on safety is assumed moderately negative, as the reduction of self-driving vehicle accident risk would be more than offset by a significant increase in the total mileage. The positive impact on accessibility will be higher in the private automated scenario compared to the shared self-driving transport scenario, as in the former privately owned cars will be available at the door-step. However, most of the survey respondents do not agree with the pessimistic forecast of road safety decrease in the private automated scenario, because they think improving safety is a must for introducing automated transport – a new technology cannot succeed if it eventually reduces safety on the roads. Moreover, the substantial increase of exposure to risk in the private automated scenario is considered plausible only for the urban sprawl and rural areas contexts, while the increase of mileage is expected to be less significant in the compact city and city networks contexts. Other social impacts include:

- ▶ Health: what impact will automated demand responsive vehicles have on our health? Will we cease to walk or ride a bike? Cities are promoting active travel today, especially for the first/last mile.
- ▶ Well-being/quality of life
- ▶ Urban space redesign: with fewer private cars in the city, there would be the opportunity to use parking facilities for other purposes (offices, homes) leading to new high quality urban fabric, which is denser without giving the impression of higher density.
- ▶ Residential relocation: on the one hand, automation may offer the option of moving away from the city to areas where housing is cheaper. On the other, it may induce forced relocation

because accessible areas in the city could push up property prices, thereby pushing poorer people out of the city.

- ▶ Improved access to employment – the absence of transport is no longer a barrier, unless it is unaffordable.
- ▶ The perception of travel time will change – as it will be possible to work or sleep while travelling.

Environment

The *environmental impacts* computed with the qualitative methodology include *energy and emissions, land saving, urban space requalification and infrastructure modification*. According to the computations, energy and emissions impacts will worsen in the private automated scenario, due to the increased mileage not compensated by better vehicle and driving performances. In this scenario, the other environmental impacts are expected instead to remain more or less the same (with the exception of the impact on land saving and urban requalification in the rural/touristic area context, which is expected to worsen). In the shared self-driving transport scenario, the environmental impacts are always expected to improve – with the exception of infrastructure modification - for all four urban contexts, and particularly favorable for land saving and urban requalification in the city network context. However, most of the survey respondents do not agree with the pessimistic forecast of increasing energy and emissions in the private automated scenario whatever the urban context, as they think the total mileage will increase significantly only in the urban sprawl and rural area contexts, not in the other more compact urban contexts (small compact city and city network). The most relevant insights from the workshop discussion of environmental impacts include the following:

- ▶ Private automation may increase accessibility of remote areas and facilitate urban sprawl. This will cause an increase in distances and in number of trips and may naturally lead to shift away from environmentally friendly modes such as soft and PT.
- ▶ On the contrary, collective scenarios may increase *urbanisation* by attracting citizens to live where flexible mobility options are available. The city in this scenario may be manageable *through integrated PT management* in which all available mobility solutions are considered and can be compared in relation with many different criteria such as cost, time, comfort, need to drive/wish to “do something else than driving” or environmental impacts. In any case, it is important to avoid mode shifts from soft and collective modes (and understand how to do this).
- ▶ Concerning *energy and emissions* in the private scenario the main concern in the urban sprawl pattern is the increased mileage that cannot be compensated by better vehicle performances, use of platoons and lower cruising speeds. Only increased use of carpooling solutions may compensate the increased VMT. For vehicles able to search parking on their own, the vehicle owner may be more inclined to enter city centres without the burden to search for a parking place or pay for one as the vehicle may even drive a couple of km to reach an empty parking place. This is highly unattractive for city authorities.
- ▶ In the collective scenario the *investment in fleets* offers eventually much more potential to further improve the system gradually as demand increases. Most waste comes from relocation of the empty vehicles but this may be balanced by the increased carpooling which becomes a kind of flexible public transport system.

- ▶ In the private scenario most of the *land saving* is connected with parking in urban areas. In the urban sprawl case there will be a high demand on land use outside city areas and higher infrastructure and city running costs. In the collective scenario there will be positive impacts in land use due to a very low need for car parks and no need for car parks in city centres. It will be easier to manage the interface with the public transport and car sharing fleets.
- ▶ A private scenario will have less *impact on infrastructure modifications* in comparison with the collective one. On a macroscopic point of view, the *impacts on urban requalification* will be negligible in terms of road network length because there will be the need to maintain an urban road network which can accommodate for both automated and manual vehicles. However, in a collective scenario, part of the urban environment is converted to full automation mixed with pedestrian and cyclist traffic. This may lead to a radical requalification of the centre urban environment, offering to cities the option to become *more liveable* keeping vehicles outside the city centres. It will give the opportunity to rethink the urban environment for pedestrians, autonomous vehicles and deliveries. The need of dedicated lanes will require investments in *infrastructure modifications*.

Transport

The *transport impacts* computed with the qualitative methodology include *road capacity and use, and travel comfort/convenience*. According to the computations, for the private automated scenario these impacts are expected to be respectively neutral (road capacity) and highly positive (comfort) in all the urban contexts. The road capacity constraints are lessened in the shared self-driving transport scenario, as the total expected mileage is lower than in the private scenario, while the comfort of sharing is considered still positive, but more moderately. However, also in the private scenario the road capacity constraints are somehow lessened in the compact and especially in the city network contexts, because the increase of total mileage is lower than in the urban sprawl and rural contexts. Finally, the impact on road capacity will be particularly favorable for rural/touristic areas in the shared self-driving transport scenario. Besides road capacity and travel comfort, the participants wanted to re-discuss some of the key variables in the survey, to suggest few other elements for the qualitative impact evaluation procedure:

- ▶ Modal share is expected not to change in the urban sprawl context for the private automated mobility scenario, while to significantly favour public transport in the collective scenario (with shared automated vehicles mostly serving last mile legs of high capacity public transport routes).
- ▶ Earlier adopters of automation would benefit the greatest. Too many automated vehicles would be detrimental to mobility due to limited space. Automated small vehicles (whether private or collective/shared) cannot replace the high capacity public transport systems (bus, tram, etc.). This capacity issue may be resolved with pods operating in ‘train mode’.
- ▶ The overall travelled vehicle-kilometre are expected to increase significantly (very negative impact ↓↓) in the urban sprawl context for the private automated mobility scenario and even worse (↓↓↓) for the collective scenario (due to self-driving empty trips)
- ▶ Few more impacts were asked to be considered, including *travel time*, its *reliability* and the *connectivity* (maybe overlapping with the accessibility in the social category). Travel time is expected to be negatively affected by congestion in the private automated mobility scenario

and be very positive in the collective scenario, while its reliability would require further investigation. Connectivity is expected to be positive in both scenarios for the urban sprawl context.

Vehicle Automation and its potential benefits

NHTSA 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, 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), 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 automation bring to different levels of achievable benefits.

Here the achievable benefits coming from different levels of automation will be discussed and analysed.

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

Automated vehicles are expected to have a positive impact on traffic safety; however many studies argue that only cooperative systems allow the safety and efficiency benefits to be gained. For example ACC (Adaptive Cruise Control) allows maintaining 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 significant safety issues. Many studies addressed this topic; agree that Advanced Driver Assistance Systems (ADAS) while increasing safety on one side might decrease it on several others:

- Some drivers might fail to intervene effectively in automation failure scenarios; ADAS seems 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 s 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 experienced reactions to emergency situations 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 because they do not have the possibility to rely on the driver presence in case of automation failure.

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. Setting an average time gap of 1.4 s, the greatest impact is found 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 2,100 v/h of the reference scenario to the 2,250 v/h of the best scenario. Moreover, increasing ACC penetration to 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 not contemplating driver intervention at all through CACC or platooning. CACC set with a time gap of 0.5 s can potentially double the capacity of a highway lane at a high market penetration. It is worth to consider that such a result can be reached only with a 100 % market penetration: even 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 in 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/s² and a reaction time of 1 s this criterion returns a maximum lane capacity of 1,500 v/h at 25 km/h that lowers when increasing the speed: 1,300 v/h at 50 km/h, 1,125 v/h at 70 km/h and so on. Basing on this criterion, a lane capacity of 2,100 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.

Environment

A recent study 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.

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, there is ACC, with an addressed CO₂ reduction slightly above 2.5 %. Benefits of platooning in terms of CO₂ reductions are addressed in many other studies. A 15 % reduction can be achieved by platooned trucks driving at 80 km/h with a gap of 4 m. Some studies measured between 7 and 15 % 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 is keeping the total driving mileage constant, reducing congestion and smoothing driving conditions and platooning to reduce aerodynamic drag at high speed.

Lifestyle and Business Model

Automation, the full automation which allows sending empty vehicles to relocate them to where needed most, and therefore allows implementing shared mobility and transit systems. These are 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) segment 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. On the other hand automation of the individual vehicles can lead to longer travelled distances and lower occupancy rates resulting in significantly increased VMT which will increase the negative impacts of mobility.

IMPACTS

ARTS and its benefits

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 as defined by the CityMobil2 project can potentially reach the high magnitude for all potential impacts of automation without causing the negative effects individual automated vehicles would.

In the following detailed summary all the impacts measured by the CityMobil2 project are listed below.

Congestion, land use, safety and environmental issues are the main challenges that European cities are facing to make mobility more sustainable, and mainly result from high car ownership and usage rates.

The EU-funded CityMobil project showed that road vehicle automation can make urban mobility more sustainable and can be implemented in many different ways.

However, the project identified three main barriers to the deployment of automated road vehicles: the implementation framework, the legal framework and the unknown wider economic effects.

The objective of the EU-funded CityMobil2 project has been to provide valuable insight into the nature of these barriers and eventually how to overcome them in order to smooth the way for the procurement and implementation of automated road transport systems.

CityMobil2 has delivered both large and small demonstrations to test and show automated road vehicle capabilities as well as to gather more evidence of their potential impacts.

The main objective of this deliverable is to provide a comparative evaluation of the seven CityMobil2 city demonstrations based on the analysis of the results of the ex-post surveys carried out in the city of La Rochelle (France), Lausanne (Switzerland), Oristano (Italy), Trikala (Greece) and Vantaa (Finland).

In general, the findings provide valuable insights and understandings and enable the requirements for the next stages of deployment to be specified. Most specifically, the outcomes are positive for ARTS, and no factors have been found which would preclude its future application in urban areas.

The main findings of the comparative evaluation of users' mobility behaviour and their level of satisfaction with the ARTS system are:

- The most effective awareness tools were city-specific;
- Most users wanted just to test the ARTS rather than using it as an alternative transport mode, except for Trikala, where the ARTS service was the one most similar to a real PT service, and where there was a significant increase in walking mode share and a significant decrease in car shares;
- In all cities, most users were unaware of the technical incidents which occurred;
- In all cities, more than 4 out of 5 users thought it useful to implement the ARTS service on a permanent basis;
- The results relating to user acceptance indicators of the ARTS service (Usefulness of the service, level of integration with other modes and level of service) were in general positive in all cities with average ratings above mean values, but only a low percentage of users were willing to pay more than the current Public Transport fare;
- The results relating to quality of service indicators of the ARTS service (comfort, jerk, information availability and perception of safety) were in general positive in all cities with average ratings above mean values, except for perception of security (in terms of fear of attack) and perception of emergency management which were rated, in general, below the mean value;
- The results of the factor mapping analysis showed that in order to increase the overall level of satisfaction of the ARTS service, designers would need to focus on choosing more appropriate

locations/routes for the ARTS service. Particular attention should be given to providing adequate integration between ARTS and other transport modes;

- The factor mapping analysis showed that in order to improve the level of service, designers should focus more on waiting time at stops and on board time rather than on frequency of decelerations.

The main findings of the comparative evaluation of the results of the ex-post stated preference survey are:

- Users' relative preference for the ARTS or conventional minibus is case-specific;
- The ex-post results are consistent with the ex-ante results in each city, i.e. users show a relative preference for the ARTS in La Rochelle and Lausanne and for the conventional minibus in Vantaa, while in Trikala the ASC attribute was not statistically significant both ex-post and ex-ante;
- Both ex-post and ex-ante, the share of users who prefer the ARTS is significantly reduced in all cities (from a minimum of 35% in Trikala to a maximum of 67% in Lausanne) when an extra-fare is applied to the ARTS service;
- The impact of socio-economic characteristics on users' preference for the ARTS or the conventional minibus are not consistent between cities.

The main findings of the comparative evaluation of the results of the wider public survey are:

- In each of the four cities, most of the respondents had previously heard of automated vehicles before participating in the surveys.
- In each city, the majority of the respondents were positive that expected benefits of automated vehicles will occur (from the responses, fuel consumption and pollutant emission benefits would be more likely to come about than other benefits expected, and the result was consistent across the four cities);
- Public views on the safety benefits of automated vehicles varied with cities;
- Overall, public attitudes towards implementation of automated buses were positive. On average, about two thirds of the respondents stating that they would choose an automated bus if both automated and conventional buses were available on a route.
- In general, people surveyed were interested in automated cars. (From the responses, the most attractive benefit of automated cars was 'to increase mobility for all, followed by reduced fuel consumption and pollutant emissions', while the issue of most concern related to automated cars was equipment or system failures);
- In general, safety is believed to be one of the most important factors influencing people's attitudes towards mode/vehicle choice. (However, only a third of the people surveyed were positive about the potential safety benefits of automated vehicles, with the majority showing high levels of interest in using automated vehicles in the future).
- The public's awareness/understanding of automated vehicles should be monitored in order to assess how their attitudes change with increased levels of awareness/understanding of self-driving technology and their performances.

The main findings of the comparative evaluation of the results of the stakeholder survey are:

- In all cities, the stakeholders had a positive approach towards the automated mobility for a range of reasons and motivations;
- In all cities, automated vehicles were considered most likely to be used for public transport in the future;
- Concerning the possible interaction between automated vehicles and other modes, in La Rochelle, Lausanne and Trikala, the majority of stakeholders preferred total ARTS segregation with dedicated lanes. A high number of respondents agreed with the possibility of having automated mobility on low speeds roads, with pedestrians and cyclists. However, in Vantaa, stakeholders had a completely different opinion with 69% of them agreeing on the ARTS sharing roads with other motorized vehicles.

- In order to enable the widescale implementation of automated vehicles, the opinion from all the cities was that public authorities and urban planning operators needed to be proactive;
- On possible future development of this technology, in all the cities the majority of stakeholders agreed on the need for an increase in safety, comfort and convenience and, except for La Rochelle, a decrease of personal trip costs and fines;
- In all the cities high percentages of participants agreed that collective automated cars would have a positive impact on energy emission and on land saving.
- In La Rochelle, Vantaa and Trikala the majority disagreed on the possibility of having negative impacts on land use, while in Lausanne almost 50% of stakeholders agreed on the possible risk of an increase in land consumption.
- City stakeholders agreed that the two most important drivers connected with automated vehicles development are the commitment of key actors based on political or strategic motives, and accurate or visionary technical planning and analysis to determine requirements for implementation;
- City stakeholders agreed that the most important barriers to the deployment of automated technology are analysis of and proposals to change impeding rules, structures, legislation, different views and interests concerning the sustainable development of the cities, and a lack of involvement of key stakeholders;
- Concerning the priority of activities in the future research and development of automated vehicles, all cities agree on the need for large scales field operational tests.

The main conclusions that can be drawn from the comparative evaluation of the results of the survey carried out in the cities hosting demonstrations are:

- In general, positive attitudes towards the implementation of automated vehicles in urban areas are shown by all groups;
- New large scale field trials/practical developments are needed, would be supported by city authorities, and are recommended;
- ARTS demos have shown the advantage of automated vehicle control (accurate and consistent);
- Human interventions observed during the ARTS vehicle running (with the onboard operator having to make emergency braking in order to ensure safety) may have negatively impacted on the ARTS users from safety and comfort perspectives;
- Current ARTS vehicles need to be further developed (e.g. hardware and software for object detection and vehicle control) in order to run safely with full automation and at higher average speeds. These improvements will allow ARTS to provide practical and attractive long term services;
- ARTS vehicles should be operated in real traffic situations (Legal barriers must be overcome);
- Route selection should enable integration with other modes to provide realistic modal choice alternatives (Good level of service);
- Applications covering a range of weather and context situations are needed to confirm practical operations
- ARTS needs to be developed to be able to operate at higher average operational speeds. Solutions are both vehicle and context related.
- Complete operational/security/emergency management systems should be designed and implemented;
- More comprehensive surveys are needed to improve understandings of socioeconomic impacts and behavioural responses/interactions in situations of significant modal change opportunities.
- The development and applications of targeted awareness tools are needed;
- Financial and economic assessments, including fare payment options are needed, based on larger scale applications.

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