Title
International legal framework for fully automated vehicles and road transport systems

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Problem
Auto manufacturers worldwide are preparing for the introduction of full automation within a decade. Without a parallel effort by road jurisdictions to prepare for the introduction and use of fully automated vehicles, in terms of defining appropriate harmonious legal framework for the behaviour, permitting, and appropriate use of such vehicles, the onset of vehicle automation may be delayed and chaotic. Differentials in legal treatment resulting from a non-uniform approach will likely escalate costs as control systems will need to conform to multiple rules of the road depending on jurisdiction. The proposed research is to initiate an international legal framework for fully automated vehicles and road transport systems, analogous to the Geneva Convention of 1949 which in effect defined the international legal framework the manually driven automobile.

Main benefits\(^1\) of road vehicle automation will be achieved with the highest levels defined by NHTSA\(^2\): Automation Level 4 (Fully “Autonomous”\(^3\)) when human […] is not expected to be available [even] for [occasional] control and Automation Level 3 (Conditionally “Autonomous”\(^4\)) when driver can cede full control authority under certain traffic and environmental conditions such as platooning. But most of all automation will give its best, in terms of impacts on the economy and lifestyle, when automated vehicles will be allowed to leave highways and to drive automatically (even with no driver on board) in rural and urban roads completing a full door to door journey\(^5\).

Currently Nevada, Florida, DC, and California have all passed legislation to expressly govern automated vehicles. Nevada has also enacted early regulations, and California’s rules are expected by early 2015. All national legislations and regulations define a driver (being on board or not) for an automated vehicle

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\(^1\) Annex 1 provide a summary and literature reference to justify such a strong affirmation


following the concept of the Geneva Convention of 1949\(^5\), which defined the driver for any road vehicle and directed most of its rules to her (see Smith Bryant Walker 2012\(^6\) for a very detailed analysis of present legal frameworks and its history).

Nevada regulations, the most advanced so far, somehow define the new figure of the vehicle operator and her duties but fail to define the following issues which are essential to managing safely automated vehicle:

- whether an empty vehicle travelling need to be in contact with any supervising system (or its operator) and which are communication and supervision systems necessary;
- which are the rules (including information to exchange and how) two or more automated vehicles need to follow when platooning (accepting to lower the safety distances below the Brick Wall Stop safety criterion\(^7\)) and how responsibility for accident-related-damages is shared between the vehicles in the same platoon;
- the road characteristics which allow automated driving\(^8\);
- the set of rules the automated vehicle will need to follow when driving on each category of road as a function of the sensor perception performance.

The technological achievement presented to the press by Nissan showing an automated vehicle capable of detecting and avoiding a pedestrian “jumping” on the road from an hidden position between parked cars (autonomous emergency steer\(^9\)) is the typical example of why an internationally harmonised legal framework is needed. Though the technological result is outstanding the situation reproduced there, to mimic a situation often happening with manually driven cars, might create more safety problems than it solves. An automated vehicle and the infrastructure it uses should be designed (as it is for trains) to minimise potential safety hazards and not to creatively do evasive manoeuvres when such an hazard becomes an imminent danger. As road side parking hides (or may hide) potential hazards would it not be better to re-design the infrastructure to make road side parking safer and eventually imposing a lower speed limit on those roads where hidden obstacles might come from the side unexpected? Should not the speed limit to enforce be made dependent on the detection range of the sensors (including any eventual range limitation due to any obstacle impeding longer view)? Automating vehicles might even be the occasion to revamp the international road-code to make even manual driving safer.

A national and international effort is then required for level 4 automation; if any new rule regulating them is not harmoniously discussed at national and international level it may become an impediment to

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\(^7\) BWS criterion is used by the road-code to define the safety distance; it states that the if one vehicle stopped instantaneously the vehicle behind can stop before a collision occurs. This is also the legal foundation to put the entire blame of a rear-end collision on the vehicle following no matter the behaviour of the vehicle in front.

\(^8\) deliverable 15.1 of CityMobil2 project has already started drafting urban road characteristics to safely allow automated vehicles on it

\(^9\) http://www.youtube.com/watch?v=Jzd3XaBoBZo from 1:50 to 2:30 of the video
level 4 risking to jeopardise the main benefits of road automation. European project experience (CityMobil and CityMobil2 EC projects\textsuperscript{10} above all) of automated urban road transport systems and their clash with a road-code which impose a driver on board is of example to that.

**Objective**
The main objective is to develop the technical and legal basis of a common interstate and international legal framework to regulate harmoniously the certification of automated vehicles and transport systems and their circulation on public roads themselves certified to allow automated vehicle circulation. Such an effort should also consistently classify roads and define specific rules which applies in different road classes (Interstates, major arterials, minor arterials, collectors, local streets, and driveway).

**Key Words**
Autonomous vehicles, Automated Road Transport Systems, legal framework

**Related Work**
California, Nevada and other states attempts to expressly govern automated vehicles; Center for Internet and Society at Stanford Law School researches on the matter in US.
CityMobil2 project (http://www.citymobil2.eu/en/), BAST legal work on the matter in Europe

**Urgency/Priority**
Avoiding national legislations to impede a national and international harmonious legal framework. Taking just highways into account will not use at their best the transport options automation is opening. Most of the announced benefit of automation (environment and capacity above all) will be possible only when level 4 kicks in when at least platooning will be possible which will mean that a driver must rely on the vehicle technology to control the vehicle

**COST**
CityMobil2 project has budgeted a similar task (centered on urban application therefore excluding motorways) €935 000.00 which correspond to 1 240 000,00 USD

**USER COMMUNITY**
US: US DOT, state DOTs and DMVs, automotive industry, standards communities (ISO, SAE, etc.)
EU: European commission, national states, regional governments (to plan build and operate new forms of public transport systems), vehicle industry, transport systems operators, ...
Japan:

**IMPLEMENTATION**
The main outcome of the research would be the international standard which would set the basis to:
Certify automated vehicles
Certify automated transport systems
Certify roads suitable to be used by automated vehicles
Certify the duties and skills of automated transport system operators
And to be the basis for national and international legal framework to guarantee automated vehicles to be internationally interoperable

EFFECTIVENESS
This research would promote the diffusion of automated vehicles and transport systems and the consequent mobility revolution that will depend on it. The business model of one-person one-car might cease to exist in favour of a shared ownership and ridership business model for mobility decreasing congestion delay, increasing road capacity and mitigating effectively a number mobility-related-externalities. Furthermore a new service related economy might take-up.
ANNEX 1 – Main benefits of automation will be available with level 4 automation

The potential benefits of automation for on-road vehicles are: increased road capacity, increased safety, lower environmental impact, opportunity for new business models. However different levels of automations bring to different levels of achievable benefits. In this section the achievable benefits coming from different levels of automation will be discussed to strengthen the concept that the major evident, objective and measurable benefits come only from the full automation level (level 4 according to NHTSA and level 5 according to SAE). None of the outlined potential benefits can be completely achieved with lower levels of automation.

DAS and ADAS support the driver automating some of the control tasks and relieving her/him from manual control of the vehicle. A rapid growth has been seen worldwide in the development of such systems in the recent years and many car manufacturers are now making them available in some of their fleets. Vehicles equipped with one or some ADAS can be considered to be in the level 1 or level 2 of automation depending on how many functions of the dynamic driving tasks can be automated. In [1] is reported an in depth review of ADAS which points out benefits and limitations of the various systems considered. In general cooperative systems (i.e. vehicles relate to the environment by communication with other individual vehicles or road infrastructure), unlike autonomous system which are mainly driven by car manufacturers, allow to reach those benefits in terms of safety and efficiency. For example ACC allows to maintain a desired time gap from the preceding vehicle but for driving comfort convenience the braking capacity is limited and the driver has to take over the control when a higher level of braking is needed. Such situations can bring to not negligible safety issues.

Many studies addressed this topic. For example in [2], reviewing the early studies addressing the relationship between vehicle automation and driving performance, the authors concluded that some drivers fail to intervene effectively in automation failure scenarios. From the point of view of the present paper it represents a great concern. In ADAS system, characterizing vehicles with automation levels of 1 and 2, the driver is allowed to take over the control of the vehicle whenever needed. Also in level 3, where all driving tasks are automatized, definitions clearly state that the driver is expected to be available for occasional control (NHTSA) and there is the expectation that the human driver will respond appropriately to a request to intervene (SAE). So the naturally arising question is whether level 1, 2 and 3 of automation are really safe or not. In [3] the effects of automating driver’s control tasks have been analyzed. The presence of vehicle automation seemed to make drivers less likely to reclaim control in an emergency-braking scenario. In [4] the braking performance in case of request to intervene has been investigate. It has been found that total brake time is 3 times higher and the brake reaction time is 2 seconds higher than the corresponding ones in a non-automated scenario. It seems evident that partial automation does not imply an increase in safety. Moreover the expectation that the driver will respond appropriately to a request to intervene seems optimistic. Such an expectation requires on the one side in depth studies on the human-machines interactions and on the other side specific training for drivers to get the driving license. On this regard in [5] is reported that is conceivable that newly qualified drivers with basic training could immediately use a vehicle equipped with ADAS. This may improve their performance in the short-term, but since novice drivers do not possess the knowledge or experience to react in a critical situation, there will be no over-learned reactions to emergency situation and errors
may occur. The issue for driver licensing is therefore whether more frequent refreshers will be necessary in order to mitigate skill degradation. Anyhow the issue of the eventual driver licensing goes beyond the aim of this paper. What is important here is to point out that levels 1, 2 and 3 of automation require to face with this topic too. Level 4 (according to NHTSA) and levels 4 and 5 (according to SAE) do not since the driver is not expected to be available for control at any time during the trip or, in the worst case, is not expected to respond appropriately to a request to intervene so no specific training is required.

Safety wise it seems much more convenient to implement at least level 4 on-road automated transport systems rather than lower levels of automation.

Automation impact on traffic capacity is another big deal for transport researchers. Many studies have been carried out to state the effects of ADAS on road capacity. In short, when automation is present, road capacity is mainly a matter of time gap between 2 adjacent vehicles. ACC helps to maintain this time gap constant. In [6] the effects of both autonomous and cooperative ACC on highway capacity have been evaluated using a Monte Carlo simulation in a single-lane highway. They represent the typical results that can be obtained in terms of road capacity using ACC. Setting an average time gap of 1.4 s they found the greatest impact is from 20% to 60% of ACC penetration in the flow but, even in this best case, the estimated capacity increase with ACC remain quite modest, at best less than 10%. This means going from the 2100 v/h of the reference scenario to the 2250 v/h of the best scenario. Moreover, increasing ACC penetration above 60% leads to modest loss of capacity. The conclusion is that sensor-based (autonomous) ACC can only have little or no impact on highway capacity even under the most favorable conditions. Other studies agree with this conclusion.

To solve the capacity issue the solution is twofold: on the one side reducing the time gap between the vehicles and on the other side using communication-based (or cooperative) systems. Actually these solutions are strictly linked since reducing the time gap under 1.4 s leads both to user acceptance and safety issues. These issues can be solved using CACC or through platooning. According to [6] CACC set with a time gap of 0.5 s can potentially double the capacity of a highway lane at a high market penetration. Here in this paper it is worth to consider that such a result can be reached only at a 100% market penetration: even just a single vehicle not communicating with the other vehicles and/or with the infrastructure let arise not negligible safety concerns.

AACC and especially CACC are logical steps in a progressive path leading toward future automated highway systems (AHS) [6]. However, even if logical, their practical utilization could led on the one hand to the already outlined safety issues and on the other hand to a negligible effect on capacity increase. So it worth it? Probably not. A fully automated system is the desirable solution. If not human intervention is planned and allowed there is the real chance to get all the advantages of a full automated transport system both in terms of road capacity and safety. Time gap between the vehicles can be reduced without safety reduction: vehicle-to-vehicle and vehicle-to-infrastructure communications allow to manage all emergency braking and cut-in situations (i.e. a vehicle changes lane abruptly into the gap between two vehicles traveling in an adjacent lane) without human intervention that in such circumstances and with short time gap between the vehicles could be untimely, inadequate and unsafe.
Safety has been and will continue to be a not simple issue to solve in partial-automated systems. More research is needed to further study the problems related to human-machine interface and driver’s behavior in using such systems. Furthermore machines can be programmed so that every reaction to external inputs can be known in advance, humans can not. There will not never be a unique reaction to a certain external input so different drivers could react in different ways to the same external condition that requires, for example, an emergency braking. Is such a scenario safe? Probably not.

Furthermore due to the very low level of market penetration of ADAS, most of the current impact assessments are based on micro or macroscopic traffic simulation where the driver’s behavior is modeled. It represents a huge limit since driver’s behavior under different traffic conditions is still a major subject of research. In addition to the driver’s behavior in baseline conditions, the driver’s behavior driving with ADAS should be studied. And again, how about driver’s behavior with no ADAS when surrounded by other vehicles equipped with ADAS? Road to full knowledge of driver’s behavior seems to be still very long for a completely safe coexistence of humans and machines on road.

Getting at this point it seems the most significant benefits both in terms of road capacity and safety come from fully automated systems. From the environmental point of view the results are similar, meaning that the most significant benefits are again obtainable from fully automated systems. A recent study [7] performed the comparison between an automated highway system (AHS) and ADAS in terms of environmental impact, technical feasibility and economic affordability. AHS was found to be the most promising technology for increasing capacity and reducing CO2 emissions. There is no need to build new roads but to introduce intelligence in both the vehicles and the roadside since AHS are based on cooperative vehicle-infrastructure systems. However nowadays the gap between in-vehicle intelligence and roadside intelligence is getting larger [1] since on the one hand automotive industries are making huge investment in the development of ADAS systems while on the other hand for road authorities any modification to the road infrastructure is seen as a large investment from government, including all the long and inefficient process of policymaking. But probably these investments should be done. In terms of economic affordability in [7] is reported a range of the break-even fuel price of 1.71-3.98 €/l for passenger cars for AHS. The range is due to (sorted by influence on the break-even fuel price): AHS penetration rate, fuel economy by AHS and vehicle lifetime. So considering the current average fuel price and his inexorable increasing trend, AHS might be currently considered as cost-effective.

Besides full automation on the highways the same benefits can be also expected to be in non-highways contexts. European CityMobil2 project is currently on-going and his objective is, among the others, to demonstrate that automated urban on-road transport systems are technically feasible, safe, environmental friendly and cost effective.

Fuel consumption (and CO2) reduction is another benefit addressed to road automation. In [8] is reported an in-depth overview of many ICT-based solutions and their contribution to CO2 reduction. Among the most promising technologies of road automation platooning is the one guaranteeing the greatest CO2 reduction, approximately between 5 and 7.5%. At second place it can be found ACC, with an addressed CO2 reduction slightly above 2.5%. These numbers indicate the maximum obtainable effect so their real potential depends on many factors like implementation issues and driver’s
compliance. So once again it appears clear that the greatest benefits are obtainable only with a full automation level where the human intervention is not contemplated. Platooning is a fully automated solution that enables vehicles operating much more closer than is possible under manual driving conditions so any intervention by the driver would be late and inadequate. Benefits of platooning in terms of CO2 reductions are addressed in many other studies. Among those in [9] a 15% reduction is reported for three trucks driving at 80 km/h with a gap of 4 m. In [10] a fuel save between 7 and 15% is reported for three cars with a gap of 8 m following two heavy trucks at 85 km/h.

From the environmental point of view the major contributors to fuel consumption, keeping the total driving mileage constant, are congestion on the one hand and aerodynamic drag at high speeds on the other hand. Platooning can contribute to the second cause by reducing the drag coefficient of the vehicles but for reducing (or even eliminating) congestion the whole road transportation system has to be thought back and renewed. Automation has surely a primary role toward this issue but besides individual-and-autonomous based ICT solutions (e.g. like ADAS) it has to be thought as a cooperative and fully integrated system as well as fully automated. The system is intended to be composed by vehicles, infrastructure and communication systems, both vehicle-to-vehicle and vehicle to infrastructure. Only this way the whole road transportation system can be carried to the “next level” guaranteeing all the benefits in terms of road capacity, safety and environment independently of being on an highway or in the city.

Such a view of the future implies for sure economic changes too, the greatest being represented by the overall business model of the road transportation system. There will be the real chance to substitute the one person-one vehicle business model with other business models. Such a topic deserves an in depth argumentation that, however, goes beyond the aims of this section.

Proceeding toward the conclusion of this section it can be concluded that the more the level of automation the more the benefits. The opinion of the authors here is that full automated road transport systems should be supported and developed by now focusing the attention not only on vehicles but on the system as a whole. Legal issues are probably one of the most difficult obstacles to overcome. Automating transport and making it legal is obviously mandatory for complete automation both on and outside the motorways. If no tackle today on fully automated road transport systems too much constraints for the future. Currently is even a challenge making ADAS completely legal and making self-driving vehicles legal on the highways because at the time nobody could imagine them. California and Nevada bill, beside a somewhat contradictory language, seem to allow automated vehicles on their highways: according to the in-depth analysis of legal issues related to automated vehicles on public roads reported in [11], automated vehicles are probably legal in the United States. In Europe, due to the fact that many countries are party of the Vienna Convention on Road Traffic, the issue is even much more complicated to solve. Also for this reason fully automated road transport systems shall be considered by now in solving the legal issues related to automation. If the attention is only focused on automation of autonomous vehicles only in specific environments (on highways) in the future there will be again huge legal issues to solve for legalizing such systems. And it would be a pity to not be able to legalize them only because at the time nobody could imagine them.
References for ANNEX 1


