Introduction

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In the first half of 2016, car manufacturers saw a record-breaking 45.6 million sales worldwide, an increase of almost 4 percent, according to WardsAuto. With this constant growth, the final score will come in at nearly 93 million vehicles sold this year and at this pace, annual global sales could even top 100 million by late 2018 (similar figures can be found in other reports, McKinsey, 2016; KINKEL & ZANKER, 2007).

Automotive is one of the oldest industries and will face numerous stakes in the near future (BECKER, 2010), in terms of environment (SELES *et al.*, 2016), security (KIRK, 2015), urbanization with smarter cities especially in developing regions, etc (DAVID & TERSTRIEP, 2015). Today, the automotive industry is at the core of different revolutions regarding motorization (electric car introduction, REZNAVI *et al.*, 2015), digitalization of its products and societal behaviour modifications (car sharing, BECKER *et al.*, 2017).

The first step of the car digitization is the connectivity inside the car, enabling connected car services. According to IDATE, in 2021, 498 million automobiles will be connected, representing a 35% CAGR, since around 81 million were connected in 2015.

The main driver of the adoption remains the different regulations around the globe, promoting more security on roads and not really the willingness to subscribe to these services. Indeed, regulation runs deep through the automotive market, mainly focusing on safety and security. The eCall Initiative of the European Commission aimed to encourage Member States, public safety access points (PSAPs), automobile manufacturers, mobile network operators, service providers and automotive suppliers to collaborate in developing an in-vehicle automatic crash notification system. Various aspects of eCall include in-vehicle systems, wireless data delivery and public safety answering point systems (OORNI & GOULART, 2017).

In addition, for several years, more and more automotive manufacturers have been embedding sensors into cars to improve road safety. According to industry specialists, the adoption of telematics could be similar to that of airbag systems in the past (DOTZAUER *et al.*, 2015), as they were initially well adopted in high-end and luxury cars, to be embedded into all cars nowadays. Telematics (including ADAS[1]) and predictive maintenance should gain traction in the near future, at least on the B2B2C side at first (fleet managers chiefly).

The take-off of infotainment (a kind of mobile internet in the car) will essentially be based on the offering itself. The connected car will require innovative and affordable applications that the consumer can pay for. Some offerings will replicate traditional services (mail, social networks) and others will be exclusive and suitable tools for driving time, such as streaming radio or tools for navigation. To make it happen, in 2014, GM, as a pioneer started to equip all its new vehicles with a 4G module, which enables the car to benefit, for example, from high-speed downloads, to enjoy video streaming and to share the connection among all passengers. Some major car manufacturers are already offering mobile hotspot features for up to seven or eight devices in a car. To enjoy a smooth QoE, the connection requires LTE specifications, both in terms of download/upload speeds and latency features (PARK *et al.*, 2015)

However, this market suffers from various barriers and mainly from costs issues. From the OEM perspective, connected car services is a CAPEX business at first, as they need to embed (expensive) technology (cellular modules, user interface with huge touchscreens and obviously data oriented IT platforms for device management), before expecting service revenues. This additional cost will reduce profit margins in a highly competitive market, where the general trend is to drive prices down. If high end luxury car OEM may reach over 10% profit margins, low cost providers may only have a profit margin of as little as 3%, overall with a clientele, not really willing to pay for such services. Indeed, this actual willingness of people to pay for such services is, and will remain, the major issue. Again, some questions

[1] Advanced Driver Assistance System

may arise around the probability that, ultimately, services will be on the mobile Internet in the car and everyone will possess a substitute smartphone. Moreover, pricing is relatively high and the rate of smartphone adoption for people addressed is very high too. The smartphone could well be seen as a strong substitute for subscriptions to connected-car services.

Security risks are a major issue for connected objects in general and in connected cars in particular, as life is therefore in danger. Numerous security breach issues around the connected car were first unveiled during the summer 2015. Indeed, Chrysler issued a formal recall for 1.4 million vehicles that may have been affected by hackable software vulnerability in the Chrysler Uconnect dashboard computers. More generally, security issues will be even more challenging while infotainment gains traction, given the threats of, say, malwares and viruses that will come from OTT services and, above all, from telematics services. Thus, a security breach will lead to the opposite primary goal: to improve security on road by embedding connectivity (SCHELLEKENS, 2016)

Actually, the revolution is a bit further down the road. Indeed, today the future of automotive relates to the self-driving vehicles. The leading manufacturers are mainly luxury car manufacturers in a first step. But the autonomous vehicles are on the tracks to be a strong game changer in the coming years with massive impacts on everyone's lives.

These transformations should modify the traditional barriers. Connected car services have already seen the emergence of new car manufacturers like Tesla, FF, LeEco or BYD. The autonomous car has already introduced new entrant manufacturers, which are already in advance on the technological perspectives. The strategy of each car manufacturer will have to manage the reasonable arrangements with the digital big names, the GAFA and Internet platforms, the telcos, in addition to their peers, new entrants and traditional suppliers. Indeed, the self-driving car introduces the openness of the industrial car system to newcomers based on their competencies in the electronic and digital technologies; beside or beyond new car manufacturers the insiders may fear a value migration towards the GAFA and their services. More generally speaking, the autonomous vehicle is also seen as a key driver in the OEM servicization strategy.

This servicization will have impacts on the customer loyalty as not only the product (the car) will be transformed, but also the consumption model with the development of various offerings of "car as a service", mainly led by hailing car service emergence (Uber, Lyft and Didi at first). Even OEMs are also investing this area by acquiring car sharing start-ups (GM with Maven and Lyft) and reorganizing themselves towards a mobility service company, a trend initiated by Ford and recently imitated by Tesla which changed its company name (from "Tesla Motors" to "Tesla"). Ford is trying to anticipate the transportation as an overall service (from a point A to a point B, mixing different ways of transportation – car, ride sharing, etc) and no longer a product (a car).

Moreover, the various steps toward the self-driving cars such as those different challenges cannot be analysed without a wider scope taking into account the whole new mobility system: public transportation, sharing economy, smart cities… indeed, the future of transportation is also much related to urban transport services and the "smart city" will therefore play a key role around autonomous car development as cities will also be required to invest in a costly infrastructure that cars will communicate with. This will take time and is one of the key issues. The smart city concept (which is also a buzz topic) will need to develop by taking into account various requirements and to anticipate such change in terms of applications, technologies to deploy, etc.

Other challenges have been already identified in the autonomous car:

- the impact on the R&D expenses for the car makers, their components providers and the possible consequences with a next consolidations wave (BUTLER & MARTIN, 2016);
- The emergence of China and its BAT as a leading new power in the digital economy coincides with the momentum about the "self-driving car" and taking into account the issue of the Chinese market for the occidental car manufacturer, the autonomous car may be a possible vector of a Chinese leadership on the industry (WAN *et al.*, 2015; DEMIR & SU, 2016);
- There is also a huge issue for the public regulation with a mix of authorities and interest: at the local level, national/European and International (McCHRISTIAN & CORBETT (2016); BRODSKY (2016).

It has not been possible to accumulate articles on all the themes that we have just reviewed in summary.

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However, the reader will be able to continue his reflection by taking note of an applied modelling work on the impact of the autonomous car. Indeed, Gonçalo HOMEM de ALMEIDA CORREIA from the University of Civil Engineering and Geosciences (Delft University of Technology) implemented a model to find out the impacts of autonomous vehicle on urban traffic congestion, compared with a traditional car based configuration.

On the one hand, we selected two articles with a predominantly legal content. The first by Alexander SOLEY aims at looking at how the United States of America and the European Union are approaching and regulating the connected vehicle and how different types of players are currently positioned and are already anticipating this upcoming game changer.

On the other hand, François GORRIEZ opted for a different approach as he investigated the legal landscape of autonomous cars through an overview of the different current regulations worldwide and overall an emphasis on the regulation regarding data generated by the autonomous cars.

We are very pleased to have also interviewed three different personalities to complete this issue. Thierry VIADIEU is very well placed to share with us the views and projects of a car company. He provides us the key insights to better understand how the automotive ecosystem will be impacted in the near future.

Gion BAKER as a representative of a major telecommunications operator gives us another perspective on the stakes of the connected car and its evolutions. He also analyses how network technologies will enable the arrival of innovative services.

Finally it seemed very interesting to us to propose this interview exercise to a third personality, an academic but wise observer of the automobile industry, Mr Bernard JULLIEN, as he delivers an independent point of view through an overview of the recent automotive industry evolutions.

We hope that this first issue of the DigiWorld Economic Journal will stimulate your interest and will give rise in two or three years to a new issue, highlighting the new trends taken by the connected subject and the very rich field of analysis that it offers to academics.

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Understanding Changes on Urban Mobility Patterns in an Automated Driving Scenario: results from a model application to Delft (NL)

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Abstract: Automated vehicles (AVs) are becoming a reality with several pilot projects demonstrating that the technology will be available soon. Still, most of the modelling research that has been done in the field is focusing on interurban traffic. Urban mobility, particularly the impacts that these vehicles may bring on mobility patterns, has hardly been addressed. In this paper we present a Mixed Integer Programming (MIP) model to assign family trips to their own AVs along a day. The model takes into consideration that a vehicle is now free to move empty in the network to satisfy the multiple household trips. The model is run for the case-study city of Delft, Netherlands, with and without automation for comparison purposes, moreover, a lower value of time is also considered for the AVs scenario. We concluded that the AVs are able to satisfy more trips with some added traffic congestion. Nevertheless, with a lower value of travel time, it is possible to satisfy many more trips while actually maintaining congestion levels according to our case-study results. It appears that rerouting the vehicles to satisfy more trips of the families leads to less competition in the same highly used paths. Sharing the AVs leads to great mobility efficiency as demonstrated in previous research; however, this is always limited by the willingness to pool with strangers.

Key words: automated vehicles; self-driving cars; traffic assignment; optimization; urban mobility; mobility impacts.

Despite the uncertainty regarding the moment in which a car will first drive without a driver in a city (CORREIA *et al.*, 2016; MILAKIS *et al.*, 2016) vehicle automation is becoming a reality as field experiments by key research organization such as universities and technology companies are developed. For instance, the google car has travelled over 1 million miles in the US (Google Self-Driving Car Project Monthly Report Updates from Austin Google Self-Driving Car Project Monthly Report, 2015). As the experiments roll out, more information is gathered which will make this technology safer (ALESSANDRINI, 2014).

Researchers have so far been mainly concerned with developing the electronic systems which will make these trips possible through the use of lasers, radars and cameras installed in the cars (BROGGI *et al.*, 2013). Moreover, considerable attention is being given to modelling the movement of these cars in a cooperative or non-cooperative form in freeways under scenarios of partial or full automation in order to measure their effects on road capacity and delays (ANTONIOTTI *et al.*, 1997; ARNAOUT & BOWLING, 2011; CALVERT *et al.*, 2011; HOOGENDOORN *et al.*, 2014; KALA & WARWICK, 2013).

More rare is to find research on methods to estimate the impact of automated vehicles (AVs) in the mobility of urban areas. This has been mainly focusing on the study of using AVs for carsharing and ridesharing (JORGE *et al.*, 2015a, 2015b; JORGE & CORREIA, 2013), in a sort of self-driven Uber/shared taxi systems (MARTINEZ *et al.*, 2015; MARTÍNEZ *et al.*, 2017, 2014). The studies by Kara KOCKELMAN (FAGNANT & KOCKELMAN, 2014) and the International Transport Forum (Itf, 2015) are two examples of such type of studies which use agent-based simulation to find a balance point between demand and supply in a city taking into consideration fleet size, demand behaviour and vehicle operation strategies. Other research exists on assessing the usage of these vehicles as a complement to mass public transport in a first mile/last mile mode of oepration (AREM *et al.*, 2015; LIANG *et al.*, 2016; YAP *et al.*, 2015, 2016).

The perspective of AVs being used as private cars is not being considered often. An interesting recent study addressed the modelling needs of privately owned AVs by proposing a modified 4-step model. LEVIN and BOYLES (LEVIN & BOYLES, 2015) change the classic 4-step model to address the option of empty vehicle relocation after a vehicle drops its passengers off. This is compared with the cost of parking at the destination and using public transport (PT) for the same trip. Despite recognizing the advantage of an AV being able to move while empty, the method so far ignores that relocations can lead to higher or lower costs, depending on the next trips due to being served by that vehicle in the same household.

CORREIA and van AREM (2016) address the effects of automating vehicles in satisfying more trips of the families who own them, by proposing a model to assign families trips to their AVs considering all trip schedule constraints. The model puts in competition these vehicles and a simplified PT alternative with the objective of studying the effects of increased degrees of freedom of these cars on the number of trips, traffic congestion, and parking demand. A case-study of the city of Delft was used for applying the model under automation and non-automation scenarios and changing the value of travel time. The method used is a combination of traffic assignment and vehicle routing that is formulated as a Mixed Integer Programme (MIP) model run in a solver.

In this paper, we revisit this model to better explore its limits and add scenarios to the original ones under a substantial demand increase of the case-study which puts stress on the model creating more traffic congestion and hence being more realistic. A new scenario that considers families sharing several private vehicles has been added.

In the next section, the User Optimum Privately Owned Automated Vehicles Assignment Problem is revised. In the next section, the Delft case-study and its data (updated in relation to the first application) is introduced. This is followed by running several scenarios for the case-study. The paper ends with some conclusions taken from the case-study and future work to be done next.

■ The User Optimum Privately Owned Automated Vehicles Assignment Problem (UO-POAVAP)

The system optimum (SO-POAVAP)

The model is first developed to be solved from a system optimum perspective (SO-POAVAP) as this formulation is simpler to define in mathematical programming. This means that the objective function will be one that minimizes the total transport cost of all the families in the city. The assumptions of the SO-POAVAP are:

- The trips performed by the household members are either satisfied by the AVs or by PT according to the global generalized transport costs minimization function.
- The generalized transport costs incurred by the household include: vehicle kilometers done by the AVs; PT costs for the trips not satisfied by the AVs; parking costs of the AVs which can vary within the city; and penalties for arriving early or late to each trip destination.
- AVs are allowed to drive empty in the network without any human supervision

- Each AV routing adds to the traffic flows of the city.
- Each AV has a certain passenger capacity that must be respected.
- The PT trips do not contribute to the traffic flows in the network for simplification purposes, thus PT only influences mode choice.
- No external trips to the city are considered in the network.
- The problem is solved to system optimality which means that the total transport costs will be minimized without considering any household selfish behaviour.

The model is formulated as a MIP problem. Integer variables are used because of the vehicles' routing, meaning that instead of flows being continuous variables, they will be expressed as integer quantities. The proposed MIP formulation can be found in the Annex 1.

Method to approach the user-optimum (UO-POAVAP)

In order to find a user optimum or user equilibrium solution to the POAVAP we assign the cars of every family to their trips throughout a day by the order in which they appear in the database thus the model will not be able to benefit or penalize a specific household over another in a system perspective. All households are assigned and in the end travel times in the network are updated in function of the car volumes. Another assignment of all the households is repeated in the next iteration. The model stops if changes in the travel times and flows stabilize. The algorithm can be seen in Annex 2.

■ Case-study of Delft

As in the previous paper (CORREIA & van AREM, 2016), the UO-POAVAP is applied to a small city in the Netherlands, Delft, in the province of South Holland. Despite using real travel data, only the trips of families who travel inside the city during the course of a whole working day in the year 2008 were obtained. This means that traffic flows which are observed in the network cannot be validated in reality. The mode choice model between a private vehicles (automated or not) and PT uses the coefficients obtained from a study on multimodal mobility in the Netherlands (ARENTZE &

MOLIN, 2013). That study provided us with reference values for the generalized cost functions that families use to choose their transport options.

The purpose of the case-study is to test and exemplify the model's application and at the same time to get a first look at the type of effects we may expect from the introduction of fully-automated vehicles in urban areas. In relation to the previous paper (CORREIA & van AREM, 2016) in this one, we double the travel demand (137,280 trips). Figure 1 shows the simplified road network of Delft superimposed on the satellite view of the region. The city centre is marked with an ellipse.

Figure 1 - Map of the case-study area
(topological network on Google Earth satellite view)

The network has 61 road links and 46 nodes (white lines and black dots). Some of the links have two lanes per way corresponding to the road profile that can be observed in the city. Figure 1 shows all the nodes and links of the network. The centroids of the TA zones (13 postal code areas) are also indicated (white circles around 13 nodes). All the origins and destinations of the trips are georeferred to the postal code centroids.

The mobility data was obtained from the Dutch mobility dataset (MON 2007/2008). The Dutch government makes this database available for mobility research, in the form of daily information collected on the movements of a sample of individuals. They record the purpose of travel, the origin, and destination, transport mode, departure and arrival times. Information about the household is also collected. Details include the composition and size of the household and age, gender and education level of all its members. Until 2008 all trips made by a household were surveyed, which is the information needed to apply the UO-POAVAP.

152 trips were used (29 households sampled), which were made by residents who travelled only within the city of Delft during the surveyed day. Sampling expansion factors for each family were also given for a normal working day, this coefficient varying from 200 to 1300. All modes and motives are included in the sample. With the sampling rate expansion, the 152 trips represent 68,640 trips taken by 14,640 households yielding an average sample rate of 0.2%. However, in this paper, we experiment with double the real demand hence we are considering 137280 trips in Delft (29,280 households). We could not analyze all these households given the time-consuming algorithm, so we used the previously defined expansion coefficient μ_h (whereby each analyzed *h* household represents μ_h number of real households as explained in Annex 1). In this application, a surveyed household that represented, for instance, 480 real households according to the mobility survey was transformed into 24 synthetic households with exactly the same characteristics, which means that an expansion coefficient of μ_h=20 is used for all households. Therefore, for the 29,280 real households, 29,280/20=1464 synthetic households are analyzed. The model is therefore capable of greater detail regarding the households characteristics, but our case-study was limited by the quality of the original travel survey.

The following simplifications and considerations were used to operationalize the method in its application to Delft (base scenario with automation) (all parameters defined in Annex 1):

- The time step of the optimization is 2.5 minutes (time_step).

- The capacity of each link was defined for one hour, which, within the model, is divided uniformly according to the time-step size that is being considered. This means that no rigorous estimation of the link's capacity for each time step of the optimization is computed.
- Only two capacities were considered for the network, one for one lane per direction roads and another for two lanes per direction, which were 1600 and 3200 vehicles (Q_{ij}) respectively. The maximum speeds were assumed to be 50 and 70 km/h respectively for the lower and higher capacity links.
- The departure and arrival times of the surveyed trips in Delft are used as reference to establish the a^{emh} and b^{emh} data vectors (lower and upper limits for departure and arrival) with a 15-minute slack. For the earliest departure the slack is subtracted from the original departure time, and for the latest arrival the slack is added to the original arrival time.
- The preferred departure and arrival times are assumed to be those recorded in the survey.
- The trips only relate to adults. No extra occupants are allowed for when the trip is to facilitate taking a child to school, hence the representation of the loads in the vehicles is not entirely real. All occupants are assumed to be able to drive an automobile if required.
- All families have at least one vehicle available or the number of vehicles stated in the survey. In practice this allows the model to always consider the possibility of using a car for the family trips. In Delft, all families had at least one vehicle.
- All trips within the same zone are assumed to be made by walking, thus they are not part of the objective function.
- The optimal paths will only be computed for a selection of nodes which are called the notable nodes. These include the origins and destinations of the trips made by the household and also any other public parking locations. This definition is useful to reduce the computational time because for instance when parking charges at the nodes are the same, there is no reason why a node other than an origin or destination of a trip should be chosen for parking (note that there are no parking capacity limitations in the model).

The data needed to run the case-study is as follows (all parameters explained in Annex 1):

$H = 1464$ households

μ_h=20 families (the same expansion is used for all synthetic households)

$T = \frac{24\ hours \times 60 min}{2.5\ min} + 1 = 577\ time\ instants$ (2.5 min time step used).

$G = 576\ time\ steps$ (the time between the time instants)

t_{ij}^{min}: minimum travel time by car in time steps for each link (i, j) which is obtained from the free flow speed with an absolute minimum of one time step (2.5 minutes in this application). This introduces limitations because it happens that certain links have lower travel times than the $time\_step$ precision. This is however needed to use the time-space network. It also implies that it is not possible to use big time steps which would accelerate the computation but would make the case-study totally unrealistic. No impedance was considered at the nodes.

t_{ij}^{max}: maximum travel time by car in time steps was computed for a speed of 5km/h where the curve between the minimum and the maximum travel time is given by the previously referred Bureau of Public Roads curve.

t_{ij}^{PT}: the travel time in PT was defined for a BUS based PT trip for a commercial speed of 12 km/h. It was computed through the free-flow shortest duration paths in the road network. 5 minutes were added to all travel times to emulate walking to the BUS stop and waiting for the vehicle.

Cap^{hv}: the capacity of the vehicles was set to 4 passengers per vehicle for all vehicles.

ρ: the generalized cost penalty of using PT is 7.622 euros (people have a preference for the car)

β: total travel time cost per minute in PT (includes waiting) is $0.755\ euros/min$

α: travel time cost by time step in a car is $0.806\ \left(\frac{euros}{\text{min}}\right) \times time_{step}$

α_l: cost for arriving late is $1.306\ (\frac{euros}{\text{min}}) \times time\_step$

α_e: cost for arriving early is $0.306\ (\frac{euros}{\text{min}}) \times time\_step$

ω: fuel costs by time step in a car are equal to $0.1\ (\frac{euros}{\text{km}})$

γ: scale for the parking costs in relation to the fuel and maintenance costs is 1.81 (needed to normalize the cost functions)

ς: scale factor of the ticket cost in relation to the fuel and maintenance costs is 2.11 (needed to normalize the cost functions)

$Tick$: the PT ticket was considered constant and equal to 1.5 euros per trip

Pk_i: the parking costs are 1 euro/hour for all locations, which is a compromise between the highest value charged per hour and the hourly rate for staying one day in several parking lots in Delft. By default there are three locations that have free parking: the home location of the household in Delft and two locations outside the city which correspond to nodes 15 and 41 (Figure 1).

Scenarios

In this paper, we run five scenarios to study the impact of AVs on urban mobility. In the first, we run the model with no automation thus not allowing any routing of the vehicles if there isn't anyone inside. In the second scenario, the model is run with full automation in which each family owns one and only one AV which can satisfy their trips on a typical day. In the third scenario, we consider that every four families share the same conventional vehicle in a sort of carpooling mode with a normal car (CORREIA & VIEGAS, 2005). In the fourth scenario every four families share one automated vehicle. Finally, in the fifth scenario, the model is run for half of the value of time for the people inside the vehicles under the assumption that this time would be felt as more productive once it is possible to use the time for work, leisure or even rest. This is actually under discussion and latest results point to changes in the value of travel time which can be contradictory with this assumption if the time inside a vehicle is used for work for example (YAP *et al.*, 2016) thus more research is needed on the topic.

Each scenario was run in an Intel® Core™ i7-46000 CPU@2.10GHz computer with 16GB RAM. For each scenario, a maximum number of 10 + 1 iterations were allowed (S=10). The computation time is not indicated on Table 1 but each iteration took an average of 100 minutes to be computed (it depends on the scenario). The potential number of trips to be satisfied by an AV never changes across scenarios always being 120,600 (the other 16,680 trips of the 137,280 are taken in the same zone).

Table 1 – Scenario run results

Scenario	Transport Costs	Cost per trip	Number of trips in AV	Number of trips in PT	Car split	Number of vehicles	Total Active vehicles[1]	Trips per act veh	Delay(h)[2]	Parking time (h)	Park time of act veh(h)	Avg park time per act veh	Driving time of act veh (h)	Driving time per veh (h)	% of congestion	Time inside a vehicle aggregate (pax x h)	Human travel time per trip (min)	Total distance loaded[3]	Total distance empty (km)	Total distance (km)	Percentage empty kilometers
1) Model with no automation	3.22E+06	26.75	45400	75200	37.6 %	29,280	14518	3.13	2464.05	689315	335031	23.07	13404.9	0.92	18.4%	13884.7	18.6	359750	0	359750	0%
2) Full automation	3.23E+06	26.69	46280	74320	38.4%	29,280	13916	3.33	2786.66	688341	319614	22.96	14379.2	1.03	19.4%	14015.6	18	350149	38651.6	389746	9.9%
3) Every four families share one conventional vehicle	2.77E+06	22.70	73020	47580	60.5%	7320	6209	11.7	702.99	169796	143134	23.04	5884.1	0.94	11.9%	20558.2	16.9	182584	0	182584	0%
4) Every four families share one AV	2.71E+06	22.33	78820	41780	65.3%	7320	6187	12.7	908.67	167704	140519	22.71	7975.7	1.29	11.4%	22358.1	16.9	202975	31645.9	236720	13.3%
5) Full Automation with lower value of time	2.86E+06	23.68	49860	70740	41.3%	29,280	14729	3.39	3399.73	686271	337049	22.88	16448.7	1.12	20.6%	16226.6	19.8	387147	42075.2	430014	9.7%

[1]Vehicles that move either with or without passengers for at least one time step
[2]Delay here is defined as the travel time driven above the free-flow speed
[3]Distance done by the vehicles, not by the people inside the vehicles

In table 1 it is possible to observe that the scenario with automation leads to an increase in the number of trips in an automobile, although not a very significant one. The delay increases slightly but not significantly. There is a significant percentage of empty kilometers associated with satisfying the extra trips.

Looking at the scenarios where there is ridesharing between every four families (scenarios 3 and 4) a decrease in the generalized transport costs (objective function) can be seen which happens due to the sharing of the vehicles for many of the trips of these families. The sharing of trips using the car increases considerably from 37.6% to 60% (conventional vehicle) and 65% (automated vehicle). There is a 5% increase due to the automation, which has a bigger effect than when families do not share. This happens because with lower transport costs more trips of the households are viable to be made in a car thus taking more advantage of the automation degrees of freedom. The added demand attended in the sharing mode is not accompanied by an increase of congestion as it can be seen on the delay because there are fewer cars on the road. This indicates the expected advantages of mobility sharing as documented in previous research (CORREIA & VIEGAS, 2011, 2010; CORREIA, 2012).

The total distance done by these shared cars is lower because of the advantages of pooling in one vehicle, thus the empty kilometers of the vehicles despite being lower in number represent a higher percentage of the total driven distance in scenario 4. The number of trips satisfied by active vehicle goes from 3.33 in the scenario only with automation to 12.7 trips per vehicle in the scenario with carpooling which is on average one trip more than in regular carpooling (scenario 3). Parking time also drops significantly which can contribute to higher quality city centres.

The lower value of travel time (scenario 5) leads to low generalized transport costs as it can be observed in the first column of Table 1. This happens directly because of the travel time component in the objective function. Cars are now driving much more and satisfying 41 % of all trips in the city (no sharing in this scenario). The average delay in the network actually does not increase considerably and this might be due to the fact that now vehicles are being rerouted in the network using less used paths for satisfying other trips in the households which were not cost effective before having AVs (and its corresponding possible value of travel time changes). This effect was also observed in the previous application with less demand on the network (CORREIA & van AREM, 2016). In order for this to happen it is necessary that people spend more time in their cars and this can be seen in the average human travel time per trip which is now 19.8 minutes instead of 18 like in the scenario only with automation.

Conclusions

The model described in this paper has been introduced in (CORREIA & van AREM, 2016). In this paper, we apply the method to the small network of Delft but with more travel demand than in the previous application. Interesting conclusions can be drawn from the application. We concluded that the AVs can satisfy more trips than the conventional vehicles and create only a small increase in congestion despite the extra kilometers. Though in this case-study not many more trips which might have to do with the low PT costs not making car trips very attractive, the extra kilometres are thus very expensive compared to just having a PT trip.

Sharing AVs between several families leads to great efficiency increases as can be seen by the number of trips that each car now satisfies. However one should take into consideration that our case-study is simplified in that the families are clones of each other i.e. they have the same origins and destinations.

It was also possible to conclude that if in the future car users perceive a lower value of travel time in a redesigned vehicle interior for leisure and work, this could lead to an even greater number of satisfied trips that might actually not come at the cost of more congestion: we have seen that the lower value of travel time can be an advantage by creating an opportunity for satisfying more trips which will reroute the vehicles thus having a positive side effect of competing less with other family cars on traffic.

As future work, we will continue to work on the methods of doing the assignment since the current model lacks a deeper analysis in what concerns its convergence. Moreover, it is rather slow making it impractical to apply in a big city. Model simplification is required as well as more sophisticated methods and computational power in order to be possible to apply the same kind of model framework. The alternative being using simulation, for instance, an agent-based model like MATSim, however, problems with convergence may still exist.

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Annexes

Annex 1

Sets:

$\boldsymbol{H} = \{1, \ldots, h \ldots H\}$: set of households in the city, where H is the total number of households.

$\boldsymbol{T} = \{1, \ldots, t \ldots T\}$: set of time instants in the operation period, where T is the last optimization time instant.

$\boldsymbol{G} = \{1, \ldots, g \ldots T-1\}$: set of time instants that represent the beginning of a time step between two instants (it does not include the T instant). This also represents the set of time steps which are $T-1$.

$\boldsymbol{I} = \{1, \ldots, i \ldots I\}$: set of nodes in the network, where I is the number of nodes.

$\boldsymbol{M} = \{1, \ldots, m \ldots M\}$: set of members of household h, where M is the number of members of household h (for brevity purposes the index of the household is omitted from the set name).

$\boldsymbol{E} = \{1, \ldots, e \ldots E\}$: set of trips of each member m of household h, where E is the number of trips.

$\boldsymbol{V} = \{1, \ldots, v \ldots V\}$: set of vehicles of household h where V is the total number of vehicles.

$\boldsymbol{X} = \{1_1, \ldots, i_{t-1}, i_t, i_{t+1}, \ldots, I_T\}$: set of nodes of a time-space network combining the $\boldsymbol{I}$ nodes with the $\boldsymbol{T}$ time instants.

$\boldsymbol{R} = \{\ldots, (\mathrm{i,j}), \ldots\}\ i, j \in \boldsymbol{I},\ i \neq j$: set of arcs of the road network where vehicles move.

$\boldsymbol{A_1} = \left\{\ldots, \mathrm{a_1}\left(\mathrm{i}_{t_1}, \mathrm{j}_{t_2}\right), \ldots\right\}, i_T \in \boldsymbol{X}, (\mathrm{i,j}) \in \boldsymbol{R}$: set of arcs that represent the movement of each vehicle of household h between node i and node j of the road network, between time instant t_1 and $t_2 = t_1 + \delta_{ij}^{t_1}$ where $\delta_{ij}^{t_1}$ is the travel time (in number of time steps) between nodes i and j when the movement starts at time instant t_1. Because travel time changes in function of the vehicles' routing this means that this set of arcs is in constant change and must be a function of the congestion effects on the network.

Data:

D_{ij}^{emh}: has the value 1 if there is an e^{th} trip from member m of household h from node i to node j, $\forall\, i, j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}$.

Θ_a^{emh}: desired departure time for the e^{th} trip from member m of household h, $\forall\ e \in \boldsymbol{E}$, $m \in \boldsymbol{M}, h \in \boldsymbol{H}$.

$a_{\square}^{emh}$: earliest departure time for the e^{th} trip from member m of household h, $\forall\ e \in \boldsymbol{E}$, $m \in \boldsymbol{M}, h \in \boldsymbol{H}$.

Θ_b^{emh}: desired arrival time for the e^{th} trip from member m of household h, $\forall\ e \in \boldsymbol{E}$, $m \in \boldsymbol{M}, h \in \boldsymbol{H}$.

$b_{\square}^{emh}$: latest arrival time for the e^{th} trip from member m of household h, $\forall\ e \in \boldsymbol{E}$, $m \in \boldsymbol{M}, h \in \boldsymbol{H}$.

t_{ij}^{max}: maximum travel time by car in time steps for arc (i,j), $\forall\ (i,j) \in \boldsymbol{R}$.

t_{ij}^{min}: minimum travel time by car in time steps for arc (i,j), $\forall\ (i,j) \in \boldsymbol{R}$.

t_{ij}^{PT}: travel time in PT in minutes for trips going from node i to j (in this case we opt for using minutes as unit), $\forall\ i, j \in \boldsymbol{I}$.

Cap^{hv}: capacity of vehicle v of household h, $\forall\ h \in \boldsymbol{H}, v \in \boldsymbol{V}$.

$Lg_{ij}^{\square}$: length of arc (i,j) in kilometers, $\forall\ (i,j) \in \boldsymbol{R}$.

μ_h: expansion coefficient of household h (number of households with the same characteristics in the population), $\forall\ h \in \boldsymbol{H}$.

Q_{ij}: capacity of each link (i,j) which is the number of vehicles that go through the link at the highest travel time, $\forall\ (i,j) \in \boldsymbol{R}$.

The parameters for building the generalized transport costs function that should be minimized (explained in the objective function):

ρ: penalty cost of using PT (specific disutility of the mode).

β: total travel time cost per minute in PT (includes waiting).

α: travel time cost by time step in a car.

α_l: penalty time cost for late arrival at destination by car.

α_e: penalty time cost for early arrival to destination by car.

ω: fuel cost per kilometer in a car.

γ: scale factor between the fuel costs and the parking costs (costs are perceived differently and fuel costs are used as reference).

ς: scale factor between the fuel costs and ticket costs (costs are perceived differently and fuel costs are used as reference).

$Tick$: Ticket cost per PT trip.

Pk_i: Parking cost at location i per time step, $\forall\, i \in \boldsymbol{G}$.

Decision Variables:

$x_{i_{t_1}j_{t_2}}^{hv}$: binary variable equal to 1 if vehicle v of household h drives on road link (i,j) from time instant t_1 to time instant t_2, $\forall (i_{t_1}, j_{t_2}) \in \boldsymbol{A_1}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$.

δ_{ij}^{t}: current travel time by car in time steps for arc (i,j) beginning at time instant t, $\forall\, (i,j) \in \boldsymbol{R}, t \in \boldsymbol{T}$.

$w_{i_t}^{hv}$: binary variable equal to 1 if vehicle v of household h parks at node i at time step t, $\forall\, h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$, $i_t \in \boldsymbol{X}$.

Tr_{ij}^{emhv}: binary variable equal to 1 if trip e from node i to node j of member m belonging to household h is done using vehicle v, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$.

P_{ij}^{emhvt}: binary variable equal to 1 if trip e from node i to node j of member m belonging to household h starting at time instant t in vehicle v, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$, $t \in \boldsymbol{T}$.

A_{ij}^{emhvt}: binary variable equal to 1 if trip e from node i to node j of member m belonging to household h finished at time instant t using vehicle v, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$, $t \in \boldsymbol{T}$.

ϕ_{ij}^{emhv}: continuous variable of the difference between the real and desired arrival time of trip e from node i to node j of member m belonging to household h iusing vehicle v, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$.

$l\phi_{ij}^{emhv}$: continuous positive variable of the difference between the real and desired arrival time of trip e from node i to j of member m belonging to household h in vehicle v when the arrival happens after the desired time, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$.

$e\phi_{ij}^{emhv}$: continuous positive variable of the difference between the real and desired arrival time of trip e from node i to j of member m belonging to household h in vehicle v when the arrival happens before the desired time, $\forall\, i,j \in \boldsymbol{I}$, $e \in \boldsymbol{E}$, $m \in \boldsymbol{M}$, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$.

L_t^{hv}: discrete variable equal to the number of persons being transported in vehicle v of household h at time step t, $h \in \boldsymbol{H}$, $v \in \boldsymbol{V}$, $t \in \boldsymbol{G}$.

$F_{i_{t_1}j_{t_2}}$: flow of vehicles on arc (i,j) from time instant t_1 to time instant t_2, $\forall (i_{t_1}, j_{t_2}) \in \boldsymbol{A_1}$.

Objective function:

$$
\begin{aligned}
Min(C) = & \sum_{\substack{i,j\in I\\ e\in E, m\in M, h\in H}} \left(D_{ij}^{emh} - \sum_{v\in V} Tr_{ij}^{emhv} \right) \times \left(t_{ij}^{PT} \times \beta + Tick \times \varsigma + \rho \right) \times \mu_h \\
& + \sum_{\substack{\left(i_t, j_{t+\delta_{ij}^t}\right)\in A_1\\ h\in H, v\in V}} x_{i_t j_{t+\delta_{ij}}}^{hv} \times Lg_{ij} \times \omega \times \mu_h \\
& + \left(\sum_{\substack{i,j\in I\\ e\in E, m\in M, h\in H,\\ v\in V, t\in T}} \left(A_{ij}^{emhvt} \times t \right) - \sum_{\substack{i,j\in I\\ e\in E, m\in M, h\in H,\\ v\in V, t\in T}} \left(P_{ij}^{emhvt} \times t \right) \right) \times \alpha \times \mu_h \\
& + \sum_{\substack{i\in N, t\in G\\ h\in H, v\in V}} w_{i_t}^{hv} \times Pk_i \times \gamma \times \mu_h \\
& + \sum_{\substack{i,j\in I\\ e\in E, m\in M, h\in H\\ v\in V}} \left(l\phi_{ij}^{emhv} \times \alpha_l + e\phi_{ij}^{emhv} \times \alpha_e \right) \times \mu_h
\end{aligned}
\quad (1)
$$

This function minimizes the total generalized cost of transportation of all households for one day and has five components (each of which with its own line in Equation (1)). It considers first the cost of the trips done in PT which includes the value of in-vehicle time, the ticket cost and a penalty cost for opting for PT; then the cost of vehicle fuel which is a function of the kilometers driven; the following component is the value of travel time (VTT) which is a function of the time spent inside the vehicle for all its occupants, hence it cannot be indexed to the x variables as these only represent the time lost by the vehicle itself; the following component regards the parking costs. Costs of vehicle depreciation are not included in this function as these are regarded as sunk costs not being considered by the traveler in his choice. Early and late arrivals are penalized in the last component of the function in order to speed up the process of finding an optimal solution of a particular routing since there may be many possible routing combinations yielding the same objective function. The assumption $\alpha_e < \alpha < \alpha_l$ is made to avoid cyclical routes which might occur if arriving early is more onerous than traveling (Small, 1982)(Levin et al., 2015). Nevertheless we acknowledge that there could be differences in these penalties whether it is a trip to work or a return home for example.

This function is the sum of the costs of two transport options: PT and AV. In the way that the model is built the function translates the utility of the two modes expressed in monetary units. The two underlying generalized cost functions are the following:

$$C(car) = \alpha \times Travel\_Time + Fuel\_cost + \gamma \times Parking\_cost \quad (2)$$

$$C(PT) = \rho + \beta \times Travel\_Time + \varsigma \times Ticket\_cost \quad (3)$$

These functions only have in consideration the mode attributes, whilst it is known that mode choice depends on other factors such as the socio-demographic profile of the decision maker as well as other more subjective attributes. The only effect which is not connected to the mode attributes is introduced by a special disutility parameter ρ. Most importantly these two functions represent only the deterministic part of the utility of choosing a mode ignoring the random part which would call for using a choice model structure such as a Logit or a Probit. For simplification purposes we assume to ignore in this work the random part of the utility and its statistical distribution.

By minimizing this objective function, the MIP model is opting for a solution that maximizes the global systematic utility of the mobility of all the households. This means that a cheaper solution for one of the households may be balanced with a more expensive one for another.

The objective function is subject to the following constraints:

$$Tr_{ij}^{emhv} \leq \sum_{\substack{(i_{t_1} l_{t_2}) \in \boldsymbol{A_1} \\ t_1 \geq a^{emh} \\ t_2 \leq b^{emh}}} x_{i_{t_1} l_{t_2}}^{hv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (4)$$

Assures that a trip e from member m of household h can only be satisfied by vehicle v if that vehicle has passed through node i (trip origin node) after the earliest departure time a^{emv}.

$$Tr_{ij}^{emhv} \leq \sum_{\substack{(l_{t_1}, j_{t_2}) \in \boldsymbol{A_1} \\ t_1 \geq a^{emh} \\ t_2 \leq b^{emh}}} x_{l_{t_1} j_{t_2}}^{hv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (5)$$

Assures that a trip e from member m of household h can only be satisfied by vehicle v if that vehicle has passed through node j (trip destination node) before the latest arrival time b^{emv}.

$$\begin{aligned} & P_{ij}^{emhvt} \leq Tr_{ij}^{emhv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T} \\ & P_{ij}^{emhvt} \leq \sum_{\substack{(i_t, l_{t_1}) \in \boldsymbol{A_1} \\ t \geq a^{emh} \\ t_1 \leq b^{emh}}} x_{i_t l_{t_1}}^{hv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T} \\ & P_{ij}^{emhvt} \geq \sum_{\substack{(i_t, l_{t_1}) \in \boldsymbol{A_1} \\ t \geq a^{emh} \\ t_1 \leq b^{emh}}} x_{i_t l_{t_1}}^{hv} + Tr_{ij}^{emhv} - 1, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T} \end{aligned} \quad (6)$$

This set of constraints forces the departure of a trip e to exist at a specific time instant t if the trip is satisfied by a vehicle v and the vehicle passes through the trip departure node at time instant t.

$$\sum_{t \in \boldsymbol{T}} P_{ij}^{emhvt} \leq 1, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (7)$$

Assures that each trip only departs at a specific time instant or that it is not satisfied at all by any vehicle.

$$\begin{aligned} & A_{ij}^{emhvt} \leq Tr_{ij}^{emhv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T}, v \in \boldsymbol{V} \\ & A_{ij}^{emhvt} \leq \sum_{\substack{(l_t, j_{t_1}) \in \boldsymbol{A_1} \\ t_1 \geq a^{emh} \\ t \leq b^{emh}}} x_{l_{t_1} j_t}^{hv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T}, v \in \boldsymbol{V} \end{aligned} \quad (8)$$

$$A_{ij}^{emhvt} \geq \sum_{\substack{(l_t,j_{t_1}) \in A_1 \\ t \geq a^{emh} \\ t_1 \leq b^{emh}}} x_{l_t j_{t_1}}^{hv} + Tr_{ij}^{emhv} - 1, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, t \in \boldsymbol{T}, v \in \boldsymbol{V}$$

This set of constraints forces the arrival of a trip e to exist at a specific time instant t if the trip is satisfied by vehicle v and there is a vehicle route passing through the trip arrival node at time instant t.

$$\sum_{t \in \boldsymbol{T}} A_{ij}^{emhvt} \leq 1, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (9)$$

Assures that each trip only arrives at a specific time instant or that it is not at all satisfied by any vehicle.

$$\phi_{ij}^{emhv} = \Theta_b^{emh} \times Tr_{ij}^{emhv} - \sum_{t \in \boldsymbol{T}} A_{ij}^{emhvt} \times t, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (10)$$

Computes the difference between the desired and the real arrival time of a trip in time steps. If the trip is not satisfied by a car the variable is zero. This variable is negative if the real arrival time is later than the desired one and positive vice versa.

$$l\phi_{ij}^{emhv} \leq -\phi_{ij}^{emhv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (11)$$

Yields the absolute time difference in time steps when the arrival of a trip happens after the desired time.

$$e\phi_{ij}^{emhv} \geq \phi_{ij}^{emhv}, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (12)$$

Yields the absolute time difference in time steps when the arrival of a trip happens before the desired time.

$$\sum_{t \in \boldsymbol{T}} (P_{ij}^{emhvt} \times t) \leq \sum_{t \in \boldsymbol{T}} (A_{ij}^{emhvt} \times t), \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H} \quad (13)$$

The departure instant of a trip must happen before the arrival instant.

$$\sum_{v \in \boldsymbol{V}} Tr_{ij}^{emhv} \leq 1, \forall i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H} \quad (14)$$

A trip is only satisfied by one car and one car alone.

$$L_t^{hv} = \sum_{\substack{i,j \in \boldsymbol{I} \\ e \in \boldsymbol{E}, m \in \boldsymbol{M} \\ h \in \boldsymbol{H} \\ t_1 \in \boldsymbol{T}, t_1 \leq t}} P_{ij}^{emhvt_1} - \sum_{\substack{i,j \in \boldsymbol{I} \\ e \in \boldsymbol{E}, m \in \boldsymbol{M} \\ h \in \boldsymbol{H} \\ t_1 \in \boldsymbol{T}, t_1 \leq t}} A_{ij}^{emhvt_1}, v \in \boldsymbol{V}, t \in \boldsymbol{T} \quad (15)$$

Yield the number of people in each vehicle v of household h at each time instant t.

$$L_t^{hv} \leq Cap^{hv}, v \in \boldsymbol{V}, t \in \boldsymbol{T} \quad (16)$$

Assures that the number of persons inside vehicle v of household h is not above the vehicle capacity.

$$\sum_{i \in \boldsymbol{I}} w_{i_t}^{hv} \leq \frac{Cap^{hv} - L_t^{hv}}{Cap^{hv}}, t \in \boldsymbol{G}, v \in \boldsymbol{V}, h \in \boldsymbol{H} \quad (17)$$

These constraints impose that when the vehicle is transporting a person, it should not stop idle at any node. It avoids the model producing solutions that may minimize the generalized transport costs but that would not be logical from a practical point of view.

$$\sum_{i \in \boldsymbol{I}, j_t \in \boldsymbol{X}} x_{i_1 j_t}^{hv} + \sum_{i \in \boldsymbol{I}} w_{i_1}^{hv} = 1, v \in \boldsymbol{V}, h \in \boldsymbol{H} \quad (18)$$

Each vehicle v of household h is created and these constraints make sure that the vehicle will only be in one of two possible states in the beginning of the day: stopped or beginning a route. This also means that the variables which characterize the state of a family vehicle will always be created, that is, the model does not have the option of eliminating a vehicle. If the vehicle is not used throughout the day it just stays parked at the same place.

$$\sum_{j_{t_1} \in \boldsymbol{X}} x_{i_t j_{t_1}}^{hv} + w_{i_t}^{hv} = \sum_{j_{t_1} \in \boldsymbol{X}} x_{j_{t_1} i_t}^{hv} + w_{i_{t-1}}^{hv}, \forall i_t \in \boldsymbol{X}, h \in \boldsymbol{H}, v \in \boldsymbol{V} \quad (19)$$

These make sure that the vehicles will have continuity of activities in each node throughout the model period.

$$F_{i_{t_1} j_{t_2}} = \left(\sum_{h \in \boldsymbol{H}, v \in \boldsymbol{V}} x_{i_{t_1} j_{t_2}}^{hv} \right) \times \mu_h, \forall (i_{t_1}, j_{t_2}) \in \boldsymbol{A_1}, h \in \boldsymbol{H} \quad (20)$$

Flow of vehicles in each road link (i, j) between time instant t_1 and t_2.

$$F_{i_{t_1} j_{t_2}} \leq Q_{ij}, \forall (i_{t_1}, j_{t_2}) \in \boldsymbol{A_1} \quad (21)$$

Flow limited by the capacity of each link.

$$\delta_{ij}^{t} \geq t_{ij}^{min} + \left(t_{ij}^{max} - t_{ij}^{min}\right) \times \left(\frac{\sum_{t_2 \in \boldsymbol{T}} F_{i_t j_{t_2}}}{Q_{ij}} \right)^4, \forall (i,j) \in \boldsymbol{R}, t \in \boldsymbol{T} \quad (22)$$

Non-linear constraints that compute the travel times as a function of the traffic flow. It considers the travel time increase given by the Bureau of Public Roads (Dafermos and Sparrow, 1968): $t = t_0 \left(1 + a \times \left(\frac{V}{Q}\right)^b\right)$ where t_0 is the free-flow travel time; V is the volume; Q is the capacity; and a and b are estimation parameters. In this case an a of 1 and a b of 4 will be used for experimental purposes. An inequality is used because in some particular cases link consistency must be imposed (see constraints (24)). In the expression, the summation $\sum_{t_2 \in \boldsymbol{T}} F_{i_t j_{t_2}}$ does not mean that there can be flows simultaneously for two travel times starting at the same time instant t. Because travel time is a variable, only one of those travel times will exist between the minimum and the maximum. This is guaranteed because of constraints (20) where the flow is computed as a result of summing the $x_{i_{t_1} j_{t_2}}^{hv}$ variables and these will be related to the travel time in the next constraints (23).

$$x_{i_{t_1} j_{t_2}}^{hv} \leq \frac{\delta_{ij}^{t_1}}{t_2 - t_1} \; \forall (i_{t_1} j_{t_2}) \in \boldsymbol{A_1}, h \in \boldsymbol{H}, v \in \boldsymbol{V}, t_{ij}^{max} \geq (t_2 - t_1) \geq t_{ij}^{min}$$
$$x_{i_{t_1} j_{t_2}}^{hv} \leq \frac{t_2 - t_1}{\delta_{ij}^{t_1}} \; \forall (i_{t_1} j_{t_2}) \in \boldsymbol{A_1}, h \in \boldsymbol{H}, v \in \boldsymbol{V}, t_{ij}^{max} \geq (t_2 - t_1) \geq t_{ij}^{min} \quad (23)$$

These two sets of constraints only allow for the existence of routing variables, $x_{i_{t_1} j_{t_2}}^{hv}$, whose time interval (between instants t_1 and t_2) is compatible with the congestion level at link (i, j) defined by constraints (22).

$$t_1 + \delta_{ij}^{t_1} \leq t_2 + \delta_{ij}^{t_2}, \forall t_1, t_2 \in \boldsymbol{T}, (i,j) \in \boldsymbol{R}, 0 \leq t_1 < t_2 < t_1 + \delta_{ij}^{t_1} \quad (24)$$

These are link-consistency constraints that assure that vehicles do not pass one another, i.e., that among two platoons traversing a link, the one which enters later does not leave earlier.

$x^{hv}_{i_{t_1}j_{t_2}} \in \{1,0\}\ \forall\ i_{t_1}j_{t_2} \in \boldsymbol{A_1}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(25)
$w^{hv}_{i_t i_{t+1}} \in \{1,0\}\ \forall\ i_t i_{t+1} \in \boldsymbol{A_2}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(26)
$Tr^{emhv}_{ij} \in \{1,0\}\ \forall\ i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(27)
$L^{hv}_t \in N^0\ \forall\ t \in \boldsymbol{T}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(28)
$F_{i_t j_{t+1}} \in N^0\ \forall\ i_t, j_{t+1} \in \boldsymbol{X}$	(29)
$\delta^t_{ij} \in N^0\ \forall\ (i,j) \in \boldsymbol{R}, t \in \boldsymbol{T}$	(30)
$\phi^{emhv}_{ij} \in R\ \forall\ i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(31)
$l\phi^{emhv}_{ij} \in N\ \forall\ i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(32)
$e\phi^{emhv}_{ij} \in N\ \forall\ i,j \in \boldsymbol{I}, e \in \boldsymbol{E}, m \in \boldsymbol{M}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(33)

Set the domain of the decision variables.

The model can be transformed in such a way that it renders the current mobility situation in a city with conventional vehicles. All vehicles are owned by the families but in this case they cannot drive without a driver. This can be imposed by the following extra set of constraints:

$x^{hv}_{i_t j_{t_1}} \leq L^{hv}_t\ \forall\ (i_t, j_{t_1}) \in \boldsymbol{A_1}, h \in \boldsymbol{H}, v \in \boldsymbol{V}$	(34)

These assure that there cannot exist routing variables if the vehicle is empty (L^{hv}_t=0).

Annex 2

The following parameters are needed for running the UO-POAVAP:

$\boldsymbol{S} = \{0, \dots, s..S\}$: number of iterations where S is the maximum (iteration 0 is the initialization of the algorithm).

$\delta^{t,s}_{ij}$: are defined as the travel times in the network in the current iteration s and they are not decision variables as in the SO-POAVAP.

$\delta^{t,0}_{ij} = t^{min}_{ij}, \forall (i,j) \in \boldsymbol{R}, t \in \boldsymbol{T}$ Initial travel times in each link are defined as the minimum travel times.

$error$: error between the previous and the current iteration. The number of trips satisfied by the cars will be considered as the reference indicator for that convergence.

$Trips^s$: are the number of trips satisfied by an automobile in iteration s.

π: limit for the error

$\phi = \frac{1}{s}$: is the coefficient for the equilibrium computation that will balance the contribute of the previous and current assignment for the computation of the volumes and other performance indicators in each iteration.

$Vol^s_{i_{t_1}j_{t_2}}$: are the volumes on link (i,j) from time instant t_1 to t_2 in iteration s.

The following is the pseudo-code of the UO-POAVAP algorithm:

Regulation, Industry, and the Internet of Cars

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Abstract: The rise of the connected vehicle is inevitable; the main questions are how the market will be regulated and how businesses will make money in this sector. This article looks at how the United States of America and the European Union are approaching and regulating the connected vehicle and how businesses are entering and adapting to the new market.

Key words: Automobile, Automotive, Car, Connected Vehicle, European Union, Government, Internet, Internet of Things, Regulation, United States

The rise of autonomous vehicles and vehicles with Internet-accessible sensors is effectively inevitable. Too many governments have done studies on the subject, too many businesses have invested, and too many people show interest in autonomous and connected vehicles for the concept to simply go away. With the outline of the future set in stone, corporations need to know how to make money from the future. To do this the corporations need to know how the connected vehicle market is regulated in order to create their own stakes in the industry. This paper looks at the environments in two of the world's largest markets for automobiles, the United States and the European Union (EU), and analyzes the discussions and actions made by policymakers and corporations to see how they are approaching the connected vehicle. The United States is looking at the Internet of Cars (IoC) market through a free market paradigm, which means the government is mostly letting the market work on its own, with the proviso that laws need to be introduced to allow self-driving cars to operate in parts of the United States that presently do not allow autonomous cars. Legislators may need to intervene to assure the population that autonomous cars will be as safe as, or safer than, manually driven cars. By contrast the EU and its member states are viewing the IoC through a market failure paradigm, which is leading the EU to build the new market. Furthermore, it is considering regulations through the public interest paradigm to ensure issues such as privacy and safety are accounted for. As the two governments are considering different approaches to regulation, the OEMs and the technology companies are investing greatly to ensure that however the regulations look, they will be ready to act in the burgeoning IoC markets by selling autonomous vehicles and considering a number of ways to stay relevant in a more shared economy.

■ Regulatory Paradigms

If a company wants to do well, it needs to identify how the countries they are operating in perceive the market they are operating in. To do this, the company needs to identify what legislation is being discussed or has been passed and what concerns led to their passage or consideration. Those concerns will influence how policy is made in the future and will impact how companies are run in the IoC sector. One such approach is the free-market paradigm, where the government either allows the companies to act as they please or removes regulations that restrict companies' autonomy, such as regulations that ban cars from driving themselves. The United States federal government, and most of its states, has no regulations on self-driving vehicles, which means self-driving cars are neither forbidden nor permitted in most of the country. Some states require a human driver to actively "operate" the vehicle and only a few states expressly allow self-driving cars to operate on public roads (HG.org Legal Resources, 2016). If one looks into the various U.S. state laws one can see a web of confusion, as Florida allows anyone with a valid driver's license to "operate" an autonomous vehicle while Nevada requires the driver to have car insurance, not make phone calls or texts, and to pre-test the car on a highway to ensure it meets safety conditions (National Conference of State Legislatures, 2016). The Vienna Convention on Road Traffic allows self-driving cars, as long as a human driver can take over at a moment's notice. The United States, unlike much of the EU, is not a signatory to this Convention (Department for Transportation, 2015). Countries that perceive the market through this paradigm are likely to reduce regulatory hurdles between jurisdictions to allow companies to focus on competing with each other instead of adapting to variable regulations.

Countries that see the IoC through the market failure paradigm have different concerns about connected vehicles. Regulators that operate in such an environment are concerned with eliminating market inefficiencies such as externalities. They are also interested in reducing market concentrations, ensuring that whoever buys an autonomous car can transfer his or her ownership of the car, or building markets where none currently exist. For instance, in a market-failure environment regulators will attempt to break up a monopoly supplier of a single good because they believe the good will be cheaper if there are a variety of suppliers instead (The Linux Information Project, 2016). Such regulators may also seek to prevent original equipment manufacturers (OEMs) from operating the cars, similar to how "unlocked" phones allow consumers to change operators, or prevent one service from controlling the mapping services and the cars themselves. They may also be interested in fixing one perceived market failure in particular: the market's apparent inability to grow without the aid of the policymakers in question.

A government that perceives a market through the public interest paradigm may intervene at an early stage by laying the groundwork for standards or helping to create standards along the lines of the GSM standards for mobile telephony because such actions are "in the public interest". This may involve making the supply of services more equitable or making access to certain technologies more widely available. Governments operating through this paradigm may also conclude that setting such standards can lead to more innovation, if it believes such innovation is in the public interest.

■ The United States: Enabling the Private Sector

The United States government (USG) and its constituent states appear to be viewing the connected vehicle through a free market paradigm. The Obama Administration announced in 2016 that it planned to invest almost $4 billion on testing and making nationwide IoC regulations (United States Department of Transportation, 2016) and President Donald TRUMP has yet to make an announcement about the IoC. However, Congress controls the budget, not the presidency, and as of writing Congress only appears to care about the privacy and safety of the IoC. There are two bills in the national legislature that may pass at some point- the Security and Privacy in Your (SPY) Car Act which subjects vehicle manufacturers to technological safety standards under the oversight of the Federal Trade Commission and the

NHTSA and the Safety Technology Investment Flexibility Act of 2015 which focuses on improving safety through the establishment of vehicle-to-infrastructure (V2I) networks (EIDAM, 2015) - but otherwise Congress appears uninterested in tackling the subject further as of writing. This is not to say it is impossible; when companies seemed to believe that it was cheaper to not put airbags into their cars, even though they made cars safer, Congress intervened in 1991 by mandating that all cars have them (History, 2016).

This is not to say the USG has ignored the IoC; the National Institute of Standards and Technology (NIST) released a draft framework to help manufacturers create cyber-physical systems such as connected cars and smart watches that work seamlessly with other smart systems (National Institute of Standards and Technology, 2015) and the National Highway Traffic Safety Administration (NHTSA) is defining how "autonomous" a car is on a scale of level 0 (incapable of being autonomous) to level 4 (no human necessary to drive the car) (KIM *et al*., 2014). The Department of Transportation (DoT) appears to be pushing for agreements to adopt safer technologies instead of mandating their use and endorsing pilots designed to advance the IoC. For instance, the NHTSA, the Insurance Institute for Highway Safety, and 20 automakers such as Ford and Toyota agreed on March 17, 2016 to make a new braking system known as the AEB system standard on all cars and light trucks by 2022. While the AEB system- which uses sensors to sense an imminent crash and brake the car- is not necessarily an autonomous system, it sets a precedent of government-industry coordination to create standards. While organizations such as Consumer Watchdog dislike such agreements because they are not enforceable and in this particular case formalize an existing system, it also means that companies can undo the agreement easily if a better system is found before 2022, and can create a new agreement for that system. In terms of testing, the DoT selected three "Wave 1" pilots in October 2015: a Wyoming project dedicated to reducing incident-related delays through new sensors with V2V (vehicle-to-vehicle) and V2I (vehicle-to-industry) communication capabilities with two universities and a few companies, a New York City project that tests V2I capabilities in terms of tracking red lights and pedestrians in crosswalks to improve traffic between Manhattan and Brooklyn, and a Tampa project that also focuses on V2V and V2I communication (United States Department of Transportation, 2015). While these projects are significant, they are also few given the size of the U.S. economy. It seems that the federal government is focusing on other issues for the most part.

The states do not have a uniformly pro-business or anti-business approach to regulation. As of February 2016 only seven states and the District of Columbia have laws related to the connected car, and two of them, Arizona and North Dakota, only have laws that require the creation of reports on the IoC. California allows companies to test autonomous cars on public roads, but only if they adopt a set of safety standards and have their vehicles pass performance requirements to ensure safe operations (National Conference of State Legislatures, 2016). California also requires that federal regulations created by the NHTSA supersede state laws when they conflict and that there is an "operator" who is licensed to operate the car. The law says this is to make sure someone in "the driver's seat" can be on hand to "monitor" the "safe operation of the vehicle" and take over in case the "technology" fails or there is an emergency[1]. Florida, Michigan, Nevada, and Washington, D.C. also require a "test driver" that is capable of taking over in case something goes wrong, but otherwise allows autonomous cars to drive on public roads. In all of these cases the state law treats the test driver as if he or she is driving the car manually. Not all of these laws are simply about whether one can drive on state roads or not; Tennessee prohibits governments below the state level from prohibiting the use of vehicles with "autonomous technology". The state reserves to itself the ability to block such laws, but otherwise ignores the issue. Michigan's laws go into more detail on issues such as the liability incurred from "modifications made by a third party" to automated vehicles or automated vehicle technology in certain circumstances. Other than those laws, legislators in dozens of states such as Alabama, Hawaii, and New York have introduced laws that are related to autonomous driving, but have not passed them (National Conference of State Legislatures, 2016). In the rest of the states, autonomous driving is neither prohibited nor permitted, creating a grey area where testing can happen, but issues such as insurance could make things more complicated than working in states where autonomous driving is explicitly legal. While some of these laws do predict a future with driverless cars, none of them explicitly allow it. Overall all of these laws ban the effective use of driverless cars, at least for now.

Overall, neither the U.S. federal nor state governments are actively involved in the sector. While there are elements of public interest in the national government's approach, the existing legislation tends to either call

[1] SB-1298 Vehicles: Autonomous Vehicles: Safety and Performance Requirements, Sess. Of 2011, § 570-38750
https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB1298

for new research or explicitly allows testing. The United States may change in the short run; right now it is approaching the IoC through a free market paradigm that focuses on testing and enabling. This is in contrast to the Europeans, who are more involved in the process of building the market than their American brethren.

The European Union: Building the Market

The EU appears to have a more unitary approach to regulation. Most of the EU countries are members of the Vienna Convention on Road Traffic, which require someone to be at the wheel of the car at all times (Vienna Convention on Road Traffic, 1968). This treaty was amended in 2014 to allow autonomous cars on the streets as long as their autonomy can be turned off. The European Commission and the European Parliament are interested in regulating autonomous vehicles, but are taking some time to propose such laws (STUPP, 2015). In fact, the EU has already created connected car standards. Two organizations with ties to the EU, ETI and CEN, created connected car standards in 2014. These standards were designed to make sure that cars created by different manufacturers can communicate with each other (European Commission, 2014). Furthermore, European policymakers from all 28 EU member states and members of the European transport industry signed the Amsterdam Declaration on April 14, 2016, which delineates what steps appear necessary to develop self-driving technology in the EU (EU2016.NL, 2016a). The document suggests the EU is looking at it through a public interest lens. Although the member states are interested in how the IoC can "strengthen the economy of Europe," it also praises how "[f]urther automation of vehicles" will "provide excellent opportunities to improve traffic flows and to make transport safer, cleaner and easier". Furthermore, the rise of the connected car will improve "social inclusion," "mobility services in rural areas and cities," and develop "mobility as a service and lower travel costs". Overall, the EU believes the IoC will benefit the public interest, especially the "aging population, vulnerable road users and disabled persons". The signatories of the Amsterdam Declaration promise to create a "coherent European framework" for deploying "interoperable connected and automated driving…if possible, by 2019". The policymakers are still concerned about issues such as data protection and privacy, and want to ensure that autonomous cars "improve road safety, human health, traffic flows, and to reduce the environmental impact of road transport". The EU governments have committed themselves to identifying and, if possible, removing the legal barriers to testing and deploying connected and automated vehicles, as well as making "large-scale cross-border testing of connected and automated driving technologies" possible by "facilitating" the sharing of best practices within and without the member states and contributing to discussions about the IoC (EU2016.NL, 2016b). As grand as this declaration is, however, this is not an altogether new development; the EU member states have been working on and promoting this for some years.

The EU states have shown an interest in regulating this space. The German government believes that the "existing levels of automation" comply with German law but new laws will be needed to legalize "highly and fully automated vehicles" according to a British report on the subject, the French government published its own roadmap for regulating the market and allowing "large-scale" testing of self-driving cars, and the British government believes no new regulations are needed in the United Kingdom to test automated vehicles (Department for Transportation, 2015). As the United States is considering the creation of new regulations, the EU member states appear to believe that existing regulations such as the Vienna Convention is the only regulation the IoC needs right now. The EU member states may also believe they should wait for the IoC to develop before creating new regulations. Regardless, the main work appears to be creating a supranational framework and promoting testing.

The EU and its member states are promoting the IoC to a greater degree than the USG's three public pilots. Baden-Württemberg's government is allowing Daimler to put autonomous cars on the road as long as they have drivers in the car who can take control of the car and the UK is allowing companies to do the same under similar conditions (STUPP, 2015). Various European states, and the EU itself, have sponsored a variety of programmes designed to test autonomous technologies. The EU has sponsored research projects such as the Integrated Project PReVENT (European Technology Platform on Smart Systems Integration, 2015) and tests that involve testing advanced driver assistance systems (ADAS) technologies such as HAVEit (HAVEit, 2011) from 2008 to 2011. The EU funded the 2009-2012 SARTRE Project to test "roadtrains," or platoons of cars, for personal transport and is planning to finance its successor, the COMPANION project (European Technology Platform on Smart Systems Integration, 2015) through fall 2016. This project was given €5.4 million in funding and is comprised of the Volkswagen (VW) Group Research, Stockholm's Royal Institute of Technology KTH, Oldenburger Institut für Informatik (OFFIS) in Germany, IDIADA Automotive Technology in Spain, Science & Technology in the

Netherlands and the Spanish haulage company Transportes Cerezuela (COMPANION – Cooperative dynamic formation of Platoons for sAFe and eNergy-optimized gOods transportation, 2016). There are many other such projects such as interactIVe, which involves 29 companies from 10 countries and the CityMobil2 project that does practical tests in urban environments in Oristano in Sardinia, Italy (European Technology Platform on Smart Systems Integration, 2015). While the NHTSA is backing a few programmes, the EU is sponsoring a large number of its own, and the member-states are also making their own.

A number of countries have sponsored their own initiatives without the express help of the EU. There are a great number of reports which discuss projects all over the world (see e.g. FIA, 2015), such as the UK Auto drive programme in Milton Keynes and Coventry and the "Automated Transport System" process being held in the Lindholmen Science Park and the "Drive Me" programme in Gothenburg. The latter will involve more than 100 self-driving Volvo cars that will run on the public roads, and it will be the first large scale project in the world when it starts. One should note that it is run through a joint initiative between the Volvo Car Group, the Swedish Transport Administration, the Swedish Transport Agency, The Lindholmen Science Park, and the City of Gothenburg with the Swedish government's endorsement. This project includes all the key players- legislators, transport authorities, the city authorities, and the customers, which makes it unique among many other projects around the world (FiA, 2015).

Overall the EU governments are pursuing a different approach to the USG: instead of focusing on facilitating private sector testing, perhaps with an eye to regulating away the problems later, it is pushing the testing itself. Because of this the EU is by and large looking at the IoC through the market failure paradigm of building a new market through the creation of standards and promotion of testing. Instead of sponsoring a few projects and facilitating such a transformation, these governments are trying to make the market a reality. They are advancing research in the area and perhaps pushing companies to collaborate more and innovate more to become stronger overall.

Observations on the Regulatory Paradigms

As of writing, the United States is viewing the market through a free market paradigm that gives private sector companies like Google and Ford room to grow and the EU is approaching the market through a market failure one where the government seeks to help companies such as Daimler and Volvo. The U.S. market does show signs of a market failure approach, but not many of them; President Obama's call for funds and a national set of regulations was in the last year of his term. The NHTSA and NIST are making some moves in terms of standardization and research which signal more of a market failure approach in terms of coordination and public interest in terms of safety, but they are more limited in comparison to their European equivalents. However, the two markets are similar in one respect: for now, both governments are considering the markets through a public interest paradigm when it comes to issues of safety, as seen in the various regulations made by various U.S. states and the Amsterdam Declaration. There have been calls in both markets to consider the security and privacy of people's private information, and there are questions as to who should "own" the data that is being used, but for the most part the governments are giving little focus to other important issues. While safety and data security and privacy are important, they ignore a great deal of other questions governments will have to face over time: will future cars need to have a manual override so that if a car's computer becomes inoperative, the driver can take over? If so, will that person need a driver's license? There is a great deal of focus on the need to understand who is liable for a car crash if it occurs, but if an unmanned car is robbed, who should charge the thief with damages? The entity that "owns" the car or the service that is currently employing the car? Should safety data be owned only by the companies that own the cars, or should that data be made public? If a company wishes to hide a new project but deny other companies access to its proprietary research, how can it test the new technology on public roads and not yield its data if it is involved in an accident? Will there be a process for approving untested technology? If a company builds a piece of infrastructure, such as a "connected" traffic light, can it own the information that flows through it for a period of time and license it out to the government and potentially others? All of these are important questions that need to be answered, since such confusion can scare investors from investing in portions of the IoC. All of these questions ignore one important part of the IoC entirely: the information infrastructure.

One of the most important questions that need to be answered is how to ensure the creation of a resilient information infrastructure so that V2V and V2I do not collapse. One should note the issue of information infrastructure- that is the infrastructure that will be needed to keep cars connected to the Internet- has yet to see much movement. There have been discussions about the need to make access to the Internet more widely available so that cars can potentially speak to infrastructure connected to the Internet such as roads, traffic lights and services such as Google Maps and weather stations to improve their understanding of the environment. These connected cars can create a network of their own. For instance, if an area is hit by a natural disaster that takes down the network infrastructure, a number of cars can form their own web and pass data back and forth. While these cars may not be able to connect to the Internet as a whole, they can form a temporary intranet to pass along emergency information (INOUE, 2016). However, there is little action in this area.

Furthermore, more Internet capacity will be needed in a future where people will not have to drive. In that future, people are likely to consume an increasing amount of data by streaming entertainment media or working online instead of driving, hence the need for a more resilient infrastructure with a larger capacity that is accessible across the country (CARTER, 2016). A more robust telecommunications infrastructure may be required to better secure the IoC from hacking, and this infrastructure could be expanded to other areas such as emergency response. So far, however, there has been little movement at the supranational, national, or local levels to expand the mobile Internet infrastructure to enable such a change. Such a development may require more information gathering, since one does not want to build a mobile telecommunications technology infrastructure if it will be made obsolete in a few years by a newer one. This could be accomplished through several means such as investing money in creating the information infrastructure. As of 2016 however, the issue of information infrastructure has been mostly ignored.

Overall, the regulatory paradigms are set and, barring a large shift, unlikely to change. Many of these "missing" regulations may appear over time. The regulatory paradigms are designed to give regulators a way to understand new markets and trends. The main issue is that the IoC is so new that people are unsure in which direction the IoC will move. It is possible that the regulators are missing part of the big picture. The IoC is not just about giving people another form of transportation; it may replace many jobs with unmanned vehicles. Truck drivers may be replaced as companies put their cargo in driverless cars. Furthermore, these companies may use cars in new ways. For instance, they may decide to create a car that acts as a mobile hotspot, and this car would constantly move to expand Internet access to people who do not have access to mobile networks. Unmanned cars could be sent to areas with chemical spills for emergency response reconnaissance. These are just a few examples of how the IoC may evolve past the transportation sector's current state. Therefore regulators must keep in mind how these new markets can come about and how traditional OEMs such as Honda and nontraditional car companies such as Baidu will enter the new space. The businesses themselves are already considering a more autonomous future and are planning to be a part of that future.

■ Business and the IoC

While the USG and the EU are discussing how the market needs to be either managed or built, the companies in the private sector are concerned with how they are going to remain relevant. A market that seemed impervious to outside interference is now in great flux as new entrants are challenging the old. Google, Tesla, and Uber have been around for less than twenty years, and now it is difficult to talk about the future of the connected vehicle without mentioning Tesla's autopilot feature, Uber's talk of switching out its human drivers for an autonomous fleet, and Google's own experiments. This does not mean that OEMs such as Ford and Daimler are being left in the dust; they are investing in new technologies to stay ahead of the curve and building strategic partnerships to create a more autonomous future for their consumers and, if they are lucky, a more profitable future for themselves. To show how the field is changing, this paper has selected eight companies as examples of how the field is changing: three U.S. OEMs, two of whom are classics and the third an upstart; three German OEMs that have made big strides and are finding ways to ensure their economic survival; and two technology firms that will remain part of the conversation for some time.

■ The U.S. OEMs: Ford, GM, and Tesla

The American car companies are approaching the future in their own different ways. Two of the classic U.S. OEMs, Ford and General Motors (GM), believe a more connected future is in the offing. Tesla is one of the first to push near-total autonomous driving, although it warns its customers that it does not make fully autonomous cars yet.

Ford has been considering different ways to take driving out of the driver's hands, although not at the point at giving the computer total control as of now. It is considering a project called "Remote Repositioning". This project would involve a "remote driver" from afar moving the cars without anyone giving commands from within the car. This could be done simply to move a car overnight to better enable ridesharing. For instance, an owner's car could be remotely driven from of the owner's house to the airport. As far as the owner is concerned, the "driver" could be a programme or a driver from afar and facilitate the same roles autonomous driving could accomplish (ZIEGLER, 2015). Ford is also experimenting with full autonomy. It expanded its fleet of Fusion Hybrid autonomous research vehicles in 2017 to a point that it is now the largest fleet of all the automakers. It is accelerating the creation and testing of its virtual driver software (WALFORD, 2017). This work will help Ford advance into a more modern age where ridesharing has become more common. Ford would have the power to control its own fleet or sell cars on a fleet-by-fleet basis as opposed to depending on its users to share their cars.

GM has been involved in automating technology as far back in the 1960s and 1970s. It collaborated with RCA to test the concept of automated highways that magnetically propelled and guided ordinary vehicles (WOOD, 2015). In 2005 GM collaborated with Carnegie Mellon University for an autonomous vehicle competition sponsored by the Defense Advanced Research Projects Agency (DARPA) (DAVIES, 2015). It developed the OnStar service, which allows people to contact OnStar representatives to obtain emergency services, get their vehicles' diagnostics, and directions. The service also allows the owners to remotely disable their vehicles. OnStar's representatives can use built-in global tracking devices to locate stolen vehicles and remotely disable the gas pedal, thus allowing the police to find the vehicles and return them to their proper owners (ROHLIN, 2009). GM promises that any cars that have OnStar installed will respect GM's privacy policies and that OnStar's anti-theft features will only be used if the car owner gives the police permission to chase the thief, and the police are not allowed to activate the feature without the owner's permission, which seems to have satisfied the regulators thus far (WOODYARD & USA TODAY, 2009). More recently, it is focusing on an ADAS feature that allows it to drive automatically on freeways and launch a fleet of "robo-Volts" that have engineers at the wheel in case something happens. This feature, among others, is being tested in Detroit itself (DAVIES, 2015). GM has not limited such testing to Detroit; it is also testing abroad, such as its test of its Electric Networked-Vehicle (EN-V) in Tianjin (DEMORRO, 2014). GM appears to be focusing on expanding what it has, with automation as just the next step in the process.

Of all the OEMs, Tesla is seen as the first one to put a nearly autonomous car on the market. Unlike the Detroit Three, Tesla was created less than a decade ago and instead of having a range of brands to serve different consumers, Tesla focuses on selling a single brand which differs only in features such as how many people can sit in the car. In respect to the IoC, Tesla is the first firm to sell cars that go beyond ADAS and approach full automation. This system is known as the "Autopilot". It integrates cameras, radar, ultrasonic, and GPS with real-time data feedback from the Tesla fleet to create a programme that is capable of self-improvement. This data is augmented by over-the-air (OTA) updates that improve the car given the technical capabilities of the car being updated. In fact, anyone who owns a car fitted with the necessary sensors to operate the Autopilot can use it, even if the said car predates the autopilot feature (Tesla, 2015). This update should not be mistaken for full autonomy; Tesla reminds its drivers that it does not consider the Autopilot as an alternative to a human driver. In May 2016 a driver was killed while his car was on Autopilot because the Autopilot mistook a white truck as being part of the bright sky behind it and drove the car into it. The crash was widely covered in the press because it was the first fatality caused by an error in a connected vehicle's programming. While Tesla took a knock to its reputation, the regulators cleared the company of responsibility because the driver had at least seven seconds to recognize that the error would occur. While the computer did make an error, it was the driver's fault for not paying attention to the road; the Autopilot worked as intended and the regulators saw no fault in the system itself (BOUDETTE, 2017). It has since updated the car, but it is clearly still a work in progress. Tesla will remain the most visible carmaker in the field until another company makes a bigger splash, and that company may not necessarily be an American one.

■ Europeans OEMs: Daimler, VW, and BMW

Just as the governments of Europe are interested in building the European market for connected vehicles, European companies are just as engaged in building it. Three German car companies in particular are deeply involved: Bayerische Motoren Werke (BMW), Volkswagen (VW), and Daimler. All three of them are involved in different ways, and they are also working together to ensure they will still be in the driving seat once the connected future comes to pass.

BMW is betting heavily on its own self-driving technology. In terms of connectedness, 90% of its new vehicles are now "fully" connected (KEOGH, 2017). The company announced that about 40 autonomous BMW vehicles will be on the roads by the second half of 2017, and some of its newer cars, such as the BMW 5 Series Sedan, will not require drivers to operate the accelerator, the brake pedal, or the wheel because an onboard computer continuously cross-checks the car's position and its surrounds against a digital roadmap (WALFORD, 2017). BMW seems to be far ahead in terms of development and is willing to go further.

VW has its own experiments. At the Consumer Electronics Show in 2017 one of its manufacturers, Audi, demonstrated that its Nvidia-powered vehicles can recognize and understand its environments. Audi is expanding testing of its artificial intelligence (AI)-equipped vehicles in California and a few other U.S. states in 2018 (WALFORD, 2017). This testing may be related to VW's own partnership with Stanford University; its website boasts of VW's and Stanford's success in winning the DARPA Grand Challenge twice, one of which included the creation of a car that drove without a human through 132 miles of desert racing (Volkswagen, 2017). VW is proud of its reputation and wants the world to believe it will only get better.

Daimler has made its own advances, which is to be expected from one of the first companies to develop autonomous vehicles. One of its manufacturers, Mercedes-Benz, experimented with driverless vehicles that could accelerate, brake, steer, and otherwise drive through traffic without human intervention back in the 1980s and 1990s. The Eureka PROMETHEUS (Programme for European Traffic with Highest Efficiency and Unprecedented Safety) Pan-European project was started by Daimler-Benz with several other European OEMs, electronic producers and suppliers, institutes and universities on October 1, 1986. Through this programme it released many driverless prototypes, including a modified W140 S-Class that almost completely drove itself from Munich to Copenhagen in 1995. This car functioned through computer commands based on evaluating the information received through the four cameras attached to the car. However, these experiments and their successors are designed to create an accident-free experience as opposed to eliminating the driver entirely (OAGANA, 2016). Daimler continues to innovate in this area. Mercedes-Benz announced a new partnership with Nvidia that focuses on deep learning and AI (WALFORD, 2017) and the manufacturer is testing its cars (Daimler, 2017a) and trucks on Nevada's public roads (Daimler, 2017b).

Perhaps the most interesting work coming out of the three German automakers is not their willingness to build driverless cars, but their interest in working together in select areas. In August 2015 BMW, Daimler, and VW's Audi division bought the "Here" mapping service from Nokia so they would have an independent provider of mapping services that was outside Google's control (The Economist, 2016a). Here is a mapping service seen by many as a worthy alternative to Google Maps and thus a way to ensure that the connected future is not dominated by Google. When they made the purchase, the German OEMs invited other OEMs such as Ford, Toyota, and Renault to join what they now call an "open platform for everyone" (BOSTON, 2015). As of now no other OEMs have joined, but the chip maker Intel bought a 15% stake in Here International and is partnering with the firm to support real-time updates of traffic and road conditions, among other business opportunities (BOSTON, 2017). The German car companies worked hard to ensure they can shape the future itself, especially *vis-à-vis* the technology companies.

■ Technology Firms: Uber and Google

Perhaps the most important change to the automotive industry over the last few decades is the arrival of the technology companies. Some companies are focusing on communication issues such as V2V communication, some are supplying chips to the OEMs, and others have found new roles for themselves in the industry. Two of the best-known companies in this field are Uber, a company that has accelerated the arrival of the ridesharing economy, and Google, which promoted a more public discussion about autonomous cars over the last decade.

Uber is shifting from its current business model of enlisting drivers to share their rides to a market where Uber operates a fleet of autonomous cars. Uber makes its money by taking a cut from the fares paid to its ridesharers; it does not own the cars its drivers use to take their customers from place to place (LASHINSKY, 2016). If Uber eliminates its human workforce and replaces it with an autonomous fleet, it will eliminate the costs and liabilities that come with a human labour force and replace them with an increase in autonomous assets owned by the company. Uber CEO Travis Kalanick argues Uber has to make the shift because the world will have autonomous cars, so if Uber does not do it, "it's not going to exist either way". This future may only happen in the coming decades, but to Kalanick this is a future Uber will have to adapt to (WOOD, 2015).

Last September Uber began an autonomous ridesharing service in Pittsburgh. The service works like any other Uber service, with one main difference: it has two people in the front, an engineer that analyzes the car's performance and a driver that takes over in case the car makes a mistake. These cars are designed to "see" other cars, upcoming traffic, potential obstacles and elevation and come with a screen for those in the backseat so the passengers can understand what the car is sensing (The Economist, 2016b). It's worth noting that Pittsburgh was selected for its legal openness. Pittsburgh resides in one of the many U.S. states that lack regulations on self-driving cars, which Uber interpreted as a green light (KANG, 2016). Since then, Uber attempted to enter San Francisco in December 2016 but was rebuffed after a few hours regarding state permits; Uber has appealed the case and it has not finished as of writing (PRITCHARD & LIEDTKE, 2016). In the meantime, Uber is still doing tests elsewhere, such as its programme in Arizona with the University of Arizona (LARSON, 2016), and making strategic acquisitions- such as its acquisition of the self-driving-truck startup Otto (MUOIO, 2017) - to ensure it maintains an important position in the connected future.

While it is true that many OEMs and technology companies are working in the IoC, there is no company more synonymous with autonomous vehicles than Google. While Daimler has been working on self-driving cars since the 1980s and Tesla is making headlines, for many "self-driving cars" is synonymous with the term "Google Car". It began work in 2009 or so by hiring a number of people from Stanford, Carnegie Mellon, and other well-known schools to use their computational power and data to begin creating self-driving vehicles (BOGOST, 2017). Since then Google's test cars have driven at least two million miles across at least four cities in the United States. Its success led some to believe that Google was the first company to put autonomous cars on the road, and while this is not true, Google has made a great deal of progress (HARTMANS, 2016).

Google recently spun out "Google Cars" and renamed it Waymo. As of December 2016 Waymo appears to be designed to make a profit either by partnering with an existing OEM according to USA Today (DELLA CAVA,

2016) or by becoming a supplier to the OEMs according to Business Insider. As of writing it announced it would manufacture a suite of sensors in-house, is expanding its partnership with Fiat Chrysler, and is in talks with Honda about creating an autonomous car fleet (MUOIO, 2017). Instead of joining an OEM, Waymo may become a supplier of technology instead. That way Waymo can become a central source of goods and technology that can equip the future fleet of autonomous cars, a company that refuses to compete with Ford or VW but supplies them instead. Whatever happens, Google's future in the industry promises to be as exciting as the IoC as a whole.

■ Conclusion

The connected future is happening already and the autonomous one will be here soon. People have been testing autonomous vehicles for decades. Investments in AI, testing, and research have paid off handsomely. Google may have brought the issue to the public eye, but the old OEMs and other technology firms are also heavily invested in the future. The players in this strategic game may change, but there will be OEMs and so forth. Some of the entrants are multinationals like Daimler, a German OEM that manufactures some of its cars in the United States. Those multinationals take regulations in mind when they decide where to test, manufacture, and sell their products. For example, Daimler is testing some of their autonomous vehicles in Nevada due to the state's regulations. How these markets are regulated will also influence how these markets adapt and evolve. What people tend to forget is that there will be a wide range of new opportunities due to the rise of the connected vehicle. If there is a disaster, a fleet of connected cars can create an emergency response network made up of a fleet of cars. The French are experimenting with solar roads that generate power (ANTHONY, 2016) and Lexington, Massachusetts is considering installing solar panels on their highway noise abatement walls (GENTILE, 2017). Roads may no longer be just roads but also power generators in the same way cars will be more than vehicles but also part of the communication infrastructure. All of these technologies will have to adapt to a range of different regulatory environments, which will affect how or if different companies adapt to the IoC. How its markets are regulated will push Ford, Daimler, Google, and the other companies to react in certain ways. This is the beginning of a fascinating future, and it promises to become more fascinating with time.

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The Legal Landscape of Autonomous Cars

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Abstract: All over the world, governments are trying to regulate the autonomous car in two areas: the conditions of testing and the deployment on public roads. The first part of the article gives an overview of autonomous car regulations, especially in the USA, France and Spain, with a special focus on core topics such as the legal definition of autonomous cars, conditions related to the "driver", liability and requirements for tests on public roads.
As autonomous cars generate a huge amount of data, the second part analyzes the legal framework regarding data. Indeed, several regulations apply in the field of privacy and data protection (General Data Protection Regulation 2016/679 in Europe for instance).
Key words: autonomous car, automation, driver, liability, public road, data, data privacy, cybersecurity

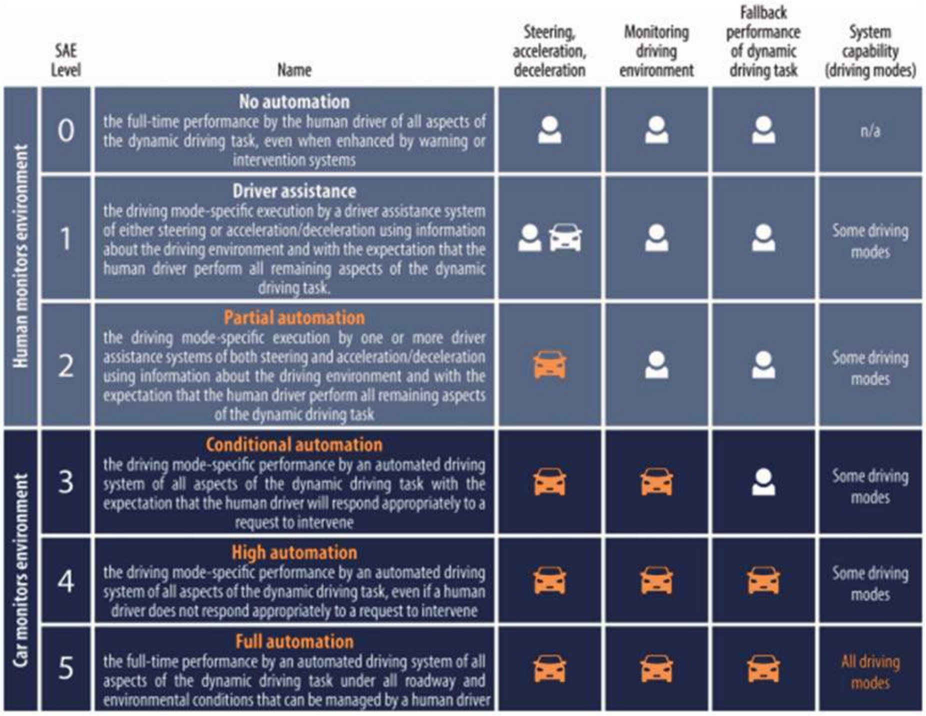
Tested on American roads since 2009, the Google cars[1] had driven over 1,600,000 km in June 2015. The cars were involved in collisions on 14 occasions. On 13 of these the other drivers were at fault. The last collision happened on February 14, 2016 in California. The Google car, circulating at about 3 kilometers per hour, changed traffic lanes and moved into the path of a bus[2]. As a Google report mentioned[3], the Google cars "will inevitably be involved in accidents", but is the law ready to deal with accidents caused by an autonomous car?

"Smart cars", "connected cars", "driverless cars" and "robot cars" refer in general terms to the so-called "autonomous cars" hereafter, which use technologies to run with a minimum level of autonomy. In the "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving" SAE International Systems (a professional association in transport

1 https://waymo.com (previously known as the Google self-driving car project).
2 Google's Self-Driving Car Caused Its First Crash, Wired, 29 February 2016, https://www.wired.com/2016/02/googles-self-driving-car-may-caused-first-crash/.
3 Google Self-Driving Car Project, Monthly Report, May 2015.

industries) published in 2014 a standard with six different levels of classification for autonomous cars, from level 0 (automated system has no vehicle control, but may issue warnings) to Level 5 (fully autonomous cars driving without human control)[4].

Table 1 - Level of driving automation



	SAE Level	Name	Steering, acceleration, deceleration	Monitoring driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human monitors environment	0	**No automation** the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	[human driver]	[human driver]	[human driver]	n/a
	1	**Driver assistance** the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.	[human driver] [system]	[human driver]	[human driver]	Some driving modes
	2	**Partial automation** the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	[system]	[human driver]	[human driver]	Some driving modes
Car monitors environment	3	**Conditional automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	[system]	[system]	[human driver]	Some driving modes
	4	**High automation** the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	[system]	[system]	[system]	Some driving modes
	5	**Full automation** the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	[system]	[system]	[system]	All driving modes

Source: Automated and Autonomous Driving, OECD/ITF, 2015 (adapted from SAE Standard J3016, SAE International 2014)

Autonomous cars may be the solution to many of the problems caused by traditional automobiles. Volkswagen, GM and BMW expect the first autonomous cars to hit the market by 2019[5]. Autonomous cars regulations have already emerged, in the USA, France, and Spain for instance, mainly to provide legal test conditions. These rules must be complied with to test autonomous cars on public roads. In addition, one must comply with the legislation regarding data privacy and cybersecurity.

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4 SAE international Standard J3016, January 2014.

5 See for instance: GM Executive Credits Silicon Valley for Accelerating Development of Self-Driving Cars, WSJ, 10 May 2016.

Overview of autonomous cars regulations

France, Spain and some American States have passed laws on autonomous cars. In Switzerland, an authorization to test autonomous vehicles was given to Swisscom on 24 April 2015 but no specific regulation has been adopted[6]. The United Kingdom Department of Transport has recently pointed out that "real-world testing of automated technologies is possible in the UK today, providing a test driver is present and takes responsibility for the safe operation of the vehicle; and that the vehicle can be used compatibly with road traffic law"[7]. In China the use of autonomous cars has not yet been authorized, however the government is strongly supportive of the R&D and promotion of autonomous cars, meaning that the law is likely to evolve[8] soon. Others have no specific rules governing autonomous cars.

The need arose to pass specific legislation regarding autonomous cars. Nevertheless, other legal regimes such as those regarding intellectual property, product liability and insurance are applicable too.

The European Union adopted the Directive 2010/40/EU of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems (ITS) in the field of road transport and for interfaces with others. This directive establishes four priority areas for the development and use of specifications and standards: optimal use of road, traffic and travel data, continuity of traffic and freight management ITS services, ITS road safety and security applications and linking the vehicle with the transport infrastructure (article 2). Also some priority actions are set out such as the provision of EU-wide real-time traffic information services (article 3). Nevertheless, this directive does not provide specific rules regarding the tests of autonomous cars on public roads.

In the USA, traffic regulations vary from state to state. Pursuant to The Tenth Amendment to the United-States Constitution, the federal government

[6] Research for TRAN Committee – Self piloted cars: the futur of road transport, Study, European Parliament, 2016.

[7] The Pathway to Driverless Cars, Summary report and action plan, Department of Transport, February 2015 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401562/pathway-driverless-cars-summary.pdf.

[8] Comparative Hanbook: Robotic Technologies Law, A. BENSOUSSAN, J. BENSOUSSAN, LARCIER, 2016.

exerts only the powers granted to it by the Constitution; these do not include traffic regulation. As a consequence, autonomous cars regulation is exclusive to the states. However, the National Highway Traffic Safety Administration (NHTSA) provided federal standards and sets the framework for the safe and rapid deployment of autonomous cars. The NHTSA updated in January 2016 the recommended principles that States may apply as part of their considerations for autonomous cars operations, especially with respect to testing and licensing (certification requirements, driver licensing programme …)[9]. A Safety Assessment is recommended for autonomous cars to be ready for use (testing or deployment) on public roads. This assessment covers several areas such as privacy, system safety, vehicle cybersecurity, human machine interface and crashworthiness. Several states in the USA have adopted laws to deal with autonomous cars[10]. The District of Columbia and Florida enacted one of the most comprehensive regulations.

France, Spain, the District of Columbia and Florida have adopted regulations regarding the definition of autonomous cars, requirements related to the driver, liability and requirements for tests on public roads.

Definition of autonomous cars

The French law 2015-992 of 17 August 2015 (article 37) allows the testing of autonomous cars on public roads for private cars, freight and passengers transport vehicles. This piece of legislation defines autonomous cars as "partial or total driving delegation cars" (*véhicules à délégation partielle ou totale de conduite*).

In Spain, the DGT Instruction 15/V-113 adopted on November 13, 2015 defines an autonomous car as "any motor vehicle equipped with technology that allows its operation or driving without requiring the active control or supervision of a driver, whether such automated technology is enabled or disabled, permanently or temporarily".

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[9] DOT/NHTSA policy statement concerning automated vehicles 2016 update to Preliminary statement of policy concerning automated vehicles, NHTSA, 2016.

[10] For the list of enacted autonomous cars legislation: see Autonomous, self-driving vehicle legislation, National Conference of States Legislature http://www.ncsl.org/research/transportation/autonomous-vehicles-legislation.aspx.

In the District of Columbia, an "autonomous vehicle" is "a vehicle capable of navigating District roadways and interpreting traffic-control devices without a driver actively operating any of the vehicle's control systems. The term "autonomous vehicle" excludes a motor vehicle enabled with active safety systems or driver- assistance systems (…)" (DC B 19-0931 section 2).

These three definitions show that autonomous cars refer to different levels of autonomy. The highest level of autonomy can be found in the French law, which allows a "total driving delegation" and therefore the absence of a driver. The laws of the District of Columbia and Spain do not allow fully autonomous cars because in any case the driver must be able to operate, control or supervise the car.

Requirements regarding the "driver"

The Vienna Convention on road traffic of 8 November 1968 has recently been amended to allow the deployment of autonomous car technologies. Previously, article 8.5 of the Convention provided that "every driver shall at all times be able to control his vehicle (…)". This article 8.5 has been replaced and now provides that "vehicle systems which influence the way vehicles are driven" are allowed in traffic if they are in conformity with the United Nations vehicle regulations[11] or can be overridden or switched off by the driver[12].

Spain has not ratified the Vienna Convention. The DGT Instruction 15/V-113 precisely describes the requirements applicable in Spain regarding the drivers of autonomous cars. In order to obtain authorization to undertake autonomous car testing, the driver must submit a statement of responsibility accrediting that she/he is "familiar with the automated technology of the vehicle" and "have received the training required for the type of test requested and have the ability to drive, operate or control the vehicle safely and under any condition". The driver must also hold a driving license for the category of car being tested.

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[11] See agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions, UN, 16 October 1995.

[12] Report of the sixty-eighth session of the Working Party on Road Traffic Safety, UN, 17 April 2014.

Likewise in the District of Columbia (DC B 19-0931 section 2) as well as in Florida (FL HB 1207 section 3), the driver must possess a driving license to operate an autonomous car.

French law does not mention any requirements regarding the driver. Nevertheless, where an authorization is granted for the testing of autonomous cars on French public roads, this authorization, as it must provide security measures, could mention special features applicable to the driver.

Liability

Whereas in the European Union product liability is strongly harmonized by the Directive on liability for defective products[13], there is no framework harmonizing the rules on liability damages caused by accidents in which a motorized vehicle or an autonomous car is involved. The regulations differ from one Member state to another.

The French law 2015-992 mentions that an "appropriate liability legal regime" could be implemented. To this day, no legal regime has yet been adopted. An impact assessment undertaken by the Parliament in 2014[14] explains that this law is a first step in the liability regime evolution in the area of transport and mobility. Nevertheless, the Badinter law[15], which establishes the principle of full compensation for victims of road traffic accidents, might also be applicable to autonomous cars. For instance, any victim who proves that the conditions for applying the Badinter law (these conditions are: "a road traffic accident involving a landborne motorised vehicle") are all present has in principle a right to 100% compensation. This principle is fully transposable to autonomous cars.

In Spain, the DGT Instruction 15/V-113 mentions that the driver of an autonomous car "shall at all times be the person responsible for driving and operating the vehicle". An insurance contract covering the limits of compulsory motor vehicle insurance as well as civil liability for possible injury

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13 Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products.

14 Projet de loi relatif à la transition énergétique pour la croissance verte, étude d'impact, 29 July 2014.

15 Law 85-677 of 5 July 1985 enacted to improve the situation of the road accident victims and accelerate their injury payment process.

or damage to people or property has to be kept in force and concluded by the owner of the autonomous car or any person having an interest in its insurance. Insurance requirements also apply in Florida where the entity performing the tests must submit to the Department of Highway Safety and Motor Vehicles, prior to the test of autonomous cars, an instrument of insurance, surety bond, or proof of self-insurance acceptable to the department to the amount of $5 million (FL HB 1207 section 5). Finally, in Spain as well as in Florida, insurers will have to assume the risks of autonomous cars accidents.

In the event of a car conversion, the District of Columbia law (DC B 19-0931 section 4) provides that the liability of the original manufacturer will be limited. The law mentions that "the original manufacturer of a vehicle converted by a third party into an autonomous vehicle shall not be liable in any action resulting from a vehicle defect caused by the conversion of the vehicle, or by equipment installed by the converter, unless the alleged defect was present in the vehicle as originally manufactured".

Requirements for tests on public roads

To this day, two conditions regulate the testing of autonomous cars on French public roads:

- an authorization must be granted by the Ministry of transports (ordonnance 2016-1057 of 3 August 2016, article 1);
- testing is only allowed on dedicated roads for collective transport, except for passenger transport autonomous vehicles which are not limited to specific areas (law 2015-992 of 17 August 2015 article 37).

An authorization is also required in order to test autonomous cars in Spain. Automated vehicles manufacturers, body-builders, official laboratories, companies that manufacture or install the technology that enables vehicles to be fully automated, universities and consortia involved in research projects may apply for such an authorization. To ensure the maturity, safety and reliability of autonomous cars, the owner must prove that the car has passed special procedures within a technical service that is accredited by the National Accreditation Body and that the vehicle has "fulfilled the necessary technical characteristics to be driven on public roads". There are no specific restrictions regarding the scope of the authorization. The instruction mentions that "this authorization is national in scope and sets out the sections of urban and interurban road on which tests or trials of the vehicle are permitted".

Specific requirements are also applicable to autonomous cars in Florida. The car shall especially "have a means to engage and disengage the autonomous technology which is easily accessible to the operator" and "have a means, inside the vehicle, to visually indicate when the vehicle is operating in autonomous mode (FL HB 1207 section 4).

Drivers, manufacturers or companies that manufacture or install the technology in the cars must comply with the legal requirements applicable to autonomous cars but they must also comply with the laws regarding the protection of data in order to ensure privacy and security.

■ The legal framework regarding data stored by autonomous cars

U.S. department of Transportation published nationwide guidelines to make the introduction of driverless cars in the US a safe one[16]. Autonomous cars are equipped with sensors and collect, record and process a great amount of data. Therefore data protection for customers and cyber security are priority topics highlighted by the US guidelines.

The European institutions' work is focused on the development of intelligent transport systems and autonomous cars. The European Parliament is focused on cybersecurity and underlines the need "to protect personal privacy from the early stages"[17]. National data protection authorities also work on improving cybersecurity and personal data protection. For instance, the French data protection authority (CNIL) is developing compliance measures named "Connected cars" to ensure that cars comply with the principles of data protection by design (from the research and design stage)[18].

[16] Federal Automated Vehicles Policy, U.S. department of Transportation, NHTSA, September, 2016.

[17] Automated vehicles in the EU, Briefing, European Parliament, January 2016 and European Parliament resolution of 23 April 2009 on the Intelligent Transport Systems Action Plan.

[18] Véhicules connectés : pour une utilisation responsable des données, CNIL, 3 October 2016, https://www.cnil.fr/fr/vehicules-connectes-pour-une-utilisation-responsable-des-donnees.

Data privacy

Autonomous cars collect and process data for different purposes, such as the improvement of the vehicle, the prevention of future accidents and the assessment of liability. This data may be kept in the car (to assess the performance of the car for instance) or transferred to a third party such as an insurer. For example, in the case where a "Pay as you drive" contract (a car insurance programme that adjusts rates based on the amount driven) is subscribed to, the insurer will know driving habits data such as speed and distance driven, if the driver uses a mobile phone or smokes while driving, GPS location[19] …

Data collected, processed or transferred through autonomous cars can be related to an identified or identifiable natural person, as it is the case for license plates, car serial numbers, speed and geo-location data. Therefore, the autonomous car technology must comply with data privacy laws.

In Europe, domestic data privacy laws apply such as, in France, the Law 78-17 of 6 January 1978 on information technology, data files and civil liberties and, in the United Kingdom, the Data Protection Act of 16 July 1998.

From 25 May 2018, the General Data Protection Regulation 2016/679 will apply all across the European Union. Autonomous cars protagonists (service providers related to the cars, manufacturers ...) will have to comply with this regulation, especially provisions regarding Privacy by design (article 25-1). To do so, appropriate technical and organizational measures have to be implemented in autonomous cars such as data minimization (which means that processed personal data must be adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed). Several principles relating to the processing of personal data govern privacy and impact directly the services provided by autonomous cars: lawfulness, fairness and transparency of the processing for instance (article 5). Infringing the Regulation 2016/679 shall lead to administrative fines up to 20 000 000 EUR or 4 % of the total worldwide annual turnover of the preceding financial year, whichever is higher (article 83).

In the USA, bills were published at the federal level to deal with the data privacy implications of autonomous cars. The Security and Privacy in Your Car Act of 2015 in particular requires motor vehicles to notify drivers about

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19 Threat to privacy found in auto insurance 'pay as you drive' programs, ScienceDaily, 10 September 2013, https://www.sciencedaily.com/releases/2013/09/130910165316.htm.

the collection, transmission, retention, and use of driving data and provides drivers with the option to terminate such data collection and retention. In November 2015, the Autonomous Vehicle Privacy Protection Act was also introduced. Moreover, self-regulation is rising; the Alliance of Automobile Manufacturers published in November 2014 privacy principles for vehicle technologies and services which provide a framework for the protection of personal data and establish, as the European General Data Protection Regulation, data minimization as a principle applicable to the collection and processing of personal data.

Cybersecurity of autonomous cars

In addition to privacy issues, autonomous cars present concerns relating to cybersecurity. Cyber-attacks, unauthorized intrusions and false or spurious messages are potential risks. In the report "Tracking & Hacking, Security & Privacy Gaps Put American Drivers at Risk", U.S. Senator Ed Markey mentioned that "nearly 100% of cars on the market include wireless technologies that could pose vulnerabilities to hacking or privacy intrusions"[20].

To deal with this issue, general legal regime regarding computer hacking could be applicable to autonomous cars. In this case, an autonomous car may be considered as a computer system[21]. For instance, article 550bis and 550ter of the Belgium criminal code applies to someone who accesses a computer system without being allowed to do so (hacking and sabotage of data and informatics). The same legal regime is applicable in France since the criminal code punishes anyone who accesses or remains fraudulently within all or part of an automated data processing system (article 323-1) and obstructs or interferes with the functioning of an automated data processing system (article 323-2).

Security of personal data is a major obligation provided by the European General Data Protection Regulation 2016/679. Appropriate technical and organizational measures must be implemented in the autonomous car "to ensure a level of security appropriate to the risk" (article 32). Recommended appropriate measures are, inter alia, pseudonymisation and encryption. For

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[20] E. MARKEY, "Tracking & Hacking, Security & Privacy Gaps Put American Drivers at Risk", February 2015.

[21] See footnote 6.

example, encrypted data could be stored in a black box, similar to that of an airplane. In the case of a personal data breach, the data controller must notify the breach to the competent national supervisory authority (article 33).

In the USA, an Automotive Information Sharing and Analysis Center (Auto-ISAC) has been established by automakers to "enhance cyber security awareness and coordination across the global automotive industry"[22]. To do so, best practices have been published and include seven "Key cybersecurity Functions":

- Security by design,
- Risk assessment and management,
- Threat detection and protection,
- Incident response,
- Collaboration and engagement with appropriate third parties,
- Governance,
- Awareness and training.

Cybersecurity is absolutely critical to decrease the risks related to autonomous cars. To meet the best practices mentioned above, car manufacturers will have to design autonomous cars able to detect, respond to and warn the driver of cyber-attacks.

■ To conclude: the need of rules to ensure the development of autonomous cars

Even if autonomous cars are expected to make future road transport safer and more secure, new dangers, especially with regards to data protection, arise and could weaken the whole intelligent transport system. Moreover, in the case of an accident involving an autonomous car, it might be difficult to establish the exact cause and prove it is due to a car defect or the behaviour of the driver. The new possible causes of accidents might interfere with current liability regimes. Therefore, an adaptation of liability law to autonomous cars seems necessary.

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22 https://www.automotiveisac.com.

States must now regulate autonomous cars "to fully exploit their economic potential and benefit from the positive effects of technological trends"[23]. Autonomous technologies are more and more usable on the road. Nevertheless, the lack of regulation currently creates legal uncertainty and could hinder implementation and jeopardize competitiveness.

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Interview with

Thierry VIADIEU

Program Director for Connected Car & Autonomous Driving, RENAULT

Conducted by **Yves GASSOT**
CEO, IDATE DigiWorld Institute

DW Economic Journal: Could you describe the scope of your responsibilities at Renault?

Thierry VIADIEU: As far as connected cars are concerned, the field of endeavour for the Product Planning and Programs department covers on-board systems (multimedia systems), offboard systems (servers) and connected services. For autonomous vehicles, it covers autonomy and the components that enable that autonomy (sensors, radars, cameras, LIDAR, etc.).

Our task is to ensure that what we want to deliver to our customers (as set out by the Product Engineering and Sales and Marketing departments) is properly expressed, then taken into account by those in charge of development. We give them the budget they need, and we ensure that the plan they put into effect lines up with their mandate. These projects are then contracted with the Vehicles Program departments which will adopt these developments and we commit to results.

Over the course of its lifespan, we ensure that the project is on track and make the necessary decisions when it deviates. Top management receives progress reports on a regular basis.

We often associate the notion of the self-driving car with that of the connected car, as the latter is a stage in and a prerequisite for making a car autonomous. But users are not terribly clear on exactly what services a connected car provides. What does Renault offer its customers in this regard? And which applications do you believe are the most promising for the next five years? Can you share any figures on your connected car output?

Autonomy and connectivity cover two different technical fields, and exist independently of one another. But of course the autonomous car will be highly connected.

The connected car has been around for some time. For instance, the traffic information given by navigation systems requires connectivity. Today, through its RLink systems, Renault offers a range of connected services: traffic information, Coyote, access to e-mail, access to a variety of apps from the app store, data for fleet management or pay-as-you-drive insurance contracts, opening car doors using a smartphone for car-sharing services (RAccess), and so on.

In a not too distant future, the range of services on offer will be very broad and cover different value fields such as monitoring the state of the vehicle (preventive maintenance), remote actions (setting the vehicle's inside temperature, opening the boot for deliveries), easy driving (booking parking spots, travel recommendations), mobility services (opening doors with a smartphone, multimodal solutions), personalised virtual assistant with connections to one's digital devices (links to calendars, appointment bookings, restaurant reservations, etc.). Depending on their needs, each customer will choose the services they find most useful.

The job of the autonomous car is to gradually relieve drivers of certain driving tasks, aiming to take a complete control of the vehicle. This will give drivers more time to do other things during their drive time, so an advanced connectivity solution will be absolutely vital to the offer of autonomy. This offer could go as far as the ability to work in one's car, and videoconference from the vehicle.

The ubiquity of the smartphone and the apps designed for the two main platforms, iOS and Android, is pushing car-makers to offer drivers the ability to replicate the familiar digital environment on their vehicle's display. At the same time, car-makers also want to protect the independence of their relationship with customers for certain services, such as maintenance. What are the services that the car manufacturer must deliver directly or indirectly, but independently from mobile application platforms?

A fluid relationship between the customer's smartphone and the car's multimedia system (which we call smartphone integration) is key to ensuring the digital continuity our customers demand. That being said, we need to keep in mind that – while awaiting the autonomous vehicle – the driver is still in the driver's seat, and any activity that might distract her/him and threaten her/his safety must be avoided. This is why certain apps are "replicated" in the multimedia system, and in a very strict fashion. So drivers will have access to a very limited number of their smartphone's features.

As to the relationship with the two digital giants, Google and Apple, it is clear that all car-makers have certain concerns over the ultimate consequences of smartphone integration. Some have taken the path of defining integration standards that allow them not to rely on those developed by Google and Apple, while others have even announced they would not be offering those applications.

At Renault we have chosen to offer CarPlay (Apple) and Android Auto because we think that's what our customers want. On the other hand, we are very careful about creating a balanced relationship and about the data being relayed, by ensuring that it in no way jeopardises our customers, or our business models.

To illustrate the merits of having a good relationship between the car-maker and an application, let's use the simple example of looking for a petrol station. An application that indicates all of the petrol stations in the vicinity is clearly useful when we are driving and need to fill up. However, its value increases tremendously if it can also gauge how full the tank is and tell us the best time and place (cost, mileage remaining) to fill up the tank.

The car dealership obviously has a very important role in selling vehicles and promoting the latest innovations, and in maintenance and customer relations. In what way do you take this into account? What is their role today, and how will it change in future?

Renault dealers play a key role in our relationship with customers, and in informing them about our products. We believe this will continue to be the case with connected services. Naturally this relationship is evolving as customers are getting more and more information from the internet, and are able to discover products online from home, but it is undeniable that physical contact with a product and an informed representative will remain an important ingredient in quality of service. As proof, I offer up the direction being taken by certain major internet companies, such as Amazon, which plan on opening up brick and mortar shops in major cities. In this respect, the density and proximity of the Renault network is a major asset that we will be sure to leverage.

We can also cite the initiative taken by a number of Renault dealerships which offer what we could call "RLink genius bar sessions" to give customers an opportunity to familiarise themselves with the system.

When we move into the autonomous car stage, we have to stress the impact of regulatory imperatives, of consumers' reactions – be they enthusiastic or disoriented – and the influence and role of the internet big five (GAFAM) and of new entrants: could you comment on these central issues and challenges ahead?

Regulation is a very important, so as not to say crucial aspect. Laws and regulations will need to evolve to allow extensive use of the autonomous car, and Renault is naturally involved in the discussions that are underway on the matter. It is a difficult exercise because, as with most car-makers, we sell our models in a great many locations around the globe, and there is still no overall regulatory framework that applies to autonomous cars.

On the matter of users, I think they have a tremendous ability to adapt, and when the services on offer are useful and have been carefully designed, there will be no obstacles to adopting them. On the contrary!

For us, the internet giants are certainly potential partners. As with all of our partners and suppliers, we look closely at what they can offer us, while also be vigilant about the skills and responsibilities we want to maintain or acquire. Today, they appear to be positioned solely in the driverless autonomous car, and we don't know if one day they will be direct competitors.

What are the most strategic technological developments that self-driving car vendors will need to master? What R&D and partnership (with its peers, and with electronics and IT companies) policies is Renault putting into place? Do you think that the costs associated with the connected/autonomous car will drive a period of consolidation in the automotive industry?

When it comes to the development of autonomous cars, the different sensors that become the car's "eyes and ears" naturally play a major role. They will evolve, be able to "see" farther and under any conditions (snow, rain, etc.), will be increasingly reliable and especially increasingly affordable so that all product ranges can benefit from them.

But if there is one area in which all automotive manufacturers, and of course the Renault-Nissan alliance, are investing massively, it is the development of the software that will manage all of the vehicles' sensors and systems. We need to develop the right algorithms, incorporate elements of artificial intelligence, ensure the robustness of zero-fault execution (the bugs that are such a familiar part of our daily lives are "forbidden" in an autonomous car, whose software needs to be as robust and reliable as the software that drives the most sensitive installations) and have a self-learning capacity that allows it to improve on an ongoing basis.

I believe this is the key to the development of the mass-produced autonomous car.

As to the impact on a consolidation of the automotive industry, this sector has already undergone considerable consolidation in recent years, creating several "titans" that produce more than 8 million vehicles a year, and I expect to see more close partnerships over certain technologies rather than corporate mergers.

The autonomous car will generate thousands of Gigabytes, often with stringent quality and latency requirements that will mean connectivity costs cannot be overlooked in vendors' business models. What are your views on this? Do you believe, like some, that your business model will include monetising some of the data generated? How much are you banking on the advent of 5G which is currently mobilising the telecoms industry?

Today, the cost of relaying data over the GSM network is a significant element in connected services' business model. The use of a SIM card that allows users to switch from operator to operator, or plans that allow them to pool or spread out their consumption are important factors in limiting the impact of this cost. As is monetising generated data. That being said, data traffic still carries a high price tag in some countries which creates an impediment to deploying services to all of our customers around the world.

Regarding 5G, naturally we are keeping a close watch over its development, but current projections indicate that coverage will still be very slim in 2020, so we cannot concentrate our developments for the next five years around 5G.

We often stress the time lapse between automotive industry cycles (four to five years) and digital innovation cycles. But if we take the example of the transition from LTE to 5G we see that, even in the digital world, not everything progresses as quickly as the latest version of WhatsApp or the rollout of the latest smartphone model…

The vision for the connected car, as for the self-driving car, needs to be part of a more wide-reaching thought process devoted to the different components of the digital transformation that is affecting mobility: the servicisation of car use, the influence of the first car-sharing platforms and ride services, how cities are changing, smart roads, etc. What initiatives are you taking with respect to these various trends, and how would you describe a car-marker 10 years from now?

As with most other car-makers, Renault is not focusing all of its attention or investments on the development of the car solely, even if it is autonomous and connected. Either directly or by having a stake in other ventures, we are interested in all aspects of innovation in what we call the mobile digital ecosystem (car sharing, car pooling, multimodality, peer-to-peer rental, etc.). It is also an opportunity to engage in discussions and run trials in large cities such as Lyon and Bordeaux where Renault is partnered with Bolloré.

Here, it is likely that the development of the autonomous car will run parallel to investments in outfitting roadways (smart roads and motorways), paving the way for new forms of mobility. One of the challenges will be managing the co-existence of classic cars and autonomous (possibly driverless) cars within a complex environment.

To answer your last question, I tend to believe that ten years from now the car-makers that remain – and of course the Renault-Nissan Alliance will be among them! – will be similar to car-makers today in many respects. We will undoubtedly see a shift in the value chain, and an expansion of car-makers' business into mobility products and closer ties with the digital world. But at the centre of all this is an object – the car – which is more and more technologically complex and subject to increasingly stringent regulations (security, emissions, CO_2). This is what constitutes an automotive manufacturer's core business, and what I believe explains why there are virtually no new entrants to the sector.

Interview with

Gion BAKER
Head of Automotive
Vodafone Automotive SpA

Conducted by **Samuel ROPERT**
IDATE DigiWorld

DW Economic Journal: Can you describe the scope of your responsibilities at Vodafone?

Gion BAKER: I joined former Cobra Automotive in 2008 and I now lead the Automotive Telematics team at Vodafone Automotive. I am responsible for the development of the global automotive projects including business development, sales, programme management and in-life support.

Could you describe your offering and positioning? Vodafone created a dedicated flagship department called Vodafone Automotive (including Cobra), which is singular in the Telco space: could you tell us more about it?

Vodafone Automotive is a leading provider of connected car products and services - which include InCar Telematics, Stolen Vehicle Tracking and Usage Based Insurance solutions - for fleets, vehicle manufacturers, logistics providers and insurance companies

Observing the market from Vodafone's vantage point as a leading total communications provider we realised that global connectivity would play an increasingly important role in automotive as vehicles went from unconnected, to connected and then towards autonomous. Furthermore, as a leader in IoT, we knew Vodafone had the global coverage, the support services and provides monitoring services in many industries. By acquiring Cobra we gained proven automotive grade telematics and sensors and the specialist capabilities that are required to operate in this market.

Combining the assets of Cobra and our global network services has enabled us to provide an end to end capability for connected cars, fleet management, usage-based insurance and stolen vehicle recovery as well as roadmap into autonomous driving.

From IDATE perspective, Vodafone seems to be the leading Telco in this space (maybe with AT&T). How do you comment your key differentiators?

Clearly owning a unique asset like Vodafone Automotive is a key differentiator: we have over 900 staff in a specialist automotive business that includes manufacturing, R&D, product development through to customer services in over 50 countries that can respond to a breakdown, emergency or vehicle theft.

Our second differentiator is the ability to provide a single global SIM and connectivity platform that allows car manufacturers to simplify their logistics process and be assured that the vehicle will have the best available connectivity due to our ability to access multiple carriers in each country.

Our third is the ability to deliver these services at scale: not only does this allow us to deliver global connectivity, but also to develop new solutions like "Internet in the Car" that provides telematics, infotainment, WiFi hotspot and consumer payment all through a single future proofed eUICC SIM with global customer services.

Today, only AT&T has a real B2C approach with embedded module implementation. Is it something Vodafone is looking at? Will it be the key app for market take-off?

The market is already taking off.

Whilst initially this was triggered by legislation (e.g. eCall in Europe) vehicle manufacturers now see the connected car as an opportunity to change the way they and their customers interact throughout the lifespan of the vehicle.

Our B2C approach is to provide the services that underpin this new model rather than simply the technology. Our secure operating centres provide direct customer support and intervention in the event of an accident or theft as well as technical support and payment services for internet access in the B2C market today.

Why is automotive a key vertical for Telcos now?

The demands of the connected car in terms of scale and global coverage fit really well with a network operator like Vodafone. In addition, the growth and innovation in this sector is phenomenal. With the advent of the autonomous car, the vehicle and network infrastructure will become even closer, making the network a key part of the connected transport infrastructure of the future.

Telco value proposition future seems to go beyond pure connectivity services. Do you intend to provide value-added services like insurance, etc?

We already provide a wide range of value added services such as vehicle recovery, fleet management, usage based insurance (UBI), intervention services (where there is an accident or break down) and even crash reconstruction where we use advanced analytics to assess the conditions associated with each event.

If you asked me whether we would provide insurance, I would say this is the core business of our insurance customers: we provide the underlying connected infrastructure that allows them to better understand and serve their customers.

How do you consider the adoption of connected car services? How do you explain this?

Connected services have been widely adopted by car manufacturers already. This connection is used to provide a range of services such as diagnostics, upgrades and navigation services. What we are now seeing is an increase in the adoption of driver services like usage based insurance and infotainment services.

Autonomous cars will be 100% connected. Their requirements will be more critical, by far. Are technologies ready for this deadline? Do you believe 2021 introduction is realistic? Do you think 5G is a part of the answer?

You are right when you define the autonomous car as self-driving with no manual input. In this case the connection with the infrastructure will be vital and 5G will be a major element in terms of providing the necessary predictability and latency to make an integrated transport infrastructure work.

We expect that we will see a gradual evolution of more automated functions using 4G and then 5G over the coming years as the volume of vehicles increases and the network evolves.

By 2021 there will be autonomous vehicles but these will use a combination of on board technology and network technology. In high density areas they will become more autonomous and in lower density areas (where the transport infrastructure has not been updated) they will become more automatic using the on board systems.

Autonomous cars will deal with tons of data due to V2V and V2X communications. Hence, transmitted traffic will be much higher compared with current connected cars. Do you believe this will impact the business model and the way to sell a car (from pure CAPEX to CAPEX+OPEX, on the user perspective)? Do you consider personal data will be part of the next generation business models? Is it realistic?

The amount of data generated by a car will increase with V2V and V2X – and it may be that we will buy data in the same way as we buy petrol or insurance today. It may also be that lease and car sharing models become the norm due to urbanisation in which case everything will be rolled up into a single fee for the usage period. The one thing for sure is that we will see a range of different business models developing around mobility in the future.

With regard to personal data this will be down to the legislation in each country and ownership of the data. Whilst many see the opportunities that arise from re-using and selling data, monetisation may not be straight forward.

Do you see geographical disruptions (emerging areas versus developed regions with strong cultural automotive habits?

In areas with a long history of personal mobility and car ownership where urbanisation and congestion are increasing, then clearly there will be different drivers to regions where car ownership is lower. In both areas, however, the main disruptor will be around access to mobility rather than the vehicle used. Integrated mobility that combines public and private transportation within a shared economy will be the main disruptors. What is interesting is, in order for this to work, connectivity is vital to track and co-ordinate the assets and meter the services associated with mobility like insurance and data.

Finally, how do you analyse the digital transformation in the automotive industry? Do you anticipate convergence with other verticals (smart cities, utilities, etc)? Do you see additional impacts?

The greatest opportunities in the new connected world of transportation will depend on multiple sectors working together. We already see this in key application areas like usage-based insurance and new shared economy models like DriveNow which is a partnership between a rental company (Sitx) and a vehicle producer (BMW) which use Vodafone connectivity.

This will extend further to create soft infrastructure like variable speed limit zones in cities, based on congestion rather than location, dynamic synchronisation of transport modes at interchange points and increasingly the integration with the city infrastructure to manage pollution, congestion, parking and the efficient use of road space.

What we see in the connected car and the autonomous car are the first steps towards an integrated transport environment – what we should not underestimate is the speed of change on this journey.

Interview with

Bernard JULLIEN
Member, Gerpisa

Conducted by **Samuel ROPERT**
IDATE DigiWorld

DW Economic Journal: Could you tell us what Gerpisa[1] is? And what is the scope of your responsibilities?

Bernard JULLIEN: Gerpisa is a global social sciences research network dedicated to analysing the automotive industry, and automotive markets and services. Created more than 30 years ago by sociologist Michel FREYSSENET and historian Patrick FRIDENSON, it quickly became a global concern, and today includes over 200 researchers from the world over who interact and share ideas through the International Research Programmes, around which the annual International Symposium is held. Gerpisa France heads up this network, and when I took over as director in 2007 my first job was to make it a Scientific Interest Group (SIG) whose members included both the top teaching establishments in France (ENS Paris Saclay, EHESS …), the main French ministries concerned (Economy, Environment) and the three trade organisations representing auto-makers, equipment suppliers and distributors (CCFA, FIEV, CNPA). I stepped down as head of Gerpisa in late 2015, and the mantle was taken up by the sociologist, Tommaso Pardi (CNRS).

Based on your experience, how do you view the digital transformation in the automotive industry?

The digital transformation in the automotive industry was implicit at first, and at the time involved both customers and processes. Customers were using digital technologies when buying a new car or looking for services, systematically documenting their transactions online, and sometimes

[1] Gerpisa: Groupe d'Etude et de Recherche Permanent sur l'Industrie et les Salariés de l'Automobile / Group for the Permanent Study of and Research on the Automotive Industry and its Employees

actually purchasing online (used cars, spare parts, rentals, etc.). By the same token, over the past 25 years, automotive manufacturing, procurement and design have been profoundly affected by the arrival of digital tools, without which product replacement cycles and their multiplication would have been unimaginable.

So that the current stage wherein vehicles themselves and the services they render – or which are rendered through them – as part of remote digital management mechanisms, does not correspond to a sudden arrival of digital technologies into non-digital universes but, on the contrary, to the continuation of a long process that enabled players to acquire a very solid digital culture. The players I refer to are automotive manufacturers, but of course we always need to keep in mind that the automotive trade is fuelled by a very broad and complex business ecosystem populated by assisters, guarantors, used car dealers, bankers, insurance companies, independent repair shops. All of these professions are involved, and all need to overhaul their practices and their products to be able to continue to earn a share of the market value and/or to develop or redefine it.

As an object, the car is the product of a system that is subject to two very heavy constraints: those of mass production and decreasing unit costs, and those tied to their safe use over long lifespans. Moreover, cars are required to belong functionally and economically to very complex ecosystems, which endows the whole with a resilience and/or an inertia which, up until now, has meant that all of the announced revolutions – for instance, the latest of which was "electromobility" or e-mobility – do not occur or, in any event, occurs much more gradually than what forecasters had predicted.

Here, there is an original element in the connectivity shift that warrants a mention: the fact that vehicles can be connected via after-market devices. Namely those famous dongles, these devices used to outfit vehicles and that will make it possible to provide connected services to owners of older cars. One of the consequences of this was that car-makers were not the first to design services for these devices, but rather joined the fray at the same times as the other components in the business ecosystem: independent auto repair chains, insurance companies, car-sharing platforms are already shaping the status quo and do not have to wait for vehicles outfitted with native solutions to leave the brand's network to begin developing these connected services. This affects the physiognomy of the automotive innovation system, and we can hope to see a steadier rate of innovation and one that is likely to take a greater variety of directions, for instance by targeting lower-income families who own older cars. As long as the devices themselves are not expensive, this can also mean that, if a city or country wanted to make them mandatory, it would be achievable.

Regarding connected car services, the cost of the service is often seen as the main barrier for market adoption. Do you believe personal data will be part of the next generation business models? Is that realistic?

Indeed it is true that, today, one of the major problems that connected services are encountering is that the "customer promise" is not consistent or innovative enough to secure users' willingness to pay the price that technology providers need to ensure their ubiquity. The promoters of these technologies sometimes push their product by saying that it will allow drivers to find their car in a parking lot or to check remotely how much petrol is left in the car it: none of this is worth a 10 euro monthly subscription fee. The same is true of a number of lane-departure warning solutions or anti-sleep alarms or parking radar systems: customers need to be able to try them out for free before they will adopt them, and there is not really any solvent demand for them today.

The subterfuge that car-markers, and especially equipment suppliers, have traditionally used has been to cite – often rightly so – road safety imperatives, to make the mechanism mandatory and thereby create a market. Regarding the connected aspect of vehicles, the starting gun has been fired since E-Call compatibility will become mandatory for all vehicles approved from March 2018 onwards, which will mean that all vehicles will eventually be connected by default, in other words outfitted with their own SIM card. The associated subscription services that the different automakers hope to sell are not enticing enough that, once the free trial period has expired, customers will systematically be willing to pay for a set of services. And this is where the argument, or perhaps the fantasy, of monetising data comes in: by knowing exactly where the car is, how it is being driven, how many passengers it is carrying or how much CO_2 it is emitting, we would be building goldmines by being in a position to resell all of this information to this or that party. Nothing could be less certain, and this for two reasons: the first is that, to be able to collect these data, the vehicle does not necessarily need to be connected, and in most instances a smartphone would suffice; the second is that companies like Google – particularly with Waze – which have already taken this direction appear to be struggling to turn it into the much-touted jackpot.

Do you think this will also be the case with autonomous cars?

An autonomous car needs to be managed, and is therefore likely to generate richer data than what a connected car produces. If we had the guarantee that data are the marvellous raw material of the personalised services and/or experiential marketing of tomorrow, then we could make them a basic element in the business model underpinning their development. As it stands today, this remains very much in the realm of the theoretical.

Regarding autonomous cars, do you believe their introduction in 2021 is realistic? Why?

It all depends on what we're talking about. If the goal is to have robots on wheels driving around slowly under simple traffic conditions, within four years we can have allocated several kilometres of roadways in certain cities to this purpose. We can even have certain sections of motorways for lorry convoys that are digitally connected to one another. If the aim is even to extend driving assistance solutions so that in parking lots belonging to such and such a company, new generation cars can go and park themselves, or that that on motorways or in traffic jams, we can leave the car to its own devices for the most part, right up to emergency braking, then things could progress quite quickly.

On the other hand, the fantasy of the driverless car under normal traffic conditions, in the city or on the motorway, is a very distant prospect since, paradoxically, the autonomous car is heavily dependent on its connections to other vehicles and to the infrastructure. In this regard, things are progressing very slowly as the different components of the very complex ecosystem I referred to earlier need to coordinate with one another, and it is still very early days, to say the least. The fact of having to ensure a lengthy coexistence of cars that are potentially autonomous and those that are not, in cities and on the roads, is an issue that is rarely raised, but obviously an essential one. A slow and very gradual implementation is thus the only way forward. This of course heightens the economic challenge: massive investments need to be made in the technologies (sensors, algorithms, etc.) to render services that will remain limited for some time to come.

What role will the Internet giants (GAFA) play? Do they represent a real threat to or the ideal partners for auto manufacturers?

When it comes to self-driving cars, there is no question that Google is the gadfly, and one that drove most automakers and equipment suppliers to get involved in the matter, to move forward more quickly than they would have otherwise done. At that stage, the companies entering the fray had very real concerns that the internet heavyweights with real firepower could cause a major shake-up in the auto industry. The fact that Google and Apple created automotive teams, and located them in Michigan only fanned the flames.

Very quickly, however, both Apple and Google took a step back, and understood that making cars was — even when the goal was to be disruptive – far more complicated and far less centralised than they had thought. Agreements and alliances that enabled them to be incorporated into car-makers product system and commercial offerings, in the same way as an equipment supplier, thus became the norm. What remains is to define which on-board services to provide: services whose value-added will be sufficiently high to create a solvent market. There are extremely interesting avenues to explore around the ride and car-sharing momentum, or cutting out the time it takes to find a parking spot, but for now no magic key has been found, and the quest is the same for the GAFA quartet and the business ecosystem's other stakeholders.

We see OEM strategies shifting to mobility services, how do you view this evolution?

Here again, we need to look beyond the somewhat conventional announcements or pronouncements that tout the acquisition of start-ups and/or investments in car sharing services, but which typically also include far more traditional things such as the spare parts trade, used car sales or car rental services. For decades now, brand dealerships have not subsisted from vehicle sales but rather from the associated services they provide, and singularly from after-sales services and financing. Automotive industry players are an extremely diverse bunch, and often develop their business without car-makers grasping what they are doing, or earning the bulk of the revenue generated as a result. The auto repair market is a prime example of this, and it is the first "mobility service": automakers manage to remain major players in this arena, but they are no longer – if they ever were – dominant economically or policy-wise. Regarding car sharing and car pooling, as with the more classic short-term rentals or leasing, this same coexistence is bound to continue for some time.

Do you see geographical disruptions (emerging areas versus developed regions with strong cultural driving habits)?

The shift in the barycentre of production and automotive markets towards emerging countries has already happened, given the impressive growth of car use in China in particular. What is striking when looking at the history of the development of the automobile in China over the past 15 years is that, first, contrary to what we might have expected 10 years ago, growth has occurred in a very conservative fashion, and has not produced either new products or new technologies, nor – as yet – any new major brands or car manufacturers. The next salient fact is that it was quickly understood that the automotive explosion, in terms of toxic emissions and physical footprint, was unsustainable, which has led to increasingly pressing policies limiting access to cars.

For both electric cars and connected cars, this second question is making emerging markets, and China in particular, a particularly attractive "playground" once public policy has the means to impose a faster and less "negotiated" implementation of technologies that will resolve all or a part of this sustainability issue.

Do you anticipate convergence with other verticals (smart cities, utilities, etc.)? What other impact are you expecting to see?

Fundamentally, in both emerging countries and the major cities of developed countries, the core issue with cars is their footprint, i.e. how much space they occupy. Resolving this would require heavier use of a smaller number of cars, to provide the same level of mobility. The connected and, eventually, the autonomous car naturally has very strong potentialities to drive progress in this direction. However, it seems painfully obvious that the real issue is the trade-off between individual freedoms and the kind of living together that societies are looking to promote. So it is a policy issue first and foremost and second, but only secondarily a technological issue.