# ASSESSMENT OF BEHAVIORAL ASPECTS IN INTEGRATED SAFETY SYSTEMS (EU FP7 project ASSESS)

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## ABSTRACT

Integrated vehicle safety systems that combine elements from primary and secondary safety have a high potential to improve vehicle safety due to their ability to influence crash conditions and/or to adapt to these crash conditions. The value of pre-crash sensing systems that employ remote exterior sensors (in combination with on-board sensors) to detect dangerous situations and activate primary and secondary safety devices was clearly shown in projects like TRACE, APROSYS, eIMPACT and SAFETY TECHNOPRO. Joint R&D efforts (e.g. PReVENT, CHAMELEON, SAVE-U) have resulted in Pre-Crash Safety systems that are already on the market or close to market introduction.

In previous and current projects, the development of test and evaluation procedures was considered to be merely a secondary objective. So far, no procedures have been developed and implemented. Moreover, all the research into test procedures was based on research systems and not on commercially available systems.

Because of the above, a project specifically devoted to the development of assessment procedures is required to enable widespread introduction of integrated vehicle safety systems such as pre-crash sensing systems into the vehicle fleet. The main goal of the ASSESS project [1] is to develop harmonized and standardized assessment procedures and related tools for commercially available pre-crash sensing systems. Procedures will be developed for:

- Driver behavior evaluation
- Pre-crash system performance evaluation
- Crash performance evaluation
- Socio-economic assessment

This paper will present the activities related to the "driver behavior evaluation". The objective is to provide a tool box for the specific evaluation of behavioral aspects of pre-crash systems and the contribution of the overall system performance.

The paper will include the complete test design: test scenarios, measurements, key performance indicators (objective/subjective data) and questionnaires. In addition, needs of behavioral aspects for "system performance evaluation" in test tracks will be discussed (e.g. driver reaction times).

The following aspects will be investigated and taken as a first approach towards assessment criteria:

- Driver reaction for intended system performance (especially for semi-autonomous systems)
- Validation of driver behavior regarding inadequate system reaction or possible side effects due to a FALSE trigger of the system

In order to carry out the experimental studies in driving simulators (6D moving based) and tests tracks with real vehicles and subjects, a common and harmonized test design, including the complete story book, will be presented. Possibilities and limitations of the methods will be also discussed.

This paper summarizes the results corresponding to the stability assistance domain of the European project ASSESS (Assessment of Integrated Vehicle Safety Systems for improved vehicle safety, FP7 – SST 2nd call, grant agreement no. 233942)

## INTRODUCTION AND MOTIVATION

ASSESS mobilizes the European research community and car industry to develop a relevant set of test and assessment methods applicable to a wide range of Integrated Vehicle Safety Systems (IVSS). IVSS that combine elements from active and passive safety have a high potential to improve both the comfort and safety of vehicles and their occupants. Methods will be developed for driver behavioral aspects, pre-crash sensing performance and crash performance under conditions influenced by pre-crash driver and vehicle actions. The acquired expertise will be implemented in proposals for test and assessment procedures that will be evaluated on the basis of actual systems currently offered to the market. ASSESS aims to stimulate the introduction of new crucial technologies in vehicles to further reduce road fatalities and injuries to car occupants in Europe and to make the traffic environment safer for road users.

To realize the project goals while taking into account results from previous projects, a structure of seven work packages (WP) has been defined. WP1 deals with defining the test scenarios as well as developing the final overall assessment methods, WP2 with legal and socio-economic aspects, WP3-4 and 5 with the development of evaluation methods for driver behavior, pre-crash performance and crash performance respectively. Management and dissemination are performed in WP6 and 7. The diagram in Figure 1 shows the work packages, their output and interaction. It is important to note that driver behavior, pre-crash and crash feed each other sequentially in time with respect to relevant parameters (as in a real accident situation) but also have its own contribution to the overall assessment.

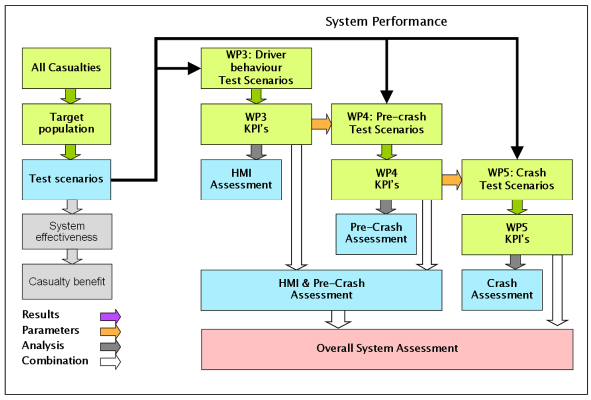



**Figure 1. Structure of ASSESS project**

The content of this paper focuses on the approach of WP3 "Driver Behavior Test Scenarios" as well as on its links to other work packages of the ASSESS project. The specific objective of WP3 is the development and evaluation of a test and assessment methodology to quantify and qualify the interaction of the driver with Integrated Vehicle Safety Systems in the context of the overall system assessment. On the basis of the accidentology [2], test scenarios for the HMI evaluation of IVSS are defined and implemented in test environments such as driving simulators and test tracks in order to perform experimental studies with volunteer drivers. The reaction of subjects to the HMI specification (e.g. acoustic forward collision warnings) is measured with the aid of "Key Performance Indicators" (KPIs). Those KPIs provide a basis for the HMI assessment as well as for the development of pre-crash test scenarios. In advance of the experimental studies, a so-called "story book" was defined as a general basis [3]. The story book describes the principles for setting up the experimental studies and thus should allow comparable studies for different and also for different kinds of test facilities.

## METHODOLOGY

### Story book as basic principle

The methodology describes the test setup and the test scenarios as well as the required output parameters and the data processing that is required to make an assessment of the system regarding human behavior. The following aspects were investigated and have been taken as a first approach towards assessment criteria:

- System performance - driver in the loop for full system performance
- Possible adverse effects on the task of driving due to a false system trigger

With respect to the assessment of the system performance, critical driving situations (known as TRUE maneuvers) must be implemented in the story book. To analyze the benefit of the HMI in such situations, the WP3 approach proposes comparing TRUE maneuvers with system performance (TRUEwith) to TRUE maneuvers without system performance (TRUEwithout). Based on the accidentology [4], "braking leading vehicle" and "cut in" maneuvers are suggested as TRUE maneuvers. For the assessment of a possible adverse effect due to false HMI activation (FALSE), the story book proposes to establish a relative comparison yardstick for the FALSE maneuver with a "reference event", which is intended to represent a commonly occurring disturbance incident (REFERENCE) – such as "stone chipping" – during driving situations. Thus, the experimental design contains four maneuvers (TRUEwith, TRUEwithout, FALSE and REFERENCE) per test run and subject. To account for the expectation effects of the maneuvers, the sequence of the maneuvers is permuted within the experimental design. Table 1. shows the four permutations proposed by the story book.

**Table 1.**
**Scenario permutations**

| sequence | maneuver 1 | maneuver 2 | maneuver 3 | maneuver 4 |
|---|---|---|---|---|
| A1 | TRUEwith | FALSE | REFERENCE | TRUEwithout |
| A2 | TRUEwith | REFERENCE | FALSE | TRUEwithout |
| B1 | TRUEwithout | FALSE | REFERENCE | TRUEwith |
| B2 | TRUEwithout | REFERENCE | FALSE | TRUEwith |

A secondary task is implemented in the TRUE scenarios. This secondary task is intended to capture the attention of the driver in the event of the TRUE maneuver and to finally allow an evaluation of the effect of a warning or comparable system function in comparison with a TRUEwithout scenario, where no warning or function is triggered. The secondary task is intended to induce a visual time off road of more than one second. Therefore, an artificial mobile phone with a small display is implemented on the center console. The task of the subject is to read the number of an incoming phone call aloud. This secondary task is to be executed several times during normal driving and within the TRUE maneuvers.

To evaluate the quality of the driver reaction and thus the benefit of the system performance during the TRUE maneuvers, the "Brake Reaction Time" (BRT) and the "Time To Collision" (TTC) are selected as KPIs. For the assessment of possible side effects with respect to the FALSE and REFERENCE maneuvers, the analysis of the mental workload leads to the requested result. As a workload indicator, the statistical parameter "Steering Entropy" is used. The "Steering Entropy" analyzes the distribution of the difference between the real steering angle and a predicted steering angle calculated with the aim of obtaining a Taylor expansion. This was proposed by Nakayama et al. in 1999 [5] and effectively used by the INVENT Project [6]. With respect to the collection of subjective data, a set of standardized questionnaires – consisting of preliminary, interim and follow-up surveys – is developed [7]. The questionnaires cover data in terms of personal details of the subjects (e.g. age, gender, annual mileage), description and subjective assessment of each maneuver as well as an overall assessment of the experienced test run and system performance.

In order to ensure the statistical value of the experimental results, a homogeneous sample of 22 test subjects is defined for the scenario sets starting with TRUEwith (A1/A2) and the same sample size is defined for the scenario sets starting with TRUEwithout (B1/B2). In principle, the intention is to follow the described story book on all test facilities (simulator and track). The following text discusses the implementation of the experimental design on the one hand, but at the same time, concessions and compromises have to be considered due to facility limitations and, of particular importance, safety issues.

**Experimental design of track test**

In order to warranty sufficient safety and the repeatability of the test results, the IDIADA's dynamic platform A (Figure 2.) was selected to perform the tests. The main advantages of this track for tests are the fact that it covers a distance of 1.6 km in a straight line and an area of 2000 m², thus making the track long enough to conduct driver reaction tests safely.

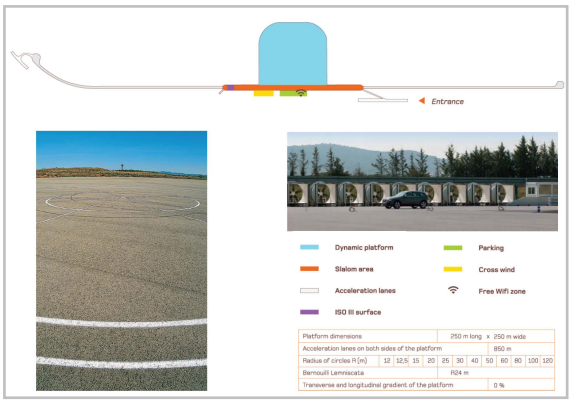



**Figure 2. IDIADA's dynamic platform A**

The target vehicle used during the tests was IDIADA's propulsion vehicle carrying the ASSESSOR target. The ASSESSOR consisted of a full-size soft crash vehicle mounted on a rectangular frame (Figure 3.). The back of the propulsion vehicle system was covered with radar-absorbent material to make the vehicle invisible to radar sensors of the subject vehicle. The subject vehicle used for the experiment was equipped with a radar based IVSS, which warns the driver optically and acoustically at a TTC of approximately 2.6 sec.

**Figure 3. ASSESSOR and propulsion system**

The following measurement equipment (Figure 4.) was used during the experiment:

- High-precision differential GPS with vehicle-to-vehicle communication to measure the relative positions, speeds and "Time To Collision" between the vehicles.
- Brake pedal force sensor to detect the "Brake Reaktion Time"
- Microphone to detect the warning time
- Seatbelt sensor to detect pretension activation

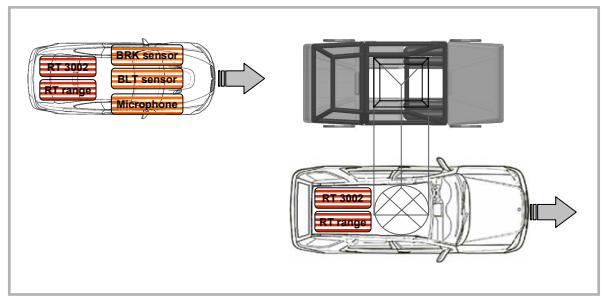



**Figure 4. Measurement equipment**

Two sequences from the story book (A1 and B2) were selected to perform driver reaction analysis. In contrast to the story book a total of just 16 subjects (22 are supposed) were selected for this test, out of which 10 achieved valid test runs. This limitation was due to the restricted availability of resources like the subject vehicle and to the complexity of implementing the complete story book in proving grounds. Subject selection was based on the following criteria:

- Age 25 - 50
- Annual mileage > 5,000 km/year
- Driving experience > 7 years

First of all, the driver was asked to drive at least one complete lap of IDIADA's general road to become familiar with the subject vehicle and the secondary task. When the driver was feeling comfortable enough, he was asked to enter the dynamic platform A. Once on the test track, the ASSESSOR and the propulsion system were briefly presented to the driver, and then the test sequence started. The maneuvers were performed as follows:

- TRUEwithout and TRUEwith: Both tests involved following the ASSESSOR, driving at 50 kph while maintaining a distance of 20 meters, and being distracted by the secondary task. After familiarization runs, the leading vehicle performed a 0.2 g deceleration, reducing its speed from 50 kph to 10 kph.

- REFERENCE The objective of this test was to measure the driver reaction to an unexpected noise, in that case "stone chipping".

- FALSE: This test was used to measure the driver reaction in the event of a false warning by the pre-crash system. After a familiarization run, a corner reflector device was placed on the surface of the test zone to trigger a warning by the IVSS of the subject vehicle.

- After each test, the subject filled out the corresponding questionnaire.

**Experimental design of simulator test**

The experiments were conducted at the Toyota Driving Simulator located in the Toyota Motor Corporation Higashifuji Technical Center in Japan. The simulator uses an actual vehicle placed on a platform housed inside a dome with a diameter of 7.1 meters. A 360-degree view is projected on the inside wall of the dome, which is mounted on a 6-degrees-of-freedom motion base. The motion base is also able to move horizontally in a 35×20 meter range [8].

**Figure 5. Toyota Driving Simulator**

The driving route used in the simulator (Figure 6.) represented a virtual 2-lane rural highway surrounding a representation of the center of the existing Japanese city of Gotemba.

The standard Japanese driving rules are applicable.

- Maximum speed limit of 100 kph

- Drive on the left

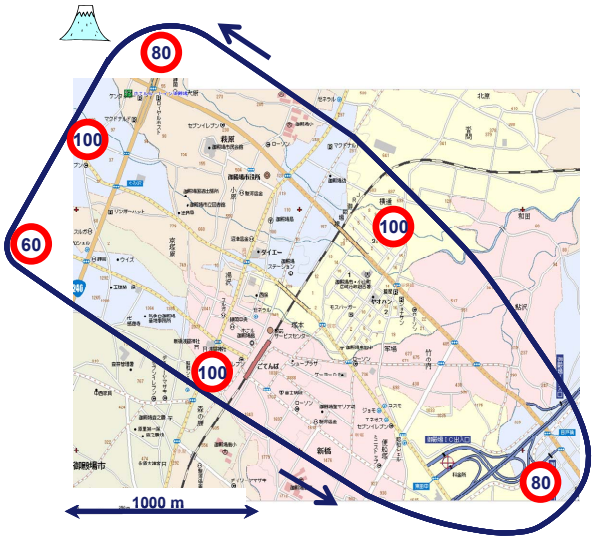



**Figure 6. Overview of virtual test route**

The critical event implemented for the TRUE scenario (Figure 7.) was "Leading Vehicle Decelerating":

- The subject was instructed to follow a preceding vehicle at the normal driving speed (80-100 kph).

- The speed and distance of the leading vehicle were automatically controlled to adjust the headway time to approximately 2 seconds (headway time = relative distance/subject vehicle speed).

- The secondary task was triggered by the test operator (only on a straight section of track). This operation was repeated several times until the subject was considered to be accustomed to the secondary task.

- The deceleration of the leading vehicle was triggered by the test operator based on his judgment that the subject is distracted.

- The vehicle in front braked at a deceleration of 0.7 g until a complete stop.

- In the TRUEwith case, an artificial acoustic warning was issued around 3 seconds before a potential collision (in case of no driver reaction). In the TRUEwithout case, no warning was issued.

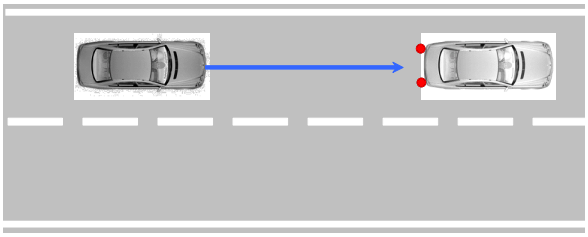


**Figure 7. TRUE scenario**

**Figure 8. Secondary task display**

FALSE and REFERENCE scenario (Figure 9. and 10.):

- The subject was instructed to overtake a truck or a bus traveling in the right-hand lane at a certain speed.

- The expected subject vehicle speed was equivalent to a velocity of approx. 100 kph and the bus/truck speed is 80 kph.

- 10 meters behind the bus/truck, a warning was issued in the FALSE scenario. An artificial "stone chipping" sound was played in the case of the REFERENCE scenario.

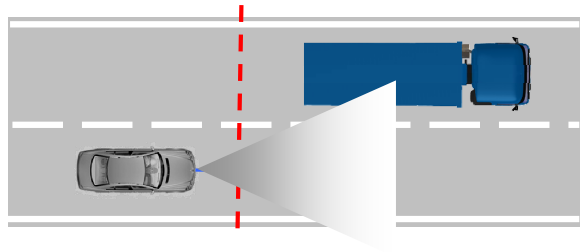


**Figure 9. FALSE scenario**

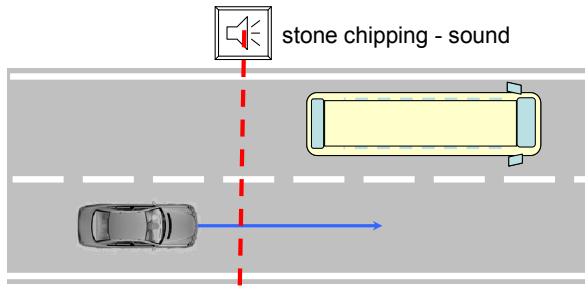



**Figure 10. REFERENCE scenario**

In total, 38 subjects without any previous experience with the Toyota driving simulator were selected for the experiments. The selection was made considering a balanced distribution in terms of age, gender and driving experience:

- 19 females and 19 males

- Age = [25, 71] y/o, average = 46 y/o

- Annual mileage = [120, 20000] = 9700 km

Some tests could not take place, were interrupted or incomplete due to inadequate setting of scenario or subject conditions.

Data obtained for TRUEwith vs. TRUEwithout analysis:

- 16 subjects started the experiments with a TRUEwith event (A1/A2 subjects)

- 18 subjects started the experiments with a TRUEwithout event (B1/B2 subjects)

- 15 subjects finished the experiments with a TRUEwithout event (A1/A2 subjects)

- 18 subjects finished the experiments with a TRUEwith event (B1/B2 subjects)

Data obtained for FALSE vs. REFERENCE analysis:

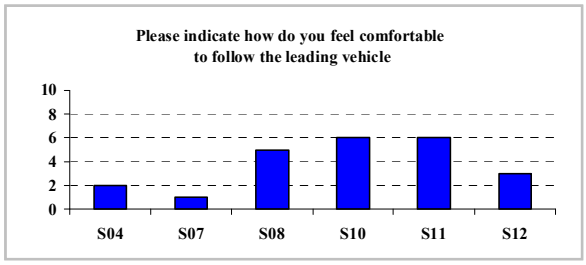
- 17 subjects experienced a FALSE event before a REFERENCE event (A1/B1 subjects)
- 17 subjects experienced a REFERENCE event before a FALSE event (A2/B2 subjects)

## RESULTS

This chapter describes the analysis of the gathered data. Within this paper the test track results are focused on the subjective data while the analysis of the driving simulator deals more with the objective data, particular with the KPIs. Thus the paper gives total overview of the evaluation of the complete data set as defined by the story book.

### Results of track test

On the track, the intended experimental conditions are more difficult to control and to achieve compared to driving simulator conditions. Actually, driving at a speed of 50 kph while maintaining a distance of 20 meters from the vehicle in front is a difficult task to perform. The margins of variation are quite high, despite the previous learning phase. The longitudinal distance varies from 5 to 30 meters. Most of the drivers maintained a distance of between 15 and 25 meters at speeds varying from 40 to 53 kph. However, subjective evaluation shows that the task of following the vehicle in front is not perceived as difficult (Figure 11.).




| very easy | | easy | | some | | difficult | | very difficult | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**Figure 11. Subjective evaluation of the task of following the vehicle in front**

Regarding the reliability of the collected data and the experimental conditions actually achieved, many subjects were rejected: Finally, only 2/10 valid drivers were analyzed in the TRUEwith condition and 7/10 valid drivers in the TRUEwithout condition (Table 2.). Considering the small number of valid drivers, it was not reasonable to compare the two conditions TRUEwith and TRUEwithout, nor was it possible to compare the two sequences (A1 vs. B2).

**Table 2.**
**Summary of rejection of subjects**

| | TRUEwith | TRUEwithout |
|---|---|---|
| **Valid drivers** | **n=2 (S04 and S08)** | **n= 7 (S04, S07, S09, S11, S12, S13, S16)** |
| **No data collected** | **n=2 (S10 and S15)** | **n=3 (S08, S10, S15)** |
| **No warning – driver brakes before the warning** | **n=3 (S09, S11, S13)** | |
| **Driver's braking and warning at the same time** | **n=3 (S07, S12, S16)** | |

The intended aim of the secondary task was to cause a visual distraction in order to create critical situations with regard to the decelerating vehicle in front. The visual requirement was not controllable, as the driver can choose the moment when he or she looks or doesn't look at the road. Observations show that some drivers carry out the secondary task quickly with one or two short glances, while others need more and longer glances. One methodological point to check was the effect of the secondary task on the driver's behavior after the familiarization phase. This effect was analyzed regarding the mental stress which was operationalized by the standard deviation of the "Steering Entropy" (SE - Std). Three sequences were used to evaluate the effect of the secondary task:

- A baseline sequence before the secondary task (Base_Std)
- A sequence during the secondary task, 1 sec. before the start and 5 sec. after the end (Event_Std)
- A sequence lasting 5 seconds immediately after the secondary task (Post_event_Std)

Regarding the collected data, 6 drivers were analyzed. The analyzed data covered two different laps by 4 drivers, and one lap each by the 2 other subjects. Considering the small number of subjects, it

was only possible to perform qualitative and individual analyses (Figure 12.).

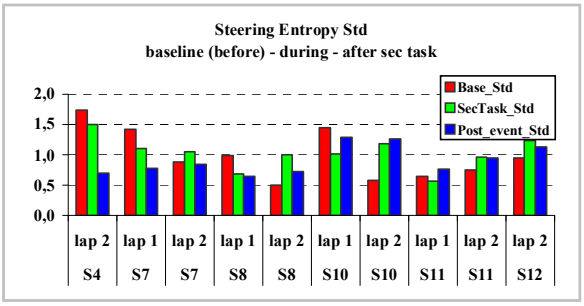



**Figure 12. Effect of the secondary task on the "Steering Entropy"**

The SE - Std increases with the secondary task for 2 drivers (S08 and S10) during lap 2. For the other drivers, the SE - Std decreases or is quite equal to thei individual baseline. It seems that the secondary task does not induce any additional mental stress. However, the questionnaires confirm the high requirement for S08 and S10, and show that 4 other drivers mention that the secondary task is difficult to achieve (Figure 13.).

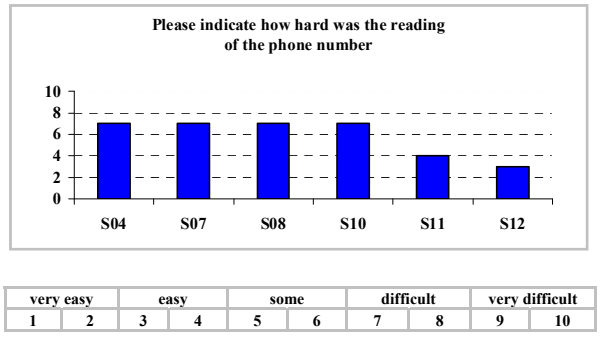



**Figure 13. Subjective assessment of the secondary task**

For the analysis of FALSE vs. REFERENCE maneuvers only the data of 6 drivers were reliable. In the FALSE situation, all drivers heard the tone and recognized it as a false warning (some drivers recalled the visual warning), some drivers had some expectations, because they saw an obstacle on the road (the corner reflector device). In the REFERENCE situation, all drivers heard the sound and did not recognize it as a "stone chipping" sound. Some drivers realized that the sound came from a laptop inside the vehicle. Figure 14. shows that the mental stress is higher with the false alarm compared with the "undefined sound" heard by the drivers.

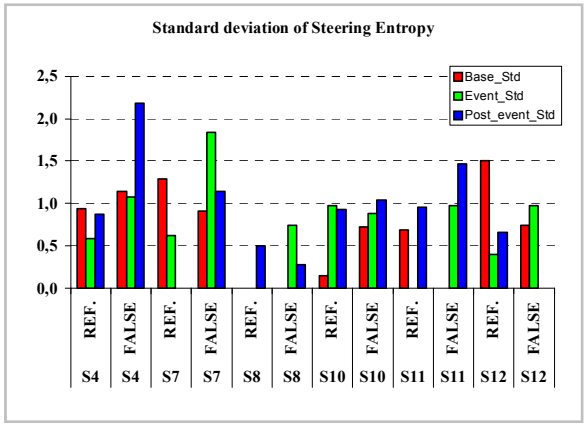
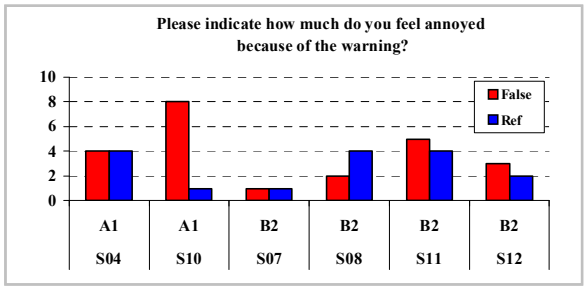



**Figure 14. Comparison of mental stress in FALSE and REFERENCE conditions (SE - Std)**

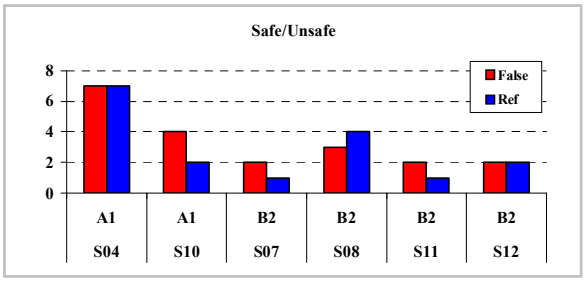
The subjective evaluation shows that the drivers were not annoyed by the false alarm because they expected it and were able to explain it, as they saw an object on the road that the IVSS might have detected by mistake, and there were no other vehicles around. A high level of annoyance was reported only once, and the driver involved (S10) reacted instinctively by decelerating (Figure 15.).




| negligible | | little | | some | | strong | | very strong | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**Figure 15. Subjective evaluation of annoyance**

Only one driver felt unsafe when the false alarm occurred, because he was surprised by the false alarm and could not infer any reason (Figure 16.).




| very safe | | safe | | some | | unsafe | | very unsafe | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

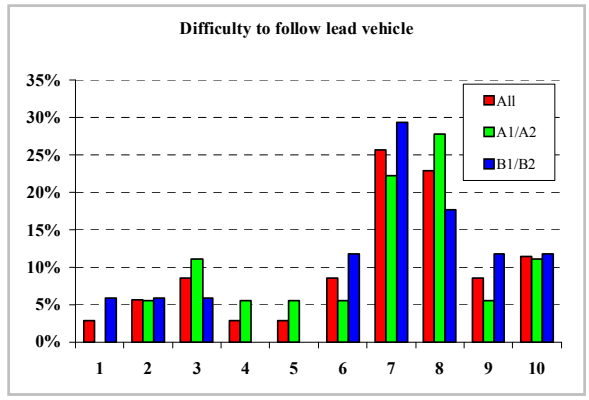
**Figure 16. Subjective evaluation of feeling of safety**

**Results of simulator test**

The results presented in this section focus on the evaluation of the proposed test design using a simulator as a tool to perform an analysis of the benefit of a pre-crash warning function. More particularly, the methodology is evaluated with regards to:

- Subject selection and validation
- Relevance of the secondary task
- Expectancy effects related to the 4th event
- Relevant KPIs to evaluate benefit of the warning function
- Finally, an attempt to specify the typical driver reaction has been made.

The advantage of driving simulator experiments compared to test track tests is that the initial conditions (speed, distance) are more controllable and should help to keep the test scenario critical. However, it was a challenge for most of the drivers to remain comfortable and drive in a natural way. Some variation in driving speed and headway time could be observed due to the difficulty that subjects had in performing the driving task as instructed (Figure 17.), resulting in different levels of imminence of a collision, represented by a higher "Time To Collision" if no driver reaction had occurred (Figure 18.).




| very easy | | easy | | some | | difficult | | very difficult | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**Figure 17. Subjective assessment of the difficulty to follow lead vehicle in front**

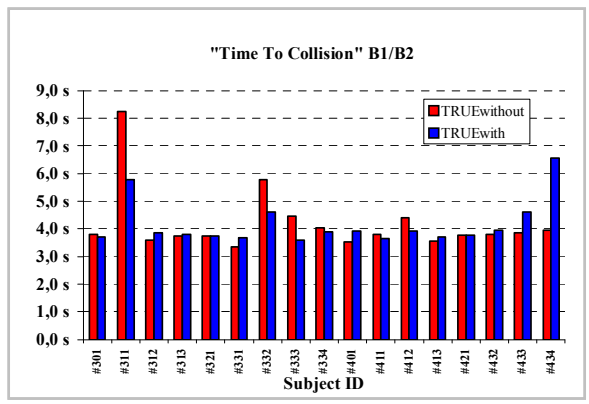



**Figure 18. Remaining TTC when leading vehicle in front starts braking if no driver reaction has occurred**

The remaining "Time To Collision" when the leading vehicle starts braking is not a boundary condition as such. However, the level of criticality of the event will depend on the combination of the imminence of the collision and of the duration of the visual distraction resulting from the secondary task. In other words, a longer duration before collision would require a longer visual distraction to ensure the event is critical enough.

As it is necessary to have a set of events which have been identified as critical enough to enable a relevant comparison between both conditions (with vs. without system), for the analysis of objective data, a preliminary filter has been applied excluding:

- Subjects who initiated a braking reaction before the start of the deceleration of the leading vehicle

- Subjects who aborted the secondary task before the leading vehicle started braking.

- Drivers who aborted the secondary task earlier than 4 seconds prior to an expected collision if no driver reaction had occurred.

As a remark, drivers who aborted the secondary task or applied the brakes after leading vehicle started braking but before a warning was issued (in the case of the TRUEwith event) were not necessarily excluded, to keep the same filtering conditions between the TRUEwith and TRUEwithout datasets. In addition, these drivers were slightly distracted and even though they could see the leading vehicle before the warning, they may not have immediately realized the criticality of the situation, and a warning function may be of help in that case to react faster or with stronger greater braking force. As a result, the data obtained are as follows:

- 15 subjects who started the experiments with a TRUEwith event (groups A1/A2) out of the initial sample of 20 subjects

- 17 subjects who started the experiments with a TRUEwithout event (groups B1/B2) out of the initial sample of 18 subjects

- 15 subjects who finished the experiments with a TRUEwithout event (groups A1/A2) out of the initial sample of 20 subjects

- 11 subjects who finished the experiments with a TRUEwith event (groups B1/B2) out of the initial sample of 18 subjects

The objective of the secondary task was to generate a visual distraction in order to achieve the situation where a collision is likely to occur. Aiming to control the visual distraction in a consistent and controllable way was a real challenge. It was observed that different attitudes were adopted by the subjects to perform the secondary task. One possible criterion to quantify the achieved level of visual distraction is the remaining duration before collision when the driver aborts the secondary task (end of last glance) (Figure 19.). Focusing on subjects who performed a TRUEwithout event at first (B1/B2 groups), an initial observation is that the secondary task resulted in a wide time range for ending the visual distraction. It can be observed that without the warning, around 65% of drivers aborted the visual distraction 2 to 3 seconds before the collision and around 29% between 1 to 2 seconds before the collision.

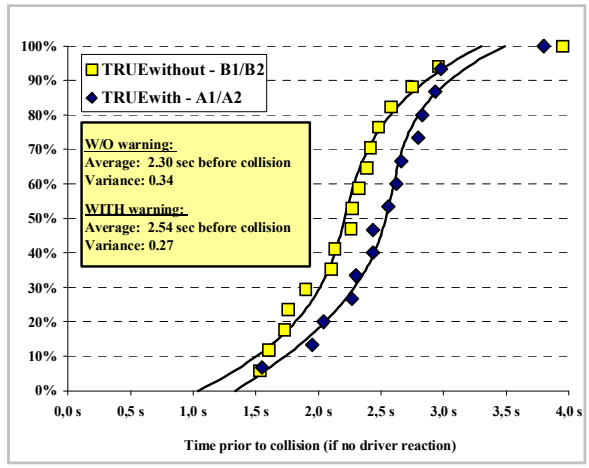



**Figure 19. End of visual distraction in first events**

All drivers aborted the visual distraction earlier than the last second before the collision. The duration of the visual distraction resulting from the secondary task and its robustness will be the main limitation to explore the benefit of a warning function. With a visual distraction which is aborted too early, it is likely that the situation would not be challenging enough to be able to observe a clear benefit from a warning function. In the experiments conducted here, by comparing TRUEwith and TRUEwithout subjects, some difference can be observed. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 1.54$, $P < 0.2237$.

To investigate possible expectancy effects, TRUEwithout situations in 1st and 4th events were compared. During the first TRUE event, the subjects were not prepared to face a critical scenario. Drivers can be considered as “naïve drivers”.

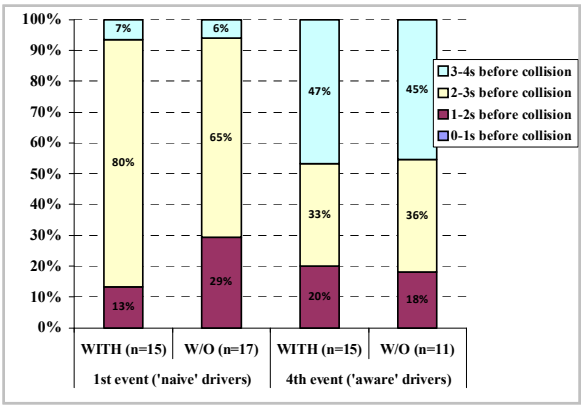



**Figure 20. End of visual distraction – 1st vs. 4th events**

In the fourth event, drivers have experienced a critical scenario a few minutes beforehand. They can be considered as "aware" drivers. It could be observed that they were prepared to face another critical event (Figure 20.):

- Indeed, a significant difference in the level of distraction can be observed between "naïve" and "aware" drivers. 45%-53% of "aware" drivers end the visual distraction earlier than 3 seconds before the estimated collision, while the figure was 6%-7% for normal drivers.

- As a result, a slight difference could be observed with the warning function in the case of "aware" drivers.

Due to the observed expectancy effects, the evaluation of the benefits of the warning is considered only for "naïve" drivers. Two KPIs were investigated related to brake timing:

- "Brake Reaction Time" from leading vehicle starts braking

- "Time To Collision" when driver applies the brakes

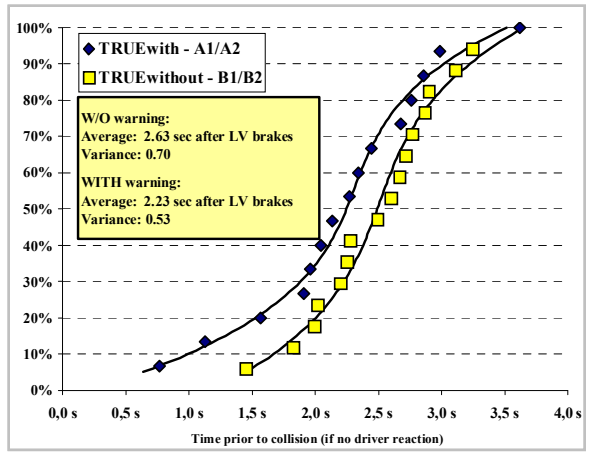



**Figure 21. BRT from leading vehicle in front starts braking**

The KPI "Brake Reaction Time" is relevant to highlight the difference in braking time of both conditions (TRUEwith vs. TRUEwithout). A benefit of the warning function can be observed here (Figure 21.), allowing earlier braking for subjects who experienced a warning. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 2.03$, $P < 0.1641$. The main limitation of this indicator is that as such it is only applicable for the "leading vehicle braking" type of scenario. In the event of another type of scenario (e.g. "leading vehicle stopped" or "slower leading vehicle") another origin point will have to be redefined. Furthermore, this KPI remains valid as long as the initial conditions in the dataset remain in a reasonable range. Excessive variations of the initial conditions may make this KPI hard to use.

The well-known KPI "Time To Collision" (TTC) is defined by:

- TTC = relative distance/relative speed

However, in the particular case of the "leading vehicle braking" scenario, TTC is not linear with time and therefore will not be used, as the intention here is to understand the hypothetical time duration remaining before a collision would occur if the subject vehicle speed did not change.

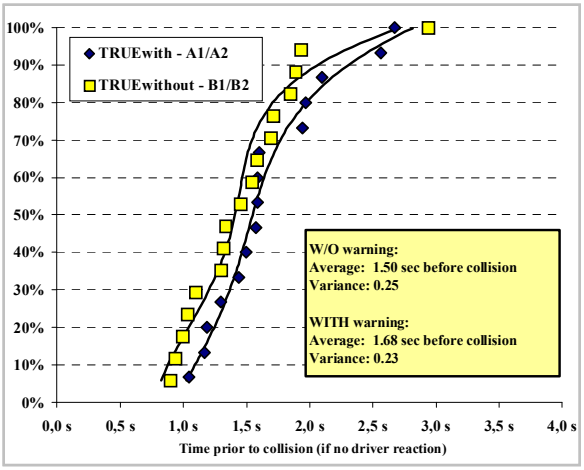



**Figure 22. TTC at brake point**

All drivers (with/without system) braked more than 1 second prior to the collision. With this KPI, a difference between both conditions can be observed (Figure 22.), showing earlier braking for subjects who experienced a warning. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 1.09$, $P < 0.3051$. The advantage of this KPI is that it is independent of the test scenario. It can be applicable to any kind of pre-crash scenario (e.g. "leading vehicle stopped" or "slower leading vehicle").

Based on the obtained results, there was an attempt to define a "typical" and "generic" driver reaction model to be applied for further actual vehicle tests in FP7 ASSESS. Some parameters could be defined and summarized below.

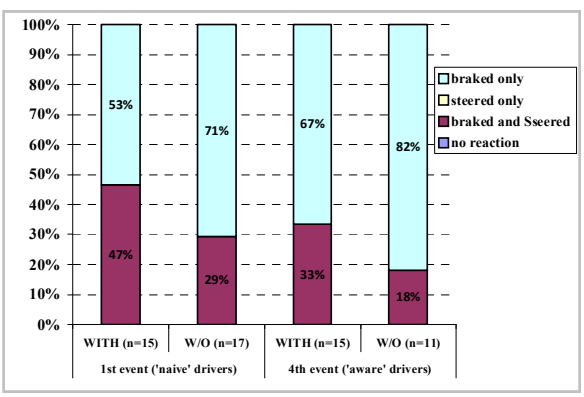



**Figure 23. Driver's reaction to warning – type of avoidance maneuver**

The type of avoidance maneuver was classified by whether the driver was only braking, making an attempt to avoid the vehicle in front by steering (confirmed visually from videos) or doing a combination of both braking and steering (Figure 23.). It was observed that in all cases, all drivers reacted by a single braking action or by a combination of braking and steering. No cases of "no reaction" were found. For those who reacted by a combination of braking and steering, it was observed that the brake was always applied before or at the same time than the steering action. However, it should be noted again that the performance of the secondary task plays a major role which can influence this result. When interpreted as a reaction to the warning function in TRUEwith cases, a model with respect to driver reaction time can be specified (Figure 24.):

- A fast reaction model would cover 25% of cases with a brake timing of 0.78 seconds after the warning is issued

- A low reaction model would cover the remaining 75% of cases with a brake timing of 1.81 seconds after the warning is issued

Considering the limitations mentioned in previous sections, it is important to note that this model is applicable for the given test scenario and the given secondary task. The result may differ in other situations.

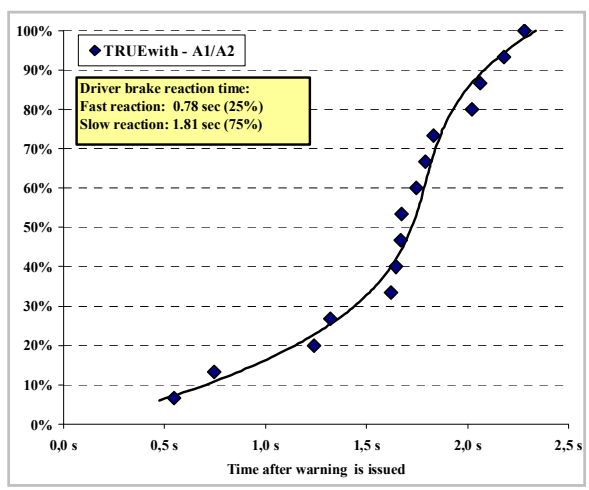



**Figure 24. Brake reaction to warning**

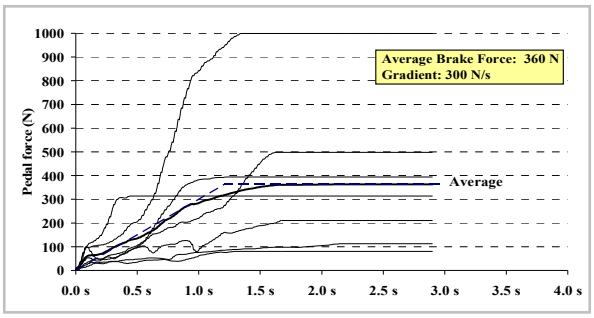



**Figure 25. Braking profile as reaction to the warning (A1/A2 subjects who applied brakes only)**

Focusing on the subjects who applied braking action exclusively (without any steering avoidance maneuver), the average braking profile has been estimated (Figure 25.):

- Brake force: 360 N
- Gradient: 300 N/sec

**DISCUSSION**

We have seen that to perform a relevant TRUEwith vs. TRUEwithout analysis, it is necessary to have a set of events which have been identified as critical enough to enable a relevant comparison between both conditions (with and without system). In that perspective, a test design in a driving simulator would be much easier to set up given the controllability of the initial conditions (speed and distance) compared to test track tests where a much higher rejection rate is expected. The test track is preferable considering testing with an actual car. However, a lot of limitations have to be taken into account (critical scenario, testing in a safe environment). The work done is promising but further work is necessary. The remaining question is "how critical should a TRUE event be?" An attempt has been made in the driving simulator experiments to define boundary conditions with respect to the criticality.

Apart from the scenario's initial conditions, the main parameter which will influence the criticality of the event is the "secondary task". Indeed, the visual distraction is expected to be dependent on the combination of the secondary task and of the scenario. A more demanding secondary task would lead to a higher proportion of distracted subjects, while a less demanding secondary task would lead to a smaller proportion. As a consequence, any observed benefit of a warning function will be highly dependent on the selected secondary task. The key question here is whether a given secondary task will induce a distraction which is representative of an "average" visual distraction in the real world.

The initial test design combined four maneuvers (TRUEwith, TRUEwithout, FALSE and REFERENCE) per test run and subject in different permutations. The intention was to optimize the number of subjects and to avoid any order or expectancy effects. Analysis of the results showed that for TRUE events, the level of expectancy is high in the 4th maneuver. After having experienced a critical scenario a few minutes beforehand, most of subjects were prepared to face another critical event, and a significant difference in driver reaction was observed. As a conclusion, such a test design combining more than one TRUE event is less appropriate.

Two KPIs ("Brake Reaction Time" and "Time To Collision") have been investigated regarding the evaluation of the IVSS's HMI benefit. Both are suitable to differentiate the effect of a warning function on the driver reaction by trend. However the differences were not significant for the conducted experiments. Some limitations regarding the application to different kind of maneuvers and regarding their interpretation have to be considered.

There was an attempt to define a "typical" and "generic" driver reaction model to be applied for further actual vehicle tests in FP7 ASSESS. It is important to note that the driver reaction model provided here is specific to one scenario ("leading vehicle braking" at 0.7 g) in combination with the secondary task used. Applicability to other test scenarios could not be verified and limitations considering the secondary task should be taken into account when further referring to this result.

Regarding the FALSE and REFERENCE scenarios, the qualitative analysis carried out for each subject indicates that subjective and objective indicators are complementary and relevant to evaluate the level of disturbance induced by the false alarm. But this result still needs to be confirmed with more subjects.

## CONCLUSION

The story book for the assessment of driver behavior with respect to the benefit analysis of Integrated Vehicle Safety Systems, which was developed by WP3 within the ASSESS project, delivered the fundament for a purposeful experimental design. Its concept could be adapted to a test track and a driving simulator environment. A third experiment will be conducted at the Mercedes-Benz Driving Simulator in the same manner. In general, the transfer of the experimental design led to meaningful results. The effect of forward collision warning systems on driver behavior could be evaluated through the gathering and analysis of subjective and objective data. On the other hand also some limitations and open issues for further improvements were found. Measures will concern in particular the secondary task, avoidance of expectancy effects and the optimized adaption to the test track environment. To compile a draft protocol for the assessment of behavioral aspects as a final goal of WP3, the story book will be accordingly revised within WP3 and in agreement with the concerned WPs of the ASSESS project.

## ACKNOWLEDGEMENT

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