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Automated Vehicles and the Rethinking of Mobility and Cities

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Abstract

The project CityMobil2 has carried out a forward-looking exercise to investigate alternative cybermobility scenarios, including both niche and large-market innovations, and their impacts on European cities and their transport systems.

The paper describes the current status of and main trends in automated vehicles, a preliminary vision of the future city with mobility supported mainly by automated vehicles, and freight distribution. The expected positive impacts derive from the development of car sharing, the reduction of space required for parking vehicles, the possibilities for older people or those with disabilities to use cars, the enhancement of safety, and the improvement of efficiency of the transport system.

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Keywords:

1. Introduction

CityMobil2 is a multi-stakeholder project coordinated by CTL and co-funded by the EU's Seventh Framework Programme. CityMobil2 began in September 2012 and will run for four years; its 45 partners have been drawn from system suppliers, city authorities (and local partners), the research community, and networking organizations. CityMobil2 is setting up a pilot platform for automated road transport systems (ARTS), which will be implemented in several urban environments across Europe. Automated transport systems are made up of vehicles operating

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without a driver in collective mode. The automated road vehicle experimented with until now range in capacity from 2/4 passengers up to that of a bus.

The first CityMobil project classified four categories of ARTS:

1. Personal Rapid Transit (PRT): automated individual transport systems that use 4-place vehicles. PRTs work on networks with stops, carrying passengers directly from an origin stop to a destination stop. The lanes used by the network can be segregated or not.
2. CyberCar (CC): the transport system is based on automated road vehicles ranging from 4 to 20 passengers. They work on networks with stops, but unlike the PRT, the passengers can have different origins and destinations. The lanes used by the network can be segregated or not.
3. High Tech Bus (HTB): the transport system is based on automated road bus with more than 50 passengers. They can use various types of automated systems, for guidance, for driver assistance, or for full automation and platooning. The lanes used by the network can be segregated or not.
4. Dual-Mode Vehicles (DMV): vehicles such as cars with zero or ultra-low emissions, driver assistance systems, parking assistance, and collision avoidance. They can either have a driver or be fully automated and driverless.

They can enable innovative car-sharing systems with platooning and automatic repositioning.

They are considered useful in the transport mix as they can supply good transport service (individual or collective) in areas of low or dispersed demand, complementing the main public transport network. A dozen local authorities and institutions involved in CityMobil2 are in the bidding to be one of the five sites to host a six-month demonstration. In addition to the pilot activities, research will be undertaken into the technical, financial, cultural, and behavioral aspects and effects on land-use policies and how new systems can fit into existing infrastructure in different cities. The legal issues surrounding automated transport will also be addressed, leading to a proposed framework for certifying automated transport systems.

Within the project, a forward-looking exercise is being carried out to investigate alternative cybermobility scenarios, including both niche and large-market innovations, and their impacts on European cities and their transport systems (Alessandrini, Filippi, 2011; Alessandrini, Stam, 2014; Alessandrini, Cattivera, 2014).

The aim is to develop a revolutionary vision based on automated collective public transport, automated vehicles for urban freight distribution, and a shift of paradigm, consisting in the decline of car ownership and the rise of purchase of mobility services.

The method is to investigate the likelihood and desirability of the vision by means of a Delphi survey with a group of international experts.

For likelihood, we identify factors that have impacts on the market take-up of the transport systems in each vision. We assess the importance and uncertainty of each factor—whether the impacts of the factor on market take-up are significant and whether its trend is more or less uncertain.

For desirability, we consult the different stakeholders and users (Delle Site, 2011; Alessandrini, Alfonsi 2014) to elicit their views and perspectives on the visions, in order to understand if the vision is shared and desired.

A final step is to develop roadmaps to achieve the visions, addressing in particular the role of policy and what governments can do to push the innovations and achieve the visions.

This paper presents the preliminary results of this exercise.

2. Current status and main trends

Urban structure and transport system developments are closely connected, and it is impossible to abstract the vision of the cities of tomorrow from that of the future configuration of their transport systems. In the past century, transformations in urban form have been linked to some kind of transport revolution (Safdie, 1998). The mass diffusion of private cars made possible low density and scattered urban developments in the outskirts and countryside, but at the same time negatively affected the quality of life in cities by creating unbearable traffic congestion, scarcity of parking, and noxious emissions.

Individual motorized transport offers greater flexibility than public transport, with its fixed schedules and paths. The inherent advantages of private cars—such as door-to-door, comfortable, and personal travel—made car ownership a status symbol. Increasing prosperity brought a continuous increase in car ownership in Europe, and

this was supported by infrastructure developments. Today cars are, as a rule, used for only a small part of each day and remain idle and parked for hours at a time. This is highly inefficient. In Seattle, where vehicle use is more intense than the national average, just under 11 percent of vehicles are “in use” throughout the day, even at peak times, though this rises to 16 percent for vehicles less than 10 years old (Fig. 1).

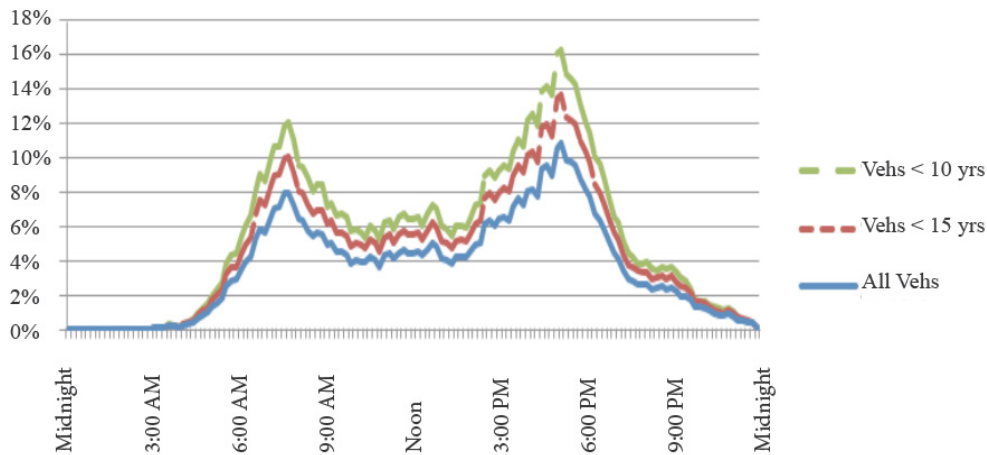


Fig. 1. Vehicle use by time of day and by vehicle age (PSRC, 2006).

Even though recession and high fuel prices have significantly affected the use of cars in terms of driven distances in many countries since 2008, car use seems to have begun to decline in the developed countries even before the economic crisis (Lyons, G., Goodwin, P., 2014). Surveys show that young people start driving later (in Germany, the share of young households without cars increased from 20% to 28% between 1998 and 2008) and that they tend more and more to consider cars as appliances rather than aspirations (The Economist, 2012), and consequently are more open to transport alternatives to private cars.

Another trend is the preference for car-sharing over car ownership. Users are thus freed of the burdens of car maintenance, insurance, and other costs associated with vehicle ownership.

Users of car-sharing schemes are increasing, even though their number is still a low percentage of the population. Three different surveys (Fig. 2) show a growth in car-sharing membership worldwide and that in Europe membership increased from 212,000 in 2006 to 334,000 in 2008 and 552,000 in 2010.

Other trends affecting the development of transport systems are the virtualization of life and work and the increasing importance of electronic communication and social media. These trends are establishing new lifestyles and habits. Among these trends are teleworking and e-shopping (OPTIMISM, 2013). A survey of 15 countries found that in areas where many young people use the Internet, fewer than normal have driving licenses. In another survey young interviewees declared that social media give them an access to their world that would once have been associated with cars (The Economist, 2012).

Important trends are related to demographics. In Europe population growth has stabilized, and stagnation and ageing of population in Europe is identified in all future projections (EEA, 2011). Age structure projections show an increased life expectancy and a proportional reduction of younger people (EEA, 2011; EC, 2009). An aging population has been identified in Europe, and specific studies conducted in Germany, the UK, and the Netherlands confirm this trend (InnoZ-Bausteine, 2008; Mobil 2030, 2011; Rogge, 2005; Su et al., 2009; Harms, 2011; Rosenbloom and Ståhl, 2002; Rudinger et al., 2006).

In many of these countries one out of four citizens will be aged 65 or older in 2020 or, at the latest, in 2030 (OECD, 2001; Rosenbloom and Ståhl, 2002), and the number of persons over 80 years of age will triple (OECD, 2001). Eurostat statistics predict that the share of persons above the age 65 in Europe is going to grow from 16% in 2000 to approximately 21% by 2020, and 28% is expected in 2050 (Brög et al., 2005; Rogge, 2005). These figures

are in line with those provided by another study (Rogge, 2005): the population aged over 65 will increase its share from 17% in 2009 to 30% in 2060.

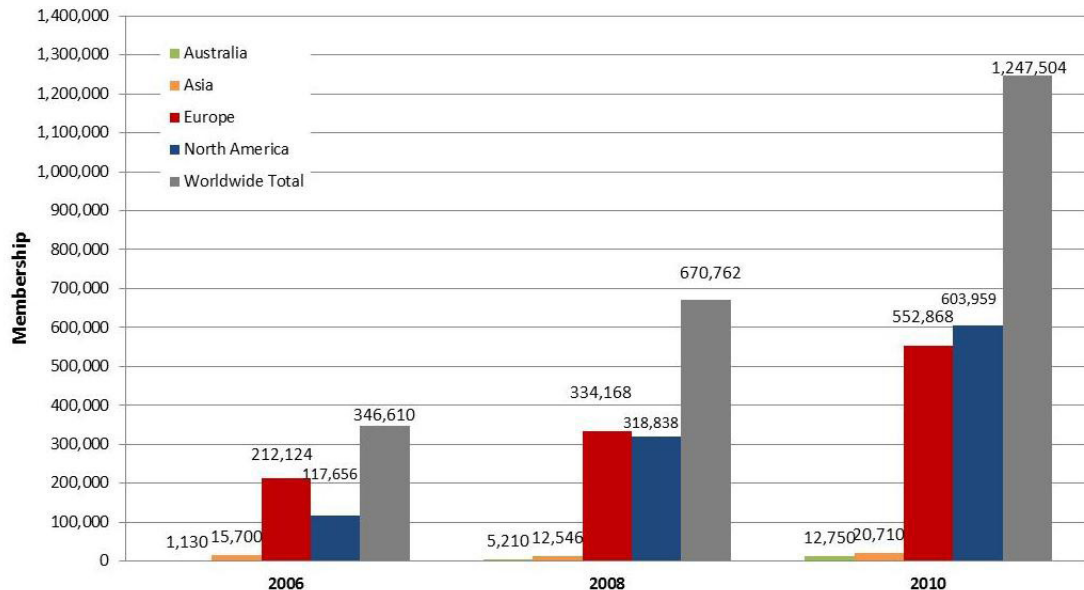


Fig. 2. Worldwide car-sharing membership growth: 2006–2010 (Shaheen, 2011).

Changing lifestyles in Europe in the past two decades have created a growing demand for personal transport. Individual mobility has become essential because of distances between homes, jobs, and leisure activities and more spread-out social networks (Donaghy et al., 2004). Demand for individual mobility services is expected to increase. Lifestyles are becoming more varied, leisure activities are gaining importance, and everyday life becomes more hectic (InnoZ-Bausteine, 2008; Brög W., 2005; Rogge, 2005). Individual mobility needs are strengthened by the liberalization of working hours and conditions, making working life less regular (Lanzendorf and Gather, 2005). Seniors are becoming more mobile; their yearly trips have almost doubled in number (Kotavaara et al., 2011; Frändberg and Vilhelmson, 2011; Dejoux et al., 2010).

Automated vehicles (AV) have significant potential to drive economic impact and disruption in the coming decades, with a revolution in ground transport, regulations permitting, that could dramatically change the status quo and have an enormous economic, social, spatial, and mobility impact. The enabling technologies are making rapid advances. One of the first AV systems has been in service since 1999 in a business park in Rivium (NL), with a reserved track length of 1800 m with 8 stations, 6 crossings for traffic and pedestrians, and 6 electric vehicles. The patronage was 3500 passengers daily, with a peak capacity of 500 p/h, and headway of 2.5 minutes.

For the last 12 years a Personal Rapid Transit (PRT) system has been servicing a 1.9-km point-to-point guided track between Terminal 5 and a Business Car Park at Heathrow with 21 vehicles. The system has carried 700,000 passengers with 99.7% system availability. Heathrow PRT makes more than 70,000 bus journeys off the road per year, saving more than 200 metric tons of CO₂ per year. It is currently completing more than 5000 journeys per week.

In its search for appropriate and sustainable transport solutions, Masdar City is piloting a PRT and Freight Rapid Transit (FRT) system of electric-powered, automated, single-cabin vehicles that offer the privacy, comfort, and non-stop travel of a taxi service with the reliability and sustainability of a public transport system. A PRT shuttle 800 m long with 13 electric vehicles has been in service since 2009. It carries mainly students between a station and the post-graduate university, the Masdar Institute of Science and Technology. The electrical air-conditioned

vehicles have a maximum speed of 40 km/h and run on a lithium-phosphate battery, which can last up to 60 km on a 1.5-hour charge, or 30 to 40 trips, before making quick stops at a terminal for a partial recharge or parking overnight for a full recharge.

The main characteristics of the system are:

- Peak capacity: 500 p/ph
- Frequency: on demand
- Times of operation: 24 hrs p/d, 7 days p/w
- Connections: Direct (non-stop)
- Size: 10 + 3 freight rapid transit vehicles
- Capacity: 4 adults + 2 children

Today a number of countries around the world aim to be the leader in driverless cars. Google has permission to test its autonomous cars in several states in the US. Volvo received permission to test driverless cars in Gothenburg, Sweden. Researchers are testing driverless cars in Berlin, and earlier this year the French government laid out a ten-year roadmap to be leaders in driverless cars, robotics, and other advanced technology.

The UK government indicates in its National Infrastructure Plan 2013 large-scale investments of €826 billion by public and private entities into driverless cars and robotics over the next decade or so to create an advanced infrastructure. It will conduct a review, reporting at the end of 2014, to ensure that the legislative and regulatory framework demonstrates to the world's car companies that the UK is the right place to develop and test driverless cars. A first pilot will be in the city of Milton Keynes with AV from Honda.

Mercedes, BMW, Audi, Lexus, Ford Renault, and Nissan are among the automakers that are deep in development of driverless technology, with such tech companies as Google, which is already road-testing a fleet of driverless cars, while IBM and Cisco are vying to get in on the action as suppliers. Even a tire producer, Michelin, is involved in the production of AV. Renault and Tesla have also announced a common plan for an autonomous car. Tesla has one of the most advanced robotic factories and electric cars available today in California.

Fig. 3 shows the convergence between car and transit. The horizontal four levels are temporal sequences of development and deployment of automated cars with no segregation.

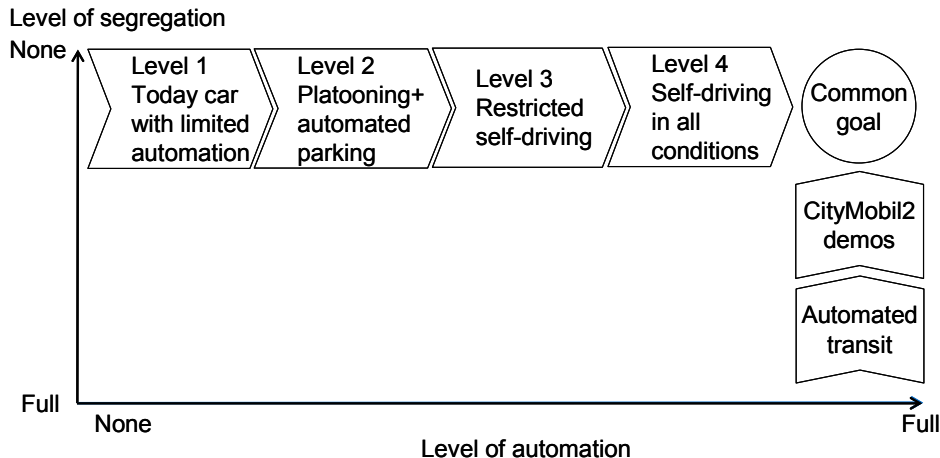


Fig. 3. Level of automation and segregation of automated vehicles.

Level 1 is the limited automation of steering, braking, and lane guidance available on new high-end cars.

Platooning plus automated parking in level 2 is currently technically feasible, but requires vehicle-to-vehicle vehicle-to-road communications capability. It is applicable to a car-sharing fleet for repositioning. There is a driver in the leader car to maximize safety, and the cars join the platoon and parking lots automatically.

Level 3 is restricted self-driving currently being tested. Google's experimental cars have driven hundreds of thousands of miles in self-drive mode under restricted conditions.

Level 4 is self-driving in all conditions, which requires more technological development. Levels higher than 2 require that autonomous vehicles must meet performance standards and regulations to legally operate on public roads. The vertical two levels for transit refer to fully automated vehicles, whose operation is today completely segregated, and a little less so for the CityMobil2 demos.

The goal of these two directions of the research on automated vehicles is to converge in solutions of full automation and no segregation.

The trends reviewed suggest that the transport system of the future should be able to provide flexible services and, more and more, address equity and social inclusion issues. Fig. 4 shows the rate projections of sales of automated cars, travel with them, and total fleet. In 2060 the market penetration is expected to be complete and almost all the vehicles sold driverless. The projections are based on previous deployment of other vehicle technologies.

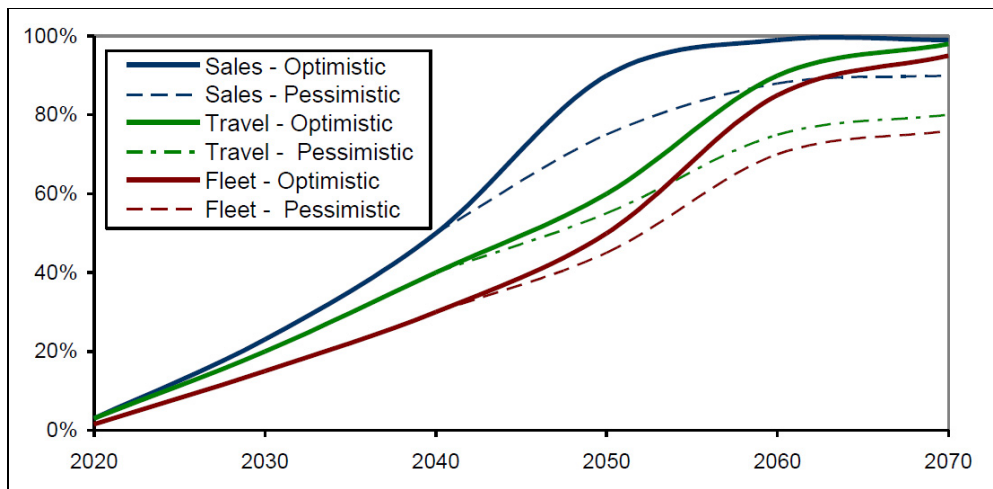


Fig. 4. Automated car sales, travel, and fleet projections. Source: Litman, 2013

3. The vision of the cybernetic city

Urban structure and transport system developments are closely connected, and it is impossible to abstract the vision of the cities of tomorrow from that of the future configuration of their transport systems. In the past century, transformations in urban form have been linked to some kind of transport revolution (Safdie, 1998). In particular, the mass-diffusion of private cars, on the one hand, has allowed low density and scattered urban developments in the outskirts and countryside, on the other hand, has negatively affected the quality of life in cities because of unbearable level of traffic congestion and polluting emissions.

The vision of the transport system of the city of tomorrow is based on the Passenger Application Matrix (PAM), developed in the framework of the EU project CityMobil (2006–2011). The rows and columns of the Matrix are the different types of origins/destinations potentially served by ARTS. Each element reports the evaluation for the specific O/D of the four categories of ARTS. The evaluation consolidates and cross-compares the results of different demonstration, study or simulation.

The origins/destinations evaluated in the PAM are:

1. City center

2. Inner suburb
3. Outer suburb
4. Suburban center
5. Major facilities

Table 1 shows the results of the evaluation in terms of effectiveness of the different ARTS for each element of the matrix. Gray indicates the ARTS is effective, white that it is not effective.

The most effective ARTS in the matrix is the DMV related to the innovative car-sharing system. Development of the automated vehicle and its massive deployment could profoundly alter the way we look at cars. It would no longer be necessary to own an under-occupied car to enjoy the flexibility and door-to-door service of a private vehicle. A shift from privately owned individual vehicles to collectively shared individual vehicles (Safdie, 1998) would combine the freedom of movement of one's own car with the convenience of a publicly run and maintained utility.

Table 1. Effectiveness of ARTS in PAM

Origin \ Destination	1		2		3		4		5	
City center	P	C								
	H	D								
Inner suburb	P	C	P	C						
	H	D	H	D						
Outer suburb	P	C	P	C	P	C				
	H	D	H	D	H	D				
Minor/suburban center	P	C	P	C	P	C	P	C		
	H	D	H	D	H	D	H	D		
Major facilities	P	C	P	C	P	C	P	C	P	C
	H	D	H	D	H	D	H	D	H	D

P = PRT Personal Rapid Transit; C = CC CyberCar; H = HTB High Tech Bus; D = DMV Dual-Mode Vehicle

■ OD where the ARTS are more effective

Automation and ICT (Information and Communication Technologies) should make DMVs particularly attractive, easy-to-use, and efficient. It should be possible to board a DMV as needed, use it as long as one wants, with time and mileage charged automatically, and leave it anywhere. Users would thus be relieved of finding a free parking place at destination, which is currently expensive in the city center. Not only: vehicles in search of parking increase traffic up to 15%, and consequently substantially increase congestion and stress.

Fig. 5 is a diagram of a compact city with inner and outer suburbs, suburban centers, transport nodes, and major facilities. A mix of traditional and innovative transport systems serve the mobility of this vast area. Traditional transport on rail and highways can be expected still to exist in the city of the future.

Digital technologies within firms have enabled fundamental reinvention of old production processes and service delivery. Consumers are starting to reach the same understanding with their mobile devices and powerful computers connected to high-speed networks. The new models of collaborative consumption and sharing economy are going to mass-market before the development and deployment of ARTS. New innovative car-sharing in the cybernetic city has the potential to alter mobility radically.

Users could have access to car-sharing DMVs parked on the street or at depots; a smartcard or similar device would contain the user profile and contract terms. If no vehicle is available nearby, users would be able to access an on-demand service using a smartphone (or similar device) to order a vehicle. Having communicated the destination

to the navigator, by voice or text message, the user would be free to read, play, web-surf, or otherwise enjoy the ride in the self-driving vehicle.

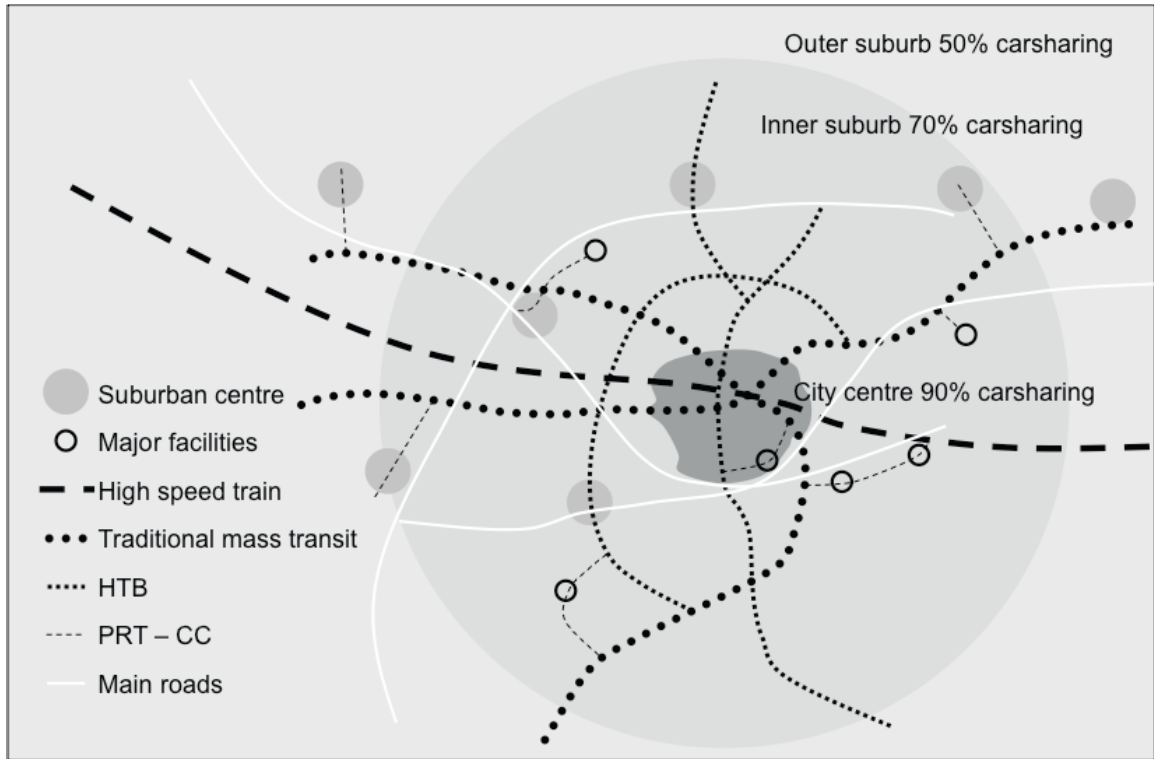


Fig. 5. The city of the future and its transport system.

At destination, users would be free of the stress of looking for a parking place; they could just leave the vehicle near a parking space along the street (the vehicle will park on its own) or on the street (an automated management system of empty vehicles will move the vehicle to the nearest depot or car park).

The vehicle's automatic self-diagnosis system would check its operational status to determine maintenance is needed before serving another user. For example, if the vehicle is electric, it will check the battery charge, and if low it will go automatically to the nearest depot/charging station. Time and mileage of effective use would be automatically charged on the smartcard.

In this vision, the anonymity of cars and their self-driving capabilities, together with greater sensitivity of people to sustainability issues, could well result in an increased use of collective, and possibly automated, transport systems. For example, DMVs or other cybercar systems could pick people up in front of their houses and transport them to bus and tram stops. Automated collective vehicles could collect children, the elderly, and people living in the same neighborhood and working in the same place. These mechanisms would optimize vehicle occupancy rates and thereby reduce traffic congestion and travel times.

Depots and large parking lots should be located in strategic urban areas such as railway and bus stations, shopping and business centers, and other places where greater demand for vehicles is expected.

A crucial issue is management. The system operation would require technologies and appropriate methods for managing bookings, access to vehicles, travel, and payment, and other operational issues, with ICT and automation technologies playing an essential role.

Each vehicle would be equipped with a localization system based on fusion between sensor information from gyroscopes or inertial systems, wheel sensors (odometers), triangulation of wireless communications and

GPS/GLONASS. Sensor fusion enables a system to measure position and velocity even when GPS is not available, such as areas with urban canyons or blocked lines of sight to the GPS satellites. Hybridation is also possible using laser-based Simultaneous Localization And Mapping (SLAM) information as a redundant localization system to increase the localization system's reliability. The localization system would provide real-time information on its current position, as well as with a communication device able to exchange data and information (e.g. operational conditions) with the management center.

The management center would collect and process information and data coming from vehicles, depots, and parking; the centralization of all information and data (e.g. vehicles' conditions and positions, parking space availability, and customers' profiles and requests) would allow the management center to efficiently meet vehicle demand and ensure a high level of service. The system would have to react rapidly to requests for a vehicle, sending a vehicle out as soon as possible. The management center would also be able to transfer users to other types of transport (train, bus, and taxis) should the system be unable to serve temporary demand peaks.

An important task of the management center is be the management of empty vehicles. On the basis of the demand, empty vehicles would be sent to serve users' requests or to depots or parking lots for maintenance or simply to be stored. The management of empty vehicles would take advantage of the vehicles' automation capabilities, such as platooning, to move them from low-demand to high-demand areas.

The vehicles would be designed to satisfy the needs for short trips typical of the urban areas, with several users at a time, including the mobility impaired. With their functional design and dedicated materials, the vehicles would be easy to maintain and clean.

4. Automated vehicles for urban freight distribution

Urban areas, in particular dense and congested inner cities, pose specific requirements for freight distribution. Goods have to be carried in and out of the area to supply stores and shops under a number of constraints, including narrow streets with limited accessibility and maneuvering space, the need for very fast up-loading and unloading to minimize traffic obstructions, and often strict environmental regulations and restricted access permits (e.g., in pedestrian zones). Recent experiences in Rome (RSM, 2013) have demonstrated that actual average speed of freight vehicles is on the order of 6–8 km/h, due to traffic, number of delivery stops, and lack of available dedicated parking spaces (loading/unloading bays). Typically, urban distribution is operated by means of light duty transport vehicles (LDV), also because of the restrictions imposed by regulation and the tendency to deliver large numbers of low-volume shipments. Experiences have also shown the viability of electric vehicles for urban freight distribution, but even if they can provide a benefit to the operator and the environment, not all the constraints mentioned are overcome.

For an LDV to overcome these constraints, it has to be small and agile but at the same time have a large enough loading capacity to make it efficient. To make it economically feasible, the vehicle has to be versatile and easy to modify for different cargoes and uses. To comply with the environmental requirements it has to be zero-emission at least when the vehicle is used in the urban context; otherwise, in case it was a parallel HEV, ICE can be used outside the city or for long travels while electric traction for short urban travels.

Several applications involving automated vehicles for freight are already running. Automated Guided Vehicles (AGV) have been well tested by industry since the late 1970s. Automated vehicles have been used in port container terminals for years. Automated trucks are being used inside mines. All these applications are operative in delimited and access-restricted areas. Different authors point out the potentials of underground transport using automated vehicles to carry goods from outside urban areas to central areas. According to Priemus et al. (2005), automated vehicles look more promising for transporting freight over shorter distances within a more complex network, with many intersections and many origins and destinations. These vehicles offer more routing flexibility and could also be used outside the tunnel above ground.

Recent European research (CityMobil, 2011) has pointed out the potential applications for automated vehicles in freight movements in urban areas. These are:

- Just-in-time refilling shops from remote warehouses;
- Drop-off points for last-mile deliveries at houses/small offices;
- Waste collection and transportation.

One application that has a high potential for implementation is a light-duty automated transport vehicle composed of a number of standardized, interchangeable components that can be reconfigured according to the specific tasks. This could represent an innovative freight delivery system for last-mile distribution. It would consist of a single automated driver module and, depending on transport requirements, one or several cargo modules. The system illustrated in Fig. 6 follows the basic concept of a multi-trailer freight train as used, for example, in airports for the transport of baggage or also for last-mile distribution (e.g. Cargo Hopper in Utrecht).



Fig. 6. The automated multitailer vehicle.

The introduction of automated guidance should be not detrimental to performance; automated guided vehicles are already used in environments involving interference with human beings (e.g., factories, warehouses), travel at 3–5 km/h, and have standardized safety systems.

One possible application scenario for such a system foresees an urban consolidation center on the boundaries of a distribution area. In this scenario, cargoes are delivered by different operators, consolidated by the logistics operator managing the center, and then shipped to the customers using the automated electric distribution system. Shipments are grouped by destination and collected in modules that can be separated from the others and automatically placed in a specific unloading bay. The system can be operated in separated lanes. Customers can take their shipments from the module using secured access (e.g., credit card, smartcard, NFC devices) as already happens with drop boxes. The system is electric and thus environmentally viable; the urban consolidation centers could also provide photovoltaic recharging stations. It is fully automated, thus reducing operating cost (e.g., driver), is safe for pedestrian areas, and reduces the need of parking bays (since the shipments are consolidated).

This system needs an ICT (Information and Communication Technology) infrastructure to operate safely, efficiently and reliably. It should be considered as an automated/intelligent transport system, to be interoperable with the systems of the operators in order to manage the flow of information related to freight distribution (orders, invoices, proof of delivery, status of cargo, tracking and tracing). This is considered to be among the most promising enablers (Rodrigue, 2013) for future transport systems, which definitely require radical behavioral changes of practices, such as the use of automated vehicles for freight. ICT can in fact enable the application of automated vehicles with increased flexibility and adaptability to changing market circumstances (origins, destinations, costs, speed, etc.), including the unforeseen, while complying with an array of environmental, safety, and security regulations.

5. Expected impacts

The current mobility culture is characterized by the fact that only private cars can provide individual and flexible mobility. This has raised the private car to a status symbol with powers well beyond its basic purpose of moving

people around. Car ownership often implies more than merely possessing access to a mobility service. This has led to an inefficient use of cars and a number of major negative impacts.

The system based on automated cars is expected to produce a number of positive impacts.

Today, cars are used only for short periods at a time and thus stay parked and unused for most of the day (and of their entire life cycle). The total number of owned cars in a city TH should be used in the peak hour only 11% on average, according to Fig. 1. In a city with shared automated cars, the total number of cars needed to provide car-based mobility services are the number of owned cars, a fraction of TH, plus the automated cars needed at the peak hour. For each 10% reduction in the number of cars owned, there should be only 11% of automated cars, but because the people willing to give up their own cars are modest users, the need for automated cars will be much smaller. The use of the automated car fleet should be optimized to increase the service and reduce the idle time.

Automated cars should save space not only by reducing the number of parked vehicles, but also by reducing the space required for parking them. In this respect, Safdie (1998) has provided an estimation of the space currently required to park an average car, taking into account the driveways, access ramps, and additional space to accommodate each car in the parking spaces. According to these estimations, and considering that the anonymity of DMVs should permit parking them compactly in depots (Fig. 7), storing vehicles should require one quarter of the space per vehicle currently required in a conventional garage.

The reduced space required for parking vehicles should free public space, which can be used to improve livability of urban environments with re-qualification of public spaces for pedestrians, bicycles and reserved lanes for HTBs.

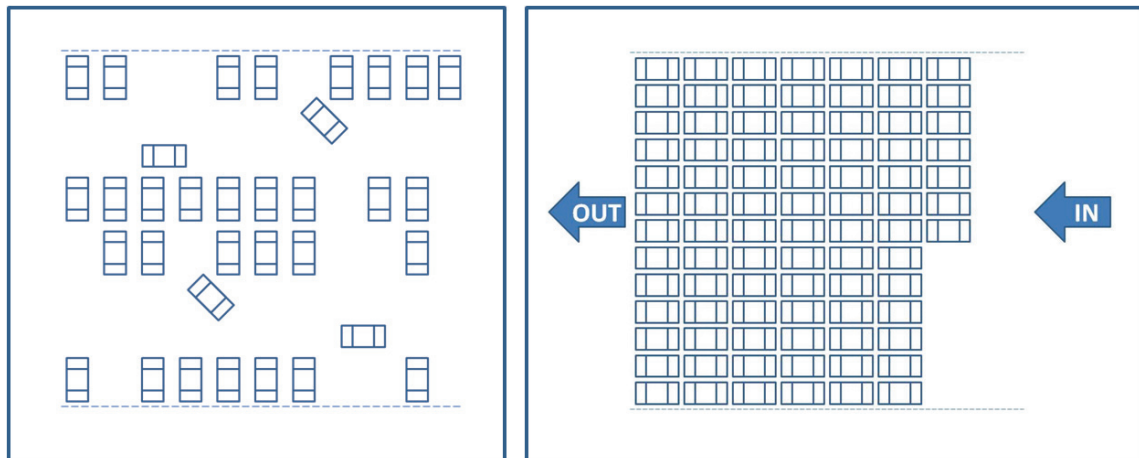


Fig. 7. Conventional garage and DMVs depot.

A number of environmental benefits would follow. Vehicles should be equipped with carbon-free propulsion; maintenance operations would be performed by expert personnel to keep vehicles in their best operating condition; and energy consumption would be reduced. Therefore, the exposure of citizens to emissions would be substantially reduced or eliminated.

Automatic driving would also allow older people or those with disabilities to use cars (because they would not have to drive the cars themselves). These social groups might appreciate automatic driving also because of the greater riding comfort (smoother acceleration and jerk). Since the users would pay only for the actual use of the cars (mileage or time), automated cars will be significantly more economical than owned cars. All this would contribute to a more inclusive society by broadening the range of citizens for which public transport is easily accessible.

Automatic driving should also efficiently integrate cars with non-motorized modes of transport (cycling and walking), reducing intimidation by cars. In fact, pedestrians and cyclists would be more confident that the cars were being driven correctly, and this freedom from fear would certainly improve the quality of life for many people. Add

to that freedom from concern about the cost of maintenance, insurance, and taxes, as well as the flexibility, ease of use, and accessibility of the system, and user acceptance of DMV systems can certainly be expected to increase.

The management of cars as a public utility should allow the efficient integration of automated cars with collective public transport systems and non-motorized modes, resulting in a mobility based on efficient and intelligent combination of all modes (provided that gaps in infrastructure and schedules are bridged by linking modes and services).

An automated car system would not only ensure improved efficiency of the transport system, but also allow the implementation of the pricing principles currently advocated according to the European transport policy (European Commission, 2011). This means a system in which, eventually, all travelers pay the true costs.

The optimized use will reduce the number of circulating vehicles and will significantly reduce the amount of space currently occupied by idle vehicles. Carbon-free propulsion has other potential environmental benefits too. Maintenance operations will be performed by expert personnel, who will keep vehicles in their best operating condition.

Vehicular traffic represents one of the main sources of pollutants in urban areas and takes a heavy toll on human lives. In Europe, urban transport is responsible for about a quarter of CO₂ emissions from transport; 69% of road accidents occur in cities. (EC, 2011).

It is commonly recognized that AVs have the potential to fundamentally alter transportation systems by reducing fatal road accidents, providing critical mobility to the elderly and disabled, increasing road capacity, saving fuel, and lowering emissions.

Estimates of potential impacts on road safety, however, are quite different, even if the expected magnitude is, in any case, significant.

Automatic driving should enhance safety, avoiding accidents currently caused by driver distraction or bad driving behavior. All vehicles should be equipped with ADAS technology, which will allow them to circulate safely. In some cases the basic, maybe simple, idea is that, since driver error can be considered the main contributing factor in a vast majority of road accidents, a self-driving vehicle should eliminate nearly all accidents. Hayes (Hayes, 2011) suggests that motor-vehicle fatality rates (per person-km travelled) could eventually approach those seen in aviation and rail, about 1% of current rates. KPMG and CAR (2012) advocate an end goal of “crash-less cars.”

However, autonomous vehicles will probably introduce new risks (Litman, 2013), including system failures. Moreover, there is the chance that drivers will take their vehicles out of self-driving mode and assume control. Experience with other safety innovations indicates that net benefits are often smaller than expected due to risk compensation (the tendency of road users to take additional risks when they feel safer) and rebound effects (increased vehicle travel resulting from faster or cheaper or more comfortable travel).

Such considerations lead to more cautious estimates. A recent study (Eno Center for Transportation, 2013) reports that AVs could reduce fatal accidents by at least 40%, in particular those involving alcohol, distraction, drugs, and/or fatigue.

This rate reduction is based on the assumption that in AVs malfunctions are minimal and everything else remains constant (such as the levels of long-distance, night-time, and poor-weather driving). Moreover, such reductions do not reflect accidents caused by speeding, aggressive driving, over-compensation, inexperience, slow reaction times, inattention, and various other driver shortcomings. Including these accidents could lead to even greater reduction rate in fatal accidents.

Aside from making automobiles safer, researchers are also developing ways for AV technology to reduce congestion and fuel consumption. It is commonly known that as traffic congestion increases, CO₂ emissions and fuel consumption also increase. In general, CO₂ emissions and fuel consumption are sensitive to the type of driving that occurs. Barth and Boriboonsomsin (2008) showed that congestion mitigation, speed management, and traffic smoothing (i.e., eliminating the stop-and-go effect) might reduce CO₂ emissions up to 20% (see Fig. 8).

Automation may be used to apply these techniques by allowing traffic to flow at better speeds and eliminating the acceleration/deceleration events associated with the stop and go traffic.

Another technique that may be easily implemented through automation is grouping vehicles into platoons. Vehicle platooning may reduce aerodynamic drag, which in turns lowers fuel consumption: a 1995 study (Zabat et al., 1995) showed that vehicle platoons could improve fuel efficiency by up to 30%.

AVs are also expected to use existing lanes and intersections more efficiently through shorter headways, coordinated platoons, and more efficient route choices. Many of these features, such as Adaptive Cruise Control (ACC), are already being integrated into cars and some of the benefits could be realized before AVs are fully operational.

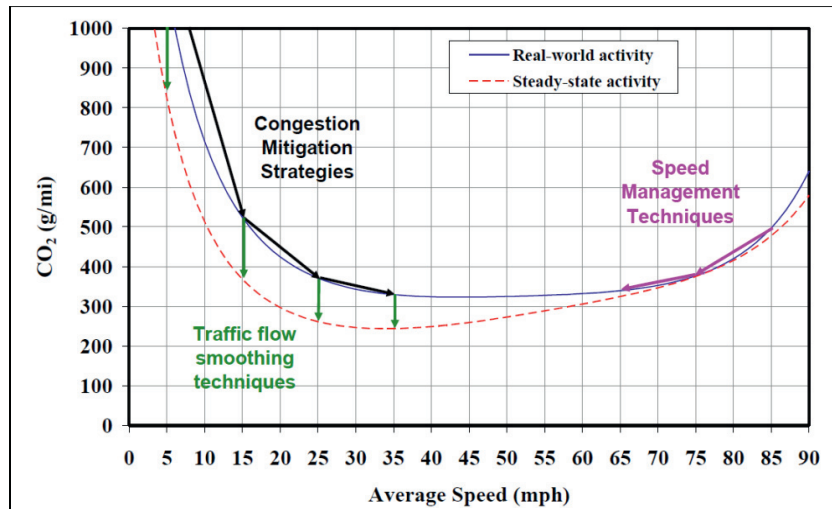


Fig. 8. Possible strategies to reduce on-road CO₂ emissions. Source: Barth and Boriboonsomsin, 2008

As the research shows, these benefits will not come about automatically. Many of these congestion-saving improvements depend not only on automated driving capabilities, but also on cooperative abilities through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. But congestion could be significantly reduced even if only the safety benefits are realized. FHWA estimates that, in the United States, 25% of congestion is attributable to traffic incidents, some half of which are accidents.

Multiple studies have investigated the potential for AVs to reduce congestion under differing scenarios.

The Eno Center for Transportation provides a rough estimate of the likely magnitudes of impacts of AV diffusion in the United States, and some of the most interesting results are reported in Table 2. The impacts vary according to the market penetration of AVs from 10% of circulating vehicles to 90% of circulating vehicle.

The results given in Table 2 show that the correlation between AV market share and externalities reductions is not linear, and the path is different for road safety compared to fuel savings. In terms of road safety, for an AV market share of 10%, the expected fatalities reduction is about 1100, while for a market share five times greater (50%), the fatalities reduction is nine times greater and nearly 20 times greater for an AVs market share of 90%. On the other hand, in terms of fuel savings, the expected results dramatically increase, mainly with a high level (> 50%) of AV market penetration.

Combining those estimates with the projections illustrated in Fig. 8, based on previous vehicle technology deployment, it emerges that significant road safety improvement can be expected as early as 2030, while, in terms of fuel consumption, later significant results are expected, more likely from 2050.

Even if these data give only an order of magnitude of the impacts, they show that the potential impacts of AVs in the near future can be significant. A huge reduction of road accident fatalities and crashes is expected as well as a significant reduction in term of emissions and fuel consumption.

The environmental impact reduction could even be greater, considering that in many cases, like those developed and tested within the CityMobil and CityMobil 2 projects, AVs have an electric propulsion, thus further reducing at least local emissions.

The available studies also stress that these reductions depend heavily on the AV market share and also on the technologies used. For example, the availability of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies will allow the AV platooning and better coordination at intersections.

Table 2. Expected results according to AV penetration in the US.

AV market penetration			
	10%	50%	90%
Lives saved*	1100	9600	21,700
Fewer crashes	211,000	1,880,000	4,220,000
Road safety economic cost savings (\$ billion)*	5.5	48.8	109.7
Travel Time Savings (million hours)	756	1680	2772
Fuel saving (millions liters)	386	847	2740
*According to NHTSA, road fatalities in 2012 numbered more than 30,000, and the overall costs of road un-safety were about 300 billion \$/year			

Source: Eno Center for Transportation, 2013.

This implies that, in order to maximize the reductions of externalities due to the spread of AVs, an overall reshaping of the transport system is needed.

There are critical impacts in the organization and management of urban mobility systems that may well encompass significant barriers to the implementation of ARTS. The first is a very old one, the drivers of public transport services can see automation as a threat to their job and at the same time the public transport companies do not have the internal skill to operate and maintain the new systems. The second is related to the need of some infrastructural adaptation.

CityMobil2 experienced some confrontations with drivers and with public opinion on the matter. In León (Spain) driver protests during the selection phase led the Project to organize only a showcase and not a demonstration there. Later, during the showcase, when local people had the chance to try the system, the vehicles and transport system were so well regarded that the Municipality regretted not having kept the demonstration candidacy. Similarly in Oristano (Italy) an adverse media campaign before the beginning of the demo led to many public discussions (even on social media); the management team gave several interviews explaining the benefits for the local workforce of such systems and at the end the most enthusiastic comments received were from the bus-drivers temporarily hired to be operators for the demonstrator.

The skill needed was acquired very quickly. The experience CityMobil2 gained in this regard is encouraging. The regional transport company in Sardinia (ARST) and its personnel adapted very easily with just two weeks' training to operate ARTS; in Lausanne a new public transport operator was created for the purpose, which might even be an interesting business opportunity ARTS offer.

The implementation of ARTS can be expected to be slow. The early adopting zones will probably be those today served by parking and ride system. Improving the feeder services to the main transport network should increase use of public transport and employment. The major impact will be on taxi services, but these are already under attack from such online companies as Uber and Lift. By the time the automated vehicles are deployed, the taxi drivers may no longer wield the power they do today.

The infrastructural adaptation, besides being a necessary action to allow ARTS to safely operate on the road, can also be used to implement some "push" policies to discourage private car use. One example is the needed reorganization of roadside parking which for safety reasons will need to be prohibited in ARTS certified lanes (Alessandrini, Cattivera, 2014). Such measures will need to be integrated into a wider set of policies and explained to the local people to help them accept the system.

References

- Alessandrini, A., Filippi, F., Stam, D., 2011. Evaluation of Automated Transport Systems, Environment land use and transportation systems, SIDT, Collana Trasporti, Franco Angeli. ISBN: 978-88-204-5655-9
- Alessandrini, A., Stam, D., 2014. Evaluation of Automated Transport Systems, proceedings of Transportation Research Board 93rd Annual Meeting, January 12-16, 2014, Washington, D.C
- Alessandrini, A., Cattivera, A., Holguin, C., Stam, D., 2014. CityMobil2: Challenges and Opportunities of Fully Automated Mobility. In Meyer, G., and Beiker, S., eds., Road Vehicle Automation. Springer Cham Heidelberg New York Dordrecht London. ISBN 978-3-319-05990-7
- Alessandrini, A., Alfonsi, R., Delle Site, P., Stam D., 2014 Users' preferences towards automated road public transport: results from European surveys. *Transportation Research Procedia*, in press.
- Barth, M., Boriboonsomsin, K., 2008. Real-world carbon dioxide impacts of traffic congestion. *Transportation Research Record*, 2058, 163–171.
- Brög, W., Barta, F. and Erl, E. 2005. Societal Megatrends: like it or not, the framework is set. 56th UITP World Congress.
- Dejoux, V., Bussiere, Y., Madre, J., Armoogum, J., 2010. Projection of the Daily Travel of an Ageing Population: The Paris and Montreal Case, 1975–2020. *Transport Reviews* 30(4): 495–515.
- Delle Site P., Filippi F., Giustiniani G., 2011. Users' preferences towards innovative and conventional public transport. *Procedia - Social and Behavioural Sciences* 20, 906-915.
- Donaghy, K., Rudinger, G., and Poppelreuter, S. 2004. Societal trends, mobility behaviour and sustainable transport in Europe and North America. *Transport Reviews* 24(6): 679–690.
- The Economist (2012), Seeing the back of the car. In the rich world, people seem to be driving less than they used to. 22 September 2012. <http://www.economist.com/node/21563280>
- EEA (European Environmental Agency). 2011. The European Environment—State and Outlook 2010: Assessment of Global Megatrends. EEA, Copenhagen.
- European Commission. 2011. White Paper. Roadmap to a Single European Transport Area: Towards a competitive and resource efficient transport system. COM(2011)144, Brussels.
- Eno Center for Transportation. 2013. Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. <http://www.enotrans.org/wp-content/uploads/wpsc/downloadables/AV-paper.pdf>
- Frändberg, L., Vilhelmson, B., 2011. Population change and accessibility by road and rail networks: GIS and statistical approach to Finland 1970–2007. *Journal of Transport Geography* 19(4): 926–935.
- Harms, L., Jorritsma, P., Hoen, A. and van de Riet, O., 2011. Blik op de personenmobiliteit. KiM project.
- Hayes, B. 2011. Leave the Driving to it. *American Scientist*. 99: 362–366.
- InnoZ-Bausteine. 2008. Megatrends und Verkehrsmarkt. Langfristige Auswirkungen auf den Personenverkehr. Innovationszentrum für Mobilität und gesellschaftlichen Wandel.
- Kotavaara, O., Antikainen, H., and Rusanen, J., 2011. Population change and accessibility by road and rail networks: GIS and statistical approach to Finland 1970–2007. *Journal of Transport Geography* 19(4): 926–935.
- KPMG and CAR. 2012. Self-Driving Cars: The Next Revolution. Ann Arbor.
- Lanzendorf, M., Gather, M., 2005. Special issue: Institutional, economic and demographic transition and its impact on the transport system. *EJTIR* 5(3), pp. 135–138.
- Litman, T., 2013. Autonomous Vehicle Implementation Predictions. Victoria Transport Policy Institute. <http://www.vtpi.org/avip.pdf>
- Lyons, G., Goodwin, P., 2014. Grow, peak or plateau - the outlook for car travel. Discussion Paper. New Zealand Ministry of Transport.
- Mobil 2030. 2011. Mobilitätskultur in einer alternierenden Gesellschaft: Szenarien für das Jahr 2030. Zentrum für Alternskulturen.
- OECD (Organisation for Economic Co-operation and Development). 2001. Ageing and Transport: Mobility Needs and Safety Issues.
- OPTIMISM. 2013. Deliverable 5.1: Definition of strategies for integrating and optimising transport systems. OPTIMISM (Optimising Passenger Transport Information to Materialise Insights for Sustainable Mobility) project. Seventh Framework Programme.
- Priemus, H., Nijkamp, P., Konings, J. W., 2005. The Future of Automated Freight Transport: Concepts, Design and Implementation, Edward Elgar, ISBN 1845422392, 9781845422394.
- PSRC. 2006. Household travel survey data.
- Rodrigue, J.-P., 2013. Future Transportation, in *The Geography of Transport Systems*, 3rd ed. New York: Routledge.
- Rogge, L. 2005. Working Group (WG) 4 Seamless intermodal networks and services. Final Report. Voyager project. Fifth Framework Programme.
- Rosenbloom, S. and Ståhl, A., 2002. Automobility among the Elderly: The Convergence of Environmental, Safety, Mobility and Community Design Issues. *EJTIR* 2(3/4): 197–213.
- RSM (Roma Servizi per la Mobilità). 2013. Regulations experiences: report on success stories and limitations, to be delivered within the Smartset EU project (<http://smartset-project.eu>) by April 2014. The authors have been allowed to access the final draft release.
- Rudinger, G., Donaghy, K. and Poppelreuter, S., 2006. Societal trends, mobility behaviour and sustainable transport in Europe and North America. *EJTIR* 6(1): 61–76.
- Safdie M., Kohn, W., (1998), The city after the automobile. An Architect's vision. Westview Press, Colorado, USA.
- Shaheen S. A. (2011), Worldwide Carsharing and Bikesharing Market Dynamics: Current and Emerging Trends. Transportation Sustainability Research Center (TSRC), University of California, Berkeley. Presentation held at 2011 ITS World Congress. http://tsrc.berkeley.edu/sites/tsrc.berkeley.edu/files/ITS%20World_Worldwide%20Carsharing%20&%20Bikesharing.pdf

- Su, F., Schmöcker, J. D., and Bell, M.G.H., 2009. Mode Choice of Older People Before and After Shopping: A Study with London Data. *Journal of Transport and Land Use* 2(1): 29–46.
- Zabat, M., Stabile, N., Frascaroli, S., Browand, F., 1995. The Aerodynamic Performance of Platoons: Final Report.