DRIVING SIMULATION STUDY

INFLUENCE OF ROAD MARKINGS VISIBILITY ON DRIVER BEHAVIOUR IN NIGHT RAIN CONDITIONS

RAINVISION

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ABSTRACT

The purpose of this study was to assess the impact of the visibility of different road markings in night time driving during rainy conditions, also taking into account different age groups based on a driving simulator study. Therefore, an experiment was carried out on a specifically prepared driving simulator through several driving sessions in the area of Paris, France. 123 subjects were recruited based on three age groups, including vision testing to ensure a valid interpretation of results.

Simulation test drives were carried out by night within two different road delineation conditions (standard road markings and night rain visible road marking that have enhanced visibility properties during rain) on a realistic itinerary of a two-lane rural road. With the help of data recorders, driving performance was measured by means lateral position behaviour (number of errors expressed as driving lane departures and road departures).

Enhanced visible road markings are simulated on the visual base of the simulator with a preview time of 2.5 sec, compared to standard road markings with a preview time of 1.5 sec. Preview time was calculated for the speed limit applicable in rainy conditions (i.e. 80 km/h), which is similar to the design speed of the road (posted sign speed 90 km/h). Based on the qualitative report of the operators who monitored the driving sessions, subjects generally experienced difficulties in choosing the appropriate speed in both conditions of enhanced and standard road marking visibility.

Unfortunately, driving behaviour expressed in terms of travel time, mean lateral and longitudinal accelerations was finally not investigated, as a result of the intrinsic complexity of data mining with the equipment used and due to sources of uncertainty in the identification of the drivers' sessions.

Due to unexpected difficulties, two sets of visual environment were embedded in the driving simulator. A first environment simulation (called environment simulation 1) was tested on the basis of an advanced imaging technology. Despite its intrinsic superiority, this simulation did not perform adequately: vertical objects appeared as back lighted in the road scene of the driving simulator. These abnormalities forced us to test a second visual simulation with a normal restitution of the vertical objects (called environment simulation 2).

In particular visual conditions such as in environment simulation 1, more visible road markings did not improve the situation compared to less visible ones, but the interpretation of results was probably biased by the unexpected presence of visual distractors.

In a normal environment simulation (environment simulation 2), results indicate that that road trajectory was best with visible, enhanced markings compared to less visible, standard road markings. Based on the analysis of the lateral position of the vehicle, it has been noticed that enhanced road markings may have a positive effect on the trajectory of drivers in adverse driving conditions simulated in this study. Less run-off-the road incidents and lane departures were observed with enhanced road markings compared to standard road markings. Under night-time und rain driving conditions, the enhanced road markings may generally have guided the subjects on the driving path better than standard road markings.

From a traffic safety perspective, the use of more visible road markings in a legible visual environment (environment simulation 2) may lead to a decrease in errors made by drivers (departures on the opposite lane, run-off the road), especially among the youngest and the oldest classes of age. This potential benefit was not observed in a 'polluted' visual environment, such as used in the first driving sessions (environment simulation 1).

1. INTRODUCTION

This deliverable is the WP2 Report on Driving Simulation Study of the RAINVISION project. It will present the methodology used to develop and implement the simulation study, including the recruitment of subjects, the development of the simulator (visual environment, artificial intelligence, data recording, monitoring), the description and results of the driving sessions and the obtained results.

The driving simulator is a well-known method to evaluate the effect of visual environment on driver behaviour. Despite its lack of natural ecology compared with a real driving experience, the driving simulation offers several major advantages. The experimental conditions (e.g. the visual environment) can be precisely fixed and controlled. On the contrary, the conditions of visibility on a road are submitted to numerous parameters that can influence the behaviour of drivers. Driving simulation also ensures the safety of subjects, would they commit operational errors or engage into hazardous manoeuvers compared with track or road experiments. Finally, the scope of the experiment can be precisely defined, and data may be more accessible compared with in car or roadside experiments.

As the use of driving simulators has been expanding in transportation research, it raises the question of the simulators' validity - whether results obtained in the simulator are applicable to real-world driving. Some research (Rosey and al. 2009) compared the results from driving simulator experiments and real road experiments. They obtained a good behavioural validity concerning the effect of narrowed driving lanes on lateral position (similar results for experiments in driving simulator and experiments in real roads).

For the purpose of the Rainvision project, it was decided to test the influence of the visibility of road markings on the behaviour of drivers in adverse conditions (night, rain) reproduced on a driving simulator. Two-lane rural roads represent the highest risk network for road users in Europe. For this reason, two-lane roads were selected to be reproduced and tested on the simulator.

The WP2 Report is separated into 6 chapters.

- **Chapter 2:** Recruitment of subjects for driving simulation experiment
- **Chapter 3:** Development of the driving simulator
- **Chapter 4:** Results of driving sessions session 1 (enhanced visual environment)
- **Chapter 5:** Results of driving sessions 2 and 3 (classic visual environment)
- **Chapter 6:** Evaluation of results
- **Chapter 7:** Conclusions and perspectives

2. Recruitment of Subject for Driving Simulation Studies

Recruitment is an important phase of any experiment. Depending on the quality of the process, the results may be more or less reliable. Some permanent organisations can provide subjects. In France, the most well know source of subjects is called RISC. Subjects are recruited though an extranet, for different experiments having different requirements in terms of population and profiles, and different localisations and modalities (most of experiments offer financial compensations to people for the time allocated). While financial compensations do not constitute a real income, some people tend to set up networks of relations to take advantage of this situation, which risks biasing the neutrality of the subjects, and the results of the experiment.

For Rainvision, the recruitment of subjects should have been outsourced to Develter, the company contracting the simulator and its development. Given, however, the large number of drivers to be recruited (between 90 and120 people), it was decided to diversify the sources of subjects.

Develter finally recruited the elderly drivers (age bracket 61+), among clubs of elderly people or elderly car drivers.

- During the different sessions, 38 drivers were tested on a driving simulator. Most of subjects (37) were 61+ years old, while 1 was in the 41-60 years old class.

Aximum finally recruited the young and middle age drivers (age brackets 20-40 and 41-60), among the employees of the company and of the group near Paris.

- Aximum recruited subjects from the headquarters of the company located in Chatou, enabling the recruitment of 53 people, including complete visual ability test as described below and driving session on the driving simulator. The staff included people working at the building, i.e. on the one hand, people directly working for the headquarters, covering supporting functions such as information system, law, accounting and finance, human resources and general management, and on the other, people working for a branch of Aximum electronic products (technical staff essentially).

- Aximum also received the help of Colas R&D Centre, located in Magny-les-Hameaux, enabling the recruitment of 33 people, including complete visual ability test as described below and driving session on the driving simulator.

2.1. General recruitment of the subjects to be tested on the driving simulator

A total of 123 subjects were recruited and tested as drivers on the driving simulator through several sessions (Table 1). The requirements for the recruitment were that people should be aged of at last 20 years old[2], should have hold a class B driving license for a minimum of 2 years and should usually drive a vehicle on a daily basis.

Table 1 Reconstruction of the samples for simulation sessions based on the different recruitment sessions

Class of age	Raw number of drivers	Exploitable number of drivers
20-40	47	45
41-60	41	40
+ 60	35	34
TOTAL	123	119

Gender	Raw number of drivers	Exploitable number of drivers
Male	69	68
Female	54	51
TOTAL	123	119

All the subjects were recruited on a **voluntary basis** (no fee, no obligation) among two types of population: employees of the company in France (headquarters of Aximum and research centre of Colas, Aximum's parent company) and members of cities in the area of Paris, France (Voisins-le-Bretonneux and Fontenay-le-Fleury). They were invited to perform a visual ability test, and to carry out simulator drives in two different conditions.

For practical reasons, the recruitment of the subjects for the simulation driving sessions was done geographically. The recruitment within the staff of the companies Aximum and Colas enabled to cover the two first age brackets (20-40, 41-60). The recruitment within associations or cities enabled to cover the third age bracket (61+). Each driving session generally contained participants of several age brackets, except for the elderly drivers.

After analysis, 4 drivers were not exploitable, which led to a net population of 119 drivers.

After combining the differ rent recruiting sessions, we obtained a sample of 47 subjects aged from 20 to 40 (see table Annex 1a). In this age bracket, most adults enjoy healthy eyes and good vision.

The average age of the subjects was 30.9 years. The sample contains approximately the same number of men (53%) and women (47%). After analysis, 2 drivers were withdrawn (female age 24, male age 37), due to missing data to interpret the driving tests. The exploitable population in the age bracket contains 45 drivers.

[2] In France, the minimum age for the driving license is 18 years old.

Table 2 Description of the sample of subjects, age bracket 41-60, based on the different recruitment sessions

After combining the different recruiting sessions, we obtained a sample of 41 subjects aged from 41 to 60 (see table Annex 1b). Adults aged 41 to 60 experience commonly age-related vision changes: need for more light, difficulty in close vision, difficulty adapting to glare from headlights at night or sun reflecting, changes in colour perception making it harder to see and distinguish between certain shades of colours).The average age of the subjects was 47.8 years. The sample contains more men (24 on 41 i.e. 60%) than women (17 on 41 i.e. 40%). After analysis, 1 driver was withdrawn (male, age 48), due to missing data to interpret the driving tests. The exploitable population in the age bracket contains 40 drivers.

After combining the different recruiting sessions, we obtained a sample of 35 subjects aged more than 60, one being not specified for its gender (see Table annex 1c).Adults aged aver 60 commonly experience a loss of visual accuracy, difficulty in close vision, changes in colour perception, problems seeing in low light or night-time's conditions, difficulty adapting to glare from headlights, experiencing a loss of side vision).
The average age of the subjects was 74.3 years. The sample contains approximately the same number of men (18 on 35 i.e. 53%) and women (17 on 35, i.e. 47%). After analysis, 1 driver was withdrawn (female, age 82), due to missing data to interpret the driving tests. The exploitable population contains 34 drivers in the age bracket

2.2. Selection of the subjects to be tested on the driving simulator

During the recruitment phase, people were invited to participate to a driving simulation session, lasting less than half an hour, including a visual ability test and the driving session itself. Some stickers were distributed to encourage people to participate to the test (figure 1).

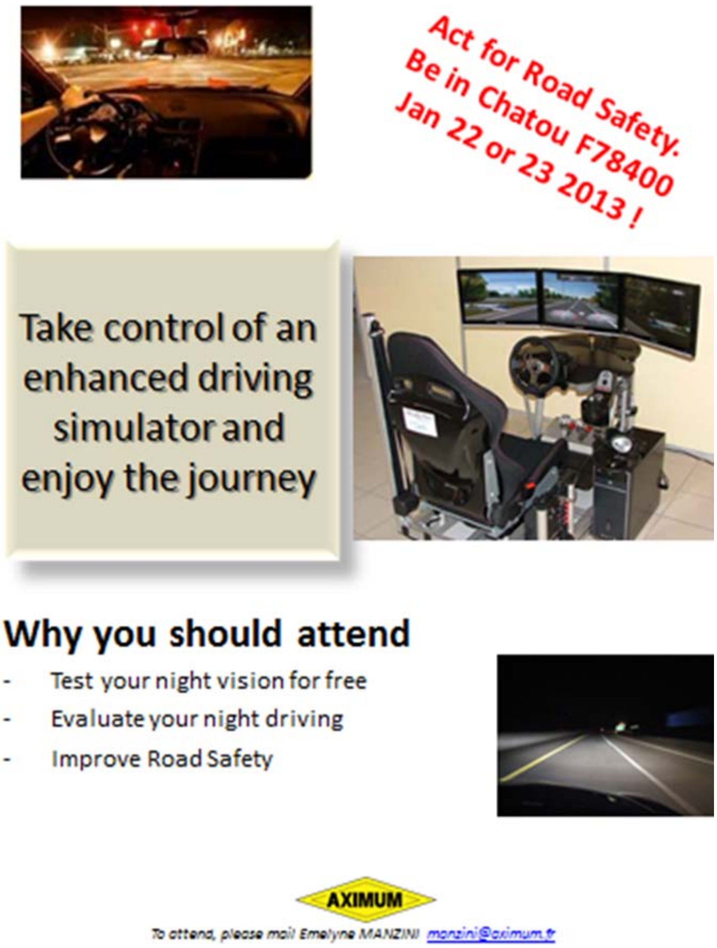


Figure 1 Example of invitation to participate to the driving sessions

All data were used in an anonymous way, without any other purpose except road safety research.

For employees especially, the recruitment indicated that neither the driving session nor the visual ability test would be used to evaluate their capacity to drive in the scope of their professional activity. All subjects had to contact the manager of the session to book a slot to be able to perform the test during a scheduled day.

2.3. Vision ability test

To avoid biased results, test subjects should have been specifically pre-selected by means of reactivity, peripheral perception and visual abilities in order to provide homogenous test groups. This top-down approach was finally not fully implemented for different reasons:

- no equipment was available to test reactivity and peripheral perception;
- a bottom-up approach was preferred, including all drivers whatever their visual abilities;
- test groups were determined based on the classes of age, which are generally representative of their visual abilities.

The information form of the visual ability test is enclosed in Annex 2. This test was tailored to cope with the visual issues indicated in the scope of the project, i.e. night time driving, different classes of age for vision and individual ability. The vision ability test has no medical purpose, and shall not replace a medical examination performed by a medicine doctor. It only gives some indications on the visual capabilities of a subject.

Consequently, the vision ability test included the following tests.

Binocular acuity for long distance vision

Long distance binocular acuity is part of photopic vision.

Photopic vision is the vision by day condition or vision under artificial lighting with a luminance of at least 10 candelas per m² (Wikipedia, 2013). Binocular acuity is used to drive, especially during day time and for high speed travels. For a static observer, the visual field is approximately 180°. As the speed increases, the accurate visual field narrows down to a few degrees and the observed distance tends to increase. Binocular acuity is a factor explaining the identification of the path of the road, and the detection of obstacles. Depending on the vision pathology, binocular acuity can be corrected or not. Minimum binocular acuity is recommended to drive, but some drivers are still permitted to drive with one valid eye only.

With Ergovision, binocular acuity is evaluated through the reading of series of figures and letters whose font size corresponds to a visual acuity ranging from 5/10 to 12/10. Binocular acuity is evaluated at the same time for the two eyes together. The subject is asked to read the line starting to a binocular acuity of 4/10, and ranging up to 12/10. Each visual acuity level is validated once four letters or four numbers are read correctly. The binocular acuity is the maximum level achieved. The subject's performance is calculated according to this scale.

Stereoscopic Vision

Stereoscopic Vision represents the short distance vision. It enables to appreciate speed, through the optical flow. The faster the driver drives, the wider the stereoscopic vision is. Combined with binocular acuity, stereoscopic vision enables the driver to appreciate the trajectory of the vehicle.

With Ergovision, stereoscopic vision is evaluated by the reading of series of black solid circles artificially shown at different optical distances (depths of view) through a system of lenses and illuminators. The subject is asked to rank the different circles properly (from the closest to the most distant one). The subject's performance is calculated according to its capacity to rank properly the different circles in coherent and conform manner (number of correct answers and arrangement of answers).

Vision of Colours

As a part of photopic vision, perception of colours contributes to long distance vision.

With Ergovision, the ability to perceive different colours is evaluated by a test showing forms of numbers made with different circles/bubbles and appearing on a complex surface of circles/bubbles of different colours in series of maps. The subjects' performance is calculated according to their capacity to identify properly the series of figures (number of correct and wrong answers).

Vision of contrasts

Vision of contrasts describes the ability to detect contrasts in different illumination conditions; it contributes to mid distance vision. Depending on age, but also on tiredness, vision of contrasts is more or less performing.

With Ergovision, the vision of contrasts is evaluated by the ability to read a matrix combining three series of letters and numbers of decreasing font size corresponding to visual acuity levels 4, 6 and 8 with three decreasing levels of contrast (0,6, 0,4 and 0,2)corresponding to three different lighting conditions, ranging from intermediary to low.

The subject's performance is calculated according to its capacity to identify properly the series of figures and letters (number of correct answers and arrangement of answers in the matrix).

Mesopic Vision

Mesopic vision also contributes to mid distance vision. Mesopic vision is a combination of photopic vision (more than 10 cd/m²) and scotopic vision (less than 0, 001 cd/m²) in low but not quite dark lighting situations. Mesopic light levels range from luminances of 0.001 to 3.0 cd/m² e.g. luminance at dawn. Most night-time traffic lighting scenarios are in the mesopic range. Humans see differently at different light levels. This is because under high light levels typical during the day (photopic vision), the eye uses cones to process light. Under very low light levels, corresponding to moonless nights without electric lighting (scotopic vision), the eye uses rods to process light. At many night-time levels, a combination of both cones and rods supports vision. Photopic vision has excellent colour discrimination ability, whereas colours are indiscriminable under scotopic vision. Mesopic vision falls between these two extremes. In most night-time environments, there is enough ambient light at night to prevent true scotopic vision.

With Ergovision, the mesopic vision is evaluated according to the subject's capacity to identify properly the series of figures and letters of a decreasing font size under low illumination conditions, corresponding to an increasing visual performance.

Glare (vision recovery time)

Vision recovery time due to glare by oncoming vehicles depends on age. For 20 to 40 years old drivers, a recovery time of 60 seconds or less is considered as normal. For 40 to 50 years old drivers, the normal recovery time is 90 seconds or less, whereas for more than 50 years old drivers, this recovery time equals 120 sec or less.

With Ergovision, the vision recovery time is evaluated according to the subject's capacity to identify properly the series of figures and letters after having looked during a given period of time at an illumination source.

2.4. Organisation of the test sessions

For the driving simulator sessions, it was decided that each subject would perform a session of 3 runs including:

- a preliminary run was planned by day in a straight section to make the subject familiar with the handling of the driving simulator: vision of the road on the different screens, hearing sensations, haptic effort on the commands of the vehicle (throttle, brake, steering wheel)…

- a first run was planned by night under rain on the complete itinerary to test the first experimental modality concerning the visibility of road markings in rain night conditions

- a second run was planned by night under rain on the same itinerary to test the second experimental modality concerning the visibility of road markings in rain night conditions

The experimental modalities were stated as follows:

- both runs were performed in simulated rain night conditions (3:30 AM, average rain),

- the driven vehicle specifications were: passenger car, windscreen wiper activated, dipped-beam headlamps, automatic gear

- an experimental modality with the use of a standard road markings (type I), offering no enhanced visibility in night rain conditions, and ensuring a limited preview time of 1.5 second to the driver; the visual delineation of the road course is poor (the preview time does not allow a good anticipation of the driving lanes and of the alignment of the road).

- an experimental modality with the use of enhanced road markings (type II), offering enhanced visibility in night rain conditions, and ensuring a limited preview time of 2.5 second to the driver; the visual delineation of the road course is good, but realistic (not excessive comfort and correct preview time which allows a good perception of the driving lanes and of the alignment of the road).

By reason of simplicity, it was decided that the subjects would drive twice on the same itinerary, but in different conditions. The fact to drive several times on the same itinerary risks nevertheless to teach the subject on the ideal handling of the simulator, and risks to bias the results of the tests.

In order to prevent this learning effect of the itinerary on the simulator, the two runs at condition 1 and condition 2 have been alternated following the sequence outlined in tables 3 to 6.

Table 3 Sequence in the runs for simulation session 1

	Jan 22 2013	Jan 22 2013	Jan 23 2013	Jan 23 2013	TOTAL
Number of subjects	10	9	17	18	54
Run 1	Enhanced road markings	Standard road markings	Enhanced road markings	Standard road markings	
Run 2	Standard road markings	Enhanced road markings	Standard road markings	Enhanced road markings	

The simulation session 1 was scheduled on the 22nd and 23rd of Jan 2013. This session includes a population of 54 drivers (table 3). Among this population, 27 subjects performed the test according to a sequence with a decreased road delineation first (first run with enhanced markings and second run with standard markings), whereas 27 subjects performed the test according to a sequence with an increased road delineation first (first run with enhanced markings and second run with standard markings).

Table 4 Sequence in the runs for simulation sessions 2

	Feb 6 2013	Feb 6 2013	Feb 15 2013 PM	Feb 22 2013 PM	Feb 22 2013 PM	TOTAL
Number of subjects	2	1	3	3	3	12
Run 1	Enhanced road markings	Standard road markings	Standard road markings	Standard road markings	Enhanced road markings	
Run 2	Standard road markings	Enhanced road markings	Enhanced road markings	Enhanced road markings	Standard road markings	

The simulation sessions 2 were scheduled on the 6th, 15th and 22nd of Feb 2013. These sessions include a population of 12 drivers (table 4). Among this population, 5 subjects performed the test according to a sequence with a decreased road delineation first (first run with enhanced markings and second run with standard markings), whereas 7 subjects performed the test according to a sequence with an increased road delineation first (first run with enhanced markings and second run with standard markings).

Table 5 Sequence in the runs for simulation session 3

	Apr 3 2013 AM	Apr 3 2013 AM	Apr 3 2013 PM	Apr 3 2013 PM	TOTAL
Number of subjects	8	8	9	10	35
Run 1	Enhanced road markings	Standard road markings	Standard road markings	Enhanced road markings	
Run 2	Standard road markings	Enhanced road markings	Enhanced road markings	Standard road markings	

The simulation session 3 was scheduled on the 3rd of April 2013. This session includes a population of 35 drivers (table 5). Among this population, 18 subjects performed the test according to a sequence with a decreased road delineation first (first run with enhanced markings and second run with standard markings), whereas 17 subjects performed the test according to a sequence with an increased road delineation first (first run with enhanced markings and second run with standard markings).

Table 6 Sequence in the runs for simulation session 5

	May 6 2013	May 6 2013	May 7 2013	May 7 2013	TOTAL
Number of subjects	7	7	4	5	23
Run 1	Enhanced road markings	Standard road markings	Standard road markings	Enhanced road markings	
Run 2	Standard road markings	Enhanced road markings	Enhanced road markings	Standard road markings	

The simulation sessions 5 were scheduled on the 6th and 7th of May 2013. These sessions include a population of 23 drivers (table 6). Among this population, 12 subjects performed the test according to a sequence with a decreased road delineation first (first run with enhanced markings and second run with standard markings), whereas 11 subjects performed the test according to a sequence with an increased road delineation first (first run with standard markings and second run with enhanced markings).

3. DEVELOPMENT OF THE DRIVING SIMULATOR

Because the contracting company planned to improve the performance of its driving simulator based on a new visual engine, Aximum (in charge of the simulation WP) decided, with the agreement of other project's partners, to postpone the specific adaptation of the tool for the purpose of the project.

This coordinated development intended to improve the capabilities of the simulator and the quality of the test sessions with the help of the following adjustments.

3.1. Visual simulation of the road for the driving task

The initial driving simulator was not designed for driving by night under rainy conditions. Moreover, this simulator had not yet been tested on sinuous sections of road, due to the intrinsic difficulty to reproduce such manoeuvers in an ergonomic way.

The visual database of the simulator should then be available to include curves, realistic rain conditions and road delineation depending on weather conditions.

Design of the simulated road

A 3D visual environment was developed based on the design of a 2 lane rural road composed of several stretches (figure 2). The simulated road is a 2 lane rural road, without paved shoulder, with two driving lanes of 3.50m wide theoretically. The intrinsic calibration of the simulator (making it difficult to adjust the position of the vehicle into the curves) led to a final width of 4.00m wide approximately.

The vehicle is parked in a car park, which access to the main road. Once on the road, one shortly arrives to a first roundabout (roundabout 1).

- The roundabout communicates with a 600m long straight section (outward run),
- Which ends into a 600m long sinuous section including 7 curves of medium radii
    - a left-hand curve (the car being located in the outer curve due to left-hand driving in FR),
    - a right-hand curve (the car being located in the inner curve due to left-hand driving in FR),
    - a right-hand curve,
    - a left-hand curve,
    - a left-hand curve,
    - a right-hand curve,
    - ending with a left-hand curve
- Which ends into 600m long straight section
- Which ends into another roundabout (roundabout 2).

Figure 2. Simulated environment of the test road

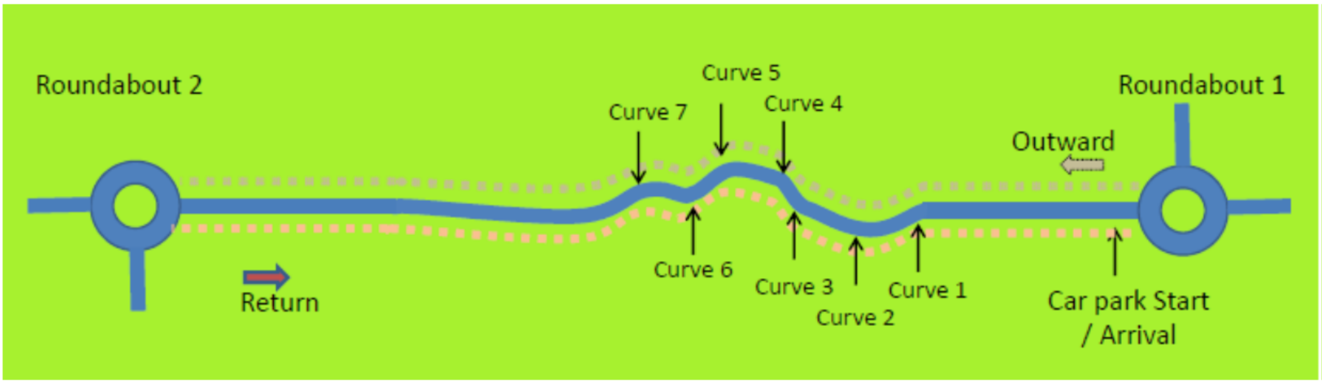


Figure 2 only provides an indicative graphic representation of the road. The sinuous section contains a series of 7 fixed-radii curves, providing intermediate values but significant solicitations for the vehicle and the driver.

Two experimental modalities were simulated:
- a driving scenario in night rain conditions including enhanced visible road markings.
- a driving scenario in night rain conditions including standard visible road markings.

Each scenario includes an outward run…

the driver starts from a car park,
- he/she turns around through the first roundabout (1),
- he/she drives on a straight section,
- he/she negotiates a sinuous section presenting successive curves without straight stretches in between
  - a left-hand curve (the car being located in the outer curve due to left-hand driving in FR),
  - a right-hand curve (the car being located in the inner curve due to left-hand driving in FR),
  - a right-hand curve,
  - a left-hand curve,
  - a left-hand curve,
  - a right-hand curve,
  - ending with a left-hand curve,

…and a return run:
- he/she drives again in a straight section up to another roundabout (2)
- he/she turns around through the roundabout 2,
- he/she drives on a straight section,
- he/she negotiates the same sinuous section in the opposite direction
  - a right-hand curve,
  - a left-hand curve,
  - a right-hand curve,
  - a right-hand curve,
  - a left-hand curve,
  - a left-hand curve,
  - ending with a right-hand curve,
- the driver stops in front of the car park.

3.2. Calibration of road markings visibility

On the new platform of the driving simulator, the visibility of road markings could be adjusted through a cursor, through an algorithm which modifies its colorimetric and photometric contrast. The choice of the distance of visibility for road markings based itself on the state of the art (literature review on both simulator and test track experiments) and on an evaluation by a panel of experts composed of the partners of Rainvision project.

This new visibility cursor was supposed to reproduce the differences of visibility performances of road markings. Depending on their nature, their wear (age, traffic …) and the conditions (day/night, dry/rain), road markings can indeed deliver very different visibility levels.

The state of the art shows that in situ visibility of road markings is generally measured through the intrinsic physical properties of materials, expressed in terms of photometry (day time visibility based on luminance, night time visibility based on retro reflectivity) and of colorimetry (trichromatic coordinates).

The Johnson criteria define the visibility of a target given the geometry of the target (dimensions of the road markings) and its relative visibility compared to the background (contrast of photometry between road markings and the road course). Based on this visual function, it is possible to determine thresholds of retro reflectivity which ensure a good visibility of road markings by night given the geometry of illumination (height of the headlamps of the vehicle – a passenger car) and the geometry of observation (height of the eyes of the driver – of a passenger car).

For simulated driving environment, it is not possible to reproduce directly a given retro reflectivity threshold for simulated road markings, due to a lot of constraints, e.g. in the display technology of screens (which do not have the same luminance dynamic as a real road scene by night). The distance of visibility of road markings should then be determined on the basis of a subjective judgment process, checking if the observable road markings are visible enough or not for the experts. Based on the empirically established visibility (expressed in preview time), the relating retro reflectivity can be estimated by calculation with the 'VISIBILITY programme' (developed on behalf of the COST 331 Management Committee), see Annex 6.

On the driving simulator platform (for both environments 1 and 2), the visibility of road markings could be adjusted through a non-dimensional index ranging from 0% to 200. Based on a collective experts' judgement on the driving simulation, realistic conditions in terms of distance of visibility for simulated road markings were obtained with index settings ranging from 80 to 110. With a value index below 80, road markings were no longer visible. With a value index above 110, road markings were visible at infinite sight distance. The adjustment of the cursor for the road markings gave a preview time which could be calculated for each expert by the number of visible broken stripes for the edge line and the centre line. As the road markings modulation is known and geometrically true for the simulated environment of the driving simulator, it is easy to calculate the visibility distance offered by road markings in a given condition.

With the help of the group of experts of Rainvision, we achieved a consensus on what visible road markings and less visible road markings were in rain condition, based on the initial visual environment of the driving simulator (simulation 2). The determination of the correct adjustment for the driving simulator was based on a collective subjective evaluation of the global visual rendering of the road, given the result produced.

While adjusting the cursor for road markings visibility, one could see that the restitution of this parameter was too binary: the obtained visibility of road markings was either too low (abruptly falls under a certain value) or too high (abruptly increases above a certain value). This problem probably occurred because the visibility of road markings was simulated as a linear process, based on the dimension of the stripes only, whereas other parameters (such as the diffusion of light depending on the texture of the surfaces or on the absorption due to mist and even the illumination zone of the headlamps and its relationship with the retro reflectivity of road markings materials) were not properly considered. This came down to consider the visibility of road markings based on a visual contrast constant whatever the distance, which is of course non-realistic, insofar specular reflexion of rain in the atmosphere and on the road surface cannot be excluded. The simulated visibility distance of road markings was the result of the decrease of their perception due to the decrease of their observable dimensions only. This meant that, with the exception of its dimensions, each of the marks in a broken line (edge line, centre line) was – for a given adjustment of the cursor – as visible as any of the others, which was naturally not true.

We decided that the appropriate levels of visibility for standard (type I) and enhanced (type II) road markings had to be determined first based on a subjective judgment. We checked afterwards that the obtained distances of visibility were realistic for the purpose of the study.

In driving simulation environment 2, experts voted for two adjustments of the visibility of road markings in night rain condition, based on a compromise between short distance and intermediate distance visibility of road marks from the cab of the simulator. For that purpose, we used a 60inch-three screens simulator, in a dark room. All the 5 experts of Rainvision project made an individual judgment of a good visibility of road marking in night rain condition. They judged personally the appropriate visibility for road markings from a point of observation compatible with the visual perspective of the test driver[3]. Each judgment was compiled in order to converge on a consensual vote on the appropriate level.

The approved distance of visibility for standard road markings in night rain condition was set to:

- a 33m distance of visibility for the edge line corresponding to a 1.5 sec visibility preview time at 80 kph
- a 22m distance of visibility for the centre line corresponding to a 1.0 sec visibility preview time at 80 kph.

The approved distance of visibility for enhanced road markings in night rain condition was set to:

- a 55m distance of visibility for the edge line corresponding to a 2,5 sec visibility preview time at 80 kph
- a 33m distance of visibility for the centre line corresponding to a 1,5 sec visibility preview time at 80 kph.

Reference speed was 80 kph (22 mps), consistent with the speed limit for 2 lane rural road by rain conditions in France.

Standard road markings offering a 1.5 sec preview time for edge line (1.0 sec for centre line) in rain condition are shown in Figure 3 below. Following calculations with the 'Visibility programme', this would correlate to a wet retro reflectivity of 15 mcd/m²/lx (Performance Class RW0 in EN 1436; assuming a 50 year old driver and 50% intensity factor to compensate for reduced transmission in rain conditions and aged or dirty headlamps)

Enhanced road markings offering a 2.5 sec preview time for edge line (1.6 sec for centre line) in rain condition are shown in Figure 4 below. Following calculations with the 'Visibility programme', this would correlate to a wet retro reflectivity of 50 mcd/m²/lx (Performance Class RW3 in EN 1436; assuming a 50 year old driver and 50% intensity factor to compensate for reduced transmission in rain conditions and aged or dirty headlamps).

Due to the software technology, it is not possible to withdraw images directly from the simulator. The low visibility road markings are represented by the mean of pictures of the screen of the visualization system taken with a digital camera. It is consequently difficult to repeat the same angles of view from one picture to another, which make it harder to compare. Moreover, the settings of the digital camera nor of the screen do not allow a realistic reproduction of the driving simulation for the purpose of this document. The visual result provides no fidelity in terms of resolution, contrast, luminance, and colorimetry. As an example, the speedometer cannot be read on the pictures, whereas they are perfectly legible on the simulator.

[3] For practical reasons, it was not possible to perform systematic, individual tests for each of the experts on the driving simulator. The evaluation was collective, all the experts standing behind the operator of the driving simulator to appreciate the visual output resulting from the adjustment of the RM visibility cursor.

Figure 3. Picture of the PC Screen for standard/low visible road markings in rain night condition

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

Figure 4. Picture of the PC Screen for enhanced/high visble road markings in rain night condition

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

3.3. Visual environment of the driving simulator

During the negotiation with the subcontractor, the possibility to shift from one technology for the visual rendering of the driving simulator to another was discussed. The shift from OpenGL (initial environment) to Direct X (new environment) was supposed to provide a more accurate simulation for night and rain conditions. A lot of improvements in the simulation of the visual environment were expected.

The new environment introduced the spray of water film of other vehicles (for following, followed, crossed or oncoming cars), a more realistic diffusion of light on the surface of the road, a more realistic appearance of rain drops and light diffusion on the windscreen.

We used the new technology Direct X for the first series of driving tests sessions (January and February 2013) For that reason, the new environment is called environment 1 in this document. As we faced important troubles in the realism of some objects of the road scene (see below), we had no choice but to come back to the old technology Open GL for the rest of the driving tests sessions.

We used the old technology Open GL for the second series of driving tests sessions. For that reason, the old environment is called environment 2 in this document.

Be that as it may, some evolutions were delivered whatever the visual technology of simulation, such as the possibility to change the driving scenarios (marking visibility / dry / wet) in real time without interrupting the driver.

The configuration of the road including different stretches and different objects was implemented.

3.4. Video recording of the driving simulator sessions

The initial driving simulator used to continuously record a lot of real time information about the vehicle dynamics (lateral and longitudinal forces, speed) and parameters (automatic or manual gearbox, gear engaged, wheel angle, accelerator and break position, windscreen wiper position; headlamp position,).

The initial simulator was also able to record a driving session, in order to replay and analyse the situation. For example, the abrupt deceleration of another vehicle could surprise the driver of the simulator, and lead to a rear end crash, due to the lack of vigilance associated with an underestimation of the needed inter vehicle distance. Another application of this simulator was the eco run, in order to give to subjects the requested techniques to decrease their energy (fuel or electrical) consumption with the appropriate use of powertrain solicitation given vehicle inertia.

It was possible to replay the video as with any digital video recorder (pause, accelerated play, direct access to any sequence of the record), In addition to these possibilities, the initial simulator offered the opportunity to change the view, by adding a bird-eye view to the in car view. This bird-eye view can also be changed once the image paused, by rotating the angle of view of the driven car in any 360° position and by zooming the driven car in a very wide range, from very close to very far away.

All these possibilities are of course very attractive, but also present some problematic limitations, linked to the initial use of the driving simulator, which was designed for training. The initial simulator was not able to record in a permanent basis the different driving sessions. Rather, it was used in live to replay the last driving session to help subjects to reconstruct the former driving situation and to debrief it, either on an individual or on a collective basis. The simulator software was not able to record several ten of sessions, and to load them on demand for later analysis.

The second version of the simulator platform was then in capacity to record as many driving sessions as requested.

3.5. Data logging of the driving simulator

One of the most challenging issues was to be able to measure, to detect and to store errors in the lateral position of the vehicle on the driving lane for each driver's session. The lateral position was then continuously measured and recorded by the driving simulator.

Concerning lateral position, it was measured for the main longitudinal sections of the itinerary (including curves and transitions). It excluded the roundabout, for which the notion of driving lane centre is more difficult to estimate.

Depending on the calibration of the data logger, the measurement of an incorrect lateral position shall permit to automatically detect and identify lane departures and run offs. The figures below illustrate the pictures extracted from the video recorder of the driving simulator. For practical reasons, it is easier to analyse the subject's trajectory with a full perception of the visual environment. As a consequence, the following selected pictures represent the vehicle in day (and not night) driving condition. This enables to appreciate the relative position of the vehicle on the driving lanes.

In case of a lane departure on a 2 lane rural road, the vehicle departs from its driving lane and begins to circulate on the opposite driving lane, increasing the risk of head-on and lateral collisions dramatically.

The first stage deals with a slight drive in the centre line of the road markings (figures 5a and 5b). All pictures below are show by day, in order to appreciate more accurately the lateral position of the vehicle related to the road and its environment.

Figure 5a. Lane departure stage 1 – rolling on the center line road marking (rear view)

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

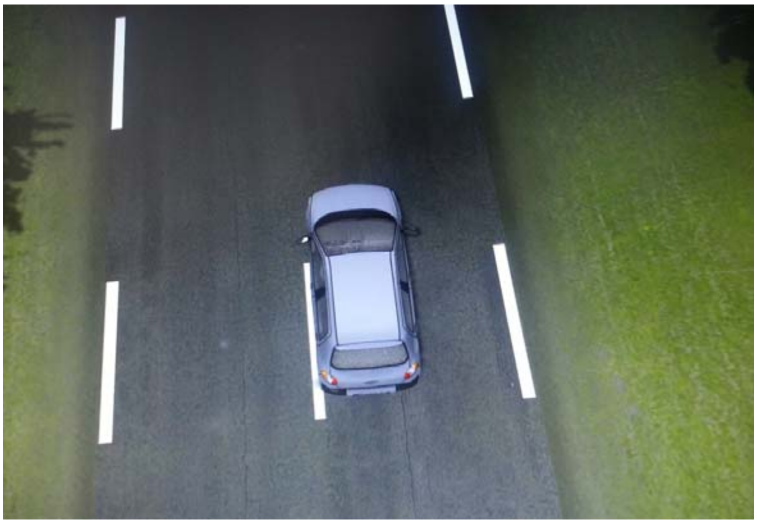


Figure 5b. Lane departure stage 1 – rolling on the center line road marking (eagle view)

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

In such a situation, would the vehicle maintain its position, it could likely lead to a near miss with a vehicle circulating on the left of its own driving lane. Depending on the perception of the driving lane, the car risks to circulate on the wrong driving lane if no correction is applied on the steering wheel.
Even with low incident angles, the offset deport may rapidly increase, so that the car circulates on the opposite driving lane (figures 6a and 6b).

Figure 6a. Lane departure stage 2 – crossing the center line (front view)

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

Figure 6b. Lane departure stage 2 – crossing the center line (front view)

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

In case of run-off on a 2 lane rural road, the vehicle departs from its driving lane and begins to circulate out of the road course (figures 7a and 7b).

Figure 7.a Run off stage 1. Crossing the edge line and leaving the road course (rear view)

Nota Bene: the picture reproduced for the purpose of this document does not render the genuine quality of the simulator.

Figure 7.b Run off stage 1. Crossing the edge line and leaving the road course (front view)

This situation represent a major risk of loss of control, possibly leading to an exit without return on the road (with a risk of rollover or collision against a lateral obstacle) or to a return on the road (with a risk of rollover or collision with a fixed obstacle on the opposite roadside, or a risk of collision with another vehicle on the opposite driving lane).

4. ORGANISATION OF DRIVING SESSIONS

During the experiment phase, subjects were welcomed individually, accordingly with their time slot scheduled in the agenda of the session. They were briefly informed on the planning of the test session: they have first to perform a visual ability test, and then to perform a driving test.

4.1. Organisation of the visual tests

For sessions held in Aximum and Colas premises, respectively at the end of January 2013 and at the beginning of April 2013 (corresponding approx.to age brackets 20-40 and 41-60[4]), people were in a first room by an operator trained by from ASNAV (FR Association for the Improvement of Vision, www.asnav.org) to perform a visual ability test (figure below).

Figure 8 Vision Room

ASNAV provided a specific device called Ergovision and manufactured by Essilor (figures below). This portable equipment is designed on a scientific basis to evaluate the quality of vision of subjects. The subjects have to look on some visual information through a given viewing window, assuming that they hold their usual visual corrective equipment (contact lenses or glasses) for the task to perform (far, intermediate or short distance vision).

The operator explains the entire procedure to the subject, and starts to fulfil the form with the personal information on the subject. Every subject was coded to preserve anonymity. Everyone was asked concerning his or her age, sex, nature of visual device (contact lenses, glasses) if any, ophthalmic surgery (if any), the type of visual correction (if any), and the time of the last medical visit for vision (if any).

Ergovision (Essilor, undated) contains three viewing windows which are accurately positioned to ensure that the eyes naturally take up the appropriate focal distance (far, intermediate or near). These windows are open alternately, to reproduce operational conditions for people wearing bi-focal or varifocal lenses. Each viewing

[4] For the sessions of end January and beginning April, one subject only was aged of more than 60 for these populations (refer to annex 3 in January), whereas for the other sessions managed by the subcontractor only, one subject only was aged of less than 61 (refer to annex 4 in May).

window is of a slotted oval shape which easily accommodates the population's variation in pupillary distance. The height of the equipment is adjustable to the height of the subject. Easy touch response buttons located at each side of the instrument help to perform the automatic examination, if selected.

Figures 9 Visual evaluation equipment: Ergovision

Ergovision can be used in two different ways.

One can let the subject perform alone an automatic examination without assistance, and without specific evaluation of the visual abilities requested for night time driving. The subject follows the instruction given by a computer generated voice, which decreases the workload of the operator. The automatic examination investigates the main visual functions, accurately identifying potential anomalies. The automatic examination confirms a standardized examination, without operator influence. Noted timed responses give additional indicator of the subject's visual quality. The results are delivered both as data and as a printed ticked.

This type of examination was used for the sessions delegated to the subcontractor Develter, essentially for the age bracket (61+). The test sessions were organized by the subcontractor on the basis of one operator managing the entire test, including the automatic visual examination and the driving simulator test. After the briefing and the pre-fulfilment of the formular by an operator with basic information (gender, age, device, surgery if any), each subject performed itself an automatic examination (test by default), without assistance (figure below). The automatic examination is described in chapter 2.3. and in Annex 2.

Figure 10 Visual evaluation process with Ergovision (automatic examination)

<u>One can also assist the subject with an operator performing a tailored examination</u>, and fulfilling a specific paper form manually, based on the results obtained in the different tests. The Ergovision equipment can reproduce any kind of test, either automatically (the subject performs the test alone, and answers the questions by typing directly on the keyboard) or manually (the subject performs the test with the assistance of a dedicated person, and answer the questions verbally; the evaluator is responsible of the launch of the successive tests with the keyboard and of the fulfilment of the tailored form). ASNAV provided the tailored test, which is described in chapter 2.3 and in Annex 1.

This type of examination was used for the sessions co-organized with the subcontractor Develter in Aximum and Colas premises. The subjects were welcomed individually in the vision room by a specialist of vision from ASNAV (at Aximum) or by an external person trained by ASNAV (at Colas). This person acted as an operator to administrate the visual test. The operator then commands the Ergovision to perform the visual test (figure below). Visual abilities were evaluated based on the different tests described in chapter 2.3 for the sessions corresponding to the age brackets 20-40 and 41-60, corresponding to the visual specifications for night time driving.

Figure 11 Visual evaluation process with Ergovision (tailored examination)

For each of the visual examinations, despite of its nature (automatic or tailored), a score was delivered. People who significantly underperformed one test or more received a red flag mentioning the importance of vision for driving, the general need for testing its vision, and more specifically the urgent need for a medical visit (see figures below).

Figure 12 Red flag for people having underperformed at 1 test or more

People who normally performed all the tests received a green flag (figure below) mentioning the importance of vision for driving, the general need for testing its vision, and more specifically the need for regular medical visits.

Figure 13 Green flag for people having correctly performed the tests

All subjects appreciated the visual test.

Most of subjects having a vision problem knew it before the examination, and were not surprised about the results.

4.2. Organization of the driving simulation tests

People were then welcomed in a second room by a professional trainer in driving simulator. In order to ensure anonymity and to avoid biased results, every subject was welcomed by a person who did not belong to its organization. This point is especially important for the employees of a company. In order to give advice for the driving test itself, subjects were shortly briefed on the reasons and on the requirements of the test: the experiment was designed for research purposes only, in order to improve road safety. People had to drive normally, while respecting the Highway Code. No information was disclosed on the real purpose of the experiment, i.e. to evaluate the influence of the visual delineation of the road on the behaviour of the drivers, expressed as road and/or lane departures.

Two driving simulators were installed back to back in the same room for the sessions hold in Aximum or Colas (figure below).

Figure 14 Installation of the simulation room, Aximum

The two driving simulators should have been installed in another configuration, in order to give more intimacy to each subject. This ideal configuration would have requested two operators for the driving simulator, which was not possible at this moment.

Simulator 1 was a 60inch three LED TV screens driving simulator. The driver is installed at a distance of 4,00m from the screens, which have a total width of 3,80m: 1,40m wide for the central screen, plus 1,20m visible wide for each of the lateral screens which are slightly slanted (figure below).

Figure 15 Installation of the simulation room, Aximum – Driving Simulator 60'

Simulator 1 has a very high dynamic contrast. Combined with its outstanding dimensions, it offers a real immersive experience of driving.

Simulator 2 was a 27inch three LCD screens driving simulator. The driver is installed at a distance of 1,50m from the screens, which have a total width of 1,60m: 0,60m wide for the central screen, plus 0,50m visible wide for each of the lateral screens which are slightly slanted (figure below).

Figure 16 Installation of the simulation room, Aximum – Driving Simulator 27'

For the tests, the simulation room was either dark (no lighting, illumination from the casement windows in a mezzanine floor room in Aximum) or very dark (no lighting, pilot light in a blind room in Colas).

Simulator 1 offers a real immersive experience of driving (figure below). This immersion is explained by the visual width of the screens and by their high performances in terms of luminance and contrast. The simulator was calibrated in order to enable the same visibility distance for road markings as tested by experts.

Figure 17 Simulation room, Aximum – Driving Simulator 60' ready for use

Simulator 2 gives a good visual immersion (figure below). This immersion is explained by the visual width of the screens (which is approximately the same as for simulator 1, given the distance from the subject). Simulator 2 was calibrated in order to enable the same visibility distance for road markings as tested by experts.

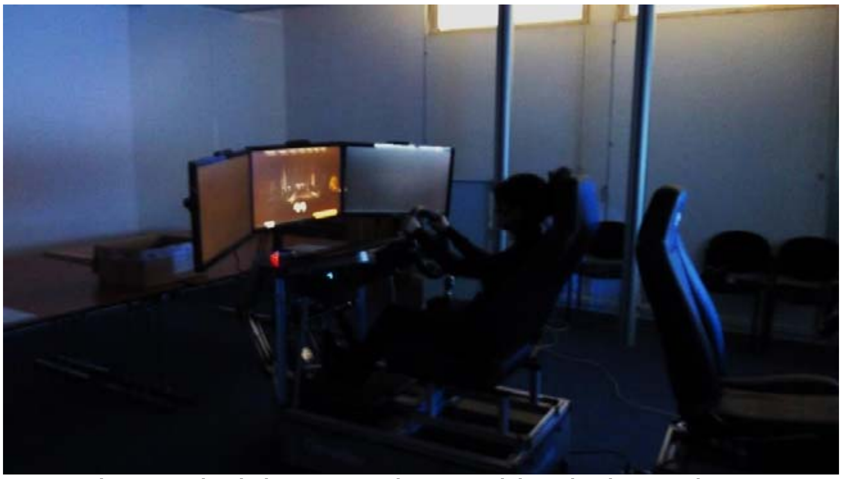


Figure 18 Simulation Room Aximum – Driving Simulator 27' in use

Driving simulator 2 could probably not compete with simulator 1 on a visual point of view, because its luminance and contrast are much lower than for the triple LED TV screens simulator.

For accuracy and further immersion, sounds should have been reproduced by headphones. This was not convenient given the organization of the test (1 operator for 2 drivers). Sounds were reproduced for low volume listening by a local monophonic speaker, in order to prevent a mutual acoustic distraction between subjects. This is a limitation for the realism of the driving session, but it was probably acceptable given the scenarios of test.

The different sessions of driving simulation were supposed to be very promising, as they relied on the latest available developments of the driving simulator, based on the requirements of the project. As they already had been postponed from January 2013 it became very important to respect the deadline.

The results of driving simulation sessions are shown in two different chapters below.

The influence of standard visible and enhanced visible road markings in night time condition was tested in two visual simulated environment, one abnormal (simulation environment 1, chapter 5) and one normal (simulation environment 2, chapter 6).

The interpretation of results is discussed in chapter 7.

5. RESULTS OF DRIVING SESSIONS IN SIMULATION ENVIRONMENT 1

The visual environment on the new platform was initially delivered and tested under a provisional version and essentially in simulated day condition. In night condition, we discovered on the beginning of the first day of massive test driving sessions that the simulation of the road scene went wrong in night condition. While vertical objects appeared as back illuminated and contrasted too much with the roadsides, markings did no longer play their expected role to delineate the road lanes.

As it was not immediately possible to improve the driving simulation, we decided to maintain the first driving test sessions and to perform them with this abnormal simulation environment. Despite its limitations, it was not possible to cancel the experiment, given the cost and complexity of the recruitment and of the installation of simulation rooms.

The initial idea was to test the subjects in a couple of experimental modalities simulating the road visual delineation delivered by standard and enhanced road markings, respectively. This target was not achievable given the unexpected visual environment provided by simulation 1. These imperfect test driving sessions enabled to keep as many subjects as possible, and to achieve the contractual targets in terms of population to be tested.

5.1. A visual environment with multiple visual objects

Due to the change in the simulator technology, the real consequences in terms of visual restitution were not properly anticipated. The change in the visual engine of the simulator and in its visual database led to an unexpected night time simulation. Despite several preparatory meetings with the contractor, the latest version of the simulator was not systematically tested and sufficiently validated.

Another parameter deals with the population of the samples of subjects recruited for the driving sessions. For practical feasibility, populations of subjects in driving simulation trials are generally limited while respecting a statistical representativeness. For Rainvision, the number of people to be tested was unusually high (120), due to the breakdown into the three ages of vision, which forced us to increase the total population in order to respect a minimum population into each age bracket (40 for each of three).

As driving sessions 1 were under the responsibility of Aximum, and relied upon the recruitment of employees of the company for sessions held in the headquarters premises, it was necessary to respect the dates scheduled, whatever the difficulties.

Because of unexpected weather events (massive snowfalls) in Paris area on the day before the sessions, 22nd of January, we had to organize the test in adverse conditions. The driving simulators were delivered from the subcontractor offices to the Aximum headquarters by a special transport company in the morning of day 1, postponing the start of the sessions to the afternoon. As other people supported the sessions (especially ASNAV), we had to preserve the planning as much as possible. The 1 ½ day sessions were rescheduled to switch the lost slot (morning of day 1) with a new one (afternoon of day 2).

During this change, we lost some subjects who could not be available for the new slots. The installation of driving simulators was also seriously delayed, which led to discover the latest development of the visual database of the simulator (more exactly, rain night conditions) too lately and without alternative but to perform the experiments.

We discovered that most of expected improvements were delivered. We also faced an unexpected problem. The simulation of trees by rain night condition was not appropriate; insofar they were simulated in a very extreme manner. By night, the trunks of trees looked like having a retroreflective film. They actually appeared more or less like white post mounted delineators, with a very important colorimetric and photometric contrast on the screens. Combined with their dimensions and vertical orientation, trees delivered significant visual delineation by night for the subjects on the driving simulator.

More generally, all vertical roadside objects (trees, energy poles, road signs poles, houses' facades) in the driver scene seemed to be illuminated from bottom up.

Figure 19. Simulation environment 1: Comparison of visual scene of the road in rain condition by day vs. by night – straight section

In the straight sections of the itinerary, the excessive visibility of the vertical roadside objects of simulation environment 1 creates an unexpected road delineation which competes with road markings. This situation occurs only by night (picture 2 to the right) and not by day (picture 1 to the left). The influence of the vertical roadside objects delineation depends on their presence and density along the roadside of the straight sections.

For the simulated road, vertical roadside objects were systematically present along the road, creating a continuous effect whatever the stretches considered: roundabouts, straight stretches or sinuous stretch.

Figure 20. Simulation environment 1: Visual scene of the road by night – curved section

In the curved section of the itinerary, the excessive visibility of vertical roadside objects (and especially the trunks of the trees) of simulation environment 1 creates an unexpected road delineation which competes with the road markings. This situation occurs only by night, and the delivered delineation increases with the visual density of vertical objects (compare picture 1 to the left and picture 2 to the right).

Given the fact that the simulated environment was a rural road without public lighting, including trees along the roadside, this problem deeply changed the expected visual delineation of the road, and the perception of the subjects tested on the driving simulator. Instead of relying on the road markings to perceive the driving lanes and the alignment of the road, subjects could use this unexpected and unrealistic delineation offered by trees, which were looking more or less as retro reflective beacons.

The successive test drives performed in session 1 and some of the drivers of sessions 2 were then affected by this default in the simulation of some objects of the visual environment. As the visual delineation was supposed to be delivered by road markings only, the visual competition with trees created an unsurpassable difficulty to test the effect of the visibility road markings. Because of this competition, it was not possible to test the influence of a difference in the perception of driving lanes in a controlled manner, as planned initially.

Nevertheless, we decided to perform the test in a complex visual environment, named simulation 1. We also decided to compare afterwards this situation Simulation 1 with the initial experimental conditions based on the delineation offered by road markings only (Simulation 2), in order to evaluate the influence of the additional delineation of the reflective trees.

A total of 63 subjects performed the test in the simulation environment 1 through different test sessions from January to February 2013. After analysis of the available records, 61 subjects were usable, 2 were not and subsequently removed from the table. For a complete description of the population, refer to Annex 3.

5.2. Results of the driving test for age bracket 20-40 simulation 1

Table 7 presents the results for the first age bracket (20 to 40 years old drivers) of the driving simulation test in simulation environment 1 which includes abnormal simulation of vertical objects in the roadside of the itinerary.

Table 7 – Results of test sessions in simulation environment 1 for 20-40 years old drivers

A DATE	B Subject Code	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road markings	
		M	F		E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
23/01/2013	107		1	22	2	3	5	0	1	1	4	400%
22/01/2013	0 14		1	23	0	11	11	0	1	1	10	1000%
23/01/2013	116	1		24	0	1	1	1	1	2	-1	-50%
23/01/2013	131	1		24	0	1	1	1	1	2	-1	-50%
22/01/2013	0 22	1		25	3		3	1	1	2	1	50%
23/01/2013	123		1	28	4	0	4	7	0	7	-3	-43%
23/01/2013	129		1	28	2	1	3	1	0	1	2	200%
22/01/2013	00 5	1		30	1	5	6	2	3	5	1	20%
22/01/2013	00 7		1	30	2	1	3	1	1	2	1	50%
23/01/2013	102		1	30	0	3	3	0	8	8	-5	-63%
22/01/2013	0 21	1		32	1	3	4	4	10	14	-10	-71%
23/01/2013	113		1	32	0	0	0	0	0	0	0	0%
23/01/2013	104	1		33	0	1	1	0	2	2	-1	-100%
22/01/2013	00 8		1	34	0	1	1	0	1	1	0	0%
23/01/2013	120		1	34	12	2	14	4	1	5	9	180%
22/01/2013	00 4		1	35	0	1	1	0	1	1	0	0%
23/01/2013	111	1		36	0	1	1	0	1	1	0	0%
23/01/2013	118		1	36	0	0	0	0	1	1	-1	-100%
22/01/2013	00 9		1	37	1	9	10	1	9	10	0	0%
22/01/2013	0 12	1		37	1	1	2	3	0	3	-1	-33%
23/01/2013	127	1		38	8	3	11	4	1	5	6	120%
23/01/2013	135	1		39	0	1	1	2	0	2	-1	-50%
TOTAL Age Bracket 1		**10**	**12**	**31,2**	**37**	**49**	**86**	**32**	**44**	**76**	**10**	**13%**

22 exploitable drivers performed the test with the simulation environment 1. During the tests, 86 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 76 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) exceed by 13% drivers' errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 3.5 errors (1.5 lane departures and 2.0 runs off the road) with visible road markings, compared with 3.9 errors (1.7 lane departures and 2.2 runs off the road) with less visible road markings.

More (or less) visible, enhanced (or standard) road markings may not affect driving errors in the same extent and direction for all drivers.. Depending on the driver, enhanced road markings (more visible in adverse conditions) may lead to a lower number of errors or to a higher number of errors compared with standard road markings (less visible in adverse conditions).

- For 9 subjects on 22 (41% of the population for this age bracket), enhanced road markings led to more errors compared with standard road markings

- For 8 subjects on 22 (36% of the population for this age bracket), enhanced road markings led to less errors compared with standard road markings

- For 5 subjects on 22 (23%% of the population for this age bracket), no difference was found between the 2 experimental modalities.

The comparison of errors between less and more visible road markings in simulation environment 1 is shown in the graphic below for the age bracket 20-40.

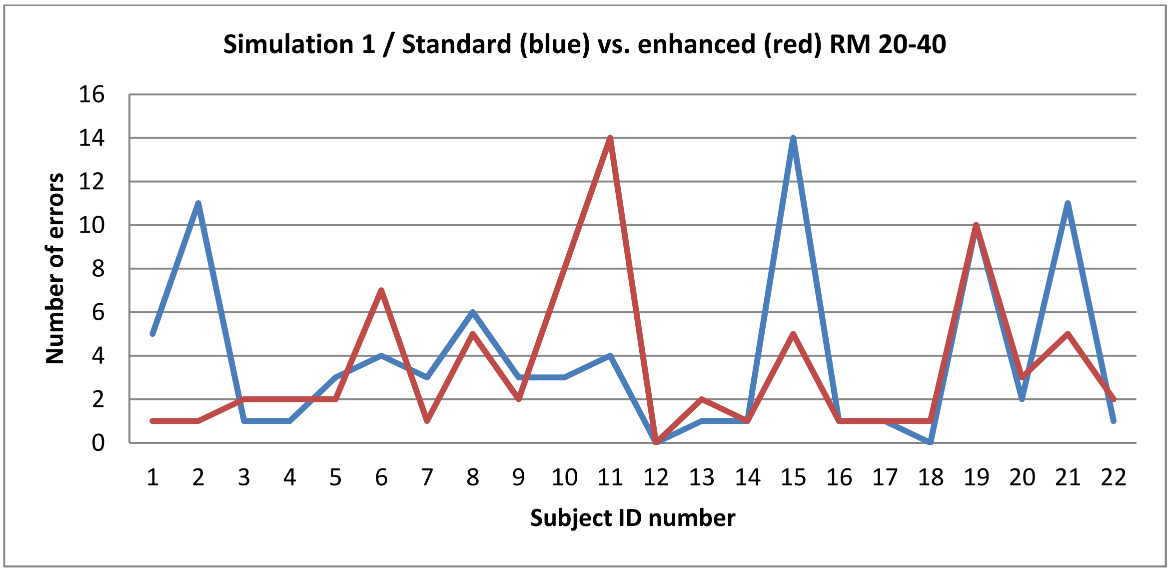


Figure 21. Comparison of errors depending on the visibility of RM – Simulation environment 1

Results are evaluated and discussed in chapter 7.

5.3. Results of the driving test for age bracket 41-60 simulation 1

Table 8 presents the results for the second age bracket (41 to 60 years old drivers) of the driving simulation test in simulation environment 1, which includes over-contrasted vertical object such as retroreflective trees in the roadside of the itinerary.

Table 8 – Results of test sessions in simulation environment 1 for 41-60 years old drivers

A DATE	B Subject Code	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road markings	
		M	F		E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
23/01/2013	119		1	41	1	1	2	0	1	1	1	100%
23/01/2013	134	1		41	5	0	5	2	1	3	2	67%
22/01/2013	0 20		1	42	2	0	2	0	1	1	1	100%
23/01/2013	109	1		42	1	1	2	3	2	5	-3	-60%
23/01/2013	130	1		42	0	1	1	0	2	2	-1	-50%
23/01/2013	121	1		43	5	2	7	6	0	6	1	17%
23/01/2013	106		1	43	2	1	3	6	0	6	-3	-50%
22/01/2013	00 3	1		44	8	2	10	6	3	9	1	11%
23/01/2013	133	1		44	1	1	2	0	1	1	1	100%
22/01/2013	00 1	1		45	6	3	9	3	2	5	4	80%
23/01/2013	103		1	46	0	1	1	0	1	1	0	0%
23/01/2013	112	1		46	0	3	3	6	2	8	-5	-63%
23/01/2013	126	1		46	3	1	4	7	5	12	-8	-67%
23/01/2013	128		1	46	2	0	2	0	1	1	1	100%
22/01/2013	0 11		1	49	2	0	2	0	1	1	1	100%
23/01/2013	122		1	49	5	1	6	1	1	2	4	200%
23/01/2013	108		1	49	2	1	3	2	0	2	1	50%
22/01/2013	00 6	1		50	0	1	1	0	1	1	0	0%
22/01/2013	0 18	1		50	4	0	4	3	1	4	0	0%
22/01/2013	0 19	1		50	3	1	4	1	0	1	3	300%
23/01/2013	124	1		50	5	1	6	2	2	4	2	50%
23/01/2013	110	1		50	4	0	4	4	1	5	-1	-20%
23/01/2013	114	1		52	4	1	5	1	2	3	2	67%
23/01/2013	132	1		53	2	1	3	1	0	1	2	200%
23/01/2013	115		1	55	0	7	7	1	5	6	1	17%
22/01/2013	0 16	1		56	0	1	1	0	1	1	0	0%
23/01/2013	117		1	57	4	8	12	0	1	1	11	1100%
23/01/2013	105	1		58	2	3	5	2	2	4	1	25%
23/01/2013	101	1		59	0	0	0	0	0	0	0	0%
TOTAL Age Bracket 2		**19**	**10**	**48,2**	**73**	**43**	**116**	**57**	**40**	**97**	**19**	**20%**

29 exploitable drivers performed the test with the simulation environment 1. During the tests, 116 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 97 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) exceed by 20% drivers' errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 3.3 errors (2.0 lane departures and 1.4 runs off the road) with visible road markings, compared with 4.0 errors (2.5 lane departures and 1.5 runs off the road) with less visible road markings.

More (or less) visible, enhanced (or standard) road markings may not affect driving errors in the same extent and direction for all drivers. Depending on the driver, enhanced road markings (more visible in adverse conditions) may lead to a lower number of errors or to a higher number of errors compared with standard road markings, less visible in adverse conditions.

- For 18 subjects on 29 (62% of the population for this age bracket), enhanced road markings led to less errors compared with standard road markings
- For 6 subjects on 22 (21% of the population for this age bracket), enhanced road markings led to more errors compared with standard road markings
- For 5 subjects on 29 (17%% of the population for this age bracket), no difference was found between the 2 experimental modalities.

The comparison of errors between less and more visible road markings in simulation environment 1 is shown in the graphic below for the age bracket 41-60.

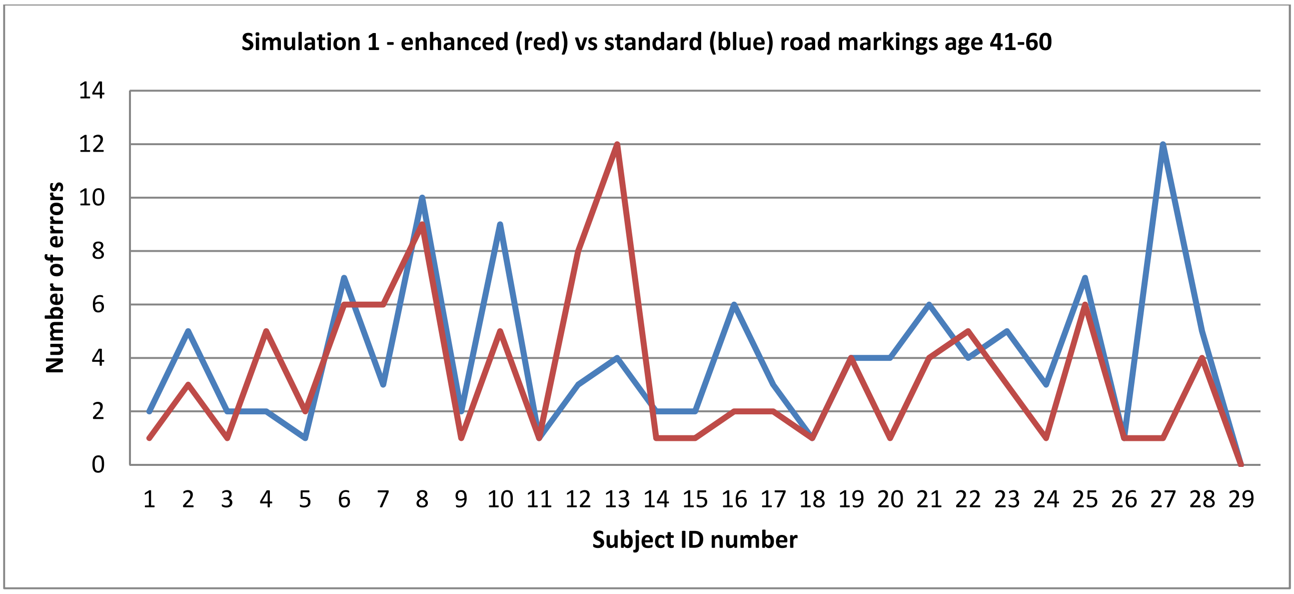


Figure 22. Comparison of errors depending on the visibility of RM – Simulation environment 1

Results are evaluated and discussed in chapter 7.

5.4. Results of the driving test for age bracket 61+ simulation 1

Table 9 presents the results for the third age bracket (61+ years old drivers) of the driving simulation test in simulation environment 1, which includes 'retroreflective trees' in the roadside of the itinerary.

Table 9 – Results of test sessions in simulation environment 1 for 61+ years old drivers

A DATE	B Subject Code	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road markings	
					E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
		M	F									
22/01/2013	00 2	1		61	1	5	6	2	3	5	1	20%
15/02/2013	G1	1		62	1	1	2	0	1	1	1	100%
22/02/2013	R2		1	65	0	1	1	0	1	1	0	0%
15/02/2013	G3	1		66	7	1	8	12	1	13	-5	-38%
22/02/2013	R3		1	66	9	0	9	2	0	2	7	350%
06/02/2013	F3	1		69	1	1	2	0	1	1	1	100%
06/02/2013	F1	1		70	1	1	2	4	1	5	-3	-60%
15/02/2013	G2	1		71	3	10	13	7	15	22	-9	-41%
06/02/2013	F2	1		72	1	1	2	4	0	4	-2	-50%
22/02/2013	R1	1		75	16	1	17	13	1	14	3	21%
TOTAL Age Bracket 3		**8**	**2**	**67,7**	**40**	**22**	**62**	**44**	**24**	**68**	**-6**	**-9%**

10 exploitable drivers performed the test with the simulation environment 1. During the tests, 62 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 68 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) are 9% below the number of errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 6.8 errors (4.4 lane departures and 2.4 runs off the road) with visible road markings, compared with 6.2 errors (4.0 lane departures and 2.2 runs off the road) with less visible road markings.

More (or less) visible, enhanced (or standard) road markings on driver errors may not affect driving errors in the same extent and direction for all drivers Depending on the driver, enhanced road markings (more visible in adverse conditions) may lead to a lower number of errors or to a higher number of errors compared with classic road markings, less visible in adverse conditions.

- For 5 subjects on 10 (50% of the population for this age bracket), enhanced road markings led to less errors compared with standard road markings
- For 4 subjects on 10 (40% of the population for this age bracket), enhanced road markings led to more errors compared with standard road markings
- For 1 subjects on 10 (10%% of the population for this age bracket), no difference was found between the 2 experimental modalities.

The comparison of errors between less and more visible road markings in simulation environment 1 is shown in the graphic below for the age bracket 61+.

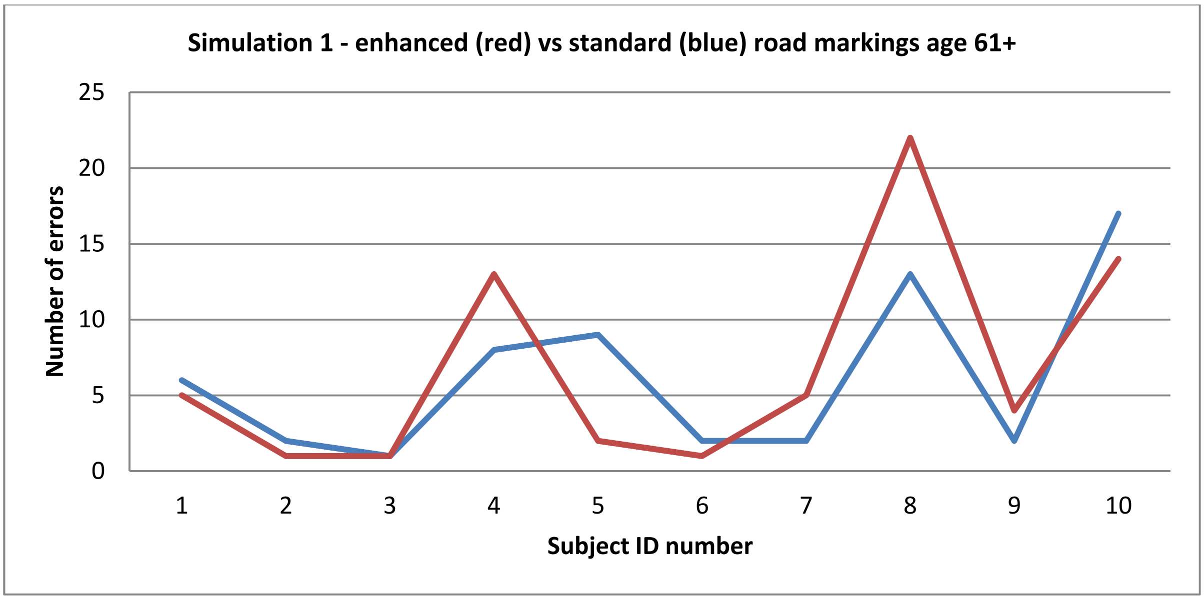


Figure 23. Comparison of errors depending on the visibility of RM – Simulation environment 1

Results are evaluated and discussed in chapter 7.

5.5. Overall results of the driving test simulation 1

The overall results of simulation environment 1 do not demonstrate a clear difference of performance between more or less visible road markings in the driving tests.

In simulated rain night conditions and for all the subjects, drivers' errors with poor road delineation (standard road markings) are 10% above the number of errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 4.0 errors (2.2 lane departures and 1.8 runs off the road) with visible road markings, compared with 4.3 errors (2.5 lane departures and 1.9 runs off the road) with less visible road markings.

Depending on the drivers, the number of errors expressed as the cumulated number of departures (including lane departures and run-offs the road) is higher with enhanced or with standard road markings in rain conditions (figure below).

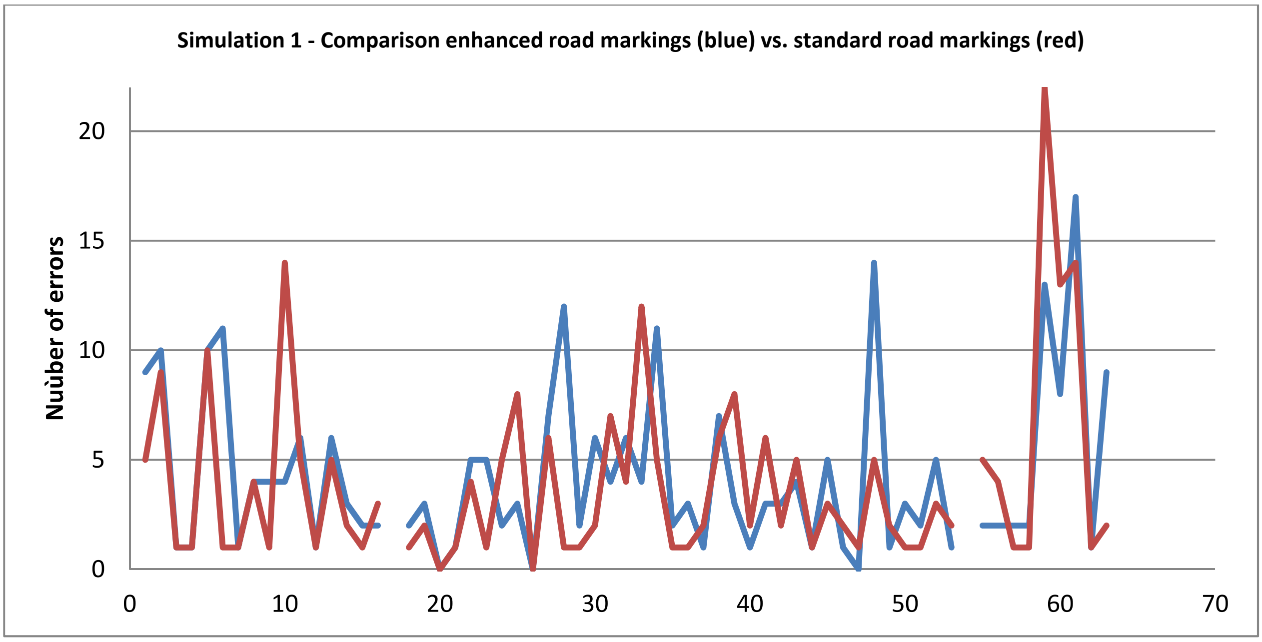


Figure 24. Comparison of errors depending on the visibility of road markings - Simulation environment 1 all subjects

Results are evaluated and discussed in chapter 7.

6. Results of driving sessions in simulation environment 2

As the visual environment in simulation 1 did not comply with the requirements of the project, we decided to go back to the former version of the driving simulation. Despite its relative lack of details, the first version was capable of simulating appropriate road delineation, without any visual pollution as they relied on the latest available developments of the driving simulator, based on the requirements of the project.

A total of 60 subjects performed the test in the simulation environment 2 through different test sessions from February to May 2013. After analysis of the available records, 58 subjects were usable, 2 were not usable and subsequently removed from the table. For a complete description of the population, refer to Annex 4.

6.1. Results of the driving test for age bracket 20-40 simulation 2

Table 10 presents the results of the driving sessions in simulation environment 2 for the 20-40 years old drivers.

Table 10 – Results of test sessions in simulation environment 2 for 20-40 years old drivers

A	B	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road	
DATE	Subject Code	M	F		E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
April 3, 2013	29	1		21	2	1	3	2	1	3	0	0%
April 3, 2013	8		1	23	2	4	6	5	0	5	1	20%
April 3, 2013	14	1		26	2	4	6	0	3	3	3	100%
April 3, 2013	30	1		26	0	2	2	1		1	1	100%
April 3, 2013	22		1	27	0	1	1	0	1	1	0	0%
April 3, 2013	18		1	28	1	1	2	0	1	1	1	100%
April 3, 2013	21	1		28	1	1	2	0	1	1	1	100%
April 3, 2013	33	1		28	0	1	1	0	3	3	-2	-67%
April 3, 2013	12		1	29	1	1	2	1	0	1	1	100%
April 3, 2013	25	1		29	0	1	1	0	1	1	0	0%
April 3, 2013	31	1		29	5	6	11	1	1	2	9	450%
April 3, 2013	4	1		31	2	5	7	0	2	2	5	250%
April 3, 2013	19		1	31	0	1	1	0	1	1	0	0%
April 3, 2013	28	1		32	0	1	1	1	0	1	0	0%
April 3, 2013	10	1		33	0	1	1	0	1	1	0	0%
April 3, 2013	20		1	33	1	2	3	0	0	0	3	NA
April 3, 2013	25	1		33	2	4	6	3	1	4	2	50%
April 3, 2013	9	1		34	1	1	2	0	1	1	1	100%
April 3, 2013	11		1	34	0	7	7	0	1	1	6	600%
April 3, 2013	16		1	36	4	1	5	1	1	2	3	150%
April 3, 2013	34	1		37	7	2	9	3	1	4	5	125%
April 3, 2013	3	1		37	1	3	4	2	2	4	0	0%
April 3, 2013	7		1	38	2	2	4	0	1	1	3	300%
TOTAL Age Bracket 1		**14**	**9**	**30,6**	**34**	**53**	**87**	**20**	**24**	**44**	**43**	**98%**

23 exploitable drivers in the first age bracket performed the test with the simulation environment 2. During the tests, 87 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 44 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) exceed by 98% drivers' errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 2 errors (1.0 lane departure and 0.9 run off the road) with visible road markings, compared with 4 errors (1.5 lane departures and 2.3 runs off the road) with less visible road markings.

More (or less) visible, enhanced (or standard) road markings may not affect driver errors in the same extent and direction for all drivers. However, road markings may present a more univalent influence for most of the drivers. Depending on the driver, enhanced road markings (more visible in adverse conditions) may generally lead to a lower , or the same number of errors compared with standard road markings. Only 1 driver showed more errors with the enhanced road marking.

- For 15 subjects on 23 (66% of the population for this age bracket), enhanced road markings led to less errors compared with standard road markings
- For 7 subject on 23 (30% of the population for this age bracket), no difference was found between the 2 experimental modalities.
- For 1 subject on 23 (4% of the population for this age bracket), enhanced road markings led to more errors compared with standard road markings.

The comparison of errors between less and more visible road markings in simulation environment 2 is shown in the graphic below for the age bracket 20-40.

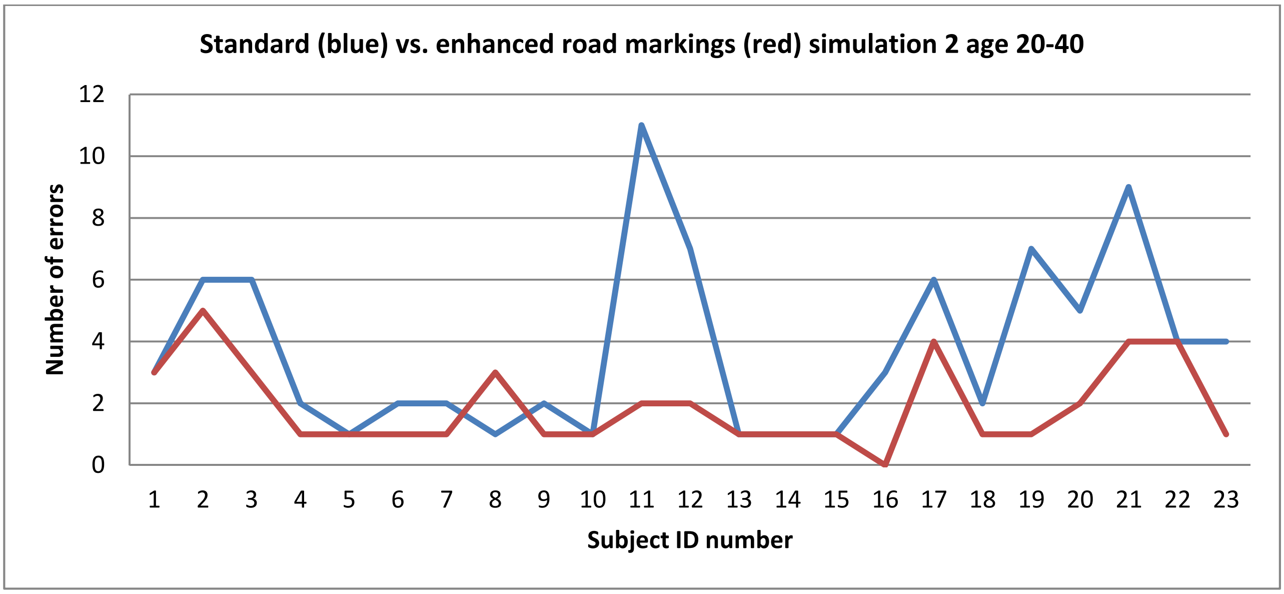


Figure 25. Comparison of errors depending on the visibility of RM – Simulation environment 2

Results are evaluated and discussed in chapter 7.

6.2. Results of the driving test for age bracket 41-60 simulation 2

Table 11 presents the results of the driving sessions in simulation environment 2 for the 41-60 years old drivers.

Table 11 – Results of test sessions in simulation environment 2 for 41-60 years old drivers

A DATE	B Subject Code	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road	
		M	F		E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
April 3, 2013	13		1	41	7	1	8	7	0	7	1	14%
April 3, 2013	26	1		42	2	1	3	2	1	3	0	0%
April 3, 2013	27	1		43	3	1	4	0	2	2	2	100%
April 3, 2013	32		1	44	0	1	1	0	1	1	0	0%
May 6, 2013	M7		1	44	2	4	6	0	1	1	5	500%
April 3, 2013	2		1	46	7	0	7	4	1	5	2	40%
April 3, 2013	15	1		46	3	1	4	3	3	6	-2	-33%
April 3, 2013	23		1	46	0	1	1	0	1	1	0	0%
April 3, 2013	6		1	47	1	1	2	0	1	1	1	100%
April 3, 2013	17		1	49	1	7	8	0	3	3	5	167%
April 3, 2013	5	1		51	1	4	5	2	2	4	1	25%
TOTAL Age Bracket 2		**4**	**7**	**45,4**	**27**	**22**	**49**	**18**	**16**	**34**	**15**	**44%**

11 exploitable drivers in the second age bracket performed the test with the simulation environment 2. During the tests, 49 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 34 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) exceed by 44% drivers' errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 3.1 errors (1.6 lane departures and 1.5 runs off the road) with visible road markings, compared with 4.5 errors (2.5 lane departures and 2.0 runs off the road) with less visible road markings.

The effect of road markings on driver errors is not systematic.

- For 7 subjects on 11 (64% of the population for this age bracket), enhanced road markings led to less errors compared with standard road markings

- For 3 subject on 11 (27% of the population for this age bracket), no difference was found between the 2 experimental modalities.

- For 1 subject on 11 (9% of the population for this age bracket), enhanced road markings led to more errors compared with standard road markings.

The comparison of errors between less and more visible road markings in simulation environment 2 is shown in the graphic below for the age bracket 41-60.

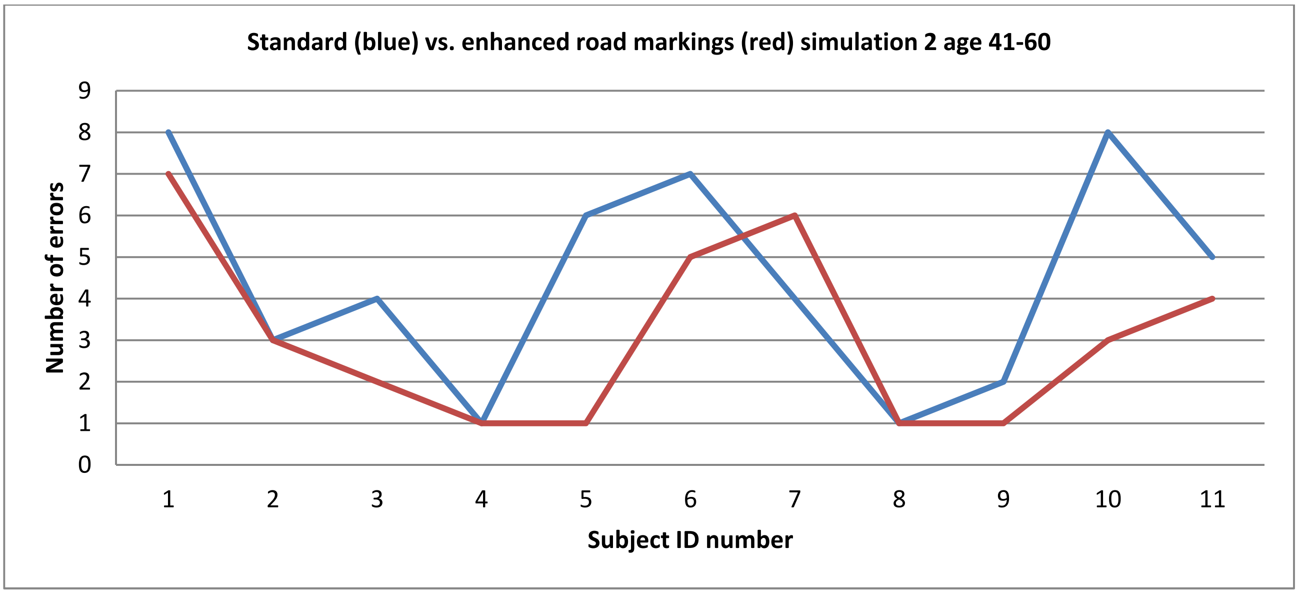


Figure 26. Comparison of errors depending on the visibility of RM – Simulation environment 2

Results are evaluated and discussed in chapter 7.

6.3. Results of the driving test for age bracket 61+ simulation 2

Table 14 presents the results of the driving sessions in simulation environment 2 for the 60+ years old drivers.

Table 12 – Results of test sessions in simulation environment 2 for 61+ years old drivers

A	B	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road	
DATE	Subject Code	M	F		E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
February 22, 2013	S2		1	65	6	3	9	7	3	10	-1	-10%
May 7, 2013	M23	1		65	9	3	12	3	2	5	7	140%
May 7, 2013	M24		1	65	13	4	17	8	1	9	8	89%
February 22, 2013	S3		1	66	0	19	19	0	6	6	13	217%
May 7, 2013	M18	1		66	7	0	7	4	1	5	2	40%
May 7, 2013	M19		1	66	3	13	16	5	5	10	6	60%
May 7, 2013	M21		1	66	14	1	15	5	2	7	8	114%
May 6, 2013	M3		1	67	0	4	4	0	3	3	1	33%
May 6, 2013	M11		1	67	1	1	2	0	2	2	0	0%
May 7, 2013	M16+		1	67	5	1	6	1	1	2	4	200%
May 6, 2013	M9	1		68	9	3	12	10	4	14	-2	-14%
May 7, 2013	M20	1		74	4	9	13	1	10	11	2	18%
February 22, 2013	S1	1		75	22	4	26	19	0	19	7	37%
May 7, 2013	M15	1		75	7	5	12	6	2	8	4	50%
May 7, 2013	M17			76	3	12	15	0	4	4	11	275%
May 6, 2013	M6		1	77	3	9	12	5	4	9	3	33%
May 6, 2013	M13		1	78	3	18	21	0	15	15	6	40%
May 7, 2013	M22	1		78	6	8	14	2	3	5	9	180%
May 6, 2013	M5	1		79	0	1	1	0	2	2	-1	-50%
May 6, 2013	M10		1	79	5	12	17	5	5	10	7	70%
May 6, 2013	M12	1		80	4	6	10	2	1	3	7	233%
May 6, 2013	M1		1	81	5	4	9	1	1	2	7	350%
May 6, 2013	M4		1	87	16	1	17	7	6	13	4	31%
May 6, 2013	M14	1		90	1	2	3	1	0	1	2	200%
May 6, 2013	M8	1		91	4	17	21	2	7	9	12	133%
TOTAL Age Bracket 3		**11**	**13**	**77,0**	**150**	**160**	**310**	**94**	**90**	**184**	**126**	**68%**

24 exploitable drivers performed the test in the elderly drivers class in the simulation environment 2. During the tests, 310 departures were observed with standard road markings offering short preview time (1.5 sec), compared to 184 departures with enhanced road markings offering acceptable preview time (2.5 sec).

In simulated rain night conditions, drivers' errors with poor road delineation (standard road markings) exceed by 68% drivers' errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made 7.7 errors (3.9 lane departures and 3.8 runs off the road) with visible road markings, compared with 12.9 errors (6.3 lane departures and 6.7 runs off the road) with less visible road markings.

More (or less) visible, enhanced (or standard) road markings may not affect driver errors in the same extent and direction for all drivers..

- For 12 subjects on 24 (50% of the population for this age bracket), the difference between enhanced road markings and standard road markings is very important, the number of errors being much higher for standard road markings than for enhanced road markings

- For 4 subjects on 24 (17% of the population for this age bracket), the difference between enhanced road markings and standard road markings is important, the number of errors being higher for standard road markings than for enhanced road markings

- For 8 subjects on 24 (33% of the population for this age bracket) no or small difference was found between the 2 experimental modalities.

The comparison of errors between less and more visible road markings in simulation environment 2 is shown in the graphic below for the age bracket 61+.

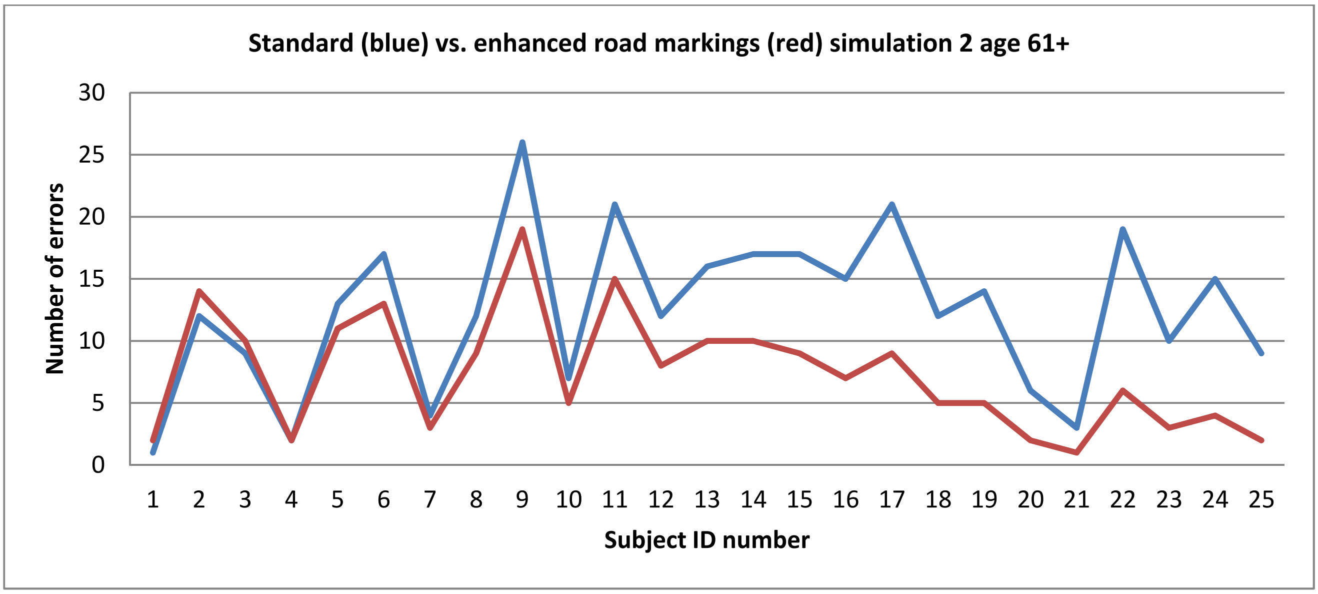


Figure 27. Comparison of errors depending on the visibility of RM – Simulation environment 2

Results are evaluated and discussed in chapter 7.

6.4. Overall results of driving simulation 2

Overall results of simulation environment 2 show a clear difference of performance between more or less visible road markings in the driving tests.

In simulated rain night conditions and for all the subjects, drivers' errors with poor road delineation (standard road markings) are 70% above the number of errors with good road delineation (enhanced road markings), including both lane departures and run-off the road. On average, drivers made approximately 4.5 errors (2.3 lane departures and 2.2 runs off the road) with enhanced visible road markings, compared with 7.7 errors (3.6 lane departures and 4.1 runs off the road) with standard visible road markings.

For most of the drivers, the number of errors expressed as the cumulated number of departures (including lane departures and run-offs the road) is lower with enhanced road markings than with standard road markings in rain conditions (figure below).

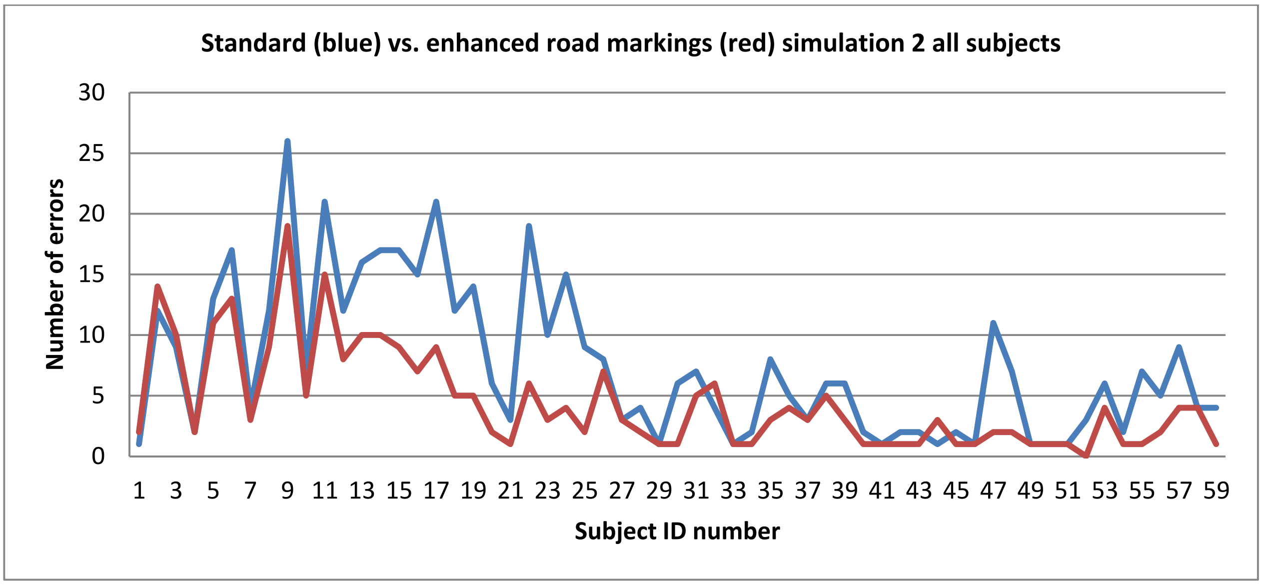


Figure 28. Comparison of errors depending on the visibility of road markings - Simulation environment 2 all subjects

7. Evaluation of Results

This chapter focuses on the evaluation of results that are presented in chapters 5 and 6.

All the paragraphs below are based on the comparison of the number of driving errors made by the drivers between the respective tested conditions (standard road markings vs. enhanced road markings) and on the useful contextual information which may complete or limit their interpretation in the following areas:
- lane departures and run-offs as driving errors in experimental conditions;
- role of the road markings visibility in a normal night simulation (environment 2);
- role of the road markings visibility in a abnormal night simulation (environment 1);
- role of the road markings visibility depending on age;
- limitations of the study.

7.1. Interpretation of lane departures and run-offs in experimental conditions

Assuming that lane departures and run-offs represent a risk for road safety, they are considered as driver errors in the handling of the car during the respective driving sessions on simulator.

Given the nature and the environment of the test, the session was considered as a serious activity by drivers. Even if people are not explicitly asked to respect the driving license rules, it was observed that they tend to drive as seriously as possible.

As the handling of the driving simulator is demanding in terms of accurate control, voluntary departures of the driving lanes (e.g. a shortcut in the curves) are quite unlikely.

The choice of the driving speed was also voluntary for the subject, in order not to influence the driver behaviour. According to the operators who monitored the subjects, the travel speed was not chosen appropriately, probably due to the lack of familiarity with the driving simulator, and to the poor visual cues available to estimate it visually within a night-time driving scenario.

It is commonly accepted that the improvement of the legibility of the road contributes to improve its safety. Cost 331 also demonstrated that a better delineation of the driving lanes by more visible road markings slightly increases speed, but that most of the increase of the preview time is devoted to a better anticipation of the alignment of the road. Another observable benefit of more visible road markings deals with a narrower distribution of speeds, with a reduction between the lower and the higher speeds.

Due to the difficulties to manage and record speed, the results of the driving simulation study were impossible to be interpreted consistently.

7.2. Discussion on the role of Road Markings visibility in a normal simulation (simulation 2)

In a normal simulated environment, road markings directly influenced both road delineation and road legibility.

In a simulated rural 2 lane road without public lighting, nor aberrant vertical roadside objects along the road, more visible road markings are likely to improve the safety of drivers in night rain conditions. A better visual delineation of the road may come down to improve the perception of the alignment of the road for the driver, and to improve its trajectory by decreasing its errors expressed as a number of lane or road departures. Even if further detailed analysis based on speed is not available, one can assume that the drivers allocated most of the extra preview time delivered by enhanced road markings to the perception of the road path and to the improvement of their trajectory, and that they allocated a minor part of the extra preview time to a higher speed.

Speed is generally considered as one of the contributing causes of road crashes, especially for fatal and serious injury crashes. Environmental factors such as the road visual delineation should not lead to a systematic increase in the users' speed. For that purpose, road designers should take into consideration the vertical and horizontal alignments of road which ensure a good distance of visibility without encouraging excessive speed. A small increase in speed may increase risk in case of the presence of a fixed or slow moving object on the road course. Be that as it may, given the prevalence of run-off-the-road crashes in 2 lane roads, a better trajectory of road users should probably lead to a better safety, even with a small increase in speed.

In the same environment, less visible road markings are likely to decrease the safety of drivers in night rain conditions. A poorer visual delineation of the road may come down to degrade the perception of the alignment of the road for the driver, and to impair its trajectory by increasing its errors expressed as the number of lane or road departures. Even if further detailed analysis based on speed is not available, one can assume that the drivers may have not slowed down in the same proportion as the decrease in the preview time offered by standard road markings in adverse rain conditions. This possible lack of adaptation may have degraded their trajectory on the road path (higher number of drivers errors compared to the scenario with enhanced road markings).

Given the prevalence of run-off-the-road crashes compared to crashes against objects on the road course for 2 lane roads, a better trajectory of road users should probably lead to a better safety.

These results are consistent with the former research on the influence of the visibility of road markings on the trajectory of drivers as inventoried in the state of the art of the project (Diamandouros et al. 2012).

7.3. Discussion on the role of Road Markings visibility in an abnormal simulation (simulation 1)

Given the fact that the simulated environment was a rural road without public lighting, including vertical roadside objects (and especially trees) along the road, the excessive and unrealistic visibility of such objects - which were looking as illuminated from bottom up - deeply changed the expected visual delineation of the road in simulation 1. The “simulation environment 1” could have been "skipped" generally, due to improper generation of simulation environment in order to assessment of possible impacts of road markings, but its presentation remains useful under the perspective of a complex visual environment.

The successive test drives performed in session 1 and some of the drivers of sessions 2 were then affected by this default in the simulation of some objects of the visual environment. As the visual delineation was supposed to be delivered by road markings only, the visual competition with trees created an unsurpassable difficulty to test the effect of the visibility of road markings. Because of this competition, it was not possible to test the influence of a difference in the perception of the road markings in a controlled manner, as planned initially.

The perception of the road was certainly biased for the subjects tested on the driving simulator for this abnormal environment. Instead of relying on road markings to perceive the driving lanes and the alignment of the road as planned in the driving scenario, we interpret that subjects might use differently this unexpected and unrealistic counter delineation offered by vertical roadside objects (and especially trees) along the road.

The influence of vertical roadside objects may depend on their presence and density along the roadside of the road. Because off their continuous visibility on the section, one can imagine that they influence the driver continuously, both in curved sections and in straight sections.

The influence of the trees in some curves may have reached a peak because of their increased visual density along the roadsides. In the straight sections of the itinerary as well, the excessive visibility of vertical roadside objects by night in simulation environment 1 might have created an unexpected road counter delineation which could compete with the road markings.

Vertical roadside objects may have contributed to help drivers to adapt their speed and their lateral position in the absence of any other visual delineation. However, the visual guidance offered by trees was not perfect, because they did not strictly align with the alignment of the road. Be that as it may, as they are visible from a far distance, they should help drivers to anticipate the alignment of the road, and to better appreciate their speed. Combined with less visible road markings, vertical roadside objects might guide the subjects and lead to less drivers errors.

Combined with more visible road markings, vertical roadside objects might play a role of visual distractors competing with the delineation of the driving lanes delivered by road markings. They could contribute to increase the complexity of the visual environment and to decrease the legibility of the road. In such an abnormal simulation environment, more visible road markings might lead to more errors for some drivers, depending on their age bracket.

The influence of age is discussed in chapter 7.4 below.

7.4. Discussion on the role of road markings visibility depending on age

As for the other sub-paragraphs, the role of road markings visibility depending on age is evaluated through the analysis of the data of the experiments with subjects tested on the driving simulator.

Role of road markings visibility in an abnormal visual simulation

Effect of road markings visibility in simulation environment 1 for age bracket 20-40

The effect of road markings on driver errors strongly varies according to the subjects.
For most of the drivers (14 on 22), the difference between standard road markings and enhanced road markings remains null or very small. For the other 8 drivers, the difference is significant (2 drivers) or very important (6 drivers), related to the number of errors during each run.

The change in the observable behaviour (number of errors) cannot be clearly interpreted, insofar as the change in the road markings nature does not lead to a clear change in the performance of the driver. For some drivers (5 on 22, subjects), the number of errors (lanes departures, run-off the road) is reduced. For others (3 on 22, subjects), the number of errors is increased.

One could argue that the first class of age contains younger drivers, who are maybe less experienced than the others, and who could be more influenced by complex visual environment than age bracket 2 subjects. Unfortunately, the differences in the fulfilment of the subjects' forms used for the experiments and the limitations in the documentation of the driving tests do not allow estimating the probability of this argument.

Effect of road markings visibility in simulation environment 1 for age bracket 41-60

The effect of road markings on driver errors varies according to the subjects. For most of the drivers (17 on 29), the difference between standard and enhanced road markings remains is null or very small. For the other 12 drivers, the difference is significant (4 drivers) or very important (8 drivers), related to the number of errors during each run.

Be that as it may, the change in the observable behaviour (number of errors) is not clearly interpretable, insofar as the change in the road markings nature does not lead to a clear change in the performance of the driver. For some drivers (17 on 29), the number of errors (lanes departures, run-off the road) is reduced. For others (6 on 29), the number of errors is increased.

One could argue that the second class of age contains experienced drivers, who are maybe less influenced than younger drivers and have a better coordination to handle the simulator than elderly drivers. Unfortunately, the differences in the fulfilment process of the subjects' forms used for the experiments and the limitations in the documentation of the driving tests do not allow estimating the probability of this argument.

Effect of road markings visibility in simulation environment 1 for age bracket 61+

The effect of road markings on driver errors varies according to the subjects. For half of the drivers (5 on 10), the difference between standard and enhanced road markings remains is null or very small (less than 20% of errors). For the other 5 drivers, the difference is important (2 drivers) or very important (3 drivers), related to the number of errors during each run.

The change in the observable behaviour (number of errors) is not clearly interpretable, insofar as the change in the road markings nature does not lead to a clear change in the performance of the driver. For some drivers (17 on 29), the number of errors (lanes departures, run-off the road) is reduced. For others (6 on 29), the number of errors is increased.

One could argue that the third class of age contains elderly drivers, who could maybe be more influenced by contradictory visual message and have more difficulties in psycho motor coordination to handle the simulator than other drivers. Unfortunately, the differences in the fulfilment process of the subjects' forms used for the experiments and the limitations in the documentation of the driving tests do not allow estimating the probability of this argument.

Global view and comparison between age brackets

As discussed before, the complex visual environment in visual simulation environment 1 might probably have biased the behaviour of drivers during the test driving sessions, leading to results difficult to interpret. One can conclude that result of simulation 1 is not really useful because of erroneous simulation.

<u>Role of road markings visibility in a normal visual environment</u>

Effect of road markings visibility in simulation environment 2 for age bracket 20-40

The **effect of road markings** on driver errors slightly varies according to the subjects. For the majority of the drivers (14 on 23), the difference between standard and enhanced road markings is very important (13) or important (1). For the other 9 drivers, the difference is small (2 drivers) or null (7 drivers), related to the number of errors during each run.

Based on the comparison of the number of errors (run-offs, lane departures) made by subjects through the driving simulator in the two respective conditions (enhanced vs. standard road markings), one can observe that, except for one subject, road markings visibility may have not decreased the driver's performance. More visible road markings played a very important role in the improvement of performance of the drivers for 60% of the subjects and a significant or very important role for 70% of the subjects in the first class of ages. Surprisingly, road markings visibility had no influence in terms of errors (lane or road departures) for 30% of the tested population. Furthermore, no clear distinction could be made for youngest drivers, whereas literature review suggests that their trajectory depends more on the delineation of driving lanes than more experienced drivers in the same age bracket. Unfortunately, the differences in the fulfilment process of the forms and the limitations in the documentation of the driving tests do not allow investigating further this observation.

Effect of road markings visibility in simulation environment 2 for age bracket 41-60

The effect of road markings on driver errors slightly varies according to the subjects. For most of the drivers (6 on 11, 54%), the difference between standard and enhanced road markings is null or very small. For the other 5 drivers, the difference is significant (1 driver, 9%) or very important (4 drivers, 37%), related to the number of errors during each run.

One can observe that road markings visibility did not decrease the driver's performance except for one subject. More visible road markings played a significant or an important role in the improvement of performance of the drivers for one third of the subjects in the second class of ages. Surprisingly, they did not really affect the trajectory of most of the drivers during the test driving session. One could argue that these drivers might have been influenced by a learning effect, e.g. an improvement of their drive through a better memorization of the itinerary when repeated in a given order. Assuming that a lot subjects performed the first run with more visible road markings, their performance could have been artificially boosted during the second run with less visible road markings, but better known road. Unfortunately, the differences in the fulfilment process of the subjects' forms used for the experimentsand the limitations in the documentation of the driving tests do not allow investigating further this argumentation.

Effect of road markings visibility in simulation environment 2 for age bracket 61+

The effect of road markings on driver errors varies according to the subjects. For more than half of the drivers (14 on 24), the difference between standard and enhanced road markings is very important (more than 50% of errors). For the other 8 drivers, the difference is important (4 drivers), small or null (4 drivers), related to the number of errors during each run.

One can observe that road markings visibility did not decrease the driver's performance except for one subject. More visible road markings played a significant or an important role in the improvement of performance of the drivers for most of the subjects in the second class of ages. These results are coherent with the visual needs of elderly drivers' population, due to the decrease into their visual performances through age. Unfortunately, the differences in the fulfilment process of the subjects' forms used for the experimentsand the limitations in the documentation of the driving tests do not allow investigating further this argumentation.

7.5. Discussion on the limitations of the study

Several issues concerning the limitations of the study are discussed in this chapter:

- limitations in the validity (of the driving simulator whatever the simulation environment 1 or 2
- limitations in the organization of the test driving session related to the subject neutrality
- limitations in the organization of the test driving session related to the data collection
- others limitations.

<u>Limitations in the validity of the driving simulator for driving experience immersion</u>

Even though the dynamics of the simulated vehicle were theoretically the same as the real ones for acceleration, braking and steer wheel, subjects had difficulties to adapt their driving to a safe speed. This difficulty to drive at a safe speed may probably be explained by several factors:

- the handling of the simulator was never tested during rain night condition
- the handling of the simulator was never tested incurved stretches of a road
- the perception of the vehicle dynamics is not the same as with a real vehicle,
    - the driving simulator being static, the lack of movements do consequently not submit subjects to G forces (longitudinal forces for acceleration, deceleration and braking, lateral forces due to cornering, and vertical forces due to speed given the longitudinal profile of the road, and irregularities in the road surface or in the embankment of the road), which give indication of the pace of the drive
    - the absence of vibrations also reduces the perception of the vehicle behaviour
    - for practical and technical reasons, noise was not completely reproduced, especially concerning its correlation with speed, and also concerning the rain condition (windscreen wiper noise and rain drop collision on the vehicle and water splash noise on the wheel arches)
    - due to the back to back installation of two driving simulators, it was not possible to play simulated sound completely (in a spatial manner) and at a normal level, through headphones or dedicated speakers.
- the perception of the vehicle speed also relies on the visual perception on the environment; due to the lack of familiarity with the simulator, and to the reduction of visual cues by night, the adjustment of speed is more complex
- moreover, as the handling of the simulator is complex, the driver generally adapts speed afterwards, i.e. after having difficulties to keep the driving lane due to initial speed
- finally, despite the driving simulation was considered as a serious activity by drivers, the perception of risk is not the same as a real test performed on a track or on a road.

Limitations in the organization of the test driving session related to the testing settings

The driving simulation experiments were performed according to different testing settings.

Two simulators with different displays (screen sizes) were used.

Notwithstanding important efforts to prepare the test driving sessions on the driving simulator, it was difficult to ensure that each subject could drive in a complete quietness during the test.

The presence of another subject / driving simulator behind them could have disturbed the drivers, and have influenced their behaviour and consequently the results of the tests.

Different testing settings create additional data noise that was not controlled for, hence leading to additional uncertainty regarding the nature of effects. As a consequence, observed number of errors could also be caused by using different equipment and by noise disturbances during testing.

Limitations in the organization of the test driving session related to the data collection

As the simulator was originally designed and used for real time training, the design of the second platform version (whatever the visual environment simulation 1 or 2) remained unfortunately based on the same concept, even if it could record multiple driving sessions.

For example, as the driving session is generally debriefed with the subject by an operator just after the driving test, the conditions of the driving and the ID of the subject were still not recorded during the session. This factor is really important, because the validity of the data depends on the correct information given by the subject sheet.

- The videos were recorded and stored separately for each driving simulator. Each subject performed the tests in a specific order (test 1 for a type of RM, test 2 for another type of RM) and at times (beginning of the driving simulator session corresponding to the time given by the operator) which were recorded on its personal form.
- As no driving condition (such as day or night time, visibility of road markings, dry or rain conditions) was recorded during the session, it was tricky to assign the different recorded files for one subject. This created the possibility of error in the order of test between standard and enhanced road markings. The replay of the video depends on the correct parameters of the initial test.
- As no ID of the subject was recorded on the driving simulator, there was a risk for some videos not to be correctly attributed between the different subjects, each video corresponding to a given session (standard markings or enhanced markings) for a subject.

The attribution of each session/video to one subject in one experimental modality was checked a posteriori, based on the correspondence between times recorded manually on the subject form at the beginning of each test driving session and times recorded automatically by the computer at the end of each test driving session.

The files transferred by the subcontractor had to be corrected for several subjects, where set of times for the attributed videos were not compatible with the agenda of the different drivers. The same was used for a few drivers sessions only, between standard and enhanced road markings. These flaws in allocation of data to the right testing conditions could have produced even inverted results, just by wrongly allocating the dataset to the other test condition respectively.

Others limitations

The “environment 2” study includes only about half the sample (i.e. 58 persons), thus limiting the validity of results in the light of the original study aim of about a sample of n=120. On the other hand, the “environment 1” study provides complementary – if less interpretable – information.

There are no exploitable recordings of speed, longitudinal and lateral acceleration. Hence observed effects (numbers of errors) could be solely attributed to a function of speed choice and could have nothing to do with impacts of road marking at all. To moderate this possible limitation, qualitative observation and comments from operators who monitored the driving sessions indicate that speed choice was not appropriate for both conditions. As travel time was generally reported as slightly shorter with enhanced road markings than with standard road markings, one can assume that speed did not impair the effect of road markings. On the contrary, the speed choice may have been better (even if slightly higher) with enhanced road markings than with standard road markings. Speed choice may result from the influence of road marking visibility, because the possible order effect of the test sessions was controlled by the appropriate organization of the sequence of the scenarios. The improvement of the trajectory may probably not be attributed to speed but to enhanced road markings.

Finally, due to the problem of data identification, no statistical hypothesis testing was performed. Consequently, presented findings and differences could solely be due to "natural" data variation and not due to road marking effects.

All this uncertainties created concerns about the validity of the interpretation of the results coming from the successive driving sessions and subjects, especially when trials are led by a single operator with several driving simulators in the same experiment.

8. Conclusions and Perspectives

The purpose of this study was to assess the impact of the visibility of road markings in night time driving by rain conditions, also taking into account different age groups based on a driving simulator study. Therefore, an experiment was carried out on a specifically prepared driving simulator through several driving sessions in the area of Paris, France. 123 subjects were recruited based on three age groups, including vision testing to ensure a valid interpretation of results.

Simulation test drives were carried out in a night-time scenario within two different road delineation conditions (standard road markings, night rain visible road marking having enhanced visibility properties by rain) on a realistic itinerary of a two-lane rural road. With the help of data recorders, driving performance was measured by means of travel time and lateral position behaviour.

The results obtained indicate that – in a normal environment - road trajectory may have been improved best when visible road markings (2.5 sec. preview time) are simulated, compared to less visible road markings (1.5 sec. preview time). This was concluded after analysing driving errors by means of lateral position run off the road and lane departures.

Driving behaviour expressed in terms of speed, (mean) lateral and longitudinal accelerations and travel time was finally not further investigated, due to the intrinsic complexity of data mining of the equipment used.

The results obtained indicate that enhanced road markings may have a positive effect on the trajectory of drivers in adverse driving conditions which were simulated in this experiment. Under night-time and rain driving conditions, the enhanced road markings may generally lead the driver to have a better lateral guidance of the vehicle on the driving path.

From a traffic safety perspective, the use of more visible road markings in a legible visual environment may lead to a decrease in the errors made by drivers, especially among the youngest and the oldest classes of age.

Annex 1a – Table 13 Description of the sample of subjects, age bracket 20-40 based on the different recruitment sessions

Men	Women	Age
1		21
	1	22
	1	23
	1	23
	1	24
1		24
1		24
1		25
1		26
1		26
	1	27
	1	28
	1	28
	1	28
1		28
1		28
	1	29
1		29
1		29
1		30
	1	30
	1	30
1		31
	1	31
1		32
	1	32
1		32
1		33
1		33
	1	33
1		33
	1	34
	1	34
1		34
	1	34
	1	35
1		36
	1	36
	1	36
	1	37
1		37
1		37
1		37
1		37
1		38
	1	38
1		39
25	22	47

Annex 1b – Table 14 Description of the sample of subjects, age bracket 21-40 based on the different recruitment sessions

Men	Women	Age
	1	41
1		41
	1	41
	1	42
1		42
1		42
1		42
1		43
	1	43
1		43
1		44
1		44
	1	44
	1	44
1		45
1		46
1		46
	1	46
	1	46
1		46
	1	46
	1	47
1		48
	1	49
	1	49
	1	49
	1	49
1		50
1		50
1		50
1		50
1		50
1		51
1		52
1		53
	1	55
1		56
	1	57
1		58
1		59
	1	60
24	17	41

Annex 1c – Table 15 Description of the sample of subjects, age bracket 61+ based on the different recruitment sessions

Men	Women	Age
1		61
1		62
1		65
	1	65
	1	65
	1	65
1		66
	1	66
	1	66
	1	66
	1	66
	1	67
	1	67
	1	67
1		68
1		69
1		70
1		71
1		72
1		74
1		75
1		75
1		75
	1	76
	1	77
	1	78
1		78
1		79
	1	79
1		80
	1	81
	1	82
	1	87
1		90
1		91
18	17	35

RAIN VISION

Directorate-General for Mobility and Transport

Annex 2 – Visual test used for age brackets 20-40 and 41-60

AsnaV		**Subject Code:** **Age:** **Man ❑** **Woman ❑** **Type of Device:** **glasses ❑** **contact lenses ❑** **surgery ❑** **Type of correction:** **Long Distance ❑** **Short distance ❑** **Progressive ❑** **Last medical visit:**
Type of test	**N° test**	Obtained Results (tick the corresponding box)
Binocular acuity (Long Distance Vision)	**2**	2 ❑ 4 ❑ 5 ❑ 6 ❑ 8 ❑ 10 ❑ 12 ❑
Stereoscopic Vision (Short Distance Vision)	**6**	● ● ● ● ● **5** ❑ **3** ❑ **2** ❑ **4** ❑ **1** ❑
Vision of Colours (Long Distance Vision)	**9**	**5** **7** **9** **2** 3 2 [ ] **1** [ ] **9** **1** [ ] 4 9/
Vision of contrasts (Mid Distance Vision)	**10**	**0,6** **0,4** **0,2** **4** [ ] [ ] [ ] **6** [ ] [ ] [ ] **8** [ ] [ ] [ ]
Mesopic Vision Vision (Mid Distance Vision)	**11**	M ❑ ❑ ❑ ❑ ❑ ❑ 2 4 6 8 10 12 P ❑ ❑ ❑ ❑ ❑ ❑
Glare (Vision Recovery Time)	**12**	≤ 40 years ❑ 0 to 60 sec ❑ + 60 sec > 40 ≤ 50 years ❑ 0 to 90 sec ❑ + 90 sec > 50 years ❑ 0 to 120 sec ❑ + 120 sec
Observations		**Green card ❑** **Red card ❑**

Session 1 (tick the box) ❑ Good Visibility Marks ❑ Low Visibility Marks	Time 1 (min, sec)	Session 2 (tick the box) ❑ Good Visibility Marks ❑ Low Visibility Marks	Time 1 (min, sec)

Annex 3 – Visual test used for age bracket 61+

AsnaV	**Subject Code:** **Age:** **Man** ❑ **Woman** ❑ **Type of Device:** **glasses** ❑ **contact lenses** ❑ **surgery** ❑ **Type of correction:** **Long Distance** ❑ **Short distance** ❑ **Progressive** ❑ **Last medical visit:**							
Type of test	**N° test**	Obtained Results (tick the corresponding box)						
Binocular acuity (Long Distance Vision)	**Auto**	2 ❑	4 ❑	5 ❑	6 ❑	8 ❑	10 ❑	12 ❑
Stereoscopic Vision (Short Distance Vision)	**Auto**	● **5** ❑	● **3** ❑	● **2** ❑	● **4** ❑	● **1** ❑		
Long and Short Distance Vision (farsightedness)	**Auto**	● **5** ❑	● **3** ❑	● **2** ❑	● **4** ❑	● **1** ❑		
Long and Short Distance Vision (astigmatism)	**Auto**	● **5** ❑	● **3** ❑	● **2** ❑	● **4** ❑	● **1** ❑		
Phoria	**Auto**	● **5** ❑	● **3** ❑	● **2** ❑	● **4** ❑	● **1** ❑		
Long and Short Distance Vision (presbytia)	**Auto**	● **5** ❑	● **3** ❑	● **2** ❑	● **4** ❑	● **1** ❑		

Annex 4 – Results of simulation environment 1 (abnormal environment)

A DATE	B Subject Code	C Gender		D Age	Standard Road Markings			Enhanced Road Markings			Comparison enhanced vs. Standard road markings	
					E Lane departures	F Run-off the road	G = E+F Total departures	H Lane departures	I Run-off the road	J = H+I Total departures	K = G - J	L = (G - J)/J
		M	F									
22/01/2013	00 1	1		45	6	3	9	3	2	5	4	80%
22/01/2013	00 3	1		44	8	2	10	6	3	9	1	11%
22/01/2013	00 6	1		50	0	1	1	0	1	1	0	0%
22/01/2013	00 8		1	34	0	1	1	0	1	1	0	0%
22/01/2013	00 9		1	37	1	9	10	1	9	10	0	0%
22/01/2013	0 14		1	23	0	11	11	0	1	1	10	1000%
22/01/2013	0 16	1		56	0	1	1	0	1	1	0	0%
22/01/2013	0 18	1		50	4	0	4	3	1	4	0	0%
22/01/2013	0 19	1		50	3	1	4	1	0	1	3	300%
22/01/2013	0 21	1		32	1	3	4	4	10	14	-10	-71%
22/01/2013	00 2	1		61	1	5	6	2	3	5	1	20%
22/01/2013	00 4		1	35	0	1	1	0	1	1	0	0%
22/01/2013	00 5	1		30	1	5	6	2	3	5	1	20%
22/01/2013	00 7		1	30	2	1	3	1	1	2	1	50%
22/01/2013	0 11		1	49	2	0	2	0	1	1	1	100%
22/01/2013	0 12	1		37	1	1	2	3	0	3	-1	-33%
22/01/2013	0 13		1	24								
22/01/2013	0 20		1	42	2	0	2	0	1	1	1	100%
22/01/2013	0 22	1		25	3		3	1	1	2	1	50%
23/01/2013	101	1		59	0	0	0	0	0	0	0	0%
23/01/2013	103		1	46	0	1	1	0	1	1	0	0%
23/01/2013	105	1		58	2	3	5	2	2	4	1	25%
23/01/2013	107		1	22	2	3	5	0	1	1	4	400%
23/01/2013	109	1		42	1	1	2	3	2	5	-3	-60%
23/01/2013	112	1		46	0	3	3	6	2	8	-5	-63%
23/01/2013	113		1	32	0	0	0	0	0	0	0	0%
23/01/2013	115		1	55	0	7	7	1	5	6	1	17%
23/01/2013	117		1	57	4	8	12	0	1	1	11	1100%
23/01/2013	119		1	41	1	1	2	0	1	1	1	100%
23/01/2013	122		1	49	5	1	6	1	1	2	4	200%
23/01/2013	123		1	28	4	0	4	7	0	7	-3	-43%
23/01/2013	124	1		50	5	1	6	2	2	4	2	50%
23/01/2013	126	1		46	3	1	4	7	5	12	-8	-67%
23/01/2013	127	1		38	8	3	11	4	1	5	6	120%
23/01/2013	128		1	46	2	0	2	0	1	1	1	100%
23/01/2013	129		1	28	2	1	3	1	0	1	2	200%
23/01/2013	130	1		42	0	1	1	0	2	2	-1	-50%
23/01/2013	121	1		43	5	2	7	6	0	6	1	17%
23/01/2013	102		1	30	0	3	3	0	8	8	-5	-63%
23/01/2013	104	1		33	0	1	1	0	2	2	-1	-100%
23/01/2013	106		1	43	2	1	3	6	0	6	-3	-50%
23/01/2013	108		1	49	2	1	3	2	0	2	1	50%
23/01/2013	110	1		50	4	0	4	4	1	5	-1	-20%
23/01/2013	111	1		36	0	1	1	0	1	1	0	0%
23/01/2013	114	1		52	4	1	5	1	2	3	2	67%
23/01/2013	116	1		24	0	1	1	1	1	2	-1	-50%
23/01/2013	118		1	36	0	0	0	0	1	1	-1	-100%
23/01/2013	120		1	34	12	2	14	4	1	5	9	180%
23/01/2013	131	1		24	0	1	1	1	1	2	-1	-50%
23/01/2013	132	1		53	2	1	3	1	0	1	2	200%
23/01/2013	133	1		44	1	1	2	0	1	1	1	100%
23/01/2013	134	1		41	5	0	5	2	1	3	2	67%
23/01/2013	135	1		39	0	1	1	2	0	2	-1	-50%
23/01/2013	136	1		37								
06/02/2013	F1	1		70	1	1	2	4	1	5	-3	-60%
06/02/2013	F2	1		72	1	1	2	4	0	4	-2	-50%
06/02/2013	F3	1		69	1	1	2	0	1	1	1	100%
15/02/2013	G1	1		62	1	1	2	0	1	1	1	100%
15/02/2013	G2	1		71	3	10	13	7	15	22	-9	-41%
15/02/2013	G3	1		66	7	1	8	12	1	13	-5	-38%
22/02/2013	R1	1		75	16	1	17	13	1	14	3	21%
22/02/2013	R2		1	65	0	1	1	0	1	1	0	0%
22/02/2013	R3		1	66	9	0	9	2	0	2	7	350%
TOTAL SIMULATION 1		**38**	**25**	**44,8**	**150**	**114**	**264**	**133**	**108**	**241**	**23**	**10%**
			63									

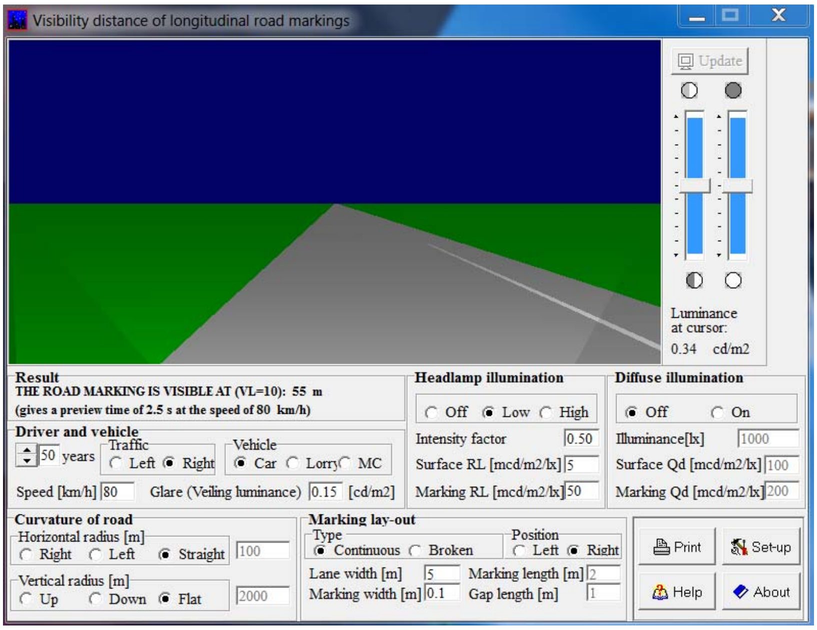
Annex 5 – Results of simulation environment 2 (normal environment)

A DATE	B Subject Code	C Gender M	C Gender F	D Age	Standard Road Markings: E Lane departures	F Run-off the road	G = E+F Total departures	Enhanced Road Markings: H Lane departures	I Run-off the road	J = H+I Total departures	Comparison enhanced vs. Standard road: K = G - J	L = (G - J)/J
February 22, 2013	S1	1		75	22	4	26	19	0	19	7	37%
February 22, 2013	S2		1	65	6	3	9	7	3	10	-1	-10%
February 22, 2013	S3		1	66	0	19	19	0	6	6	13	217%
April 3, 2013	2		1	46	7	0	7	4	1	5	2	40%
April 3, 2013	5	1		51	1	4	5	2	2	4	1	25%
April 3, 2013	6		1	47	1	1	2	0	1	1	1	100%
April 3, 2013	8		1	23	2	4	6	5	0	5	1	20%
April 3, 2013	10	1		33	0	1	1	0	1	1	0	0%
April 3, 2013	12		1	29	1	1	2	1	0	1	1	100%
April 3, 2013	14	1		26	2	4	6	0	3	3	3	100%
April 3, 2013	17		1	49	1	7	8	0	3	3	5	167%
April 3, 2013	18		1	28	1	1	2	0	1	1	1	100%
April 3, 2013	20		1	33	1	2	3	0	0	0	3	NA
April 3, 2013	22		1	27	0	1	1	0	1	1	0	0%
April 3, 2013	24	1		33	2	4	6	3	1	4	2	50%
April 3, 2013	27	1		43	3	1	4	0	2	2	2	100%
April 3, 2013	29	1		21	2	1	3	2	1	3	0	0%
April 3, 2013	30	1		26	0	2	2	1		1	1	100%
April 3, 2013	32		1	44	0	1	1	0	1	1	0	0%
April 3, 2013	34	1		37	7	2	9	3	1	4	5	125%
April 3, 2013	36	1		48								
April 3, 2013	3	1		37	1	3	4	2	2	4	0	0%
April 3, 2013	4	1		31	2	5	7	0	2	2	5	250%
April 3, 2013	7		1	38	2	2	4	0	1	1	3	300%
April 3, 2013	9	1		34	1	1	2	0	1	1	1	100%
April 3, 2013	11		1	34	0	7	7	0	1	1	6	600%
April 3, 2013	13		1	41	7	1	8	7	0	7	1	14%
April 3, 2013	15	1		46	3	1	4	3	3	6	-2	-33%
April 3, 2013	16		1	36	4	1	5	1	1	2	3	150%
April 3, 2013	19		1	31	0	1	1	0	1	1	0	0%
April 3, 2013	21	1		28	1	1	2	0	1	1	1	100%
April 3, 2013	23		1	46	0	1	1	0	1	1	0	0%
April 3, 2013	25	1		29	0	1	1	0	1	1	0	0%
April 3, 2013	26	1		42	2	1	3	2	1	3	0	0%
April 3, 2013	28	1		32	0	1	1	1	0	1	0	0%
April 3, 2013	31	1		29	5	6	11	1	1	2	9	450%
April 3, 2013	33	1		28	0	1	1	0	3	3	-2	-67%
May 6, 2013	M1		1	81	5	4	9	1	1	2	7	350%
May 6, 2013	M2	1		82								
May 6, 2013	M3		1	67	0	4	4	0	3	3	1	33%
May 6, 2013	M4		1	87	16	1	17	7	6	13	4	31%
May 6, 2013	M5	1		79	0	1	1	0	2	2	-1	-50%
May 6, 2013	M6		1	77	3	9	12	5	4	9	3	33%
May 6, 2013	M7		1	44	2	4	6	0	1	1	5	500%
May 6, 2013	M8	1		91	4	17	21	2	7	9	12	133%
May 6, 2013	M9	1		68	9	3	12	10	4	14	-2	-14%
May 6, 2013	M10		1	79	5	12	17	5	5	10	7	70%
May 6, 2013	M11		1	67	1	1	2	0	2	2	0	0%
May 6, 2013	M12	1		80	4	6	10	2	1	3	7	233%
May 6, 2013	M13		1	78	3	18	21	0	15	15	6	40%
May 6, 2013	M14	1		90	1	2	3	1	0	1	2	200%
May 7, 2013	M15	1		75	7	5	12	6	2	8	4	50%
May 7, 2013	M16		1	67	5	1	6	1	1	2	4	200%
May 7, 2013	M17			76	3	12	15	0	4	4	11	275%
May 7, 2013	M18	1		66	7	0	7	4	1	5	2	40%
May 7, 2013	M19		1	66	3	13	16	5	5	10	6	60%
May 7, 2013	M20	1		74	4	9	13	1	10	11	2	18%
May 7, 2013	M21		1	66	14	1	15	5	2	7	8	114%
May 7, 2013	M22	1		78	6	8	14	2	3	5	9	180%
May 7, 2013	M23	1		65	9	3	12	3	2	5	7	140%
May 7, 2013	M24		1	65	13	4	17	8	1	9	8	89%
TOTAL Simulation 2		**31**	**29**	**53,0**	**211**	**235**	**446**	**132**	**130**	**262**	**184**	**70%**
			60									

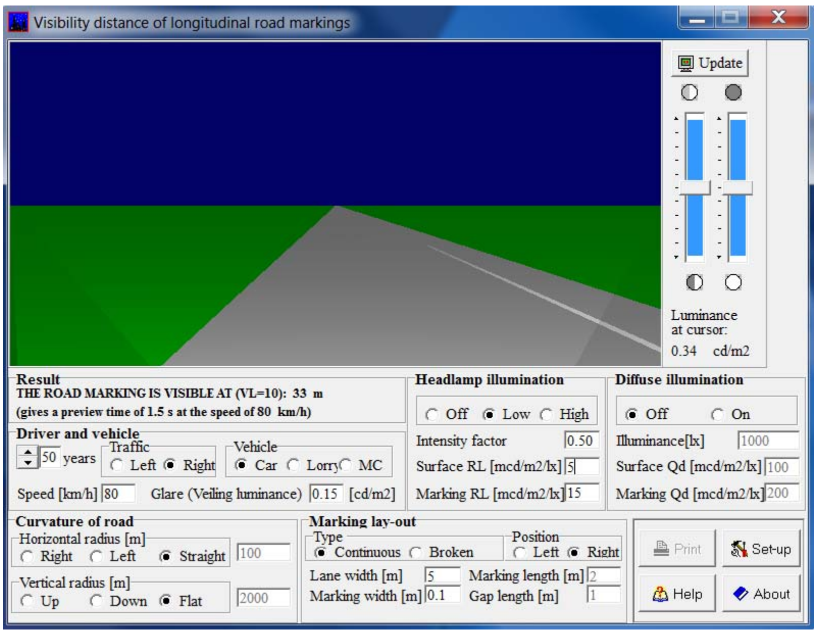
Annex 6 – Visibility Programme (Cost 331)

Estimation of the pavement marking wet retro reflectivity based on the choosen preview time for the continuous edge line on the right side.

Enhanced Road Marking: Preview time 2.5 sec.; R_L 50 mcd/m²/lx (RW 3).



Standard Road Marking: Preview Time 1.5 sec.; R_L 15 mcd/m²/lx (RW 0).



The VISIBILITY programme has been developed on behalf of the COST 331 Management Committee, by DELTA Light & Optics under contract of The Danish Road Directorate

References

COST, (1999), COST 331 Requirements for Horizontal Markings, Luxembourg, Office for Official Publications of the European Communities, ftp://ftp.cordis.europa.eu/pub/cost-transport/docs/331-en.pdf

Diamondourous K. and al. (2012), State of the Art - WP1, Rainvision Project

Essilor (undated), Ergovision data sheet, available on Nov 15th 2013 at the link http://www.essilor.ch/FR/Instruments/Centrage/Documents/17_ergovision_anlg.pdf

Rosey F, Auberlet J.-M., Moisan O. and Dupré G. (2009), Impact of Narrower Lane Width Comparison Between Fixed-Base Simulator and Real Data, Transportation Research Record: Journal of the Transportation Research Board, No. 2138, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 112–119

Wikipedia (2013), Vision, field of view

Terms and definition

Alignment of the road: the horizontal aspect of the road, i.e. the route of the road; horizontal alignment in road design consists of straight sections of road, known as tangents, connected by circular horizontal curves; Circular curves are defined by radius (tightness) and deflection angle (extent). The design of a horizontal curve entails the determination of a minimum radius (based on speed limit), curve length, and objects obstructing the view of the driver. The alignment of the road is one of the parameters influencing road sight distance.

Day condition: illumination corresponding to a normal day period

Distance of visibility of road markings (general): it is the maximum distance to which road markings are visible for an observer. Some in field track experiments evaluated the distance of visibility of road markings as the distance to which the end of the centre broken line becomes visible to a series of observers driving a car with high beam. For the purposes of this driving simulator study, the distance of visibility of road markings is defined in this report as the maximum distance to which the longitudinal road markings are visible for the subjects with low beam.

Distance of visibility of road markings (by night): for the night-time scenarios, the distance of visibility of road markings is defined and tested as the maximum distance to which the longitudinal road markings are visible in the headlight beam zone of a car with low beam. Given the shape of the headlight beam zone (longer ahead on the edge than on the centre of the road), the distance of visibility considered for road markings is defined as the distance to which the edge line was visible. The distance is calculated by counting the number of marks up to the last visible mark provided that the simulated edge road markings is a broken line and that its modulation and geometry are known and adequately simulated.

Driving simulator: equipment which simulates a vehicle, including a seat, a dashboard and its commands (pedals, steering wheel, headlamps, windscreen wipers, indicators) and its dynamics through a real time simulation including visual appearance of the road and driving noises through corresponding devices (computer, screens, speakers or headphones). Driving simulators can be static or dynamic. Static simulators can embed possible haptic devices such as operation of commands, steering wheel force feedback or vibration plates. Dynamic simulators are mounted on moving hydraulic cylinders to reproduce the respective dynamic forces and accelerations produced by a real driving experience. Both types of simulators can include the vehicle cab, or sometimes all the vehicle body.

Headlight beam zone: zone of the road ahead illuminated by the headlight beam of a passenger car in low beam; typically, the headlight beam zone ranges from 30m to 50m (sometimes from 50 to 75m). In this headlight beam zone, road markings can be visible at a shorter or a longer distance which will depend on their level of retro reflectivity.

Lane departure: an event where the vehicle adopts an incorrect lateral position and leaves its driving lane without leaving the carriageway - on a two lane rural road, lane departures mean a crossing of the centreline (if any) and an intrusion on the opposite driving lane.

Legibility of the road: capacity of the road to be correctly and immediately perceived and understood by drivers without specific explanation; capacity of the road to produce a 'traffic environment' which elicits safe behaviour simply by its design (self-explaining road).

Night condition: illumination corresponding to a normal night period (without moonlight, nor dawn)

Preview time: according to COST331, preview time is defined as the number of seconds taken to drive a distance equal to the visibility distance. In a night-time driving scenario assuming that road markings highly contribute to the visibility of the road path, the preview time is considered as the time it will take the driver to travel from the present location to the most distant road marking visible.

Profile of the road: it is the vertical aspect of the road. Profile consists of road slopes, called grades, connected by parabolic vertical curves. Vertical curves are used to provide a gradual change from one road slope to another, so that vehicles may smoothly navigate grade changes as they travel. The profile of the road is one of the parameters influencing road sight distance.

Retro reflectivity: it is the intrinsic capacity of a material to redirect by night the light emitted by a punctual illumination source from its surface towards this source. For road markings, the retro reflectivity represents their night visibility. It consists of the road markings' capacity by night to redirect the light of the headlamps of the vehicle to the eyes of the driver in a 30m geometry (angle of illumination of 1,24° with headlamps at 0,60m high, angle of observation for the driver's eyes of 2,29° at 1,20m high). It is measured with dedicated equipment in a photometric unit expressed in millicandelas (quantity of retro reflected light) per lux (of illuminated light) per square meter (given the surface of the road markings).

Run off the road: an event where the vehicle adopts an incorrect lateral position and leaves its driving lane while leaving the carriageway - on a two lane rural road, lane departures mean a crossing of the edge line (if any) and an intrusion on the roadside. Run off the road may lead to a road crash

Road Crash: an event that produces injury and / or property damage, involves a motor vehicle in transport, and occurs on a traffic way, or while the vehicle is still in motion after running off the traffic way.

Road Markings: road equipment based on horizontal marks on the surface of the road course used to delimitate the different parts of the road, including the delineation of the driving lanes. Road markings are also used in combination with road signs to reinforce the perception of intersections including give right of way. Road markings dimensions, modulations of broken lines and conditions for use are described at a national level in a technical regulatory document.

Sight distance: for road, the sight distance available is the length of roadway ahead visible to the driver.

Visibility: capacity of an object to be seen by an observer. Visibility depends both on the visual abilities of the observer and of the ambient conditions (day/night, available illumination, dry/wet/rain). For road markings, the night visibility is usually measured by its retro reflectivity. The day visibility is usually measured by its luminance under diffuse illumination.

List of acronyms

RM	Road Markings
mCd/lx/m²	Millicandelas per lux per square meter

END OF DOCUMENT