SAFE ROAD TRAINS FOR ENVIRONMENT:

Human factors' aspects in dual mode transport systems

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ABSTRACT

After being widely applied in aviation, automation is increasingly applied to surface transportation. Furthermore, with the increased reliability and reduced cost of electronics and communications, it is becoming viable to develop a safe and reliable platooning system. These intelligent systems of the future will contribute to improved safety, efficiency, and journey time of vehicles while at the same time reducing stress for passengers.

However, although new technologies make vehicle platooning possible, these new technologies will require interaction with drivers. Therefore, the development of appropriate Human - Machine Interfaces (HMI) progressively assumes greater importance, as diverse and innovative technologies are designed and implemented in vehicles. As a result of this interaction there is a need to research human aspects and the HMI.

The main objective of this study consists of analyzing human aspects involved in vehicle platooning. Accordingly, this paper describes the human factors issues that come into play when introducing autonomous driving. A further study objective is to develop a high-quality HMI, and assess the effectiveness of the HMI, including the acceptability level from possible end-users point of view.

This study is part of the European project "*Safe Road Trains for the Environment*, SARTRE", that aims to define several platoon requirements attributable to the driver's opinion, as well as to define the necessities to develop an appropriate HMI for a platooning environment. This takes into account information coming from objective parameters, logged during the simulation tests, and the driver preferences derived from acceptability assessment.

INTRODUCTION

The SARTRE (*Safe Road Trains for Environment*) project aims to support a step change in transport utilization. The project vision is to design, develop and integrate solutions that allow vehicles to drive in platoons on public motorways. Vehicle platooning is one of the innovations in the automotive industry that aim to improve the safety, efficiency and journey time of vehicles while reducing stress for vehicle occupants, as well as decreasing pollution.

After being widely applied in aviation, automation is increasingly applied in surface transportation. Since the idea of electronically coupled vehicles was introduced with the PROMETHEUS Project (Program for European Traffic with Highest Efficiency and Unprecedented Safety) in 1998 and the development of the Automated Highway System (AHS), research on this subject has progressed significantly. Furthermore, the AHS has been a large demonstration project to show that fully automated driving is feasible. Although completely automated driving is possible, existing applications aim to support the driver, or take over only part of the driver's task. With new technologies it becomes viable to develop a safe and reliable platooning system with increased levels of automation. However, there are still significant challenges with platoons interacting with conventional traffic on public motorways.

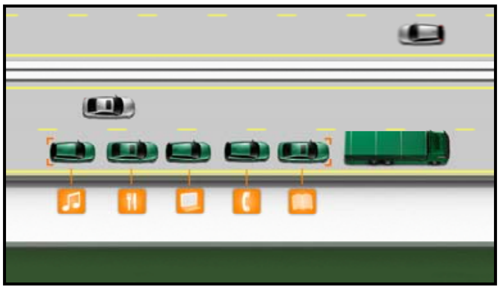

Figure 1. Platooning illustration

In the SARTRE project the lead vehicle will be a commercial truck or bus. Following vehicles will enter a semi-autonomous control mode that allows the driver of the following vehicle to undertake other activities that would normally be prohibited for reasons of safety.

HUMAN FACTOR ISSUES

When talking about autonomous or semi-autonomous driving, there are several human factors concerns. Besides acceptance and comfort, a lot of topics have to be considered, such as:

- situational awareness, does the driver still know what goes on around him and what will the system do,
- loss of skill, if a driver becomes a passive monitor, will he still be able to keep up his driving skills,

- behavioural adaptation and risk compensation, will a driver behave differently if he knows the system will respond,
- workload, which may be too high or too low,
- transitions from normal driving to autonomous/automated driving and vice versa,
- the response of the driver in case of a system breakdown and the usability and interface aspects [1].

There are significant acceptability issues to overcome – even with the understood environmental, safety and convenience benefits –, in order to facilitate that the interaction of platoons with non-platoon road users will be a near term reality. To retain drivers trust, the system should be accurate and reliable with no system failures. These aspects directly affect driver's acceptance level and are of crucial importance. Systems will only be accepted and used if driving with the system is safer or more comfortable than driving without a system. As well, it is very important that the driver understands what mode the system is in, and remains aware of the traffic surrounding him. How well a driver understands the current system mode is also dependent on the HMI that is used for providing information. To ensure information is understood when required it cannot just be provided visually; there is also a need to provide haptic or auditory information.

Conversely, with the driver support systems on semi-autonomous/autonomous vehicles there is a risk of behavioural adaptation by the driver. This means that as a result of a reduction in driver workload (when the system is operational), a driver may, over time, start to exhibit new behaviour which may result in reduced safety. To verify the behavioural adaptation, it is necessary to consider both intentional and unintentional changes in driver behaviour.

Moreover, a particular consideration, (not only related to technologies but also to human factors) is transitions from self-driving to autonomous driving and vice versa. Transitions can either be planned, i.e. a driver wants to leave the platoon, or unplanned, the system suddenly does not function or there is a system failure and the driver needs to take over. In either transition, the system should warn the driver that he or she needs to take over control. . It may be that it takes more time for the driver to get his hands on the wheel again and put his foot on the brake compared to manual driving. As consequence, the way that the HMI is developed and the interaction modes that are used to warn driver, must be deeply researched, i.e. an appropriate human machine interfaces is crucial when innovative technologies are designed and implemented in vehicles.

It is crucial to ensure high level technical performance at sustainable costs and, at the same time, design the Human-System interaction so as to be the most usable, efficient, effective and satisfactory as possible for the end-user. In addition, from a human factors perspective, safety must always be of primary importance when designing on-board systems [2]. In the driver environment a specific problem that emerges is how to adapt the technologies to different drivers. Therefore, the driver is a really important factor during the development, because the success or failure of the system depends on the end-user acceptance. In order to design usable interfaces, it is essential to adopt a “User Centred Design” approach. It is important to alternate, in an iterative way, design activities and usability assessments during all the development’s stages of the product with the involvement of both experts and end-users. With the purpose of obtaining this crucial factor, warning messages have to be easy to understand, taking for granted that the content of the message is correct [3]. Although important developments within automotive industry in advanced warning systems have been achieved to alert the driver in dangerous situations by visual and auditory interfaces, alternative modalities, such as haptic signals, must be explored for a better response speed and signal effectiveness assessment.

In this study different driver’s behaviour were evaluated to determine several platoon requirements related to the drivers perception, and first steps have been carried out, in order to define how the Human-Machine Interface (HMI) has to be designed while minimising negative impact on safety.

EQUIPMENT

The study was conducted in a fixed-base driving simulator. This platform was developed to provide solutions to SARTRE needs, in order to know the platoon requirements from a driver’s point of view, as well as to evaluate the design and development of the HMI. Next, the driving simulator hardware and software is presented.

HARDWARE

The driving simulator had a forward field of view of 120 degrees (three 42’ LCD screens), a vehicle mock-up based on a saloon vehicle dashboard with a LCD screen as the instrument cluster (speedometer, tachometer) and another one working as like an auxiliary screen where different graphical user interfaces (GUIs) were displayed, in order to evaluate the HMIs. In addition, it had two sound devices in order to provide simulated noise (engine and environmental) and acoustic warnings, and finally, the steering system which was based on a Logitech G25 game steering wheel system with force feedback and manual/automatic gear stick, customized to have a larger and more conventional steering wheel. Moreover, a haptic seat was built to allow for multimodal interaction. No rear or mirror views were used during this experiment (see Figure 2).

Figure 2. Driving simulator platform

SOFTWARE

The simulator software was based on SCANeR II under a multi PC architecture configuration (in this case, 3 PCs). Different modules of the simulator were executed on each PC, and connected via Ethernet communication in a local area network (LAN). This platform uses complex computer graphics with the purpose of providing a highly realistic driving environment. With regard to the application software, the design of the whole system has distributed control to display scenarios and to log the driver and vehicle parameters, such as speed or distance between both vehicles – Leader vehicle (LV) and Following vehicle (FV) – and Driver Reaction Time (DRT). The simulator software for lateral and longitudinal control in full autonomous driving mode was developed using fuzzy logic and runs under the Dynacar platform [4], registered by Tecnalia.

Three programming environments were used to develop the software of the whole system, i.e. SCANeR II (OKTAL) v2.24 software to configure the scenario, LabVIEW v8.6 (National Instruments Corporation) to program the main control algorithms and the acquisition of the test participants (see “Procedure” for further information) and Altia Design software to develop the Graphical User Interface (GUI) together with Adobe Photoshop CS4.

EXPERIMENTAL DESIGN

As stated above, the aim of the experiment was to determine subjective opinions of non-platoon users – henceforward other vehicles drivers (OVD) – while driving near different sizes platoons and, on the other hand, to define intra-platoon gap length thanks to logged data (objective information) and platoon users opinion (subjective information) – henceforward following vehicles drivers (FVD) – , as well as other data related to be part of a platoon, such as if platoon speed is adequate or if they prefer normal driving, etc. Furthermore, this experiment was seeking to identify the requirements to develop an appropriate HMI for a platooning environment. In order to achieve the study objectives, the next five steps were followed: create the virtual driving scenarios, design a basic Human-Machine Interface, develop the control algorithm software and finally, define and execute tests with several participants under a virtual environment.

VIRTUAL DRIVING SCENARIO

The virtual driving scenario developed for this experiment was divided into two parts:

- one truck (potential leader vehicle) and one car (potential following vehicle) - to define the intra-platoon gap size,
- had one car driven by test participants given different sizes of platoon – 5, 15 or 25 (depending on the sub-test to be executed - see “Procedure” for further information) vehicles behind the leading truck – designed to evaluate the OVD’s reactions.

Moreover, the virtual driving road was a 18 km length motorway light traffic with density randomly variable from 5 to 15 vehicles/km, driving at speeds between 80 and 120 km/h.

EXPERIMENT

The experiment was divided into two main parts, one to assess performance and another to obtain subjective ratings. The driving test included the evaluation of the intra-platoon gap acceptance, as well as the whole platoon length. The driving test was also divided into two main sessions: first one where participants drove as an OVD, i.e. they were not part of the platoon, and the second one where tests drivers were FVD, that is to say, they were part of the platoon.

During the first main session, when drivers were not part of the platoon, they had to drive near one. In this case, the OVD’s behaviour was assessed while they overtake a variable length platoon and leave the highway in its first exit. This main session, was divided into three sub-tests:

- platoon size of one leading truck and five following cars,
- with platoon length of one truck and fifteen passengers cars,
- a platoon made up of one lead truck and twenty-five cars.

Throughout these tests drivers should not exceed the highway speed limit (120 kph).

Figure 3. Test driver passing a platoon before exiting the next highway exit

Subsequently, during the second main session, participants drove as FVD, i.e. they became part of the platoon. In this case, intra-platoon gap acceptance was assessed. In order to test it, a potential leading vehicle driver (PLVD) was driving in the highway waiting for a potential following vehicle driver (PFVD) – test participants – to create the platoon.

The test sequence was: first, test driver drove to the PLV (truck) until the correct position was reached, and at that moment, an advice of correct positioning was given by the HMI. Then, participant had to accept the creation, pushing a cam in the steering wheel, and vehicle became autonomous. At this point, participants released the vehicle controls, after notification by the HMI, and gap started to reduce. Intra-platoon distance was reduced until test driver felt uncomfortable, at which point they pushed a dedicated button. This gap was recorded. However, the gap was continuously reduced, until the driver felt in danger and pushed an emergency button. The second gap was recorded as well. Finally, when participant pushed the emergency button, the platoon was dissolved, passing control back to the test driver.

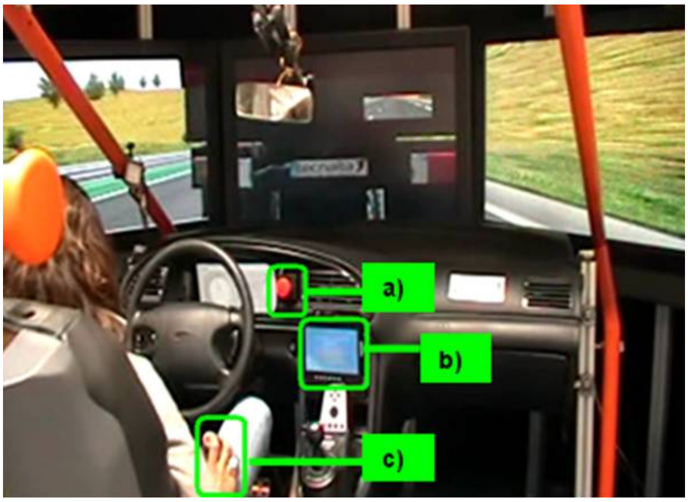	**a)**	Emergency button: Platoon dissolution by request
	b)	Visual HMI for platoon instructions
	c)	Comfortability signalisation button for test purposes

Figure 4. Use of interaction hardware in the platoon simulator during a small gap maintain manoeuvre.

The basic HMI developed was based on visual and auditory information to the driver, advising for each platoon manoeuvre what the driver had to do at every moment. Both signals were given in order to test drivers' different reactions to each one.

For the proposed scenarios, the interaction with the driver was related to the basic platoon transitions from manual driving to automatic driving and, at the end of the platoon manoeuvre, again to manual driving.

PLATOON POSITION REACHED

PLEASE ACCEPT PLATOON CREATION

AUTOMATIC PLATOON DRIVING

PLEASE RELEASE PEDALS AND STEERING WHEEL

LEAVE REQUEST ACCEPTED

PLEASE CONFIRM AND TAKE MANUAL CONTROL OF VEHICLE

Figure 5. Visual HMI for platoon transition manoeuvres

PARTICIPANTS

The sample consisted of thirty men and fourteen women (N=44). The population collaborating in this study had a mean age of 36.3 years. The yearly driving performance showed that three participants drive less than 5.000 km/year, eight drive between 5.000 and 10.000, thirteen between 10.000 and 15.000 and finally twenty had yearly driving performance of more than 15.000 km/year.

In addition, two participants stated that they had experience with driving simulators and computer racing games, twenty-two with computer racing games but not with driving simulators, while the remaining did not have any experience with either driving simulators or racing games.

PROCEDURE

The participants were invited to take part in a simulator study without being given any detailed information about the system under investigation. As stated above, the experiment was divided into two main sessions: the first one, where participants have a non-platoon users role, and the second one where they were Following Vehicles Drivers within a platoon. In order to conclude the first main session, they had to drive near a platoon – with variable platoon sizes – three times. Once the whole session was over, participants completed the surveys. The order of the three sub-tests was randomized.

During the second main session, as stated previously, participants had to become a FVD. Participants also had to complete a survey at to complete the second session. Finally, general data like age, gender and simulator experience was collected prior to the experiment in a demographic questionnaire.

RESULTS

As stated above, this experiment is divided into two main parts, one to assess performance and another to obtain subjective ratings. In addition, it can be also divided taking into account the information source, i.e. from OVD or from FVD. After each test, participants had the opportunity to evaluate the experience of being within a platoon or of driving near one. The technique used is simple and consists of one-dimensional scale – ‘1-5 rating’ (Linkert Scale) and ‘Unable to rate’ – from which respondents choose one option that best aligns with their view.

Regarding the objective obtained results to determine the intra-platoon gap, follow a normal distribution, (δ = 13,32), a 73,93% of all participants tend to average value, feeling uncomfortable under a distance less than 16,9 m, in average terms. If it is only considered men results, with δ = 13,53 a 73,01% tend to the average distance, it means that men started to feel uncomfortable under a distance less than 16,55 m. Furthermore, 75,75% of women started to feel uncomfortable under a distance less than 17,76 m, followed a normal distribution with δ = 12,85. Moreover, when emergency button results are considered, a 77,45% of all participants, follow a normal distribution (δ = 5), tend to average value feeling unsafe under a distance less than 7,5 m, in average terms. Related to men results, with δ = 3,64, a 77,45% started to feel unsafe under a distance less than 6,51 m (in average terms), and in women case, with δ = 6,54, a 77,45% started to feel unsafe under a distance less than 9,59 m. Next graphics show the obtained results, taking into account the gender or the age ranges:

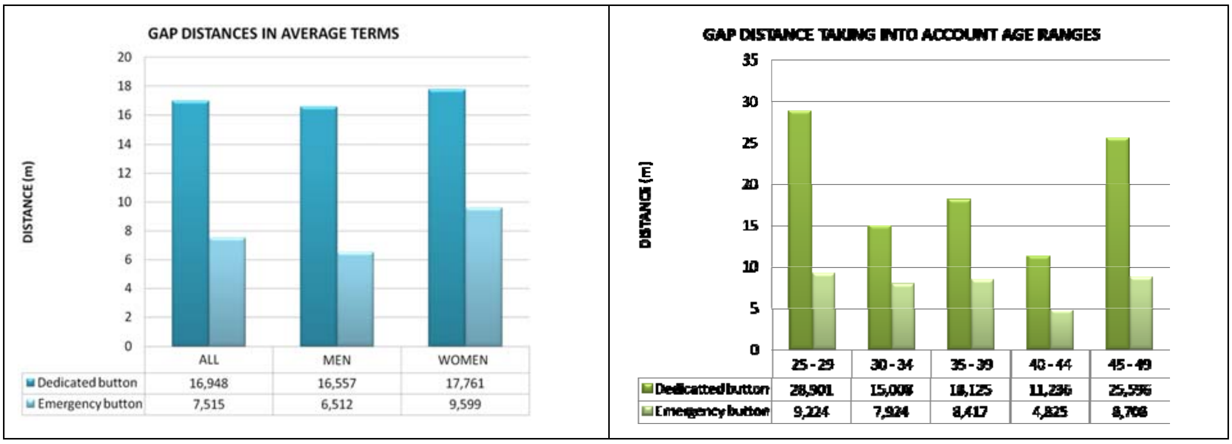

Figure 6. Gap distance objective results

On the other hand, if subjective results are considered, when participants asked if the intra-platoon gap of 10 m was adequate for them, 72, 73% accepted this assumption and 25% rejected it. In case of a 7,5 m distance, 54,55% accept it, and 40,91% not. When distance was 5 m, only 11,36% of participants accept it, and 77,27 reject it. And of 2,5 m (6,82% accept, 90,91% reject) and 1m (2,27% accept and 95, 45%) distances, in general, participants reject the assumption. Next graph shows the survey results related to gap distances.

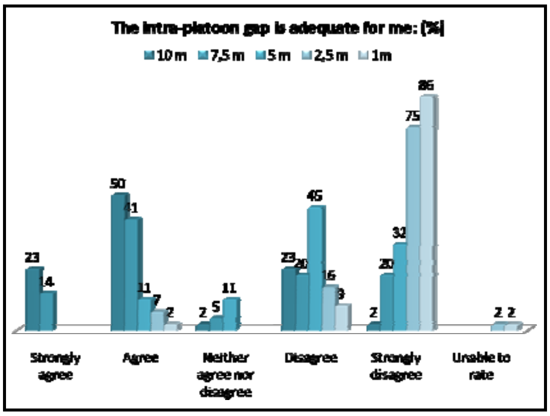

Figure 7. Gap distance subjective results

Bearing in mind that all groups (men, women) follow a normal distribution, it can be stated that, in general (around a 75%), people feel uncomfortable when intra-platoon gap length is less than 16 m, and people feel unsafe under 7 m. Consequently, for first platoon drivers, the recommended intra-platoon distance would be 15 m. for the driver to feel comfortable, but since this gap size goes against the platoon benefit and safety concept, a specific training of the driver might be necessary to allow the driver trusting the system with smaller gaps in further platoon experiences. However, in the case that the uncomfortable feeling is considered of lower significance and in view of the subjective results, the gap could be much reduced as long as safety is not compromised.

Concerning the obtained results from FVD opinion thanks to the questionnaire, it can be stated that, for instance, 90,91% of all participants think that 90 kph is a very comfortable speed for platoons, 95,45% consider that information to the driver is absolutely necessary and 86,36% that an acknowledgment from the driver before starting the manoeuvre is required, during every transition manoeuvres of the platoon, that is to say, transitions from normal driving to autonomous/automated driving and vice versa. All this kind of results are really significant because they facilitate and improve the development of a high-quality HMI.

To conclude the results analysis, obtained responses from the OVD point of view are presented. The questions were:

- OV-Q#1: I feel driving near a platoon of 5/15/25 cars + 1 leading truck is the same as driving around other normal traffic situations.

- OV-Q#2: I do not see any problems in exiting the highway while driving near a platoon of 5/15/25 cars + 1 leading truck.
- OV-Q#3: I wouldn't drive near a platoon of 5/15/25 cars + 1 leading truck.
- OV-Q#4: I feel stress/unsafe when I drive near a platoon of 5/15/25 cars + 1 leading truck.

And the results, in general terms, shows that around 72,73% of the participants feel that driving near a platoon of five cars and one leading truck is the same as normal driving, they don't see any problems to do different manoeuvres. In addition, this percentage of test drivers do not have problems and do not feel unsafe driving near the smaller platoon. When taking into account the obtained results related to medium length platoon, fifteen cars and one leading truck, the participants percentage that feel the same that in the case of small one, is reduced to 54,55%. Finally, the percentage for longer platoon was reduced to only 11,36% of acceptation. Consequently, it can be stated that medium length platoon, i.e. fifteen cars and one leading truck, it can be considered the maximum length. Following graphics show the obtained results:

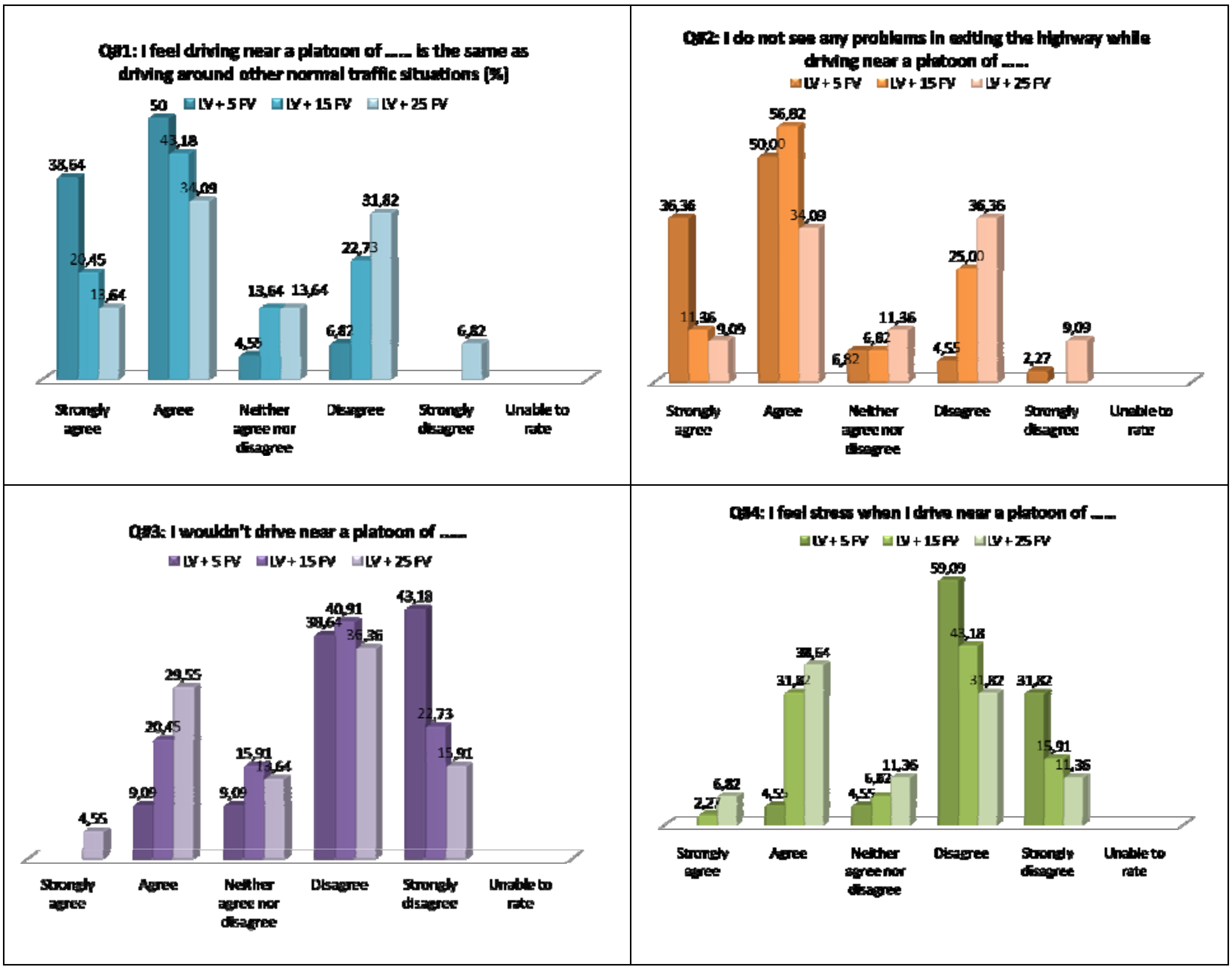

Figure 8. OVD opinions results

CONCLUSIONS

In this paper, different driver's behaviour were evaluated, in order to determine some platoon requirements related to the drivers perception, such as comfortable intra-platoon gap or a safety platoon length. Furthermore, this approach has made possible to define how the Human-Machine Interface (HMI) has to be designed while minimising negative impact on safety. However, it should take into account that, although thanks to these human behaviour and HMI simulation work a lot of results have been obtained, this study is a preliminary research. To be precise, there are other human factors to bear in mind which could improve the obtained results, such as the people experience with platoons, the rise of system trust due to the maturity of developed systems, or even people background, i.e. if they are professional or particular drivers, etc. In addition, it has also to consider the results when tests will be made in real trucks and cars under real environment. Nevertheless, the study has been really useful and the results has been very promising.

ACKNOWLEDGMENTS

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