AUTOMATED VEHICLES AND ROAD SAFETY: FIRST RESULTS OF THE SURCA[1] PROJECT

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ABSTRACT

The SURCA project (Road user safety and automated driving) has two main objectives. The first is to identify scenarios for interactions between autonomous vehicles and other road users (non-autonomous vehicles, motorised two-wheelers, pedestrians and cyclists. The second objective is to study how the posture of the occupants (driver and passengers) of a vehicle in autonomous mode affects injury risk. This paper focuses on a description of the project (which is still ongoing) and on its first results, mainly concerning the first objective. The first findings allow us, first of all, to identify the most relevant accident scenarios (especially in terms of accidents) for the introduction of automated driving. We have performed a preliminary quantification of the effects of the gradual deployment of autonomous vehicles in traffic on the occurrence of personal injury accidents. Finally, we will present some initial results on the modelling of how the posture of occupants in vehicles operating in autonomous mode affects their injury risk, and on the analysis of the needs of elderly users and their acceptance of automated vehicles.

Keywords

Autonomous transport, road safety, road users, risk perception, interactions, vulnerable road users, elderly users, posture

1. The SURCA Project (Road user safety and automated driving) is a research project financed partly by the Road Safety Foundation and the Road Safety Delegation and partly by the project partners. (For more information contact: dominique.mignot@univ-eiffel.fr).

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1. Introduction

According to the WHO Global Status Report on Road Safety 2018, road traffic accidents account for 1.35 million deaths per year worldwide, with a significant and worrying increase in developing countries, particularly in Africa. The issue is nevertheless still an important one for European countries since, after a marked improvement until 2013 (there was a drop from 10.3 deaths per 100,000 inhabitants in 2010 to 9.3 in 2013), road mortality is remaining stable in Europe, and even increasing in France and Germany.

The scale of the problem can also be measured in terms of the social cost of these accidents. At the European level, the total cost of road accidents varies from 0.4% to 4.1% of GDP, while the total cost of serious injuries varies between 0.04% of GDP in Ireland and 2.7% in Poland (Safetycube, 2017).

Research (Ferrandez dir., 1995; Fleury and Brenac, 2001) has amply demonstrated that an accident is caused by many factors: alcohol, speed, fatigue and attention are important accident risk factors, and we should not forget that driving under the influence of alcohol is linked to 28% of fatal accidents in France (Martin et al., 2017). At the European level, an average of 21.8% of road deaths are due to alcohol (IRTAD, 2017).

This context should be borne in mind when analysing other accident factors in order to assess the potential impacts of new road safety policies and technological developments.

Following the Malta Declaration, which was adopted at the Ministerial Conference on Road Safety (Malta, 28 and 29 March 2017), the Member States made numerous recommendations, for example advocating zero tolerance on speeding and alcohol, and advised members, in particular, to "support the deployment of compatible and interoperable connected and automated vehicles with proven safety benefits, as mentioned in the Declaration of Amsterdam (2016) and the Commission's strategy on Cooperative Intelligent Transport Systems" (European Commission, 2016).

To this end, autonomous vehicles have been the subject of a plan by Nouvelle France Industrielle (NFI), which led, in particular, to the creation of the Institut pour la Transition Energétique (ITE) Vedecom, to which Université Gustave Eiffel belongs. In addition, the NFI plan for the "autonomous vehicle" has also led to the development of a roadmap to define research objectives in the fields of Private Vehicles, Industrial Vehicles and Public Transport Systems.

In addition to the classical problems associated with the reliability of systems managing external disruptive events, an important dimension is the management of the interactions between the autonomous vehicle and other users. On this topic, in order to have a better understanding of the challenges posed by changes in regulations, the French Ministry of Transport is steering a Task Force made up of several directorates and, with the support of experts from Université Gustave Eiffel, is working on developing a method to help characterise and prioritise use cases and critical use case situations. Indeed, the question of the autonomous vehicle and its integration within flows of vehicles and vulnerable users has become a universal central concern today, whether at the level of States, car manufacturers and infrastructure and road safety experts, in the hope that it will help to reduce road deaths.

At the present time, drivers change their behaviours when they are in the presence of other road users and interact with them in various ways. Much research currently focuses on critical cases where drivers have mismanaged a risky situation, and sets out to design systems to address these situations. But even though the number of accidents is high, the small number of fatalities per km travelled (1 per 20 million km in 2013) is an indication that drivers are managing a large number of critical situations correctly. Indeed, the road space accommodates very diverse users who have developed a certain amount of knowledge enabling them to estimate risks and implement strategies. This cohabitation generates a certain number of interactions between the different users enabling each of them to anticipate the movements of the others.

The overall objective of the SURCA, project which is presented in this article, is to improve the integration of autonomous vehicles into today's traffic. This involves identifying the interactions that exist and the appropriate strategies implemented by drivers. This will provide a basis for making recommendations for the designers of autonomous vehicles regarding needs in terms of interactions and in terms of the behaviour of autonomous vehicles.

For this purpose, it is planned to analyse existing databases on the driving of conventional vehicles and identify factors that may explain different behaviours. We will extract from these road user behaviour databases a description of the potential interactions between autonomous vehicles and conventional vehicles, as well as with vulnerable users (pedestrians, cyclists, Motorised two-wheelers). In addition, new driver postures may appear as drivers are freed from some or all driving tasks. We will assess the injury risk associated with these postures in the event of accidents.

It will therefore be possible to use the resulting knowledge to assist in the introduction of Level 3, 4 and 5 autonomous vehicles, at low penetration rates. Indeed, the management of interactions with other users must occur as soon as vehicles can operate autonomously without driver supervision, regardless of the length of time and the road sections over which this automation will be possible. Moreover, in the case of very high penetration rates, other types of interactions may be set up which will have to be studied when such rates become a reality.

2. Aims of the project and methodology

In this context, and with financial support from the Road Safety Foundation (Dévolution de la Fondation Sécurité Routière), the Road Safety Delegation (Délégation à la Sécurité Routière) and half of the project partners, the SURCA project was jointly designed by the partners and the funders. The objectives of this partnership-based research project are as follows:

1) To identify scenarios of interaction between autonomous vehicles and other road users (non-autonomous vehicles, motorised two-wheelers, cyclists and pedestrians):
   - To study, based on non-autonomous driving databases, negotiation situations where drivers manage this interaction in advance, using the perception of factors that it are difficult for automated systems to perceive (visual expression, intuitive knowledge of intentions, etc.),
   - To identify the communication needs of the autonomous vehicle when interacting with other users.
   - To analyse the needs of elderly users and their acceptance of autonomous vehicles.
2) To study of the impact on injury risk of the posture of the occupants (driver and passengers) of a vehicle in autonomous mode:
   - To select simulation scenarios: occupant positions, impact conditions (when performing secondary tasks) and restraint systems,
   - To evaluate potential injuries by means of numerical simulations while allowing for the effects of restraint systems (e.g. air bag deployment),
   - To make recommendations about acceptable postures for different restraint systems.

The methodology is essentially based on the analysis of existing databases on conventional vehicle driving and the identification of potential improvements or risks associated with automated driving. These databases include data collected in real-life situations (mainly videos) either in the vehicle or at an observation site and accident data collected after accidents have occurred.

An initial stage, based both on the current state of knowledge and an awareness of existing databases, allowed us to make a preliminary estimate of the possible impact on road traffic accidents of introducing autonomous vehicles. Scenarios which are particularly relevant for analysis of the deployment of automated vehicles in traffic were selected. Finally, another objective was to simulate the gradual introduction of autonomous vehicles into traffic, in order to quantify its effect on the occurrence of personal injury accidents while distinguishing between the different types of users involved.

Apart from this analysis of existing databases, specific developments were carried out, involving a digital simulation platform, modelling of the impact on injury risk of the posture of occupants (driver and passengers) in autonomous mode, and analysis of the needs of elderly users and their acceptance of automated vehicles.

3. *First findings*

The first findings presented here do not fully reflect the results, but they nevertheless indicate the diversity of the contributions already made in the framework of the SURCA project. They concern first of all the identification of the relevant scenarios for the deployment of an automated vehicle in normal traffic. This is very important for our final goal, as it is the detailed analysis of accident-causing situations that will enable us to propose recommendations for the deployment of automated vehicles that target the different users, the automobile manufacturers as well as the public authorities. Next, the results of a preliminary quantified estimate of the impact of the introduction of autonomous vehicles on the occurrence of accidents are presented. Various results are then reported, some of which, although calling for further work, nevertheless show that automated driving can also have negative effects either on the occurrence of accidents or on the consequences of impacts, with, for example, the possibility of new physical injuries arising from certain postures adopted by people travelling in automated vehicles.

3.1 Identification of critical interaction situations

The purpose of the investigations described here (Ledoux et al., 2019) was to provide a list of these challenging situations in the form of prototypical accident scenarios. The investigations focused on urban traffic situations where the task of the automated system will, in principle, be particularly difficult, due to the greater complexity of the situations and the many possible false positives. 60 prototypical accident scenarios were described. The description of each prototypical scenario was accompanied by a rating expressing its magnitude as a percentage of the total number of accidents recorded by law enforcement agencies in 2018 and the annual number of accidents of that type.

Nearly 40% of fatal accidents and 60% of personal injury accidents involve a passenger car with at least one pedestrian, bicycle, motorised two-wheeler or other passenger car. Macro analysis of the detailed accident databases (VEHICLE and FLAM) has made it possible to assess the interaction issues for each accident situation (summarised accident process). Each situation was reviewed to select those likely to generate interactions that are complex for the automated vehicle to deal with. This analysis took into account the stakes in terms of accidents, the usefulness of the scenarios with regard to the operation of the automated vehicle, the fact that the scenarios involve "important" and/or "interesting" interactions between a conventional vehicle and an automated vehicle, and finally the possibility of observing these scenarios in natural databases and/or at the roadside. This work led to the identification of about fifty interesting interaction situations for which recommendations could be made.

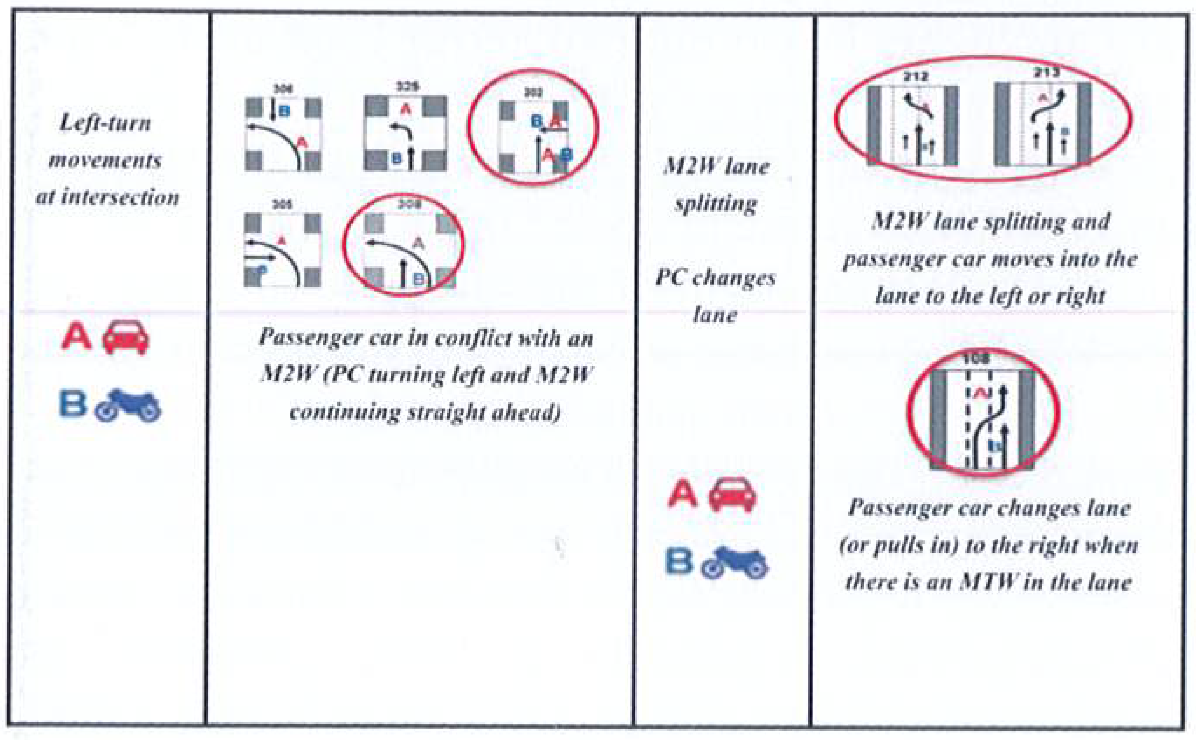

Illustration 1: An example of a set of scenarios adopted for Motorised Two-Wheelers

Thus, for the left-turn interaction scenarios, the recommendations relate to the following: What anticipation should be done by the automated vehicle when overtaking the motorized two-wheeler? What are the motorised two-wheeler' s dynamics? What are the technological challenges as regards encouraging the human to take back control? What are the behavioural norms that are shared or not in the case of lane splitting (such as civility, for example, "moving out of the way")?

The recommendations on lane splitting relate to the following: How should an automated vehicle behave when changing direction at an intersection? How can Motorized Two-Wheelers be detected? What behaviour should an automated vehicle adopt to manage road users who cut in front of them? What are the Motorized Two-Wheeler' s dynamics?

3.2 Estimating the effect of the deployment of autonomous vehicles on the occurrence of accidents

The objective of this work (Pilet and Martin, 2020) was to quantify the overall impact on the number of personal injury accidents of replacing conventional passenger cars with fully automated (SAE International Level 5) vehicles.

To do this, we hypothetically substituted a certain proportion of the passenger cars involved in personal injury accidents in France by level 5 automated vehicles, while conferring on them the probabilities of accident avoidance estimated by a number of experts on automated vehicles involved in the project. An estimate of the percentage of accidents avoided per user configuration and according to three selected penetration rates was made, taking into account the relative weight in the sample of the accident configurations in question.

We used accident data from the VOIESUR (Vehicle Occupant Infrastructure Road User Safety Studies) project. This database contains a detailed codification, established from police reports, of all fatal road accidents (n=3702) and a random 1-in-20 sample of non-fatal injury accidents (n=4839) reported in France in 2011. Each accident and the role played by each road user involved were precisely described. In particular, 168 predefined pictograms were used to describe the circumstances of the accidents. These pictograms schematically summarize the accident sequence based on the manoeuvres performed by the user(s) prior to the accident. A pictogram was assigned to each accident. On the basis of these pictograms, the experts working on the SURCA project (Safety of Road Users and Automated Driving) assessed the effect of the behaviour an AV would have, i.e. whether or not the AV would have been able to avoid the accident.

In order to evaluate how the introduction of Level 5 AVs could have modified the results of the situations previously observed and described in the ROAD database, we made a number of hypotheses. The first of these was that a Level 5 AV would be an "ideal" vehicle that would not suffer from any malfunctions or cause any accidents on its own, but might not be able to perfectly handle a situation arising because of another user. In addition, we assumed that level 5 vehicles are completely independent (no communication with another vehicle and similar behaviour when interacting with another automated or conventional vehicle). All Level 5 AVs were deemed to be equivalent in terms of technology. Then, as we were working on the basis of real accident data, we assumed comparability before and after the introduction of AVs, which means that a given situation that is similar to one in the dataset will always lead to an accident without the presence of the AV. This also implies that road infrastructure and behaviour in traffic remain the same, even after the introduction of AV. Thirdly, we assumed that all the road accidents studied were entirely independent, i.e. we did not consider possible improvements to audio-visual detection systems to change vehicle behaviour during the study. Fourthly, in order to be able to use the accident pictograms, we assumed that they fully described the circumstances of the accident, i.e. all elements of the context not described on the pictograms, such as weather and light conditions, geographical zone, age of the driver, remained constant.

The simulation study dealt with accidents of two types:

1. Accidents involving a single passenger car (n=1600);
2. Accidents involving two active road users, i.e. involving at least one passenger car and either a pedestrian, a cyclist, a motorised two-wheeler, another passenger car or a heavy goods vehicle (n=4953);

All other cases, for example accidents where no passenger car was involved, or accidents involving more than two active road users, were eliminated from the simulation (n=1988).

We used a two-step method to estimate the number of accidents avoided. Firstly, we simulated replacement rates of passenger cars by AVs of 10, 50 and 100%.

For "single-vehicle crashes", we assumed that the crash would not have occurred if the passenger car had been replaced by an AV.

For accidents involving two active road users, eight experts estimated for a given accident the probability (from 0 to 1) that the AV would manage the situation and avoid the accident on the basis of each of the 86 pictograms that covered the majority of situations (6040/8541 cases) and according to the position of the AV. Thus, the experts assigned a value of 0 when they thought that the AV would be able to do nothing more than a conventional vehicle (i.e., it would not be able to prevent the accident), and a value of 1 if the AV would always prevent the accident. In all other situations, the experts assigned a value of n/10 (with n having a value of more than 0 and less than 10) to express the probability of managing the situation. We randomly selected a sample of 100 accidents based on the probabilities given by the experts. Finally, we used the relative proportion in the database of each configuration to provide an aggregate national estimate. In some cases, the experts gave no answer for a given pictogram or it was not possible to infer the positioning of a passenger car. These accidents were considered not to have been covered.

The individual experts could have different opinions about a given pictogram. We took account of the highest and the lowest probabilities of avoiding an accident assigned by the experts to create a range of possible accident avoidance percentages. We then estimated the average percentages of accidents avoided by averaging the 100 sampled accidents.

The impact of the gradual replacement of passenger cars by AVs in traffic is described separately in Table 1 (non-fatal injury accidents) and Table 2 (fatal accidents).

Table 1: Average percentage of avoided personal injury accidents (with lowest and highest values)

	PC alone	*Two active road users including one PC*	*Calculated total number of avoided crashes*
10% AV	*1.2%*	*3.4% - 5.3%*	*4.6% - 6.4*
50% AV	*5.9%*	*14.9% - 22.2%*	*20.8% - 28.1%*
100% AV	*11.8%*	*24.3% - 34.3%*	*36.1% - 46.1%*

For accidents involving two active road users with one passenger car, the introduction of AVs only reduces the number of injury accidents by 3.4% to 5.3% with a replacement rate of 10%. The range is 14.9% to 22.2% with a replacement rate of 50%, and 24.3% to 34.3% with a replacement rate of 100%. Between 7 and 7.4% of these configurations could not be covered due to the lack of an expert response for a pictogram or the impossibility of inferring the positioning an AV. Overall, the replacement of PCs by AVs would reduce personal injury accidents in France by a minimum of 4.6% (worst case and 10% replacement rate), to a maximum of 46.1% (best case and full replacement of PCs by AVs). Non-covered accidents account for 22.9% of the personal injury accidents.

Table 2: Average percentage of avoided fatal accidents (with lowest and highest values)

	PC alone	*Two active road users including one PC*	*Calculated total number of avoided crashes*
10% AV	*2.7%*	*1.5% - 2.2%*	*4.2% - 4.9*
50% AV	*13.6%*	*7.1% - 9.9%*	*20.6% - 23.4%*
100% AV	*27.1%*	*12.7% - 16.5%*	*39.8% - 43.6%*

For fatal accidents involving two "active" road users, replacing 10% of passenger cars with AVs would prevent 1.5% of fatal accidents in the worst case. This proportion would rise to 16.5% in the best case for a totally autonomous car fleet. Accidents involving a single passenger car account for a large proportion of fatal accidents (27.1%). Considering that they would no longer occur, our hypothesis of perfect AVs leads to an overall performance almost identical to that for personal injury accidents. The percentage of accidents avoided ranges from 4.2% for the worst case and a replacement rate of 10%, to 43.6% with the most favourable expert opinion and a fully autonomous fleet. Non-covered accidents account for 25.5% of all fatal accidents.

This original simulation study gives a preliminary overall estimate of the impact of the introduction of Level 5 AVs. We show that highly automated vehicles could almost halve the number of accidents (avoiding up to 46.1% of injury accidents and 43.6% of fatal accidents).

Of course, this work has many limitations. For example, we carried out the simulations using an accident database which although very good was rather old. However, we have observed that the distribution of accident configurations as reported in the French police personal injury accident database remained stable between 2011 and 2019, which gives credence to our results.

However, due to the available data and the method used, it was impossible to foresee possible changes in user behaviour with respect to AVs, and also impossible to create accidents that are specific to AVs. Nor were we able to estimate possible reductions in accident severity, although the differences in the estimates of fatal accidents vs. non-fatal injuries give some indication of these.

In addition, due to the complexity in terms of liability and the chain of events, configurations involving more than two parties were not included in our study, which may artificially reduce the number of accidents avoided.

The strength of this research lies in its use of a very rich database, which is representative at the national level and which includes all types of infrastructures, unlike studies carried out in limited areas or in isolated experimental environments. This allowed us to compute a synthesis that is meaningful at the national level. More importantly, we were able to separately assess the impact on accidents with different configurations and of different types (injury/fatalities), which, to our knowledge, has never been done before.

This simulation work suggests that the replacement of all PCs by Level 5 AVs could almost halve the number of personal injury and fatal accidents. This finding is consistent with the findings of some other studies, but a long way from more optimistic estimates based on "human failures". Under the strong hypotheses stated above, this result is encouraging but shows, if proof were needed, that AVs would not solve every problem, particularly given the presence of all the other road users, be they pedestrians, cyclists or users of motorised two-wheelers.

3.3 Other findings

The other results presented here relate to the behaviour of pedestrians when crossing roads, the re-evaluation of the stakes involved in prototypical urban accident scenarios, the choice of scenarios for interactions between PCs and pedestrians and cyclists, cohabitation between automated vehicles and motorised two-wheelers, the problem of automated vehicles at signalised intersections, investigation of the impact of new occupant postures and, finally, the acceptability of level 3 automated vehicles for elderly drivers and what their expectations are of a fully autonomous vehicle.

Behaviour of pedestrians when crossing roads

Crossing a road is a complex activity for a pedestrian, taking place in a dynamic environment. It can also be dangerous, both because of the presence of vehicles that can increase the risk of the pedestrian being struck, and because of the dangerous behaviour of the pedestrians themselves, whether voluntary or due to an incorrect assessment of the crossing situation. Despite this complexity, autonomous vehicles need to be able to predict when pedestrians intend to cross the street so that they can facilitate the interaction by adjusting their behaviour to maximise safety.

Coeugnet et al. (2019) thus propose a literature review focusing specifically on the street crossing task and the detection of biomechanical indicators. Autonomous vehicles appear to be able to measure certain social characteristics. For example, if an AV detects a group of pedestrians, it could anticipate a different street crossing configuration which may be defined as a context that is conducive to confidence in crossing (i.e., there is a higher probability in this situation that the pedestrians will cross). However, the behaviour of groups of pedestrians interacting with an autonomous vehicle should be the subject of several studies since other social effects may emerge, such as collective distrust of the autonomous vehicle. In addition, autonomous vehicles cannot and will not be able to detect certain factors (e.g., motivation, family, nature of a residential district). However, certain elements in the environment (e.g., city centre, school zones) could be used to estimate the probability of certain behaviours (e.g., failure to give way, distraction). In order for the autonomous vehicle to detect a pedestrian's intention to cross the road, it will have to take into account all of these factors. Finally, it would seem important to enable the autonomous vehicle to interact non-verbally with other users, such as pedestrians, in order to reduce the uncertainty they feel when interacting with it. Thus, research projects on the design of external communication systems will have to be continued.

In addition, the results of two studies conducted by VEDECOM, one of the project partners, suggest that it is possible to identify certain behavioural patterns and markers that could predict the probability of a pedestrian crossing in a given configuration and thus detect the intention to cross well before the pedestrian becomes an obstacle on the roadway for the autonomous vehicle.

Re-evaluation of the issues at stake in prototypical urban accident scenarios (with and without pedestrian involvement)

The development of automated driving is often presented as a promising way to improve the safety of the traffic system. However, the ability of automatic driving control systems to handle known difficult situations is a crucial precondition for this. It is quite conceivable that situations in which human drivers make mistakes may also cause difficulties for the automatic control system of an autonomous vehicle. A knowledge of recurring accident processes is therefore an important source of information for the development of the autonomous vehicle.

The objective of the investigations we have carried out (Clabaux and Brenac, 2020) is to provide a list of these difficult situations in the form of prototypical accident scenarios. The investigations focused on urban traffic situations where the task of the automatic driving system will be particularly difficult, due to the greater complexity of the situations and the many possible false positives. 60 prototypical accident scenarios were described. The description of each prototypical scenario was accompanied by a rating expressing its magnitude as a percentage of the total number of accidents recorded by law enforcement agencies in 2018 and the annual number of accidents of that type.

Choice of interaction scenarios between PCs and pedestrians and cyclists

This work (Serre et al., 2020) identified critical interaction scenarios between a future automated vehicle and a pedestrian or cyclist. Based on the "passenger car/pedestrian" or “passenger car/cyclist” accident scenarios identified in the VOIESUR and FLAM databases, an initial "macro" analysis was conducted to identify the relevant scenarios. This analysis is based on the evaluation of the criticality of the interactions with a potential automated vehicle using four criteria: is the scenario challenging for the automated vehicle, is it frequently encountered during "normal" driving, does it often generate an incident situation and does it require decisive human intervention to avoid the accident. A second "micro" analysis enabled us to identify more precisely the parameters to be taken into account in these scenarios, and behavioural analysis sheets were created to specify the types of analysis required. The analyses that will be carried out include issues relating to the detection of vulnerable users, the abruptness of their behaviours, their presence in areas without standard road markings, the difficulty for the AV to decide which manoeuvre to perform, etc.

This analysis is limited, in particular, by the incomplete nature of the existing scenarios involving interactions between a private car and a pedestrian or cyclist. Indeed, we have mainly reported here the scenarios from accident databases. However, it is possible that certain situations encountered nowadays do not pose a problem in the case of natural driving but will do so in the case of an automated vehicle. It therefore appears difficult to anticipate the difficulties that will arise when managing such scenarios for an automated vehicle, especially as we do not yet have a clear definition of the capabilities of an automated vehicle.

Cohabitation between automated vehicles and Motorised Two-Wheelers

Krishnakumar et al (2020) present a survey of the current state of knowledge on the potential difficulties involved in cohabitation between M2Ws and automated vehicles.

A driver's ability to detect a motorcycle depends on its visibility and how used the driver is to encountering motorcycles, which is not the same thing as not minding when an M2W seeks to dominate them and weaves between the other vehicles.]However, this quick detection does promote positive behaviour, especially if the motorist has motorcycling experience, and therefore an awareness of riding practices and tasks.

The complexity of motorcycle riding means that rider errors already result in a significant proportion of accidents in which no other vehicle is involved, particularly in France in the case of inexperienced riders on high-powered machines. This characteristic is also responsible for collisions where motorcyclists leave their lane, either to cut a corner, or when leaving a curve or overtaking.

At junctions, the lightness and mobility of two wheelers mean their behaviour is unpredictable: accidents are often provoked by a motorist who cuts across a motorcycle's trajectory, as a result of late detection of the manoeuvre or over-estimation of the amount of time available. Two conditions seem to be necessary for constructive interaction to take place between motorists and motorcyclists:

- The motorist must detect the motorcycle, which may arrive unexpectedly – fast, with a small silhouette, hidden in the chord of a bend or behind another vehicle ;
- An understanding of the behaviour of motorcycles, which requires either tolerance or experience of riding one.

An automated driving system may have advantages when it comes to detection if there is no physical masking, but it will not have the experience of driving a motorcycle and will not have the benefit of human hearing. Motorcycles move around a great deal on the carriageway and the encounter with motorcycling practices is a real challenge for the design of autonomous vehicles.

The experts recommend specific solutions such as the automatic sending of an approach warning by motorcycles that are connected to the infrastructure and/or other vehicles, but this approach of adopting particularly cautious behaviour when a motorcycle arrives (like the blue flashing light of a priority vehicle) might lead to a feeling of superiority and bad behaviour by motorcyclists towards automated vehicles.

Detailed analyses and experiments should be carried out in particularly restrictive countries, such as France (motorcycle speed, lane splitting, roundabouts, etc.) or India (dense M2W traffic, anarchic driving behaviours). Natural driving tests could also be carried out on platforms such as Transpolis.

Automated vehicles at signalised intersections

Damas (2020) provides an overview of the state of knowledge on the potential difficulties of automated vehicles at signalised intersections. Signalised intersections exhibit a high degree of variation in terms of layout, operation and user behaviour, which means they are far from simple for autonomous vehicles to negotiate. On the contrary, they are particularly complex and demanding facilities. This complexity makes it easier for a large number of users to pass through them, but the usual rules of giving way to the right, giving way to pedestrians and giving way to oncoming traffic still apply. The green light does not give priority but simply gives the user permission to cross the stop line. Unless automated vehicles are confined to an exclusive right-of-way and special phases implemented to handle them in signalised intersections, priority management will remain just as complex as at other intersections, if not more so in view of the many specific phenomena that occur in signalised intersections.

Traffic signals alone cannot guarantee the safe deployment of automated vehicles, as it will still be possible for pedestrians in particular to ignore red lights. Finally, observations also show that a considerable amount of negotiation between users takes place at signalised intersections.

To conclude, Damas (2020) stresses the importance of highlighting three difficulties that pose real challenges:

- ***The manoeuvre of a left-turning automated vehicle:*** in a two-phase intersection, a left-turning automated vehicle must be stored inside the junction while respecting the rule of passing to the right of oncoming vehicles, but with the possibility that oncoming vehicles will not comply with this rule. In this case, should the automated vehicle break the rule to avoid blocking the intersection? It is impossible to identify predefined trajectories: the storage of vehicles depends a great deal on the traffic context and the types of vehicles present. Finally, the automated vehicle must identify the gaps, if any, in the flow of oncoming vehicles in order to leave the storage area: this is a complex manoeuvre, but it is essential in any intersection, whether signalised or not. It is also necessary for the pedestrian crossing on the destination street to be unoccupied, which further complicates the manoeuvre.
- ***Disobeying red lights:*** How should the automated vehicle react when pedestrians, personal transporters or bicycles disobey red lights?
- ***Illegal trajectories:*** How should the automated vehicle react when a driver does not respect the arrows on the carriageway, or when pedestrians cross outside the pedestrian crossings, and even diagonally? At intersections, many conflicts are resolved without difficulty by human interaction, which will no longer be possible in the case of automated driving.

Studying the impacts of new occupant postures

The study of the impact of the posture of the occupants of an automated vehicle on the injury risk (Grebonval and Beillas, 2019) aims, on the basis of scenario choices (postures that are made possible by automation, impact conditions and restraint systems), to evaluate potential injuries in the event of an accident. Using a numerical simulation approach, the first results show that the semi-recumbent position is potentially the most problematic of the studied postures, in particular because of difficulties in restraining the pelvis with the belt. The study will continue with a further study of the semi-recumbent case, starting with a postural study on volunteers.

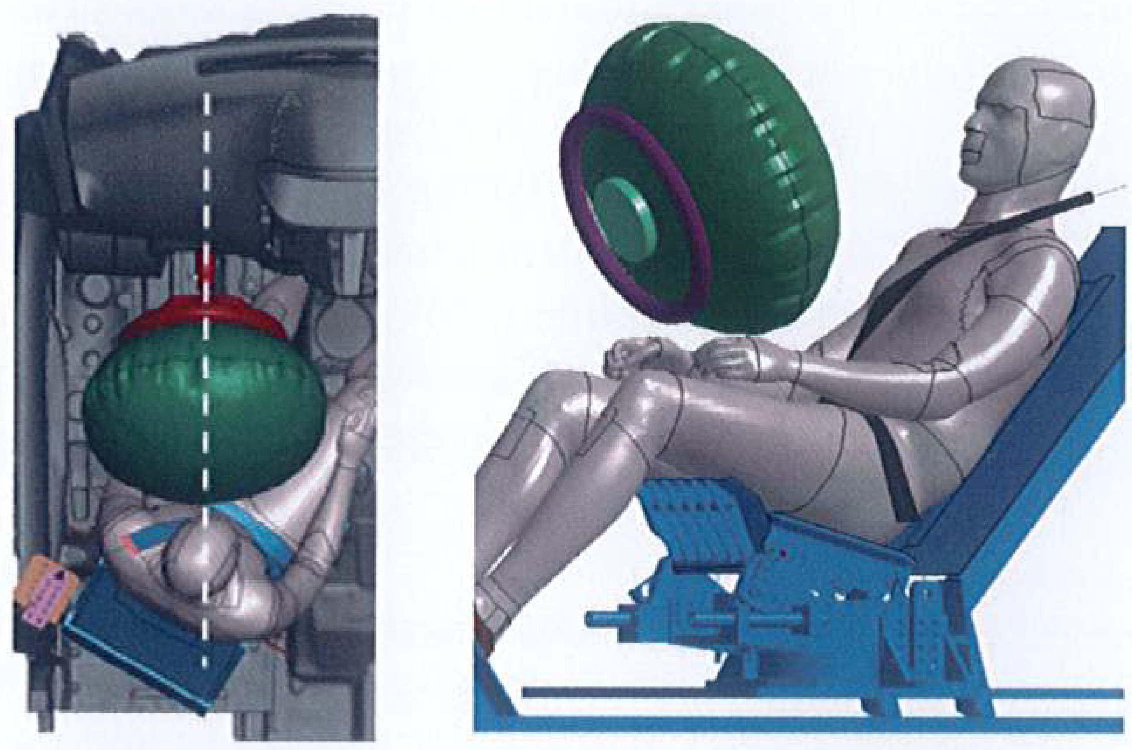

Illustration 2: rotation of the seat to facilitate conversations between the occupants in a semi-recumbent position with the backrest tilted backwards

Acceptability to older drivers of a Level 3 automated vehicle, and expectations of a fully autonomous vehicle

Acceptability was studied in a population of 573 drivers aged 75 years and older during the 6-year follow-up of the SAFE MOVE cohort (Lafont et al, 2015). 65% of this population were male, and 51% had been educated to Baccalaureate level or higher. More than half (58%) drove a vehicle every day or almost every day, and the average driving distance of the 573 participants was 160 km per week (SD=135). Only 3% of them showed no interest at all in a level 3 automated vehicle. Forty percent of the participants trusted this new technology, 32% thought they would activate it, and 19% thought they would purchase a vehicle of this type. A small proportion thought that this vehicle would enable them to increase their mobility: 7% planned to increase their use of motorways, 5% to make longer journeys, and 4% to drive during rush hours. On the other hand, this technology attracts the curiosity of older drivers: more than half of them would like to test it (56%), or hear accounts from those who have (55%), and 45% would like to be trained in its use. The participants were then asked about their fears regarding this type of vehicle through six proposals and one open question. More than half of the participants (56%) expressed at least one worry. The most mentioned was the high price (46%), followed by not being able to control situations (37%), having difficulties in using the technology (28%), the lack of reliability of the systems (26%), the difficulty of regaining control when the vehicle is no longer in autonomous mode (25%), computer piracy (20%), and finally the use of personal data (14%). In the open-ended question (5%), the most frequently-mentioned worry was liability (0.5%).

As for the expectations regarding a fully autonomous vehicle, many participants mentioned the feeling of greater safety (50%), being able to drive in spite of health problems (43%), or even in spite of fatigue (30%). They also thought they would be able to use the vehicle in difficult situations (30%), or travel long distances (29%), as well as use their vehicle more frequently (18%), carry out an activity other than driving (12%), or use the vehicle after having consumed alcohol (9%).

These initial results show that drivers with an average age of 80 years are fairly interested in the topic of vehicle automation. More than half of them are ready to test a level 3 automated vehicle, and only a small number of them are worried about difficulties involved in using one (28%). Finally, they have high expectations of a fully autonomous vehicle in terms of safety. The continuation of this work will focus on identifying the driver profiles that are relatively favourable to the autonomous vehicle.

4. Conclusion

These initial results show very clearly both the stakes involved and the complexity of the study of the impact of automated driving on road safety.

A preliminary analysis of accident scenarios enabled us to select the most relevant scenarios for the analysis of the deployment of automated vehicles in normal/real traffic. We observed that the accident scenarios show that some accidents will not be avoided by driving automation.

Thus, an initial quantification of the progressive introduction of autonomous vehicles in traffic on the occurrence of injury accidents has been made, which suggests that, at best, one could hope for the number of personal injury and fatal accidents to be halved if all the private vehicles on the road were to be replaced by level 5 automated vehicles. This is a very important result not only for all the players involved in road safety, but also for the whole of the transportation sector and the public authorities, some of whom take the mistaken view that the generalised deployment of automation is a "magic bullet" that will solve road safety problems. In addition, other preliminary findings on the impact of the posture of the occupants in an automated vehicle in the event of an impact show that new injuries may occur and will therefore have to be taken into account when designing the safety equipment in these vehicles. But will it be possible to make all these positions be safe?

Finally, we would like to draw attention to the first results for a specific target group, the elderly. The vast majority of the individuals in this group are interested in the topic of vehicle automation, are willing to test a level 3 automated vehicle, and have high expectations in this area. These last findings are very interesting in a context of an ageing population and the management, in the largest cities and metropolises, of a growing number of elderly people. The work that has been initiated in the United States and Canada on the ageing of a peri-urban population with lower levels of vehicle ownership and increasing difficulties in accessing goods and public services has resulted in a certain tendency for these groups to return to living in the city centre. Vehicle automation in conjunction with improvements to services would mean they would be able to avoid moving home.

The next phases of the project will aim to clearly explain the interaction scenarios and to highlight the capacity of automated vehicles to handle some or all of these interactions in the different studied cases - interactions between automated vehicles and conventional vehicles, motorised two-wheelers, pedestrians and cyclists.

The numerical simulation platform and the modelling of the different scenarios according to the type of interactions will allow us to make a preliminary estimate of the capacity of automated vehicles to deal with these interactions. With regard to the study of the effect of posture, the study will continue with the in-depth study of the semi-recumbent position, starting with a postural study on volunteers.

For the elderly, and to obtain a clearer understanding of the enthusiasm shown by the elderly for automated vehicles, the work will focus on identifying driver profiles that are relatively suitable for autonomous vehicles.

Depending on the results, recommendations may be made to automated vehicle manufacturers and fleet managers, but also to public authorities and all users in order to warn them about the conditions and limits that apply to the deployment of automated vehicles in normal traffic as well as the accompanying measures that may prove necessary. Indeed, it is the final goal of the SURCA project to produce such recommendations.

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