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► **To cite this version:**

Mariana Netto. Are ‘Hard Sciences’ Enough for Teaching Applied Control Design? Driving Assistance and Autonomy in Vehicles as a Case Study. IFAC-PapersOnLine, 2019, 52 (9), pp 190-195. 10.1016/j.ifacol.2019.08.193 . hal-03234305

HAL Id: hal-03234305

<https://hal.science/hal-03234305v1>

Submitted on 25 May 2021

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Are “Hard Sciences” Enough for Teaching Applied Control Design? Driving Assistance and Autonomy in Vehicles as a Case Study.

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Abstract: This note aims to discuss the increasing importance of introducing to students in applied control, domains other than those directly needed for controlling the underlined studied systems. Indeed, the numeric revolution the last decades had as consequence an increasingly possible closer interaction between controlled systems and humans. This increasing “proximity” between system(s) and human(s) generate the need to better consider the interactions between both and the possible (nice or disastrous) consequences resulting from this close interaction, and how to adjust then, if possible, the parameters, in order to maximize the positive interactions effects. This paper highlights some key issues involved in the advanced driving assistance systems (ADAS) and autonomous vehicles design, used as a case study for giving the reader some elements to the question stated in the title. Note that the goal of this paper is not to address control design for ADAS or autonomous vehicles from an educational point of view. It is aimed here instead, to discuss what else more than “hard sciences” (control, computer sciences, artificial intelligence, etc.) would a control engineer need to be aware of in order to be able to push advances in his field, in coherence with humans needs, and to also be aware of ethical issues related to his/her work. This knowledge could also help him have a good communication with experts in other domains.

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Keywords: Education, interdisciplinary research, human-vehicle cooperation, human operator, cognition, temporal frame, risk, cyber-physical system, legal issues.

1. INTRODUCTION

Many different research laboratories have been investigating the autonomous vehicles concept already for some decades, and prototypes working in autonomous mode in test tracks appeared already in the 70ies (Netto et al (2009)).

Indeed, the design of control algorithms for car automation in a normal driving situation (excluding critical situations as for example recovering a safe state after loss of control) do not normally involve challenging control design and the actual literature can be usually used (see for example in Netto et al (2006), a very simple full lateral control design). In opposition, huge challenges, of different natures, involved in the real deployment of the autonomous car concept exist, and some of them are as follows:

1. Ensuring the system reliability, which requires for example highly reliable environment perception and communications systems;
2. Ensuring safe interactions of the autonomous vehicle with other vehicles and road users;
3. Being able to manage emergence situations and the control to recover a safe state following the instable

situation, most probably requiring highly advanced non-linear control.

4. Studying in deepness the human-vehicle interaction especially if the system requires the driver to stabilize an abnormal situation.

Indeed, the transportation system is an extremely complex system involving the four classes of cyber physical & human systems defined in H-CPS-I (2014), Lamnabhi-Lagarigue et al. (2017) and Netto & Spurgeon (2017), as follows:

1. Human-machine symbiosis;
2. Humans as (a) operators,
or (b) supervisors of complex engineering systems;
3. Humans as multi-agent systems; and,
4. Humans as agents in controlled systems.

The transportation system relates clearly with classes 2, 3 and 4. The class of interactions human-machine symbiosis is present as well in the transportation domain if we consider the mobility of people using human-machine symbiosis devices (eg. prosthetic implants).

Because of this, even if different prototype vehicles have been functioning from some decades, it is only following the enormous technological advances allowed by the numeric revolution (Netto et al (2017); Lamnabhi-Lagarrigue et al (2017)) that a real possibility for the deployment of autonomous vehicles has begun to show its lights.

However, many existing locks and questionings are still under discussion, and the scientific and industrial communities' have been exhaustively studying those issues.

A first questioning concerns which modes of autonomous or semi-autonomous driving would be effectively safe to deploy. Fig. 1 shows a possible evolution scenario from manual driving to full automation, with systems (designed on different levels of automation) classified as suited for urban, rural or highway areas.

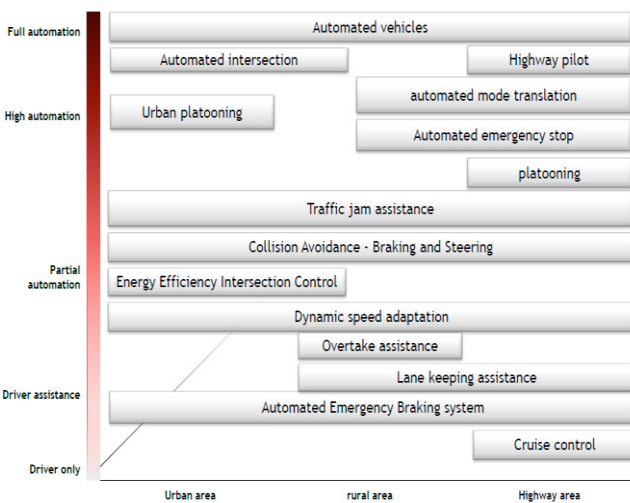


Fig. 1: Possible evolution scenario from manual driving to full automation, with the systems classified as suited for urban, rural or highway areas (Oonk & Svensson (2013)).

Going further, different laws in each country have evolved to allow technologies to evolve, and at the same time protecting citizens of potential dangers of premature advances of these technologies (Netto & Martinesco (2019)).

We will discuss for example, for ADAS, that the penal responsibility in case of accident is not dissociated from the temporal frame on which the assistance system is activated (very near, or more in advance in time with respect to the predicted accident), also in close relation with the “intrusion level” of the system with respect to the driver.

This note intends to argue why the author thinks sciences other than “hard” ones are necessary and indeed very useful to students in a masters’ course on driving assistance and autonomy in vehicles, and then in the author’s opinion, an introduction to those “soft sciences” would add precious value to these students. For this, Section 2 highlights first the different levels of automation defined by the SAE (Society of Automotive Engineers). Then, Section 3 discusses some of

the “hard sciences” topics involved in car assistance or automation. Finally, Section 4 provides some cross analysis among mixed technical & human challenges and Section 5 concludes the paper.

2. SAE LEVELS OF AUTOMATION

A common language about the meaning of vehicle automation has been necessary to define, for technicians certainly, but further, for the different communities discussing the automation issues and challenges.

The SAE has then defined six levels of automation in 2016. The revised report of the SAE automation levels also known as standard J3016™ (SAE J3016 (2018)) indicates the system capabilities for each level, pointing where the automated driving system performs partially or completely the dynamic driving task.

Figure 2 describes each one of these six levels.

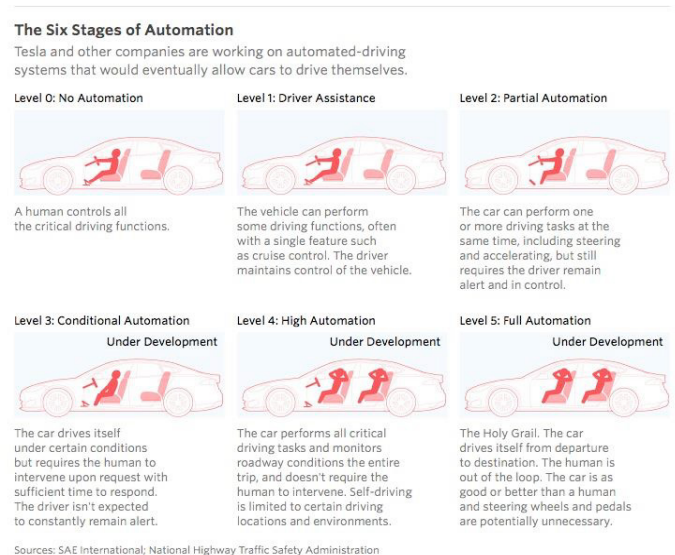


Fig. 2: SAE Levels of automation.

3. SOME “HARD SCIENCES” CHALLENGES

Future professionals working in the automotive domain, in the design of driving assistance or autonomous systems, need to study different topics where some of them are briefly discussed below:

The vehicle and the modelling of the vehicle dynamics from physics and mechanical principles. These include different models, from very complex models to simplified linearized ones: describing coupled lateral & longitudinal dynamics, or decoupled models used for dissociated lateral or longitudinal controls (eg. Di Martino (2005)). The model used by the engineer will depend on the specific situation that is considered: normal driving, lane change, emergency situation, etc.

Communications & perception algorithms. The environment detection has been one of the main challenges faced in the deployment of autonomous systems in the last decades. The numeric revolution has made possible some huge critical advances. An example is the huge advances witnessed in sensors development, as the new velodyne sensor that provides 360° field of view around the ego-vehicle. Indeed, a local dynamic map for real time tracking of the scene all around the ego-vehicle with high reliability is fundamental. For this, in order to increase the detection reliability, different sensors are used together with fusion algorithms to merge information from these different sensors (Gruyer et al, 2017a).

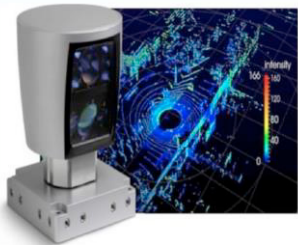


Fig. 3: LIDAR Velodyne HDL-64E (Gruyer et al (2017b)).

The advent of communications has been another revolution having been an enabling element contributing to a step towards the deployment of autonomous vehicles (Rivoirard et al (2018)).

Trajectory planning, decision and control. If we consider the mixed traffic scenario, the autonomous vehicles need to track the scene and plan continuously its trajectory to comply with the dynamic traffic changes, to make the desired manoeuvres (as lane change) and to deal with unexpected situations. The driver state, to detect for example driver distraction is another issue (Bonard et al (2012)).

Failures. Possible failures in the system need to be detected very in advance (Pous (2017)).

Systems evaluation. The designed systems need to be tested before deployment. This evaluation need to be done at different levels (components level, algorithmic level, function level) and with the use of the industry V-Cycle. Evaluation methods involve simulation, hardware in the loop simulation, tests in tracks and tests in open roads (Scholliers et al (2008)), (Scholliers et al (2011)). Technical, human factors and impact evaluations are key steps to follow (Figure 4).

4. SOME HUMAN AND MIXED CHALLENGES

Embedded systems in the vehicles for partial to full automation have “intrinsic” to them a certain number of characteristics of different natures: technical characteristics, temporal characteristics (time-to-the-accident on which the assistance system is activated, as for example the Time-to-Line Crossing in Mammari et al (2006)), intrusion level of the automated task with respect to the human, among many

others. This Section reviews some of them to help addressing the question in the title of this paper.

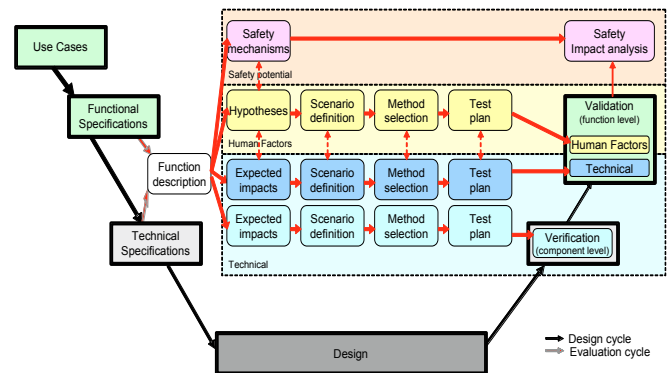


Fig. 4: The steps for technical, human factors and impact evaluations proposed in the European Project PReVAL – PReVENT, FP6 (Scholliers et al (2008)).

4.1. Automation

Let us first address the question: *from the human point of view, automation is a continuum?* This question will help analysing the changing of paradigm: from operation to supervision, when the automation level increases.

As described in (Burkhardt (2017)), car automation, in the same way as automation in many other domains, is often shown by a continuum of automation levels, coming from the absence of automation till full automation (as in the SAE classification above). However, this idea of continuity between automation levels is to question, for several reasons, notably under the light of human factors works in automation. Indeed, in different domains (industry, railway, aerospace, etc) it has been shown the existence of a changing of the nature of the human activity from a certain high degree of automation level (e.g. Bisseret (1981); Bainbridge (1983); Parasuraman & Riley (1997)). This changing appears when the *human activity of operating* disappears, being replaced by the *human activity of oversight & supervising*. This change generates many consequences in terms of the comprehension of the situation, and the construction and keeping of human competences (see Bainbridge (1983); Endsley (1999); Haslbeck & Hoermann (2016)). This questions then the simple idea of continuity of the human activity between automation levels.

The paradox of automation. This changing of paradigm between operation to supervision is not without consequences on the human performance, as described by the paradox of automation: “If you build vehicles where drivers are rarely required to respond, then they will rarely respond when required.” (Bainbridge (1983); Hancock (2014), Harford, (2016)).

Conditional automation (mode SAE 3). The SAE automation level 3 automates the driving task but nevertheless requests from the driver, that he/she recovers a safe state, in the case the system is not able anymore to manage the autonomous

mode. The driver, supervising a task, can be required suddenly to come back to control his vehicle - he is indeed required to come back to an operation task. Will he be able to do so?

The “time” parameter. To answer the question above, the “time” parameter is fundamental. The time for the driver to recover the control of this vehicle, after a request from the system, is called the “recovering time”. Here the human factors works are again needed: different results in the literature show recovering times ranging from 7 to 40 seconds, the latter considering a full vehicle stabilization, as in (Payre et al (2017); Vogelpohl et al (2016); Eriksson & Stanton (2017), Louw & Merat (2017). Indeed, “*operating a car is not the same as supervising the Automated driving system (Schellekens (2015)), while control is not just grabbing the wheel*”. The conditional automation is then controversial in the human factors community.

Linking with legal issues. The conditional automation is controversial in the human factors community and in the law community as well. Authorities are aware of the issues (Netto et al (2019)). For example, would a driver buy an autonomous vehicle being aware that he/she could be considered responsible in case an infraction is caused by his/her vehicle running in automated mode? This is a big issue indeed for car manufacturers and the acceptability of their vehicles in the market. In France the new Law PACTE establishes that the driver responsibility is engaged only after the time necessary for the driver to recover the control of the car (this time will be determined in the authorisation of experimentation on public roads). However, this sharing of responsibilities is still controversial, since it depends on the defined time, and in the view of the discussions above, it depends on the real time that would be effectively enough for the driver to do this recovering manoeuvre.

And how to characterize a possible negligence of the driver if an accident occurs? This issue is discussed in Martinesco et al. (2018) as follows: “the difficulty to separate a manufacturer’s fault from a driver’s fault lies in the difficulty of evaluating the cause of an accident. Because of that, the NHTSA calls for the industry to work with IEEE and other standard bodies to develop a uniform approach to address data recording and sharing (NHTSA (2016, 2017))”. We could indeed classify the possible accidents within three different causes:

- 1) Negligence of the driver/supervisor/operator;
- 2) Inappropriate system design (that may lead to an inappropriate behaviour of the automated vehicle); and
- 3) Fault in the system (a sensor that stops functioning, or in a higher level, an obstacle non-correctly identified).

The possible accident reason 3) is related to the verification step in the V-Cycle (Scholliers et al. (2008), please see Fig. 4

above) and 2) is related to the validation step - and then to a possibly incorrect specification of the automation *function* (for example, a too short time for the driver to recover the control of the vehicle). Finally, only negligence (in 1)) could be considered as responsibility of the driver and here legal studies connect clearly in our view to human-cooperation studies: how to qualify negligence considering SAE level 3 vehicles (SAE J3016 (2018))? The “time” parameter is the key for this connection, as we studied in Martinesco et al. (2018): only by giving sufficiently long safe time to the fallback, one could qualify a non-response of human driver as negligence. This analysis links the design levels of the system (components level, algorithms level, function levels) with the possible errors (technical errors, errors in the design of the system) to also allow classifying a possible negligence of the driver. One could use this analysis to come back to recommendations in the systems design: “Certainly negligence could not be characterized if the chosen time to the driver response is not enough to a reasonable person. So, the regulatory framework should imperatively include as a parameter, “appropriate time”. This analysis helps to understand the above discussions on the new PACTE French Law, as mentioned. For legal issues related to the autonomous and connected cars see also Guilbot & Pflimlin (2017).

4.2. Driving Assistance

Driving assistance systems are often activated on a time parameter (the time-to-collision, or the time to line crossing are examples). The choice of an activation level for this time parameter corresponds to a certain risk level on which the assistance system is chosen to be activated; or to a concept of system (as an example, the collision mitigation systems are activated within very few time before the collision, not to avoid it but to reduce its consequences).

In Scholliers (2008) we have related the temporal frames on which the driving assistance systems are activated, to the three levels of the driver performance – strategic, tactical, operational (Michon (1983)). This results in a classification of the assistance systems in three different groups. We discuss these concepts briefly in the following, anticipating that legal issues are also related to the “temporal frame” of the assistance system (Netto et al (2019)).

Michon levels in relation with temporal frames and driver cognitive capacities. Michon, already in 1983, had studied the hierarchical structure of the driver performance in three levels relating them to different temporal frames (long time constants, seconds, milliseconds). This is shown in Figure 5, where each level of the driver performance is related to a set of manoeuvres that can be done by the driver in that temporal frame. These relates also to three intrusion levels of the machine with respect of the operator, and have also called for the definition of modes of cooperation between the machine and the human (Hoc et al. (2009)).

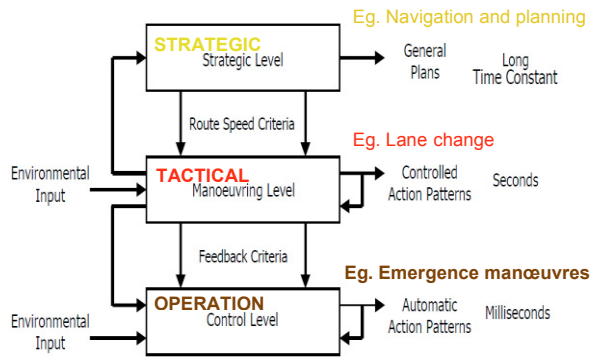


Fig. 5: Hierarchical structure of the driver performance in three levels related to three temporal frames (long time constants, seconds, milliseconds) and some examples of manoeuvres related to each level (Michon (1983)).

Three groups of driving assistance in relation with the three Michon levels. Fig. 6 shows the classification of driving assistance systems in three groups that we structured in the PReVAL subproject of the European Project PReVENT (see Scholliers et al, 2008). Each group is related to and characterized by a different temporal frame.

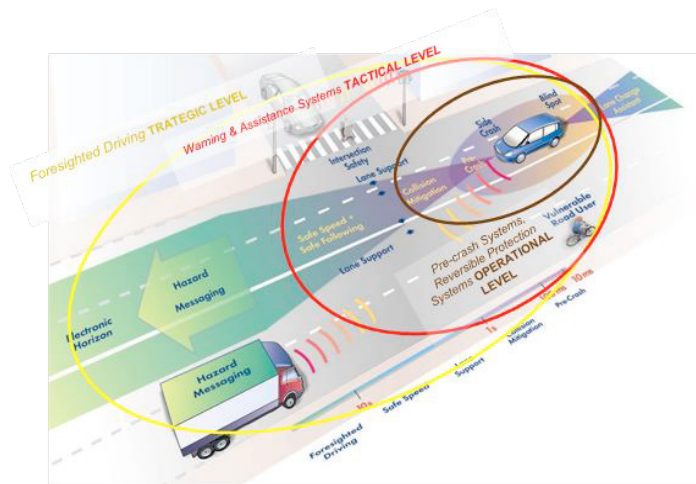


Fig. 6: The three groups of assistance systems defined in the PReVAL subproject of PReVENT, in relation with the Michon levels and the temporal frames.

In the operational level, we find pre-crash and collision mitigation systems. These systems are only activated if an accident occurs and to reduce its consequences. The human-machine cooperation is simple since no one wishes an accident, and there is no interaction then between the driver and these kinds of systems (because they act in very tight timings). The tactical level (eg. lane keeping systems), on the other hand, involves decision choices in which moment to activate the system when designing these systems (such as not to activate too early to not bother the driver, neither too late, in order to not approach too much the danger). The strategical level is more related to precaution than prevention of accidents and involves for example navigation systems.

Netto et al. (2019) discusses human factors and legal issues related to these three groups.

5. DISCUSSIONS ON EDUCATION

The aim of this paper has been to highlight to the readers that education in applied control, in the author's opinion, could have, at least in some applications, an added value by the introduction of some courses giving notions on sciences other than "hard" ones. This thought has been illustrated by the use of autonomous and driving assistance systems as a case study. Indeed, some notions on ergonomics, psychology, and social sciences could be useful for students. The latter addresses for example the systems acceptability - that, as highlighted, is not itself dissociated from the accountability in case of accident, related also to human-vehicle cooperation studies. The systems acceptability is indeed one of the numerous examples of critical issues for car manufacturers. The paper illustrates examples of notions of "cross studies" useful for ADAS and autonomous cars understanding, motivating that students could benefit for their professional lives in learning notions in domains other than the "hard" ones.

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