Behavioural Adaptation to Adaptive Front Lighting Systems (AFS): A Six Day Driving Simulator Study

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Introduction

Only 25% of driving is conducted at night but 55% of driving fatalities occur during this period. When facing situations of poor visibility, vulnerable road users are particularly exposed: 40% of pedestrian fatalities occur at dawn. Road accidents are thus a matter of great concern.

The European project CLARESCO finalised in June 2005 aimed at improving safety and drivers' comfort using innovative lighting technologies by analyzing human perception and behaviour in terms of efficiency and comfort. These objectives were achieved through the use of real-time simulation tools. During the project three main tasks were handled:

- Development of realistic AFS-Headlamp light beam patterns and corresponding algorithms for the dynamic behaviour

- Integration of the AFS algorithms and the lighting data in the Scaner II driving simulator

- Definition of test scenarios and investigations of the impact of this new lighting functions in terms of comfort and safety.

The participating organisations were Renault, Volvo 3P, Oktal, LPPA-College de France (France), AutoSim, SINTEF (Norway), TRL (UK) , Trademco (Greece) and Hella KgaA (Germany).

This paper describes the results of the SINTEF six day Driving Simulator study of behavioural adaptation to the Adaptive Front-Lighting System (AFS).

A look at the literature on evaluation of ADAS systems shows that most studies are single encounters, one day exposure to new technologies. The question is how valid conclusions from such studies are. If behavioural adaptation is apparent immediately predictions may be fairly valid, but how can we confirm this is the case?

Behavioural adaptation may be apparent immediately, but may also require an extended time period to determine longer-term effects.

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The main challenge is to assess when behaviour has found some kind of basic stability, in that the variation may be said to encircle the essence of behaviour. Draskoczy (HOPES D6) outlines chronological phases in studying safety issues of driver assistance systems, which incorporates the thought that behaviour evolves. She states that studies should be done (a) before system activation (b) Immediately (within a month) after system activation, and (c) six months with system use. Estimates of the safety impact of new in-vehicle systems should not ignore behavioural adaptation. System designers must assume that behavioural adaptation will occur (Smiley, 1999) and the nature of these changes should be identified in case they are unsafe. Based on theoretical considerations (learning theory) and practical constraints (time and available budget) a six day simulator study was designed to study behavioural adaptation to AFS beyond the initial familiarization.

The main focus of this study is to supplement trials on the TRL and Volvo Trucks simulator trials, and investigate to what extend drivers increase speed or decrease safety margins as a function of extended experience. Further, this effort aims to provide description of possible patterns of driving with AFS versus control group. A total of 22 drivers were exposed to approximately 140 kilometres of driving over six days in the SINTEF Driving Simulator. The scenarios combined city and rural road environments with low traffic density.

Results showed that drivers increased speed both in City and Rural environments over the six day test, retest and learning period.

AFS-Lighting functions

Night time driving requires the reaction of the headlamp system to different traffic situations. The lighting system should adapt to various road conditions and geometries as well as different ambient conditions and last not least to other traffic participants. There are two contradicting requirements, on one hand the active illumination of the street scenery and on the other hand the reduction of glare level. Today's static headlamp systems having only Low Beam and High Beam have to serve both demanding requirements. However static lighting systems are a compromise between optimum illumination for the driver and reduced glare for oncoming traffic.

Based on the several evaluations and discussions new design guidelines for AFS headlamp systems were derived. This enables the headlamp suppliers to design the lighting systems with much more freedom. The main goal is to improve safety during night time driving.

The results of the investigations during the project are four basic light functions with special characteristics taking the most common traffic situations into account.

Town Light:
Symmetrical beam pattern with reduced glare light for slow driving situations and a defined amount of ambient illumination.

Country Road Light:
Asymmetric beam pattern similar to today's low beam

Motorway Light:
Symmetrical beam pattern with improved illumination of fare distant areas and reduced glare in the rear view mirror for the vehicles in front

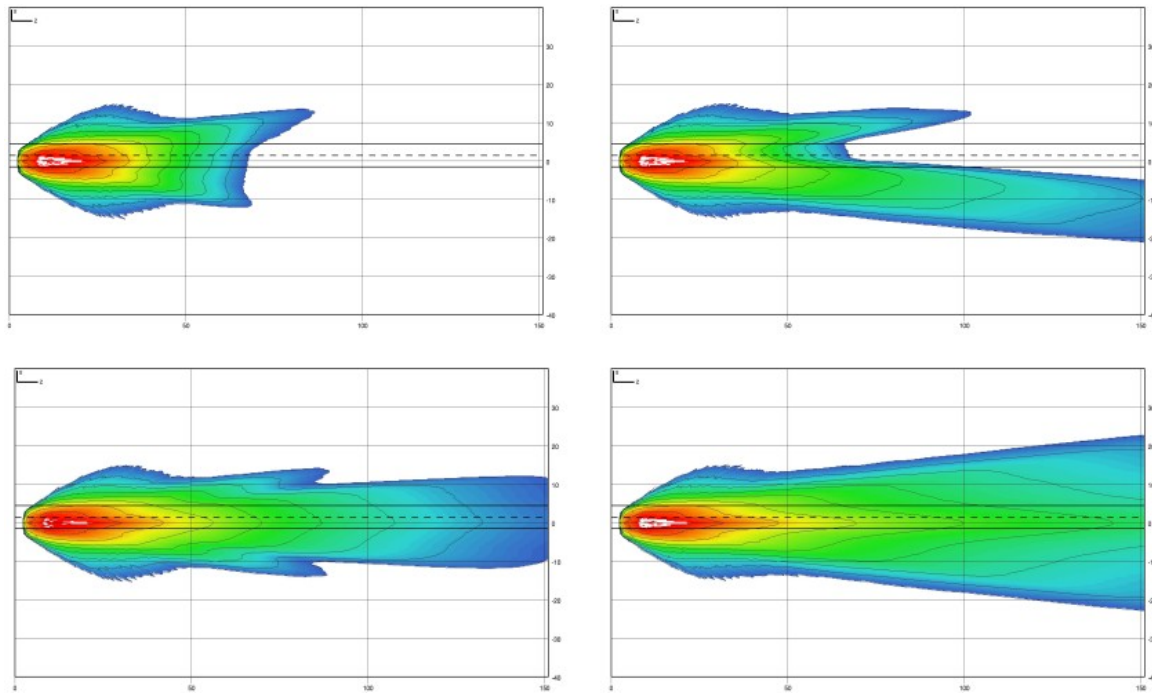**High Beam:**
Similar to today's high beam

Fig.1 Different AFS-light distributions in logarithmic false color representation: top left: town light, top right: country road light, bottom left: motorway light, bottom right, high beam (source: Hella).

Different combinations of the basic light functions combined with dynamic swivelling mode of the headlamp system and static bending lights lead to a maximum in flexibility of situation adapted beam patterns. This was the base for evaluations in CLARESCO project with the target to increase the safety and comfort during night time driving

In the SINTEF driving simulator study reported here Town light and country road light was tested.

1   Method

1.1 Experimental design

The experimental setup is a mixed design. Day 1 in the six day study was conducted using a within-subjects design, almost identical to CLARESCO studies described on the TRL and Volvo Trucks simulator for respectively city and rural road environments. Day 2-6 of the study was conducted as a between-subjects design, involving eleven drivers exposed to AFS and eleven drivers as control. Objective measures recorded on the first day was compared to objective measures on the second and last day of driving. User AFS acceptance and comfort measures were also obtained.

1.2 The SINTEF Driving Simulator

This presentation reports on AFS trials performed at the SINTEF Driving Simulator. The simulator is a 'high-end simulator' based on a full scale and fully equipped Renault Scenic 1997 model with an integrated motion system. Five channels of visual information provide the Field of View (FoV): The three front screens are rear projected and the two screens behind the vehicle are front projected (see Figure 1).

Figure 1: SINTEF Driving Simulator

The applied AFS algorithms was tested and validated before the study commenced.

1.3 Subjects

All participants recruited for the study had prior experience with the SINTEF driving simulator with an average of 5.7, ranging from 3-12 prior test drives. In total twenty-two drivers completed the full test (average age 37 years and average driving experience 16,7 years, ranging from 4 years to 33 years).

1.4 Procedure

The driver groups recruited to take part in testing AFS in the City and rural scenarios drove each test route six times. First day all experienced the city and rural test scenarios with AFS headlights, standard headlights and under daylight conditions in a randomized order. Then the participants were divided in a experimental and control group, were half drove a series of learning scenarios only with AFS lights or only with standard lights. All participants completed post test questionnaires to investigate their subjective opinions of each lighting system.

The drivers undergo a series of driving sessions consisting of an initial 4 sessions à 45 minutes in a within-subjects design (day1), then 2 sessions à 20 minutes apportioned on five days in a between-subjects design. All drivers had a three day break between day1 and day2 (weekend). Day 2-6 was conducted without pause in the program.

The sessions included approximation to the driving simulator experience and exploration of the AFS system before driving tests and training scenarios.

The experiment involved six scenarios with adhering situations and events relevant for AFS system functioning. The scenarios were centred on variations of an urban, rural and motorway road environment and containing low density traffic allowing   controlled and easy AFS and no-AFS driving.

They were as follows:

Day 1 – test of first encounter with AFS :

Training-scenario: Contains a 15 minute drive, where the driver is given the chance to approximate to the driver simulator and encouraged to explore the nature of the AFS system. Presented on day 1.

Test-scenario City: A 2 x15 minute test drive where objective measures are obtained. This scenario offers various situations and events relevant for the functioning of the AFS system. Driver is encouraged to drive as normal. Presented on day 1 immediately after the training scenario.

Test-scenario Rural: A 2 x15 minute test drive where objective measures are obtained. This scenario offers various situations and events relevant for the functioning of the AFS system. Driver is encouraged to drive as normal. Presented on day 1 after the city test scenario.

Day 2 - test of second encounter with AFS:

Drivers presented with the same test material and time schedule as on day 1.

Day 3:

Learning I: A 20 minute city drive

Learning II: A 20 minute rural drive

Day 4:

Learning III: A 20 minute city drive, different from learning I
Learning IV: A 20 minute rural drive different from Learning II

Day 5:

Learning V: A 20 minute city drive

Learning VI: A 20 minute motorway drive

Day 6 –test after AFS learning phase:

Drivers presented with the same test material and time schedule as on day 1.

As in the City scenario of the TRL simulator study drivers used the same lighting strategies and were faced with 12 critical turns (six to the right and six to the left), in the course of a 10.2 km drive through a simulated City night-time environment. These turns differed in the placement of a simulated pedestrian. For two of the six turns in each direction the pedestrian was standing in the driven lane of the bend (obstruction turns). For the other two turns the pedestrian was standing in the opposite lane (Distraction turns). For the remaining turns, no pedestrian was present at any time in the trial. All pedestrians encountered at test sites were

standing still. Traffic was only present on the ring road around the city. A moving pedestrian and a moving bicyclist were encountered on the entrance and exit of the city centre (test area). Thus drivers could not anticipate or be sure a pedestrian would always stand still.

For the rural environment, the scenario, lighting strategies and experimental design was identical to the set-up used in the Volvo 3P Trucks simulator, except the use of some additional targets.

1.5 Variables
The variables of interest in this study are mainly mean and standard deviation of objective measures:

- Speed
- Lateral distance to obstructions and distractions
- Steering wheel reversals

2 Results

Results of three test runs for the AFS and standard lighting group in the City and Rural environment are here reported as sequence 1-3.

2.1 Overall driving speed
The development in mean overall driving speed for the complete test route in the City and Rural scenarios is a measure of behavioural adaptation to driving with AFS as well as Standard Headlights in the simulated night-time scenarios.
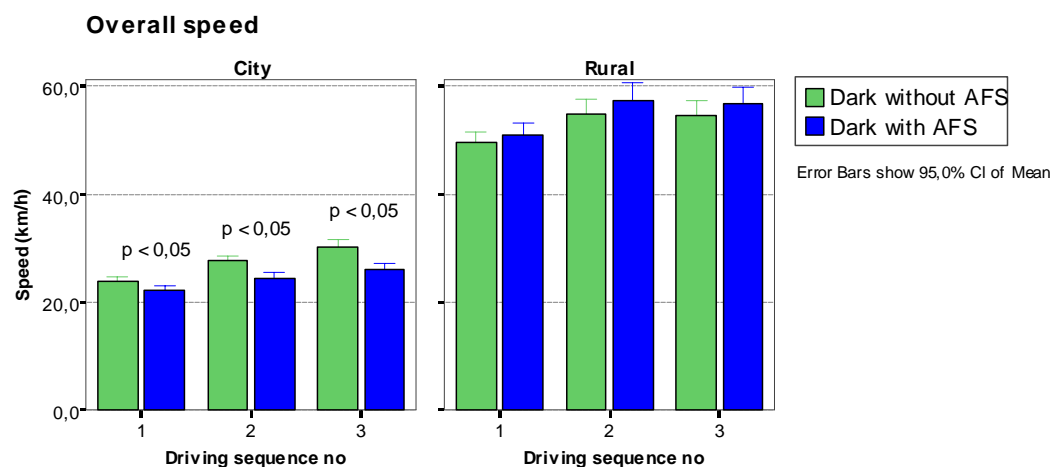
Figure 2: Overall driving speed

Figure 2 reveals (as expected) that the mean speed is higher in the rural road environment than in the City environment regardless of lighting strategy applied. Means speed increases steadily for City driving over the six day test period (sequence 1-3) but with larger increase for standard

lighting than for AFS. In the Rural road environment we can also observe a increase in mean speed from sequence 1-2, which flattens out between sequence 2 and 3.

Further Figure 2 shows that mean speed in the City scenario is significantly lower for AFS compared to Non-AFS for all sequences ($p < 0.05$), whilst the speeds for AFS and Non-AFS systems did not differ in the Rural scenario ($p > 0.1$).

2.2 City scenario

The speed at which participants entered a minor road was recorded and the mean values for the different lighting conditions are here shown for each event type (Obstruction, Distractor and Control) in Figure 3.
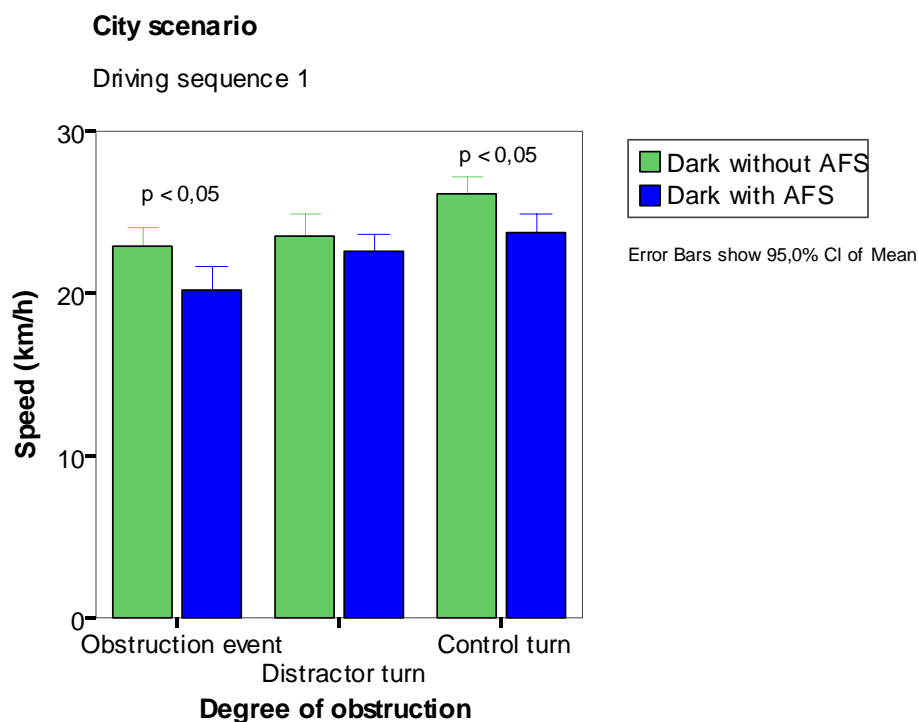
Figure 3: Mean driving speed. City scenario, driving sequence #1

Figure 3 shows that participants turn at a slower speed with AFS than with standard lighting in all events in driving sequence 1. The AFS speed at turns with obstruction and control turns differed significantly ($p < 0.5$) from that observed with standard lighting.

**City scenario
Speed (km/h)**
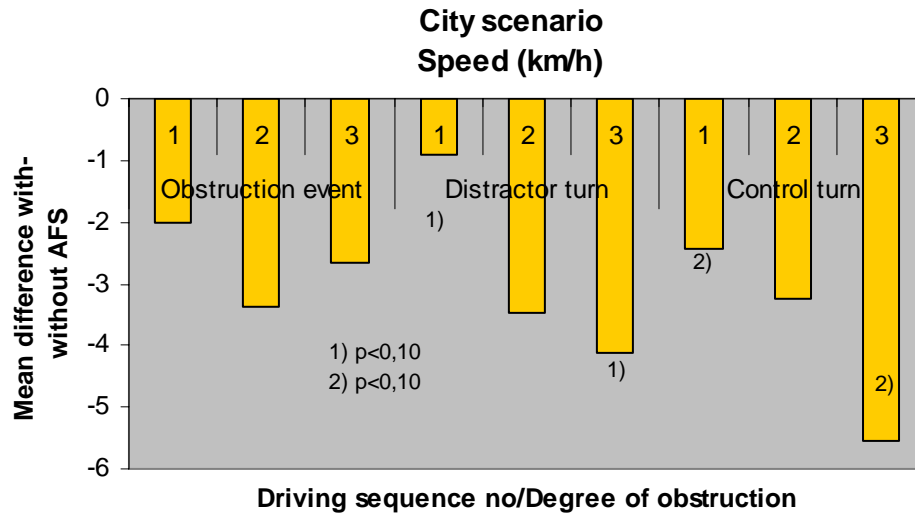
Figure 4: Mean driving speed. Difference between AFS and Non-AFS drivers. Development sections #1-#3.

Figure 5 shows the mean speed participants have in the approach (100m before) when passing and until 50m after passing the obstacle for the different lighting conditions. The approach speed is significantly higher 70m 5m before passing as well as when passing the obstacle for Non-AFS drivers compared to AFS drivers ($p < 0.05$).
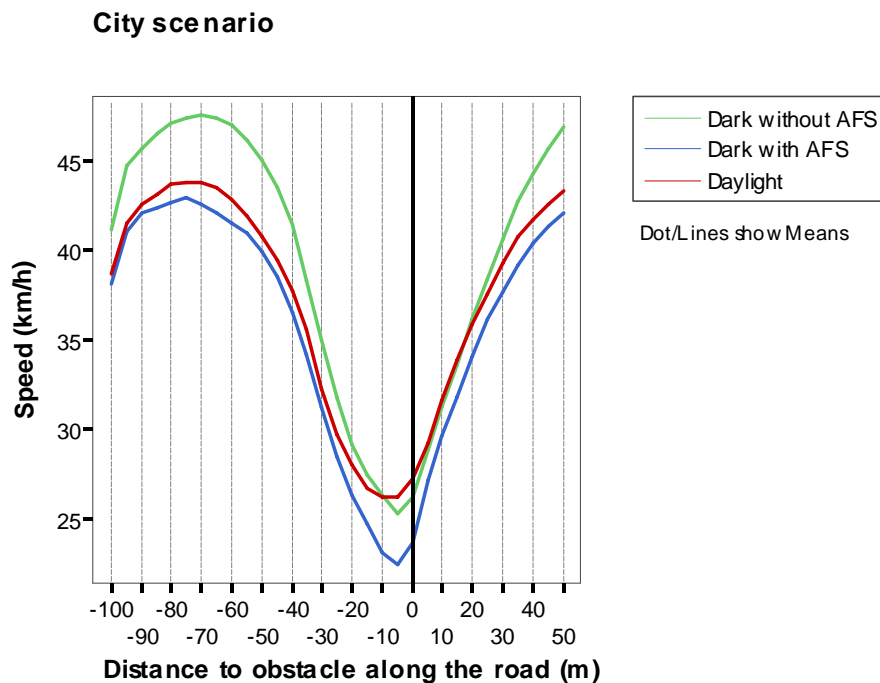
City scenario

Figure 5: Mean driving speed before and after passing obstacle. (Driving sequence #2 and #3.)

Figure 6 shows the mean speed participants have in the approach (100m before) when passing and until 50m after passing the obstacle (obstruction and distraction targets) for the different lighting conditions in sequence #2 and #3. The approach speed is significantly higher 70m and 5m before passing as well as when passing the obstacle for Non-AFS drivers compared to AFS drivers (p<0.05) in sequence 2 and 3. The mean speed curve for AFS drivers is almost identical in sequence 2 and 3 with the lowest speed when passing the obstacle (20m before to 20 m after) while Non-AFS drivers pass significantly faster both in sequence 2 and 3. For sequence 3 mean speed increases both for AFS and Non-AFS drivers in the approach to obstacles (90-40 m before) but only Non-AFS drivers have an increase also when passing obstacles compared to sequence 2.
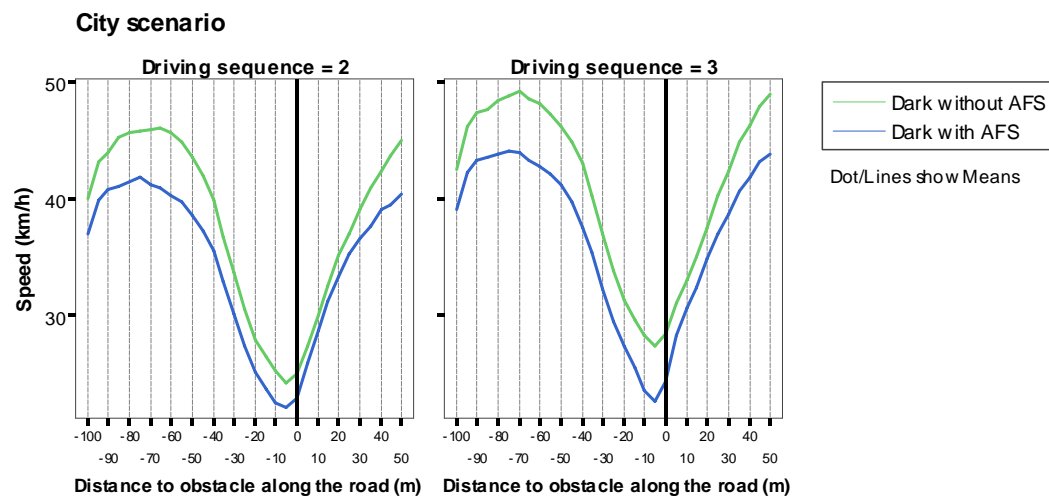
Figure 6: Mean driving speed before and after passing obstacle. Driving sequence #2 and #3 separately.

Figure 7 shows the lateral distance drivers had to the obstacles (obstructions and distraction targets) when passing. The observed lateral distance for the AFS and Non-AFS systems did not differ (p>0.1). Neither within sequence or between sequence 2 and 3
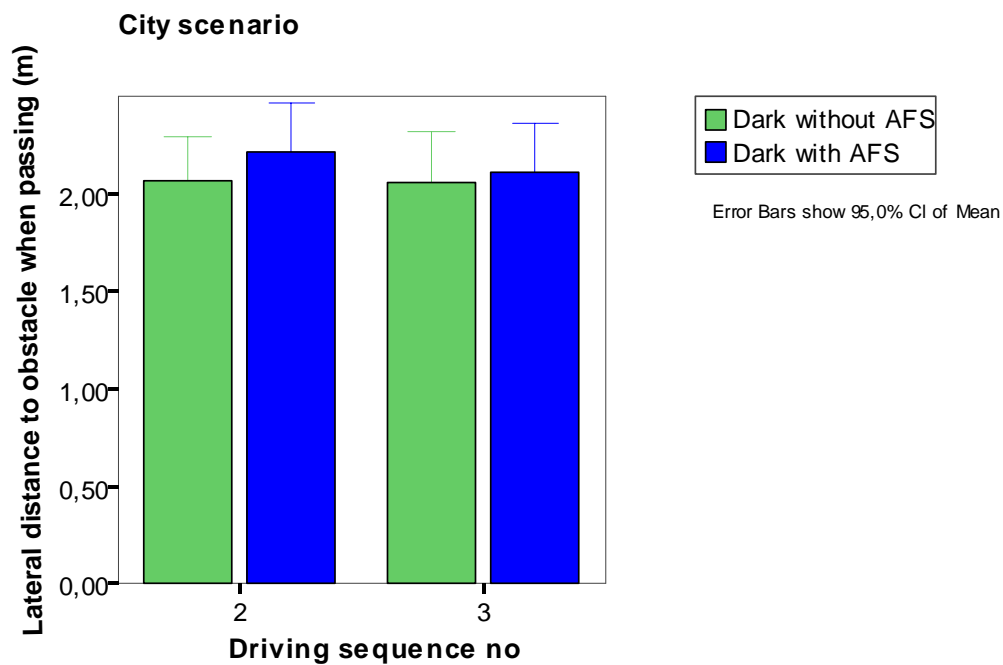

Figure 7: Lateral distance (m) when passing obstacle

Steering movement speed can be seen as a sensitive measure for driving with reduced safety margins. Abrupt steering movements as can be seen when you suddenly have to avoid an object have high speeds.
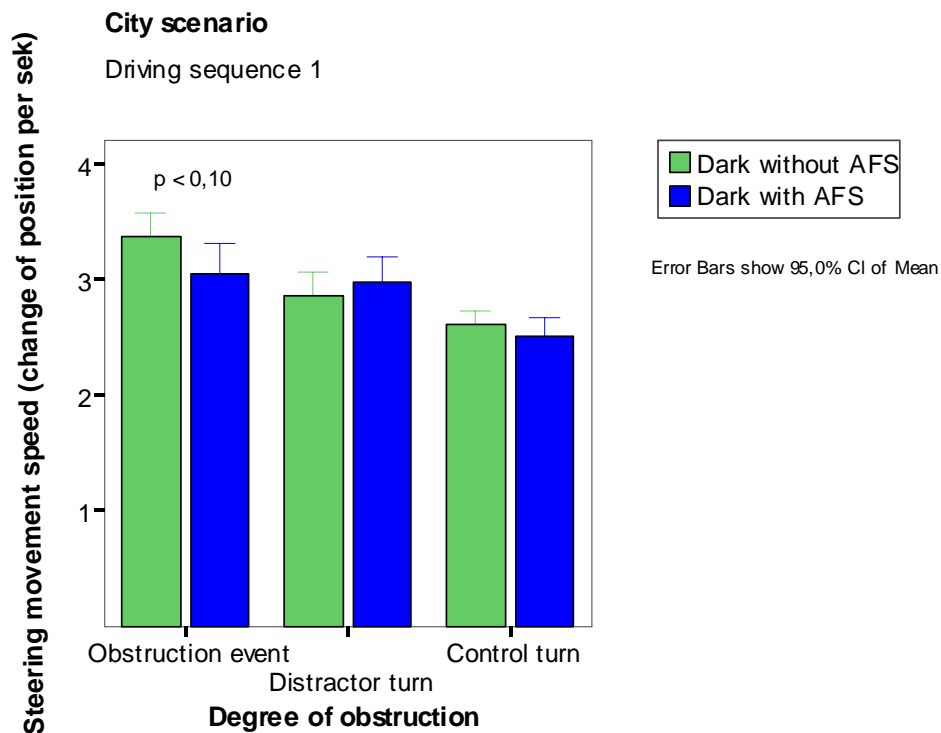
Figure 8: Steering movement speed. Driving sequence #1.

Figure 8 shows that there is a tendency towards that the mean steering movement speed is significantly higher in obstruction events for drivers with standard lighting compared to driving with AFS ($p< 0.10$), while the steering movement speeds for distractor an control turn events did not differ ($p>0.1$).
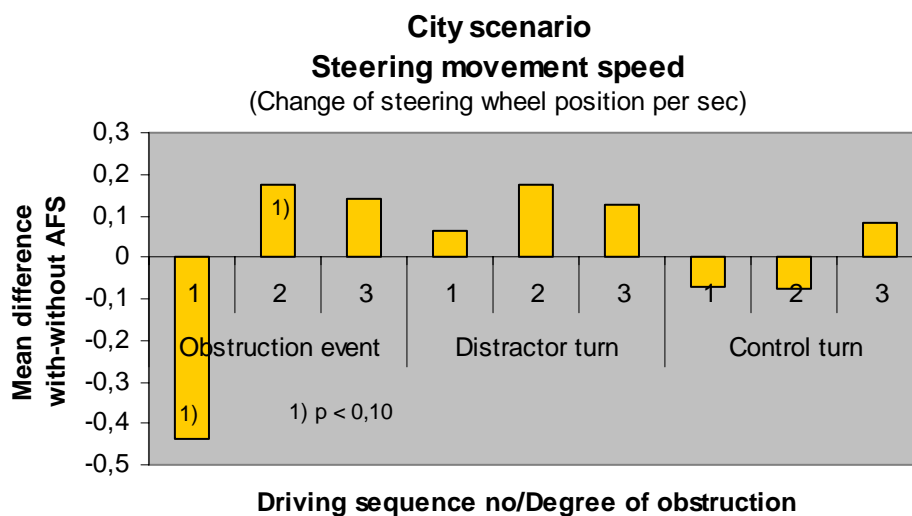
Figure 9: Mean steering movement speed. Difference between AFS and Non-AFS drivers. Development sections #1-#3.

Number of steering reversals can be seen as a sensitive measure of how comfortably or uncomfortably events are handled.
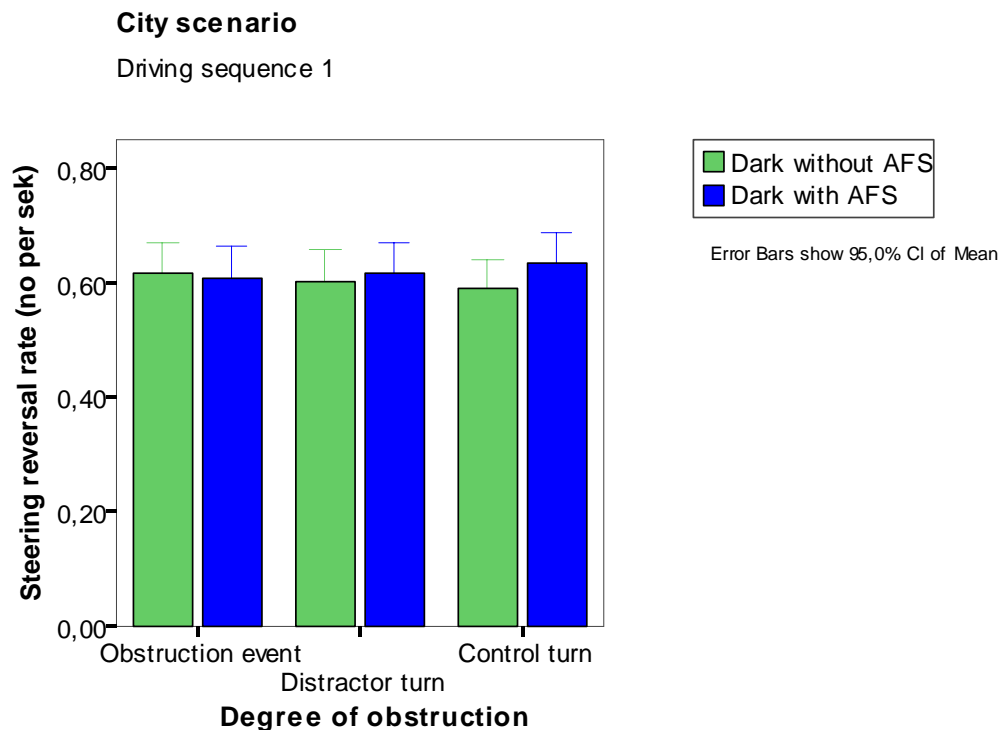
City scenario

Driving sequence 1

Figure 10: Steering reversal rate. Driving sequence #1

Figure 10 shows that steering reversal rate for sequence # 1 did not differ significantly (p>0.1).
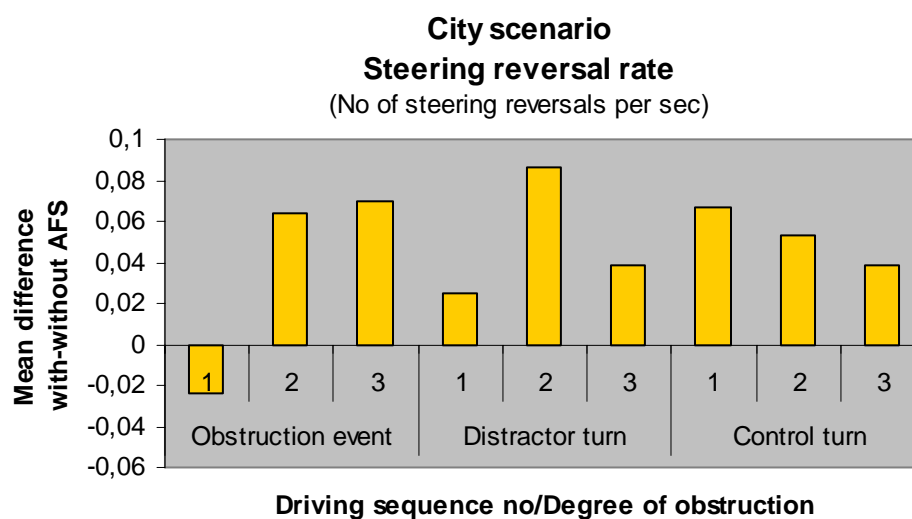

Figure 11: Mean steering reversal rate. Difference between AFS and Non-AFS drivers. Development sections #1-#3.

2.3 Rural environment

The speed at which participants enter rural curves was recorded and the mean values for the different lighting conditions are shown for each event type (Obstruction, Distractor and Control) in Figure 12.
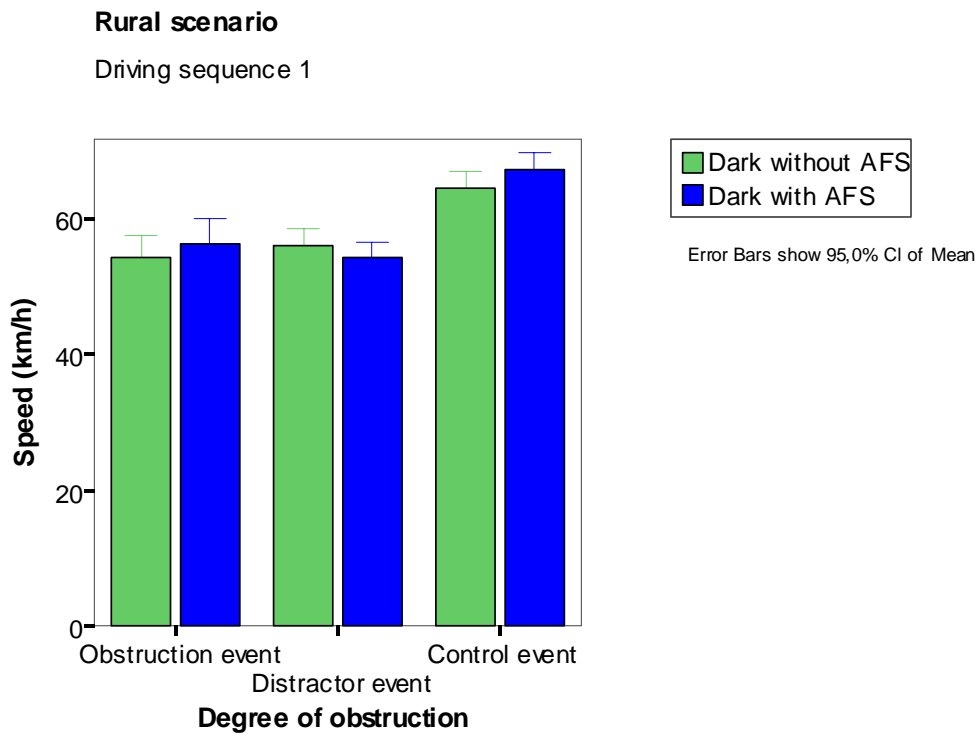
Rural scenario

Driving sequence 1

Figure 12: driving speed. Rural scenario, driving sequence #1

Figure 12 shows that the observed mean speed participants negotiate rural curves does not differ significantly ($p > 0.1$) in different events either for AFS or Non-AFS systems.
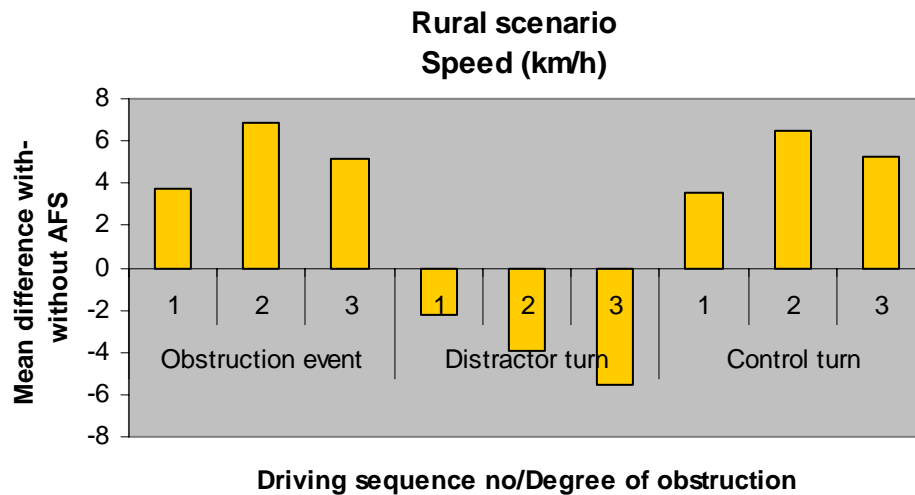
Figure 13: Mean driving speed. Difference between AFS and Non-AFS drivers. Development sections #1-#3.
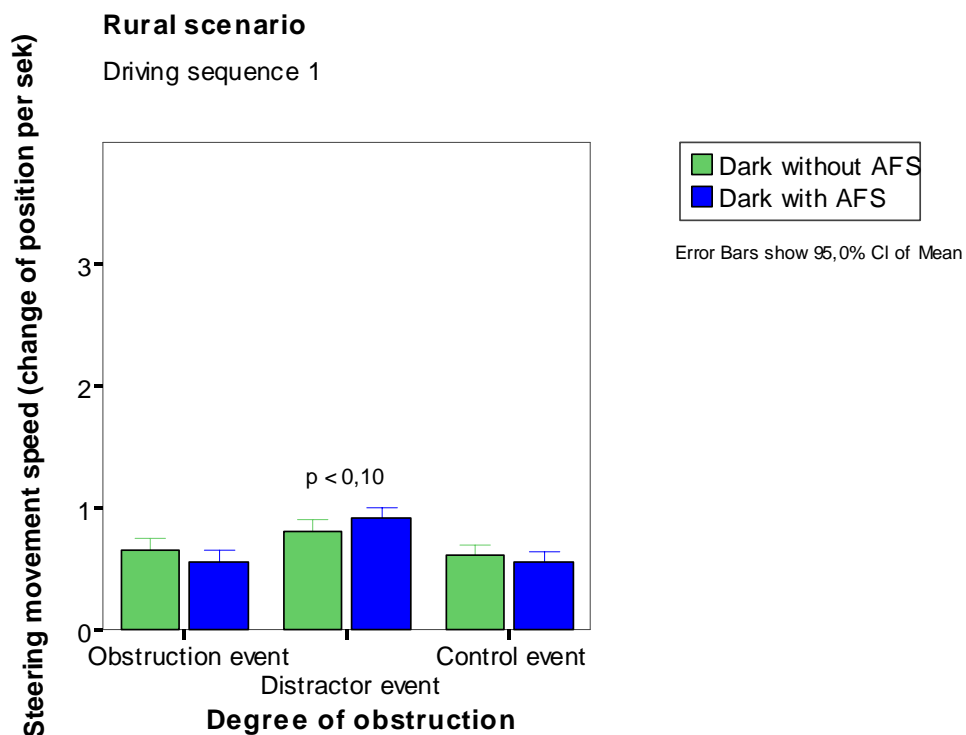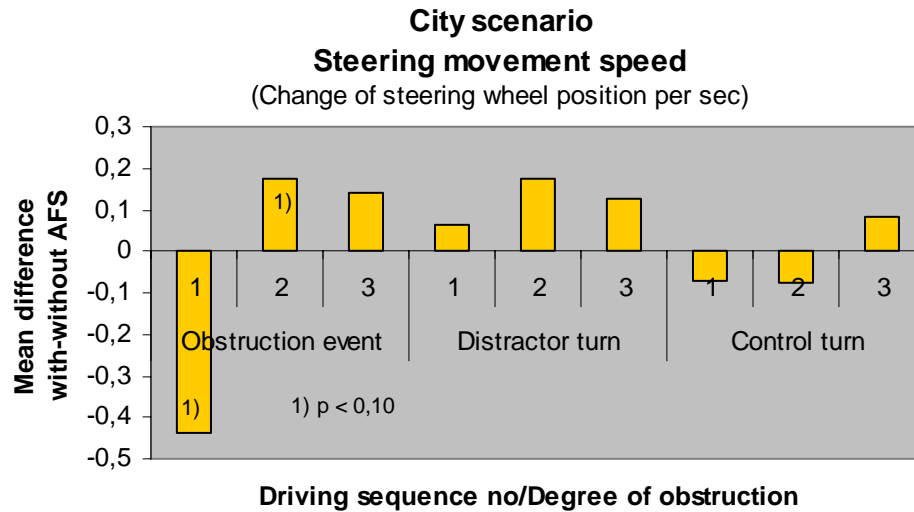

Figure 14: Steering movement speed. Rural scenario, driving sequence #1.

Figure 14 shows that there is a tendency towards that the mean steering movement speed is significantly higher in distractor events for drivers with AFS lighting compared to driving with standard lighting ($p < 0.10$), while the steering movement speeds for obstruction an control turn events did not differ ($p > 0.5$).

City scenario
Steering movement speed
(Change of steering wheel position per sec)

Driving sequence no/Degree of obstruction

Steering reversal rate may potentially be affected negatively or positively by the AFS strategy "Bending Lights" used when negotiating curves in the Rural road environment under different events.

Rural scenario
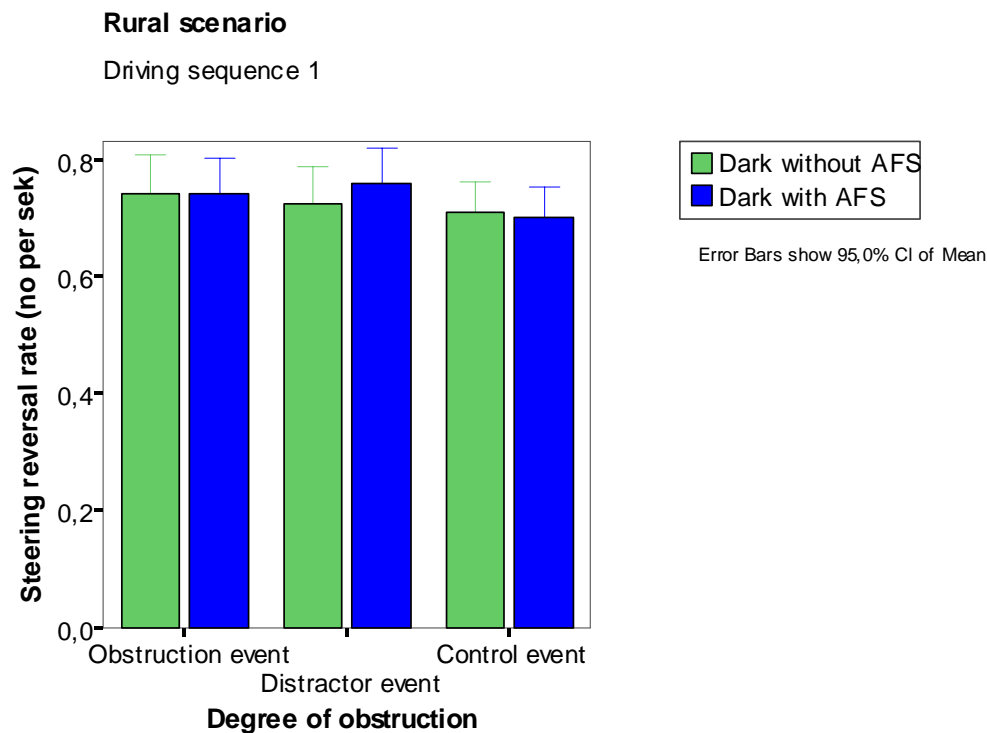
Driving sequence 1

Figure 15: Steering reversal rate. Rural scenario, driving sequence #1.

Figure 15 shows that the observed mean reversal rate for participants negotiating rural curves does not differ significantly (p>0.1) in different events either for AFS or Non-AFS systems.
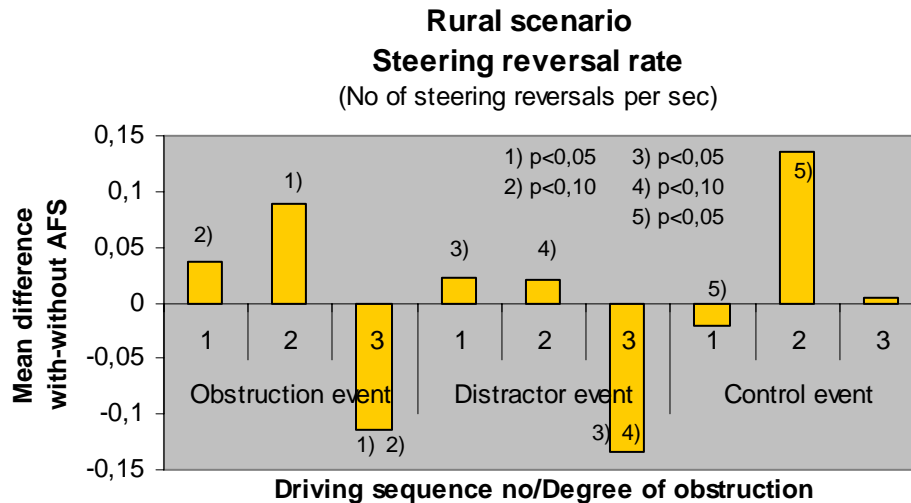
Figure 16: Mean steering reversal rate. Difference between AFS and Non-AFS drivers. Development sections #1-#3.

3   Conclusions

The primary focus of the present Human Factors evaluation has been to investigate the drivers behavioural adaptation to AFS in terms of speed choice, distance to obstacles, and steering behaviour. The choice of test variables is based on considerations of system characteristics.

The Adaptive Front Lighting System is a system witch regulates automatically the light distribution of a vehicle. Specific control algorithms are developed for different driving conditions, such as city driving, rural driving, motorway driving and adverse weather conditions. AFS can be formally defined as maintaining a presumptively desired light distribution adapted to the road environment (set by the supplier). The systems tested (City light and Rural Light) does so by way of input from in-vehicle parameters like speed, steering wheel angle etc. Future systems under development may also use external input from satellite positioning (GPS or Galileo) to determine current road environment in order to control desired light distribution. The current system tested has no user interface allowing system parameters to be set or overridden by the driver. Accordingly the learning process is different form a user controlled interface, e.g. Adaptive Cruise Control, were the user controls and learns to set system parameters according to his/her preferences. According to suppliers the current automatic AFS system matches user preference for desired light distribution in 90% of the driving situations. The AFS system should thus alleviate the driver in choice of light distribution choices, provide safety profits in terms of enhanced perception of the night-time environment, reduce accident risk, driver workload and increase driver comfort and possibly exhibit positive effects on traffic flow.

 On the other hand the hypothesis tested is that participants after the initial familiarization (novelty effect) will drive increasingly faster with the AFS due to better light distribution, increased visibility and sight distance. (measurements: Average speed and speed profile). The results suggest that the hypothesis can not be rejected. There is an observed general increase in speed over the six days exposure to lighting systems for both the AFS and Non-AFS group. However the speed increase for Non-AFS is consistently and significantly higher than for AFS in the City scenario. In the rural scenario there is no significant difference between AFS and Non-AFS headlights. A closer look at the City scenario speed profiles shows the speed

does not increase significantly for AFS users when passing obstacles from day one to six. While speed for Non-AFS increases significantly when passing obstacles from day one to six.

It is anticipated that the AFS will make it easier to plan and act earlier (situation awareness) and therefore drive smoother in curves and corners compared to driving with traditional lighting (measurements: Speed profile on approach to obstacles, High frequency steering, abrupt Steering reversals, and distance to obstacles) . The speed profiles for the City scenario shows that AFS drivers have a smoother approach with lower speed and less speed reduction, closer to the speed profile for daylight, than drivers with standard Headlights (Non-AFS). There is a general speed increase for both systems on the approach to corners (100 -70 meters from obstacle). However the speed profile for AFS is consistently smoother than standard Headlights from day one to six. No significant differences between systems can be observed for steering movement speed, steering reversal rate and distance to obstacles when passing.

In conclusion, the results of this study suggest that there is a behavioral adaptation to AFS in terms of speed choice with increase in speed after the initial familiarization (novelty fase), but not for the other selected indicators of behavioural adaptation. There is a general speed increase in both City and Rural environments from day one to six, but the increase is less than for Standard headlights. In addition the speed in the City scenario on approach is lower to corners and passing of safety critical obstacles is unchanged. If one accepts the limitations of low participation numbers and limited exposure (six days / 140 km), AFS appears to offer potential for a favorable night driving behavior potentially reducing accident risk, compared to standard headlights. Within the 6 day time frame of the experiment night driving speed level appears to be stable for passing potential traffic hazards in city environments and stable already after the initial day in terms of general speed level in Rural environments.

The results indicate that we have found some basic stability for the indicators of driver behaviour applied in this study. It would be valuable if future studies could confirm that this is representative for the essence of AFS driver behaviour. Both in terms of selected indicators and in terms of behavioural stability not only after six days but also after six months with system use.

Acknowledgement

4   References

Draskoczy (1995). Guidelines on safety evaluation of transport telematics systems. Technical report,DRIVE Project V2002 Horizontal Project for the Evaluation of Safety HOPES.

Smiley, A..(2000) Smiley, A. Behavioral adaptation, safety and intelligent transportation systems. Transportation Research Record, 1724, pp. 47 – 51.