ENSEMBLE

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ENSEMBLE

ENabling **S**af**E** **M**ulti-**B**rand p**L**atooning for **E**urope

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TABLE OF CONTENTS

Revision history

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V1	23/12/2022	Jallais, C., Vincent, F., Hoarau, A., Moreau, F., Ndiaye, D., Tattegrain, H	Methodology, analyses	Prepared
V2	28/01/2022	Jallais, C., Vincent, F., Hoarau, A., Moreau, F., Ndiaye, D., Tattegrain, H	Discussion, conclusions	Prepared
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V3	11/02/2022	Edoardo MASCALCHI, CLEPA	Review, comments	Revised
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FIGURES

TABLES

1. EXECUTIVE SUMMARY

1.1. Context

Platooning technology has made significant advances in the last decade, but to achieve the next step towards deployment of truck platooning, an integral multi-brand approach is required. Aiming for Europe-wide deployment of platooning, 'multi-brand' solutions are paramount. It is the ambition of ENSEMBLE to realize pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonization of legal frameworks in the member states.

1.2. Project scope

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. During the years, the project goals are:

- Year 1: setting the specifications and developing a reference design.
- Year 2 and 3: implementing this reference design on the OEM own trucks, as well as performing impact assessments with several criteria.
- Year 4: focus on testing the multi-brand platoons on test tracks and public road.

The technical results were evaluated against the initial requirements, after which these were updated. Also, the impact on fuel consumption, drivers and other road users will be established. In the end, all activities within the project aim to accelerate the deployment of multi-brand truck platooning in Europe.

The platoon levels as envisioned by the ENSEMBLE consortium and presented in D2.2 were revised after first results of the safety analyses. The Platooning Support Function and the Platooning Autonomous Function are fully detailed in this final deliverable. The Platoon Support Function is defined in line with the held demonstration on public road in September 2021.

1.3. Abstract of this Deliverable

This deliverable provides the different use cases that have been studied on a car simulator located at Université Gustave Eiffel, TS2-LESCOT facilities. The objectives are to evaluate how other road users of light vehicles behave when encountering a platoon in different road situations. The use cases deal with the interaction between light car drivers and a platoon of 3 or 7 trucks. All the use cases have to be seen from the light car drivers' point of view.
This deliverable describes the results obtained from the car simulator study. The platoon characteristics induced different emotions with the participants, going from fear to anger, but also a higher alert level. These negative emotional states depend on the traffic conditions and driving situations. It seems that the participants felt negative emotions when they estimated to be slowed down by the platoon or during difficult driving situations to manage (e.g, insertion on the highway).

Two important results emerge from this study: 1) the participants did not hesitate to cut-in the platoon during the insertion situations when encountering the 7-trucks platoon; 2) the insertion speed observed was below the legal speed in limit in France for any platoon and traffic conditions.

The interactions between the platoon and the other road users give lead to different behaviours and feelings of the drivers of light vehicles. During an overtaking or an exit of the highway, it seems that most of the drivers of light vehicles adopt a safety behaviour respecting the speed limit and/or waiting behind the platoon. When entering the highway, however, drivers do not wait until the platoon has passed, especially when the platoon is relatively long (7 trucks). In this case they cut in between the platoon to enter the highway and avoiding dropping their speeds too much, although the insertion speed was found to be lower than the speed of the platoon. Because the Platooning Support Function and the Platooning Autonomous Function will be able to detect a cut-in vehicle, the platoon reacts by increasing the gap. This behaviour will help to avoid dangerous situations. The problem that could rise is that this platoon specifically would be dissolved at several times at entries if one road user appears. When encountering platoons of 3 trucks, the driving simulator studies show no cutting in behaviour.

2. METHOLOGY

2.1. Use Cases and platooning levels

The objective of the driving simulator study is to evaluate how other road users behave when encountering a platoon in different road situations. To do so, we have planned to use different use cases. The use cases deal with the interaction between light car drivers and a platoon of several trucks. All the use cases have to be seen from the light car drivers' point of view.
The use cases described in the sections below come from several discussions and meetings with the different partners of the ENSEMBLE project. These use cases address several questions about the road users' behaviour while encountering a platoon. To define these use cases, some information coming from WP2 was needed.

For the interest of the reader, the main documents that describe the two platooning levels defined in ENSEMBLE are:

- Levels definitions and Use Cases – D2.3
- Requirements and Specifications - D2.5

Platooning levels

Two levels of platooning have been defined:

- **Platooning Support Function (PSF)**: the driver is responsible for the driving task. Hence (s)he is also responsible to choose a safe following distance and monitor the system e.g. whether the right platooning partner is being followed (though supported by the system as much as possible). To give the driver sufficient time to react, minimum time gaps around 1.5 s have to be respected. The Platooning support function is a longitudinal control function, but lateral driver assistance systems, such as e.g. lane keeping, might be optionally available as well. The maximum number of trucks in this level is 7.

- **Platooning Autonomous Function (**PAF): The lead truck has a driver responsible for the driving task, but the following trucks are fully automated, i.e. the system performs the complete driving task within the specified (limited) operational design domain. Taking the driver(s) out-of-the-loop offers the possibility to reduce time gaps to a minimum of 0.3 s. The maximum number of trucks in this level is 3.

In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function is not part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future vision of platooning. The latter is also due to the low technology readiness level of certain required autonomous driving subfunctions at the time of writing.

In order to be able to study the Platooning Support Function and the Platooning Autonomous Function, it has been proposed to study two-time gaps (i.e., elapsed time to cover the inter vehicle distance by a truck indicated in seconds), being 1.5 second (PSF) and 0.8 second (PAF) with a platoon speed limit fixed at 80 kph. The study will also focus on the number of trucks involved in the platoon (3 or 7). Moreover, we aim to study two traffic volumes on a highway (high and low) and three driving situations (overtaking the platoon, highway ingress and egress). The use cases are described in the following section.

Additional details on the Communication protocol and the strategic and services layers can be also found in:

- V2X Protocol - D2.8
- Security - D2.9
- Intelligent infrastructure - Strategic and Services Layers – D2.6 and D2.7

Furthermore, the deliverable related to the safety analysis performed on the two levels are:

- Safety of the intended functionality (SOTIF) - D2.13
- Functional Safety - D2.14
- Item Definition - D2.15

According to the possibilities that platooning offers, several use cases were discussed to fit the research needs regarding road safety concerns.

These use cases are composed of (see Table 1 for an illustration):

- 3 manoeuvres: entry, exit of highway and overtaking of the platoon,
- 2 platoon lengths (3 and 7 trucks),
- 2 levels of traffic volume (high and low),
- 2 levels of inter-vehicular distances in the platoon (0.8 seconds and 1.5 seconds),
- Different other road users' behaviours (aggressive behaviour and slowing down behaviour).

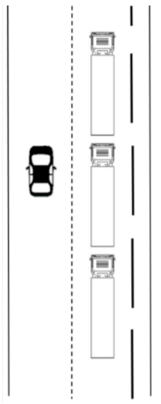
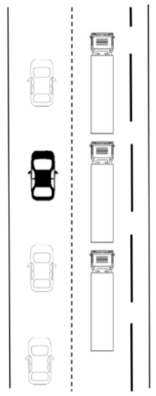
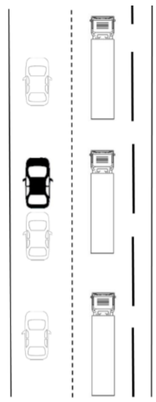
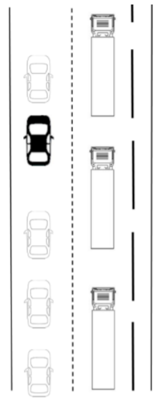
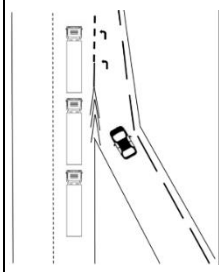
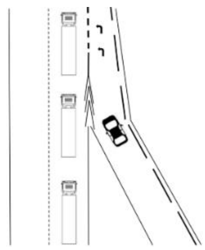
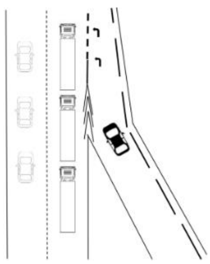
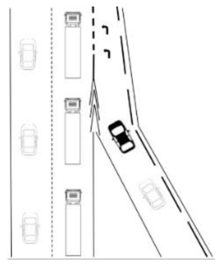
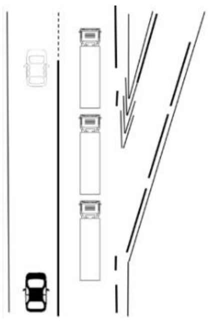
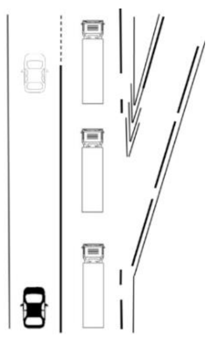
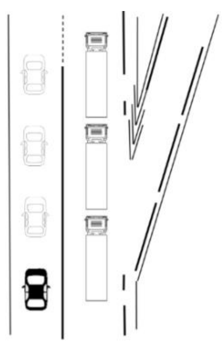
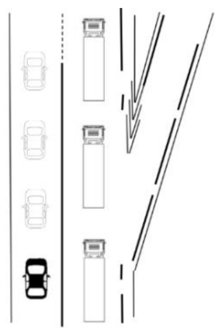
use cases	**overtaking**	**overtaking**	**Overtaking agressive**	**overtaking slow down**
Traffic	low	high	high	high
inter-vehicular	1,5 second	1,5 second	1,5 second	1,5 second
				
use cases	**ingress**	**ingress**	**ingress**	**ingress**
Traffic	low	low	high	high
inter-vehicular	0,8 second	1,5 second	0,8 second	1,5 second
				
use cases	**egress**	**egress**	**egress**	**egress**
Traffic	low	low	high	high
inter-vehicular	0,8 second	1,5 second	0,8 second	1,5 second
				

Table 1: Use cases for 3 and 7 trucks conditions.

Please note that the combination of 0.8s and 7 trucks is not part of the ENSEMBLE specifications for the Platooning Autonomous Function (PAF), since the maximum number of trucks in the platoon for the PAF is 3. Nevertheless, it has been considered appropriate to investigate this case in order to keep a balanced experimental conditions.

These driving situations are in line with the Autopilot EU project which assessed the interaction of platoon with normal traffic (i.e, events and situations for interaction with nearby traffic are distinguished, such as merging, entry and exit, cut-in, lane changing, overtaking, breaking, crossing – Autopilot D4.1, Aittoniemi et al., 2018). In contrast, this study will focus on the interaction between other road users and the platoon according to the road users' point of view.

Note that all the use cases are described in more detail in the D4.4 deliverable (Jallais, C. et al, 2020).

2.2. Simulator environment

2.2.1. Car simulator

The car simulator used in this study is developed at University Gustave Eiffel by PICS-L laboratory. It consists of a Peugeot 308 cabin surrounded by 8 screens of dimensions 220 cm × 165 cm, see Figure 1. This installation provides participants with a field of view of 280 ° (horizontal) and 40 ° (vertical). An upgrade of the simulator has been made for the ENSEMBLE project in order to have a horizontal angle of 340°.

Figure 1: Simulator platform used in the ENSEMBLE Project

2.2.2. Simulator virtual base

The driving environment in which the participants have to drive in is based on a 2x2-lanes highway (i.e., bidirectional, with 2 lanes in each direction), and several 1x1 secondary roads (see Figure 2). All roads characteristics are representative of French roads geometries, which are similar to European ones. The highway is 32 km long, the lane width is 3.5 m. Several curves are implemented. The curves have a radius of curvature of 800m and a curvature angle of between 15° and 60°.

Seven egresses and ingresses are modelled, complying with French road design policies. The ingresses are 250-metre long, the egresses are 150-metre long. The simulated environment allows letting the participants drive continuously from one highway to a secondary road, and to a highway again. There are 6 secondary roads, with lengths between 2 kms and 6 kms and with a width of 3.5 metres.

The platoon will be implemented only on highway sections while other road users (especially light vehicles) will be implemented on all types of roads.

Figure 2: Screenshot of an overtaking situation.

3. SIMULATOR EXPERIMENTATION

3.1. Participants

We recruited a total of 51 participants aged between 20 and 49 years (mean = 29.14, standard deviation = 7.85) including 19 women aged between 20 et 49 years (mean = 27.63, standard deviation = 8.62) and 32 men aged between 21 and 45 years (mean = 30.03, standard deviation = 7.35). All of the participants we recruited possess a French driving license for 3 years or more. In order to recruit, we posted an ad in our mailing list, and we used social networks.
Participants have been compensated with 50 euros.

3.2. Procedure

During the experiment, the participants had to drive on a highway according to the French traffic rules and had to respect safety.

In order to not have any fatigue issues due to the length of the experiment and also to avoid any repetitive effects, we divided randomly all participants into 2 independent groups. The first group drove the three-trucks condition, and the other the seven-trucks condition. The group of the three trucks condition was constituted of 26 participants including 15 men and 11 women aged between 20 and 49 years (mean = 29.96, standard deviation = 8.98). The group of the seven trucks condition was constituted of 25 participants including 17 men and 8 women aged between 21 and 45 years (mean = 28.28, standard deviation = 6.56).

Firstly, all participants had a training session lasting 10 minutes in the simulator. After this training session, all participants had to fill in subjective questionnaires assessing their mental workload (NASA-TLX) and feelings (Genova Emotion Wheel).
After the training session, participants started the experimental session and performed randomly all the driving situations described in Table 1 according to their group (3-truck or 7-truck platoons).
According to the experiment, the participant has to drive on the highway and will then encounter a platoon of 3 or 7 trucks in different situations. A total of 24 use cases was designed for this experiment. Each one lasted around 4 minutes. Thus, all participants had to perform 12 driving situations described above, either in the 3 truck platoon setting (group one) or in the 7 truck platoon setting (group two). The 12 use cases were composed of 3 different situations: 4 entries on the highway, 4 exits on the highway, and 4 overtaking of the platoon. There were two levels of inter-vehicular distances in the platoon which are 0.8 seconds or 1.5 seconds, and two levels of traffic, either a high traffic condition or a low traffic condition. Two of the overtaking use cases are special in the sense that the participant is confronted with aggressive behaviour from a car behind him during the overtaking (social pressure) and confronted with a road user driving in the same lane in front of the participant that slows down during the overtaking of the platoon. After each driving situation (for example, ingress with high traffic and 0.8 sec intervehicle distance), participants had to fill in the subjective questionnaires.

By manipulating these variables, participants will have are triggered to cut into the platoon. Cut-in situations represent a lane change manoeuvre performed by vehicles from the adjacent lane to the lane in which the platoon is driving, ending up between platooning vehicles.

These variable manipulations allowed us to identify and understand the feelings and behaviours of the other road users while encountering the platoon (sometimes confronted with aggressive behaviour): do light car drivers change their driving behaviours in terms of risk taking, do they feel stress or fear during the interactions? Different measures were assessed to this aim.

After all the experimental driving sessions, a 15-minute debriefing performed with the participants in which all the study objectives were described.

This study lasted around two hours and a half in total. The reception, information, signature of the consent form and the first part of the questionnaire and training session lasted around 30 minutes. The driving part itself lasted about 1 hour and 15 minutes.

3.3. Measures

In order to assess the interactions between the platoon and other the road users' behaviour, different measurements have been recorded, namely questionnaires and behavioural measurements. The questionnaires assessed the feelings of the participants during the various driving situations. All participants had to fill in the different questionnaires before and after the driving situations so as to have an idea of the magnitude of the emotional changes during the interaction with the platoon. Also data has been collected from the driving simulator in order to evaluate the possible risks taken by the participants during the cut-in procedures.

Here is the list of the various measurements that have been collected during the driving situations:

Subjective measurements:

- Questionnaires evaluating the emotional state Geneva Emotion Wheel (Scherer et al., 2013),
- NASA-TLX to evaluate the mental workload (Hart & Staveland, 1988, French version adapted by Cegarra & Morgado, 2009),

Behavioural measurements:

- Speed,
- Number of cut-ins,
- Position of the participant while being in the same lane of the platoon: ahead, between trucks or behind the platoon.

4. RESULTS

4.1. Subjective measurements

Table 2 and Table 3 summarize the subjective measurements (mean scores obtained on the emotional dimensions assessed) done during the simulator studies. We have conducted analyses according to the level of each emotional dimension that has been assessed (anxiety, anger, fear, alertness) by comparing the scores obtained at the beginning of the study (after the training session specified as the baseline) to the scores obtained after each specific driving situations.

3 trucks												
	Baseline	aggressive	overtaking	slowdown	Egress				Ingress			
					Low Traffic		High Traffic		Low Traffic		High Traffic	
					0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec
Anxiety	**2,13** *(.90)*	3,25 *(1.42)*	2,02 *(1.23)*	2,13 *(1.23)*	1.96 *(1.20)*	1.96 *(1.30)*	2.13 *(1.19)*	1.83 *(.92)*	2.04 *(1.16)*	2.21 *(1.02)*	2.67 *(1.37)*	2.13 *(1.23)*
Anger	**1,13** *(.45)*	2,54 *(1.59)*	1,52 *(1.65)*	1,25 *(.85)*	1.38 *(.71)*	1.08 *(.28)*	1.75 *(2.15)*	1.29 *(.92)*	1.13 *(.34)*	1.46 *(1.06)*	1.38 *(.65)*	1.33 *(.92)*
Fear	**1,83** *(1.05)*	2,42 *(1.35)*	1,49 *(.80)*	1,25 *(.53)*	1.42 *(.72)*	1.33 *(.70)*	1.54 *(.78)*	1.33 *(.56)*	1.50 *(.66)*	1.42 *(.58)*	2.17 *(1.55)*	1.67 *(.96)*
Alertness	**3,50** *(1.47)*	4,29 *(1.37)*	3,56 *(1.51)*	3,46 *(1.56)*	3.54 *(1.47)*	3.38 *(1.58)*	3.58 *(1.50)*	3.42 *(1.44)*	3.67 *(1.61)*	3.58 *(1.64)*	4.17 *(1.53)*	3.96 *(1.40)*

Table 2: Subjective measurements according to the conditions concerning the 3-truck platoon (mean and *sd*).

7 trucks												
	Baseline	aggressive	overtaking	slowdown	Egress				Ingress			
					Low Traffic		High Traffic		Low Traffic		High Traffic	
					0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec
Anxiety	**1,96** *(1.37)*	2,58 *(1.64)*	1,79 *(.94)*	1,71 *(1.20)*	1.63 *(.77)*	2.04 *(1.37)*	1.83 *(1.05)*	1.67 *(.87)*	2.04 *(1.50)*	2.21 *(1.16)*	2.54 (1.61)	2.04 *(1.36)*
Anger	**1,21** *(.59)*	2,75 *(1.57)*	1,46 *(1.53)*	1,63 *(1.13)*	1.25 *(.74)*	1.58 *(.97)*	1.46 *(.93)*	1.30 *(.76)*	1.13 *(1.20)*	1.46 *(1.06)*	1.48 *(1.08)*	1.61 *(1.23)*
Fear	**1,67** *(.96)*	2,21 *(1.77)*	1,50 *(1.57)*	1,50 *(.93)*	1.29 *(.55)*	1.38 *(.71)*	1.29 *(.55)*	1.38 *(.58)*	1.50 *(1.35)*	1.42 *(1.09)*	2.21 *(1.41)*	1.57 *(.90)*
Alertness	**3,50** *(1.47)*	4,17 *(1.63)*	3,15 *(1.40)*	2,96 *(1.40)*	3.17 *(1.37)*	3.08 *(1.50)*	3.21 *(1.53)*	3.09 *(1.31)*	3.67 *(1.48)*	3.58 *(1.50)*	3.87 *(1.77)*	3.78 *(1.57)*

Table 3: Subjective measurements according to the conditions concerning the 7-truck platoon (mean and *sd*).

According to the experimental plan used in this study and the fact that we have studied the overtaking driving situations (normal, with a slow down and with aggressive manoeuvres) only with a 1.5 sec in terms of inter vehicle distance, we have split the statistical analyses.

With regard to the anxiety level, the analyses show that the participants declared higher scores of anxiety only during the aggressive driving situations, for any platoon length (3-truck platoon: $F(1, 186) = 18.84$, $p<.0001$; 7-truck platoon: $F(1, 186) = 5.82$, $p<.01$).

The participants felt more anger during the aggressive behaviour situation (3-truck platoon: $F(1, 186) = 23.65$, $p<.0001$; 7-truck platoon: $F(1, 186) = 28.01$, $p<.0001$), and during the overtaking of the 3-truck platoon ($F(1, 186) = 3.69$, $p<.05$).

Concerning the fear dimension, the participants reported higher scores after encountering the 3- and 7-truck platoons during the aggressive situation (respectively, $F(1, 186) = 4.59$, $p<.05$; $F(1, 186) = 3.96$, $p<.05$). But they felt less fear while encountering the 3-truck platoon during the slowdown and overtaking situation (respectively, $F(1, 186) = 4.59$, $p<.05$; $F(1, 186) = 3.46$, $p<.05$).

Finally, concerning the alertness dimension, the participants felt more alert while encountering the 3-truck platoon during the aggressive behaviour (respectively, $F(1, 186) = 12.83$, $p<.0001$; $F(1, 186) = 9.11$, $p<.01$). But they felt less alert during the slowdown and overtaking situation while encountering the 7-truck platoon (respectively, $F(1, 186) = 6.01$, $p<.05$; $F(1, 186) = 5.13$, $p<.05$).

We then analysed the scores obtained on the emotional dimensions according to the egress and ingress situation. A repeated measure ANOVA was carried out with the Moment (baseline vs score after driving), Situation (Ingress vs Egress), Platoon (3 vs 7), intervehicle distance (0.8 vs 1.5) and Traffic (Low vs High).

The analyses have been conducted according each emotional dimension.

Anxiety level:

We proved an effect of the Situation ($F(1. 367) = 3.64$, $p< .05$) and an interaction between the Moment and Situation ($F(1, 367)= 7.86$, $p<.001$) meaning that the anxiety level changed according to the Situation and from the baseline and the driving session.

Concerning the anxiety felt by the participants during the entering the highway situation, the analyses showed an effect of the situation ($F(1. 367) = 3.64$, $p< .05$) meaning that the ingress situation leads to more anxiety. Note that we did not observe any statistical differences concerning the 1.5 seconds intervehicle distance. However, we observed that the participants felt more anxious with the 0.8 sec intervehicle distance of the platoon when the traffic was high (3-truck platoon: $F(1. 367) = 4.11$, $p< .05$; 7-truck platoon: $F(1. 367) = 4.76$, $p< .05$). The participants felt also more anxious when encountering the 7-truck platoon when the traffic was low ($F(1. 367) = 4.11$, $p< .05$).

We did not observe any statistical differences concerning the egress situation on the anxiety dimension.

Anger level:

An effect of the Moment (baseline vs score after driving) was obtained for both driving situations (ingress: $F(1, 367)= 20.52$, $p< .001$ and egress: $F(1, 367)= 12.21$, $p< .001$) considering all intervehicle distance and all traffic flow. The participants felt more angry during the ingress situation when encountering the 7-truck platoon with the 1.5 seconds distance, and when the traffic flow was high: $F(1. 367) = 5.79$, $p< .05$. The same pattern was observed concerning the 7-truck platoon with a 0.8 seconds distance and a low traffic condition ($F(1. 367) = 7.98$, $p< .01$).

Concerning the egress situation, the analyses revealed that participants felt more anger while encountering the 7-truck platoon with the 1.5 seconds distance and the 3-truck platoon with the 0.8 seconds distance (respectively, $F(1. 367) = 4.49$, $p< .05$; $F(1. 367) = 12.48$, $p< .001$).

Fear level:

The analyses revealed an effect of Situation ($F(1, 367) = 6.782$, $p< .01$), Moment ($F(1, 367)= 9.541$, $p<.01$), and some interactions between Moment x Intervehicle distance ($F(1, 367)= 3.94$, $p<.05$); Moment x Situation ($F(1, 367)= 13.70$, $p<.001$) and Moment x Platoon ($F(1, 367)= 3.99$, $p<.05$).

The planned comparisons revealed that the participants felt more fear during the ingress situation while encountering the 7-truck platoon driving at the 0.8 seconds distance and when the traffic was high ($F(1, 367)= 5.74$, $p<.01$). But surprisingly, the participants scored less fear during the egress situation while encountering the 3-truck platoon with the 1.5 seconds distance and for any traffic ($F(1. 367) = 4.89$, $p< .05$).

Alertness level:

The analyses revealed an interaction effect between Moment and Situation ($F(1, 367)= 15.08$, $p< .001$). Planned comparisons revealed only that the participants were more alert during the ingress situation while encountering the 7-truck platoon driving at a 0.8 seconds with the high traffic condition ($F(1. 367) = 7.34$, $p< .01$).

4.2. Behavioural measures

Overtaking

The data collected has been analysed by comparing the speed before the overtaking and during the overtaking situation. An analysis of variance (ANOVA) with Traffic (low vs high), Platoon (3 vs 7 trucks) and intervehicle distance has been carried out (see Figure 3).

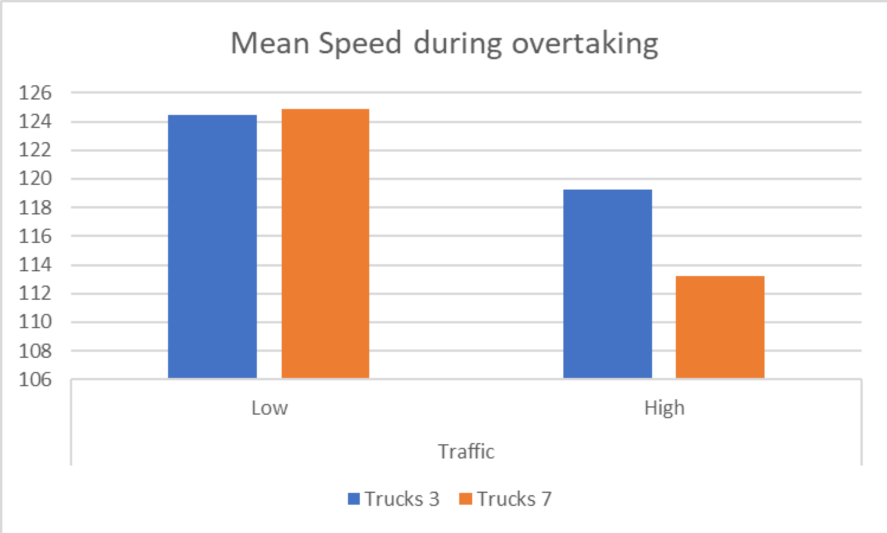


Figure 3: Mean speed during overtaking maneuver.

The analyses showed only a main effect of Traffic (F(1, 196) = 23.82, p> .001), and an interaction between Traffic and Platoon (F(1, 196) = 3.52, p> .05).

We conducted comparisons to assess the impact of the factors on the speed. The analyses showed that when the traffic was high, the participants drove faster while encountering the 7-truck platoon than the 3-truck platoon.

Slow-down situation and aggressive behaviour

We analysed the mean speed that has been observed during these two situations, considering the number of trucks involved in the platoon.

A one-way ANOVA has been carried out for each situation, considering the Platoon condition (3 vs 7 trucks). The results showed no significant effect on speed during the slow-down situation. But the participants drove at a higher speed while encountering the 3-truck platoon than the 7-truck one during the aggressive behaviour situation (F(1, 49)=6.64, p<.05).

	Slow down	Aggressive
3 trucks	107,27 *(7.42)*	126,38 *(3.63)*
7 trucks	104,59 *(7.03)*	123,89 *(3.69)*

Table 4: Mean speed during the slow-down and aggressive behaviour situation according to the platoon length (mean and *sd*).

Egress

We have considered the mean speed (mean of the 30-second window before lane changing and exiting the highway, see Figure 5) during the egress and the instantaneous speed (see Figure 4) when the participants precisely did the egress (when the car is changing the lane).

For each measure, we carried out an ANOVA with Platoon (3 vs 7 trucks), Distance (0.8 sec vs 1.5 sec) and Traffic (low vs high).

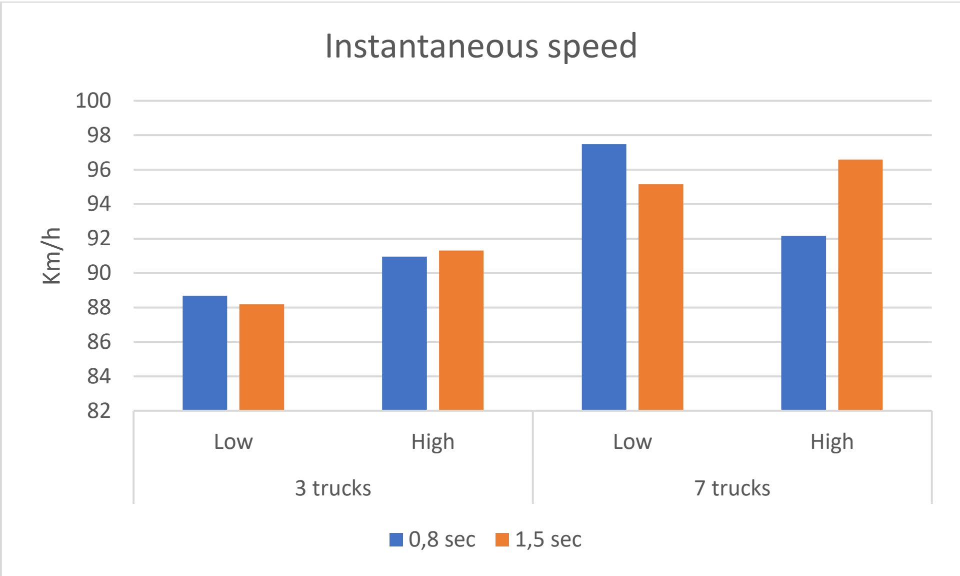


Figure 4: Instantaneous speed during egress manoeuvre.

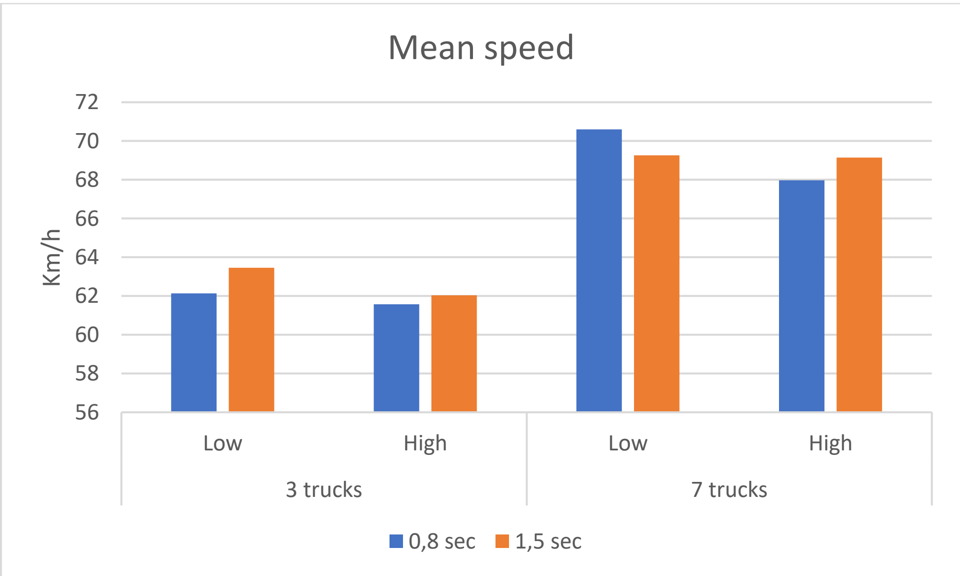


Figure 5: Mean speed during egress manoeuvre.

For both measurements (the instantaneous speed and the mean speed), the ANOVAs showed a main effect of Platoon (respectively, $F(1, 196) = 6.29$, $p>.01$ and $F(1, 196) = 16.59$, $p>.0001$) meaning that the participants drove at a slower speed when the platoon was composed of 3 trucks.

Concerning the behaviour that has been observed, most of the participants stayed behind the platoon and waited for the exit (see Figure 6). This behaviour could explain the fact that the mean speed that has been observed is below the legal limit.

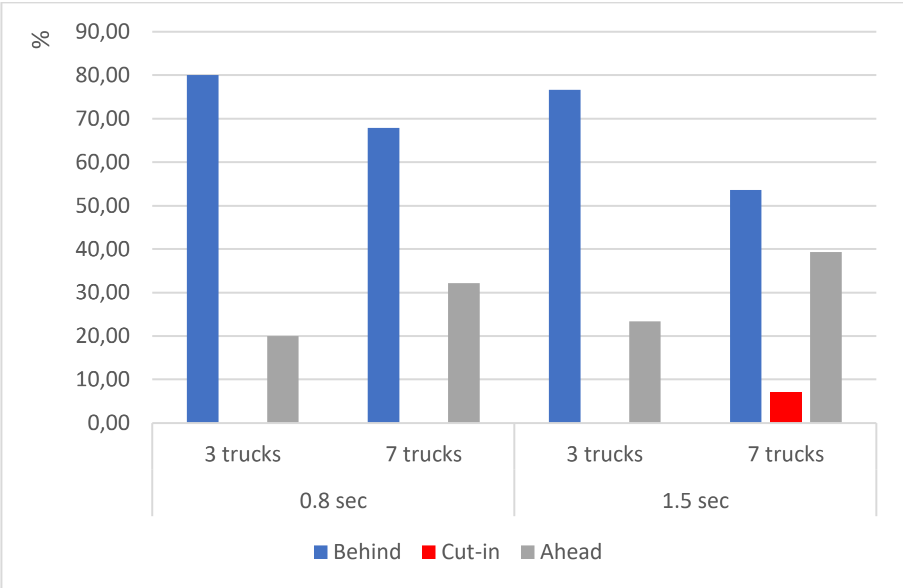


Figure 6: Repartition of the behaviour observed during egress manoeuvre according to the number of trucks and inter vehicle distance.

A Chi^2 test was conducted regarding the Traffic (Low vs High), Inter vehicle distance (0.8 sec vs 1.5 sec) and Platoon (3 vs 7 trucks). The results showed a significant effect (chi2=19.32ns), see Figure 7 and Figure 8. A second Chi^2 test was performed regarding the inter vehicle distance and the number of trucks, and revealed also a significant effect (chi2=15.26, $p<.05$).

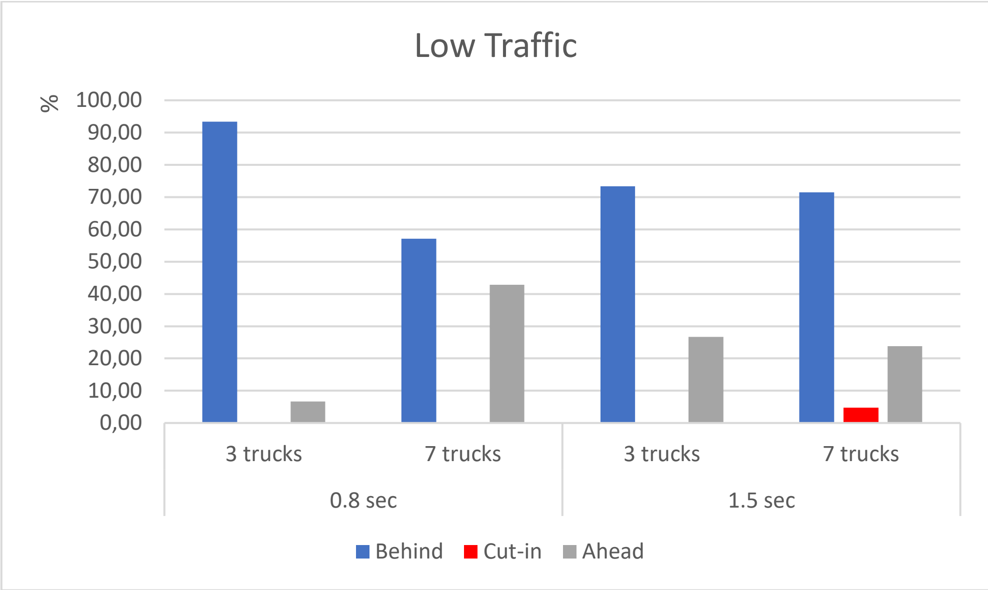


Figure 7: Repartition of the behaviour observed during egress manoeuvre and with a low traffic according to the number of trucks, intervehicle distance.

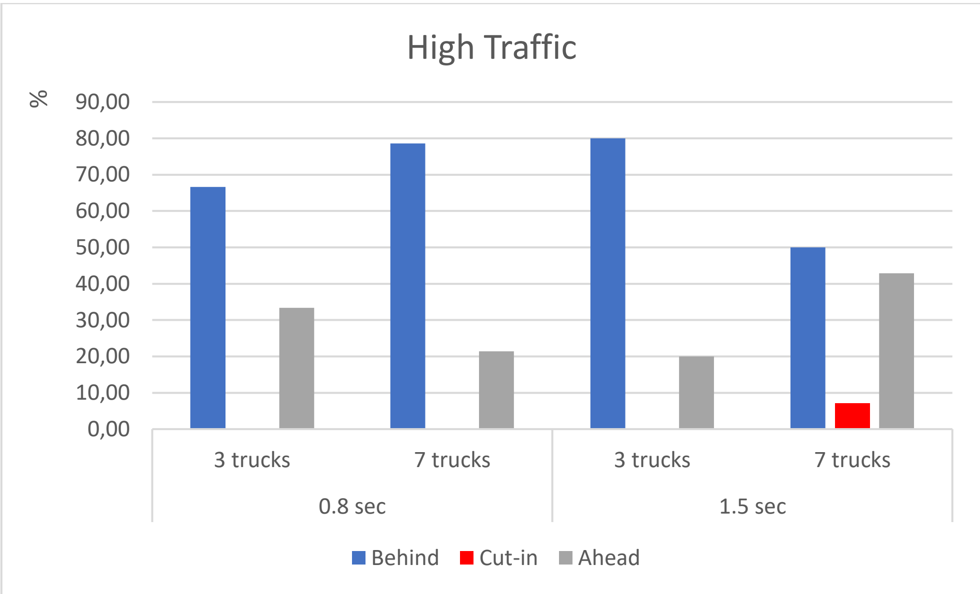


Figure 8: Repartition of the behaviour observed during egress manoeuvre and with a high traffic according to the number of trucks, intervehicle distance.

Ingress

In this driving situation, the participants had to entry on the highway while encountering the platoon.

Concerning the behaviour that has been observed, we found different strategies according to the platoon characteristics and traffic conditions (see Figure 9; Figure 10; Figure 11).

A Chi^2 test was conducted regarding the Traffic (Low vs High), Intervehicle distance (0.8 sec vs 1.5 sec) and Platoon (3 vs 7 trucks). The results showed a significant effect (chi2=46.06, p>.001). A second Chi^2 test was performed regarding the Intervehicle distance and the number of trucks, and revealed also a significant effect (chi2=42.12, p<.0001).

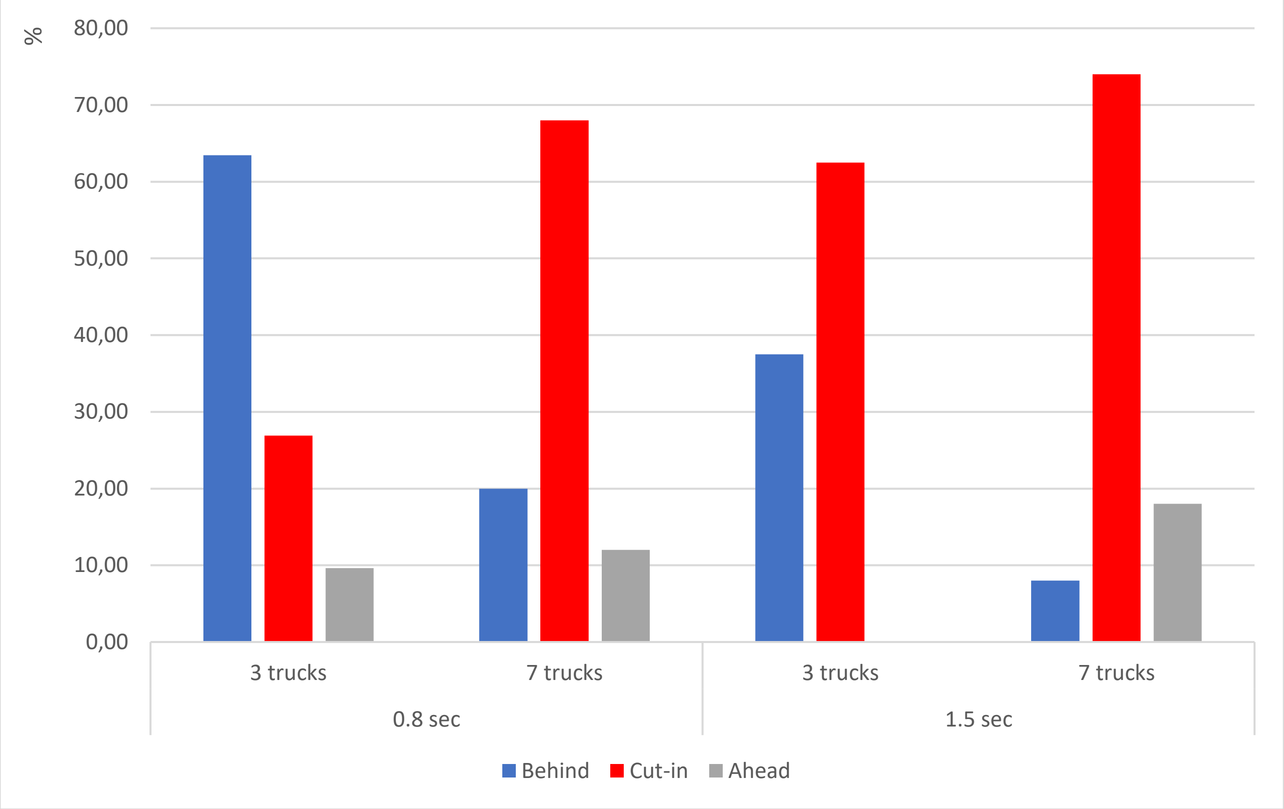


Figure 9: Repartition of the behaviour observed during ingress manoeuvre according to the number of trucks and inter vehicle distance.

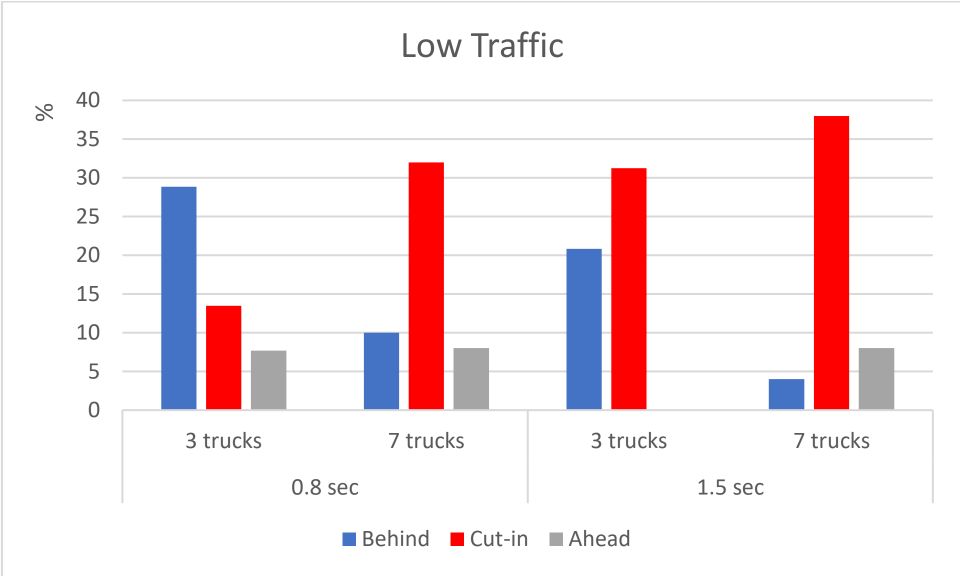


Figure 10: Repartition of the behaviour observed during ingress manoeuvre and with a low traffic according to the number of trucks and inter vehicle distance.

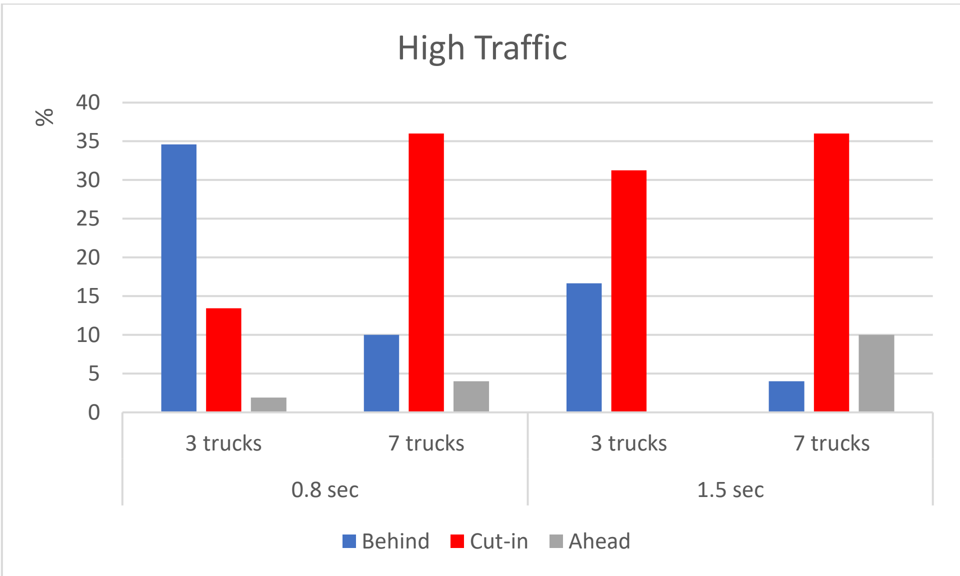


Figure 11: Repartition of the behaviour observed during ingress manoeuvre and with a high traffic according to the number of trucks and inter vehicle distance.

This driving situation was also studied regarding the instantaneous speed (see Table 5) when the participants precisely did the ingress (when the car changes from the insertion lane to the right lane on the highway). We also took into account the duration during which the participants stayed in this right lane after the insertion (when the insertion was done between the trucks (cut-in) or after the platoon). Finally, we also assessed the participants' behaviour while doing the insertion by counting the number of cut-ins, insertions done before the platoon ("ahead" meaning that the participant overtook the platoon using the insertion lane) or after the platoon ("behind" meaning that the participant let the platoon pass and did the insertion after the final truck).

Several ANOVAs have been conducted considering the Platoon (3 vs 7 trucks), the inter vehicle distance (0.8 sec vs 1.5 sec) and traffic (low vs high).

Concerning the speed at which the participants did the insertion on the highway, several ANOVAs have been conducted considering the Platoon (3 vs 7 trucks), the inter vehicle distance (0.8 sec vs 1.5 sec) and traffic (low vs high) and Behaviour (ahead, cut-in or behind).

The analyses revealed only a main effect of Behaviour (F(2, 198)=5.91, p<.01) indicating that the participants had a higher instantaneous insertion speed when overtaking the platoons (M=73.10, sd=1.96) than when doing a cut-in or letting the platoon pass (respectively M=70.43, sd=.63; M=66.78, sd=.72).

The highest speeds were obtained when the participants overtook the 7-truck platoon during the ingress at a low traffic situation compared to when the participants did a cut-in or did the insertion behind the platoon whatever the intervehicle distance (F(1, 180=9.91, p<.01). Note that the observed mean speeds are quite low, and some of them are below the speed limit in France (see Table 6).

	3 trucks				7 trucks			
	Low		High		Low		High	
Behaviour	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec
Ahead	70.47 *(3.47)*	67.67 *(6.94)*	65.49 *(6.94)*	71.95 *(4.32)*	77.88 *(12.08)*	77.62 *(4.26)*	64.79 *(1.56)*	74.41 *(13.73)*
Behind	65.72 *(4.99)*	68.49 *(4.35)*	66.26 *(4.61)*	68.60 *(2.71)*	65.29 *(12.37)*	70.62 *(5.77)*	64.40 *(5.26)*	69.57 *(3.66)*
Cut-in	72.53 *(3.79)*	68.77 *(6.01)*	68.80 *(7.48)*	70.54 *(7.40)*	68.77 *(6.67)*	69.63 *(6.73)*	71.81 *(6.19)*	72.48 *(6.96)*

Table 5: Instantaneous mean speed during the insertion according to the conditions (mean and sd).

Afterwards we analysed the time spent by the participants in the right lane (same lane than the platoon) after the insertion. Note that we did not consider this time when the participants did the insertion ahead as they did not have any more an interaction with the platoon. Therefore, we exclude the time for the "ahead" variable from the analyses.

We obtained a main effect of Traffic (F(1, 164)=92.41, p>.0001), an interaction between Traffic and Platoon (F(1, 164)=20.801, p<.0001), Traffic X Behaviour (F(1, 164)=43.71, p<.0001), Platoon X Behaviour (F(1, 164)=6.95, p<.001), and Traffic X Platoon X Behaviour (F(1, 164)=13.82, p<.001).

	3 trucks				7 trucks			
	Low		High		Low		High	
Behaviour	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec	0.8 sec	1.5 sec
Behind	4.73 *(2.65)*	5.61 *(2.82)*	19.64 *(2.03)*	15.28 *(1.36)*	20.43 (2.51)	15.99 *(3.98)*	12.88 *(4.72)*	12.05 *(3.97)*
Cut-in	6.01 *(1.69)*	5.47 *(1.28)*	23.77 *(2.32)*	24.89 *(6.14)*	4.95 *(2.14)*	4.93 *(1.19)*	19.65 *(7.86)*	23.75 *(8.28)*

Table 6: Mean time spent in the same lane than the platoon after the insertion according to the conditions (mean and sd).

Surprisingly, the mean time for the low traffic, 7-truck conditions seemed higher compared to the low traffic, 3-truck conditions. The analyses revealed that this difference was statistically different ($F(1, 164)=24.74$, $p<.0001$). We obtained the same pattern when comparing the 3- and 7-truck platoon conditions for the 0.8 sec distance in high traffic ($F(1, 164)=5.63$, $p<.01$) indicating that the participants spent more time in the 3-truck platoon condition.

5. SYNTHESIS OF RESULTS AND COMMENTS

This deliverable presents the results obtained for the study that has been conducted on a car simulator within the Task 4.4.1 of project H2020 ENSEMBLE. The objectives of Task 4.4.1 are to evaluate possible problems of other road users (light car drivers) when encountering a platoon in different road situations. Different traffic conditions (high or low traffic) have provided insights about the interactions and the impacts of road users' behaviour on both road safety and traffic flow.

During the simulator experiment, we have assessed the emotional and attentional levels of the road users during their interaction with the platoon. The results showed that according to the situation and the platoon characteristics, the drivers showed different emotions and attention levels.

The participants indicated to have higher anxiety levels when the platoon was composed of 7 trucks compared to 3 trucks during the ingress on the highway situation. Moreover, this driving situation was linked to more anxiety from the participants than the exit of the highway situation when the inter vehicle distance is fixed at 0.8 seconds and during a high traffic.

Regarding the fear that is felt by the test drivers, the insertion on the highway while encountering a 7-truck platoon with the 0.8 seconds inter vehicle distance under a high traffic condition was the most fearful situation. This specific driving situation was the one that induced the higher level of alertness to the participants.

We observed that while overtaking the platoon, the drivers could feel some anger against the platoon characteristics especially during the overtaking. Note that the anger increased for the 7-truck platoon when the inter vehicle distance is fixed at 1.5 seconds irrespective of having to exit the highway or enter on the highway.

The participants' behaviour and the speed were also assessed during the interaction with the platoon. The results observed regarding the speed during the overtaking revealed that the lower the traffic volume, the higher the speed. This result is logical regarding the traffic situation.

When the traffic volume was high, we observed that the participants drove at a higher speed when encountering the 7-truck platoon than 3-truck platoon. It is possible that the participants wanted to overtake this long platoon as soon as possible. Note that for all conditions, the measured driving speed was still under the legal speed limit, as we have asked the participants to respect the traffic rules.

On the contrary, the speed was lower in the egress situation. This could be explained by the fact that the majority of the participants stayed behind the platoon to exit the highway and did not choose to do a cut-in or to overtake. These two behaviours would have some impacts on the traffic flow. Note that the measured mean speed was below the speed limit for the two platoon lengths, as we have asked the participants to respect the traffic rules.

The two specific overtaking situations (aggressive behaviour and slow-down situations) have been implemented specifically. The results obtained here showed that the speed was higher when encountering the 7-truck platoon than the 3-truck platoon.

The driving situation that could provide the most information is the entry on the highway. This typical driving situation has a time constraint because it forces the participants to take the right (safer) decision in a minimum time window: doing the insertion by overtaking, doing a cut-in, or wait and let the platoon pass. Normally, when one wants to entry on the highway and there is already another road user in the right lane, the traffic rules in France indicate that we have to slow down or to stop (if there is no estimated possibility by the driver to do the insertion in a safety way) as soon as possible in the insertion lane in order to have a sufficient insertion distance left to be able to do the insertion at a minimum speed limit (80 km/h). What we observed in this experiment is that most participants slowed down at the insertion to a speed below the speed limit. The speeds observed for all conditions were between 64 km/h and 75 km/h/. The statistical analyses did not reveal any differences between all insertion behaviours (except for the low traffic and insertion ahead the 7-truck platoon). This means that whether the participants did the insertion by overtaking or a cut-in, they followed the rule slowdown in order to have a sufficient insertion distance left. At the same time, we see that the insertion speed was below the speed limit which is probably due to the relatively long time one has to wait to insert. Insertion on a highway with speeds below the speed that the traffic is driving on the right lane (in this case the platoon driving at 80 km/h) can be interpreted as risky behaviour.

This low speed insertion is also interesting to consider when the participants decided to cut-in the platoon to insert on the highway. Doing a cut-in at a low speed forced therefore the truck behind to slow down or brake. In this experiment, the simulated trucks automatically slowed down when the participants' car was detected because of their platooning function. One could say that the platoon put the light car road user in a safe condition but it means that the platoon will slow down at a speed below the legal speed limit (80 km/h on the right lane of a highway in France) and that the platoon momentarily dissolved. The observed low speed could be explained by the fact that, as we previously mentioned, the high time constraint situation could be difficult to manage for the drivers. One compensatory behaviour could be to slow down to have more time to decide the next step.

Regarding the observed behaviour, the platoon length characteristic also had an effect on the participants. We observed that for any inter vehicle distance (0.8 seconds or 1.5 seconds), when the participants encountered a 7-truck platoon, most of them decided to cut-in the platoon to insert on the highway. When the platoon was composed of 3 trucks only, most of them decided to slow down on the insertion lane and to do the insertion behind the platoon. But when the 3-truck platoon has 1.5 seconds as inter vehicle distance, most of the participants decided to cut-in the platoon to do the insertion.

Cut-ins have the most impact regarding both traffic and platoon fuel consumption. We assessed the time the participants stayed in the same lane as the platoon after the insertion. We obviously observed an effect of the traffic condition: the higher the surrounding traffic, the longer the time in the same lane for the car.

Moreover, the participants stayed in the same lane as the platoon for around almost 20 seconds after a cut-in with the high traffic condition. This result means that the platoon will be dissolved for a long time and that the trucks behind the cut-in vehicle will need to accelerate to build back the platoon.

This simulator study showed that the 7-truck platoon could induce the higher level of negative emotions for the participants. These negative emotions depend on the traffic condition and the inter vehicle distance. It seems that if the participants have to exit the highway and that the platoon is in the right lane, they would have to slow down and wait behind the platoon to do the egress in a safe way. This behaviour could make them feeling certainly angry because it could be difficult for them to overtake the platoon and because of a feeling of lost time.

We observed also that the ingress on the highway situation could be difficult to manage for the road users because of the high time constraint for decision making. The results revealed that even if the participants felt some fear or anger when encountering the 7-truck platoon, they felt more alert and did, in majority, cut-in the platoon to insert on the highway. One limitation to this study is that it was a simulator one, the behaviours encountered here will have to be verified in real conditions.

6. CONCLUSION

The interactions between the platoon and the other road users give lead to different behaviours and feelings of the drivers of light vehicles. During an overtaking or an exit of the highway, it seems that most of the drivers of light vehicles adopt a safety behaviour respecting the speed limit and/or waiting behind the platoon. When entering the highway, however, drivers do not wait until the platoon has passed, especially when the platoon is relatively long (7 trucks). In this case they cut in between the platoon to enter the highway and avoiding dropping their speeds too much, although the insertion speed was found to be lower than the speed of the platoon. Because the Platooning Support Function and the Platooning Autonomous Function will be able to detect a cut-in vehicle, the platoon reacts by increasing the gap. This behaviour will help to avoid dangerous situations. The problem that could rise is that this platoon specifically would be dissolved at several times at entries if one road user appears. When encountering platoons of 3 trucks, the driving simulator studies show no cutting in behaviour.

This simulator study was performed under specific and controlled conditions. Moreover, we only had one road user during the test. It could be interesting to test the same driving situations with more participants. The results obtained then could be very interesting regarding traffic, fuel consumption and of course safety issues.

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