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Comparative Study of Prototype Automotive HUD vs. HDD: Collision Avoidance Simulation and Results

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ABSTRACT

Often the level of the driver's control over the vehicle is qualitatively compromised due to the plethora and the ineffectiveness of driving interface designs. This research effort focuses on the development of a prototype Head-Up Display (HUD) interface that can complement the driver's decision-making process rather than replace it, and decrease response times under adverse weather and traffic conditions. The evaluation of the proposed system was conducted over 40 user trials using a driving simulator. In this paper we present a succinct overview of the HUD system and comment on the headway results derived from a comparative study between the HUD and a contemporary instrumentation panel.

INTRODUCTION

The abundance of automotive infotainment devices along with advances in related technologies have crowded the modern vehicle's interior with a variety of instrumentation displays. In particular, the driver's surroundings are gradually being transformed into a collective space of devices that announce, project and otherwise attract attention to various pieces of information. The end result of these attention-grabbing components is visual clutter as indicators compete intensely for the driver's mind share, which should, ideally, be mostly dedicated to the main task of driving. Instead of considering a simpler driving environment, current research trend points to alternate ways of fulfilling the prominent infotainment needs of modern drivers without reducing the amount of projected information or jeopardising the safety of the driving process.

Recent developments in vehicular manufacturing have set Head-Up Display (HUD) interfaces as an increasingly viable alternative to traditional Head-Down Displays (HDDs). HUDs appear as a surrogate method for the depiction of information using symbolic or alphanumeric representations and feature a larger viewing area, specifically a part of the windscreen, than traditional dashboard instrumentation. Notably, HUDs present a particularly suitable medium to facilitate navigation/guidance features as they, in contrast to HDDs, may situate visual queues in close proximity to the driver's road-seeking gaze. In this respect, as long as the queues are subtle and non-distracting there is little need for the driver to divert attention away from the driving task. Furthermore, the flexibility provided by these interfaces with respect to the type of information projected is well beyond the bounds set by HDDs, partly due to the larger screen estate of HUDs and the nature of presentation (superimposed to the actual objects); interestingly, HUDs can either enhance human vision, or provide visual warnings regarding potential collisions. Intuitively, achieving information portrayal parity between a HDD and a HUD may result in an overloaded and possibly illegible dashboard. A HUD display, thus, is the better medium of the two to convey additional information with.

Overall, the paper is organised as follows: The next section offers a succinct overview of our proposed HUD interface design components. In turn the "Evaluation Set-Up" section elaborates on the simulation scenarios used to evaluate the effectiveness of the interface. The simulation results are presented in "Collision Occurrences Results" section and, subsequently, the last section contains a detailed illustration of the simulation headway results that highlight differences between the proposed HUD and HDD designs. Finally the paper outlines the limitations and considerations regarding the proposed system and presents a tentative plan for future work.

HUD OVERVIEW

The proposed HUD interface has been designed for use under low visibility conditions such as fog and heavy rain, in motorway environments [1,2]. To this end the interface design offers a plethora of symbolic representations that function both as visual warnings and visual enhancements. Considering human attention limitations and performance anxiety levels in a driving situation under low visibility in a motorway, it was evident that the system should convey to the user only crucial content information. To facilitate this, HUD peripheral sensors could "feed" the interface with time and distance measurements relevant to the potential hazard objects.

The interface's symbols have been developed with the view to increasing the driver's spatial awareness by providing only crucial information pertinent to collision avoidance maneuvering or braking in an imminent collision situation. The nature and format of the depicted symbols intuitively led to the choice of a full scale HUD design. The symbols are visual representations of real objects such as vehicles, lane marks, etc. and appear in colourful visual cues in accordance with the colour coding standards of the SAE. The symbols' dimensions change relatively to the object that they represent.

During the development of the HUD display, four pieces of information were primarily identified as the most crucial for collision avoidance in motorways. This information was visualised through iconic representation of actual objects, which thereafter produced four symbols: lane/pathway recognition, lead vehicle detection, traffic warning and sharp turn notification (the symbols are presented in action in Figure 1. A brief description of the proposed HUD symbols system is provided further on.

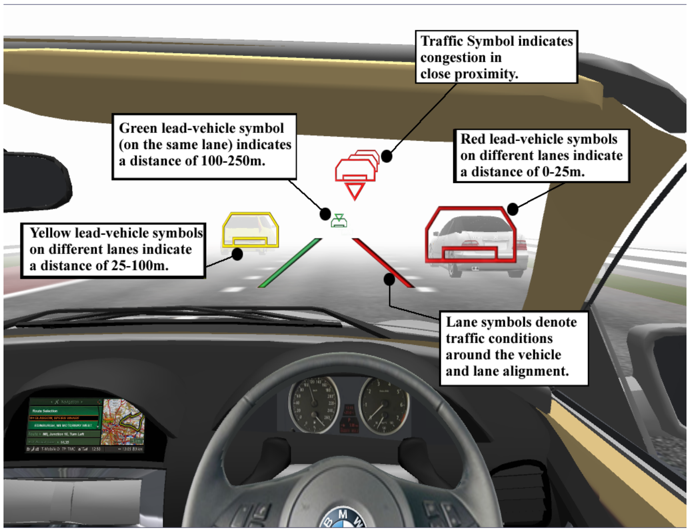


Figure 1: The HUD elements as viewed in during simulation

EVALUATION SET-UP

SIMULATION ENVIRONMENT

As the HUD interface was developed to counteract poor long-distance sight under low visibility it was deemed necessary to evaluate its effectiveness in a simulated environment. To achieve an accurate reenactment of potentially hazardous driving situations the Strathclyde Police Department in Glasgow provided us with raw data of actual traffic police reports [3]. Annual accident statistics and planning diagrams aided in predicting ' possible driver's reactions. Careful inspection of this data showed that two particular car-following scenarios occur fairly frequently and exhibit a high fatality rate. The first occurs due to sudden braking of the lead vehicle and the second, which results in rear collision, is caused by "hidden" motionless traffic congestion that is often formed in motorway junctions. This paper presents the findings of the statistical analysis of measurements derived from the first driving scenario, which is described below.

Simulation scenario - The main scenario used in this work is a variation of a generic car-following model [4]. In this, while the user is driving along the motorway and after having traveled a distance of 2km, the lead vehicles have been scheduled to brake abruptly, causing approaching vehicles to decelerate rapidly. As may be expected, this event increases substantially the chances of vehicle collision. A previous study [5] on the mapping of driver's possible reactions to similar car following accident scenarios by has suggested that a driver's performance map is comprised of four driving states: low risk, conflict, near crash and crash imminent, corresponding to four different warnings respectively. As such, the first scenario was developed along these guidelines in order to evaluate the HUD's ability to convey effectively these four collision states to the driver. Segmenting driver's performance-map into these four pre-collision periods provided the study with advantage of being able to identify the impact of the HUD information as compared to a typical HDD.

Participants - The results presented in this paper are based on 40 user tests. All 12 test subjects (7 female, 5 male) held a valid driving licence and they were aged between 20 and 75.

For validation purposes, the movement, speed and distances of the vehicles have been programmed to follow the British Highway Code.

In order to detain cost within affordable levels we decided to build a custom driving simulator using off-the-self hardware components and an initial open-source racing simulator. A detailed description of the open source-driving simulator used for these experiments is presented in [6]. Moreover, in order to enhance the realism of the simulation scenarios and their mapping degree to real-life situations, the AI controlled vehicles had to perform potential human misjudgments.

Replication of human errors by the robot vehicles (i.e. failure to brake on time) is a simulation feature that enhances substantially the driver's immersion in the synthetic environment [7]. As the authors argue in [8], the driver has to be challenged in order to react and exhibit driving skills that would normally apply in a real accident situation. Two commonplace driving situations based on a "car following" scenario have been developed as test-bed experiments following observations and accident prompt strategies produced in previous research by [9,10,5]. All the scenarios were presented in a motorway environment with heavy fog (low visibility <50m).

COLLISION OCCURENCES RESULTS

An initial but, nonetheless, informative appraisal of the effectiveness of the HUD system may be attempted by taking into account the number of crashes per trial, with and without the HUD interface. These data are presented in Figure 2. Notably, use of the HUD resulted in a dramatic drop in collisions for the car-following scenario that we present and discuss in this paper. Specifically, without HUD, 90% of participants experienced a collision; however when the HUD system was deployed there was a sharp decrease in collisions whereby only 27.5% of participants experienced a crash.

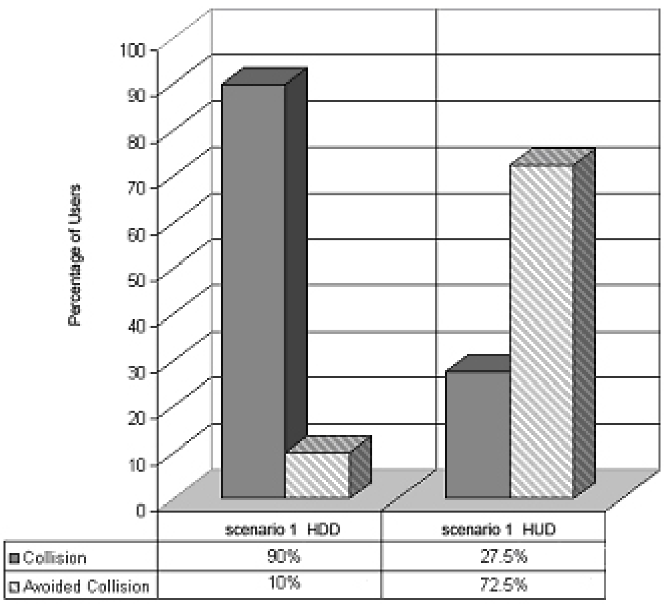
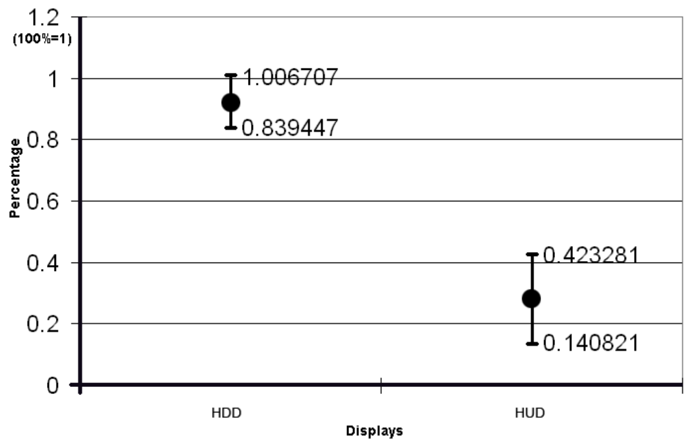


Figure 2: Number of collisions recorded with and without the HUD interface

The derivable data, presented in Figure 2, gave two obvious results, labeled "collision" and "avoided collision" respectively. Given that the proposed HUD interface aims to improve substantially human vision and reactions in rear collision scenarios, it should be suitable for the majority of motorists and not solely for a small sample of users. Therefore the above statistical significance of results was extrapolated from the sample of the study (39 subjects) to the overall population of drivers (large sample confidence interval for the population mean).

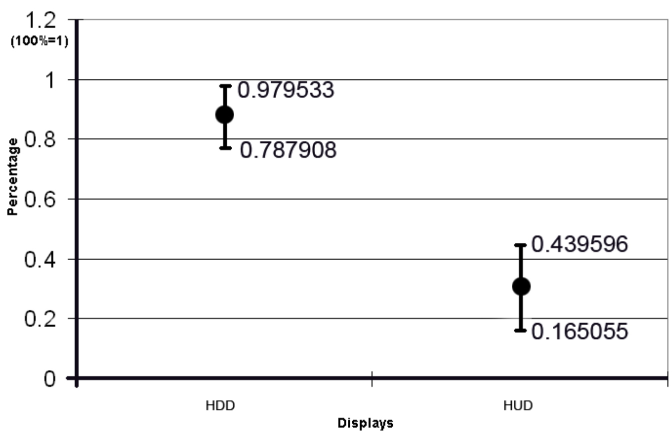
This was calculated initially with the traditional large sample confidence interval (CI) statistical analysis method. The collision occurrences results were calculated with confidence of 95%, which suggests a margin of 5% of potential error that is acceptable for the nature of this evaluation. Evidently the analysis highlighted that drivers have a probability of average 92% (1.006707-0.839447) to collide when they use the HDD as external information source in adverse driving conditions. The above number was decreased to 28% (0.423281-0.140821) when the proposed HUD interface was utilised as a guidance system in the same conditions as depicted in the Chart 1.



95% Proportion for drivers who collided HDD					
CI_L1P n=(39) x=(36) c=(.95).					
1Traditional Large sample CI for one proportion					
ptrad	zstar	se_trad	etrad	*low_trad*	*up_trad*
.923077	-1.959964	.042669	.083630	*.839447*	*1.006707*
95% Proportion for drivers who collided HUD					
CI_L1P n=(39) x=(11) c=(.95).					
2Traditional Large sample CI for one proportion					
ptrad	zstar	se_trad	etrad	*low_trad*	*up_trad*
.282051	-1.959964	.072057	.141230	*.140821*	*.423281*

Chart1: Collision Occurrences using HDD vs HUD

To verify the accuracy of the above analysis it was deemed necessary to repeat the calculation by using "Wilson formula" or Wilson score interval. This specific method is an improvement over the typical approximation interval, offering detailed estimations even for a small number of trials and subjects. The Wilson analysis illustrated that the drivers have a probability of average 88% (0.979533-0.787908) to collide when they use the HDD in the adverse driving conditions. The above number was minimised to approximately 27% (0.439596-0.165055) with the use of the proposed HUD interface as guidance system in the same conditions, as depicted in the Chart 2. The results presented by the second method were in accord with the traditional method's outcomes. A diminutive difference between the numerical marks is due to the approach of the large sample estimation of the Wilson formula, which does not raise any considerations for this work. Despite the statistical analyses' "procedural differences" between the two methods, the corresponding results validated the significance of the HUD's contribution.



95% Proportion for drivers who collided HDD					
CI_L1P n=(39) x=(36) c=(.95).					
Wilson Large sample CI for one proportion					
pwlsn	zstar	se_wlsn	ewlsn	*low_wlsn*	*up_wlsn*
.883721	-1.959964	.048885	.095813	*.787908*	*.979533*

95% Proportion for drivers who collided HUD					
CI_L1P n=(39) x=(11) c=(.95).					
Wilson Large sample CI for one proportion					
pwlsn	zstar	se_wlsn	ewlsn	*low_wlsn*	*up_wlsn*
.302326	-1.959964	.070037	.137271	*.165055*	*.439596*

Chart 2: Collision Occurrences HDD vs HUD (Wilson Method)

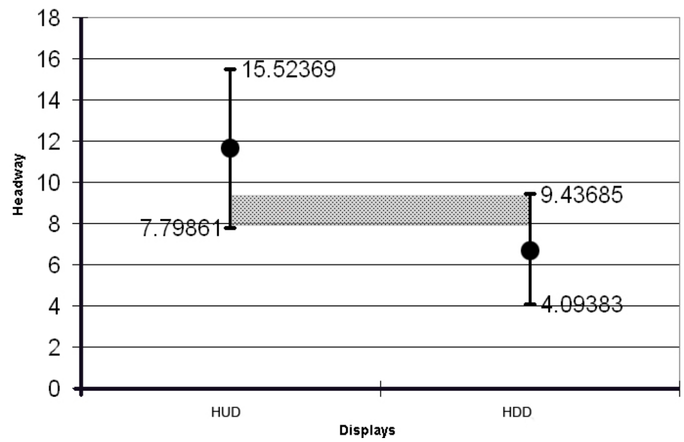
These results indicate that, in specific driving conditions, the HUD interface can be more efficient than a contemporary HDD by leading to an observed decrease in the number of driver errors and possibly allowing for faster responses as the following subsection will present.

Conclusively the above analysis of the collision occurrences (with and without HUD) suggested that the HUD warned the driver effectively about the potential collision with the lead vehicle, thus the user responded by either early braking or avoidance maneuver. The following subsection investigates further the headway (HW) benefits gained by the HUD system and to what extent these will effect the overall driving population.

HEADWAY RESULTS

HEADWAYCOMPARISON

The evaluation results were calculated with a 95% confidence interval. Chart 4 below presents the impact of the HUD on the group of participants in relation to the HW time (small sample confidence interval for the population mean).



95% CI for Headway HDD						
CI_S1M n = (39) x_bar = (6.76534) s = (8.241277) c = (0.95).						
Small sample confidence interval for the population mean						
n	x_bar	TiL	SE	err	*Lower*	*Upper*
39	6.76534	-2.02439	1.31966	2.67151	*4.09383*	*9.43685*

95% CI for Headway HUD						
CI_S1M n = (39) x_bar = (11.66115) s = (11.915451) c = (0.95).						
Small sample confidence interval for the population mean						
n	x_bar	TiL	SE	err	*Lower*	*Upper*
39	11.66115	-2.02439	1.90800	3.86254	*7.79861*	*15.52369*

Chart 3: Headway HUD vs HDD

Notably the 95% interval values for the population mean HDD, ranged from 4.09383-9.43685 while the mean for HUD was 7.79861-15.52369. The above inference favours significantly the HUD interface as shown in Chart 3. Drivers' improved performance with the use of HUD is evidently shown from the graph as the confidence intervals have a minor overlap. This partial cover can be interpreted through the minority segment of drivers that discussed above. Potentially these drivers could receive further training in order to drive with the assistance of the superimposed interface. Alternatively a trivial customisation of the interface components might be acquired to communicate their explanatory content to these drivers.

ANALYSIS OF HEADWAY GROUPS

Another interesting find is the overall mean of HW offered by the HUD and the HDD consultation during driving. The concentration of HDD and HUD HW performances in specific time frames is depicted in Chart 4 and Chart 5 respectively. For simplification purposes the performance variances were clustered and analysed in timeslots of every 2.5 seconds.

An examination of the HWs achieved with the use of HDD shows that the most cautious user managed to recognise a potential collision and sustain a safe HW of 25-27.5 seconds. Notably this performance was achieved by maintaining a very low speed for motorway standards (below 45km/h). Although the adverse weather conditions might justify this speed, it could potentially make the user vulnerable to a rear collision with incoming faster vehicles. However, most users (19) seem to belong in the first slot of 0-2.5 seconds. Furthermore the slots between 2.5-15 seconds have considerably larger concentration than the higher HW time frames, which emphasises the gravity of the visibility problem and the distance misjudgement.

Observation of the driving patterns with regard to HW maintenance with the HUD showed that the best HW time was in the timeframe of 37.5-40 seconds, which adds almost 12.5 extra seconds to the best HDD time. Furthermore, the HUD simulation shows users to be spread over a larger timeline than in HDD simulation, which again reveals that the HUD enabled them to distinguish the other vehicles and potential collisions well in advance. Users could therefore adopt a more “relaxed” driving style, following the lead vehicles.

A comparative observation between the two charts reveals that the users in the 2.5secs slot were surprisingly close in numbers (19 for the HDD and 15 for the HUD). This could theoretically raise some questions about this awkward similarity of performances with regard to the effectiveness of the HUD interface. To this end, the collision results advocate that only 11 out of 15 users collided with the HUD assistance. This suggests that 4 drivers managed to evade collision even when driving in such close proximity from the lead vehicle. Therefore the users that avoided the collision are 8, in total, in comparison to the HDD results (19 collided with the HDD and 11 with the HUD). The above difference translates in a 42% reduction of imminent collisions in exactly the same driving conditions and HW maintenance. Evidently, the 4 users (with HUD) that did not collide were driving behind the lead-vehicle but could notice it through the HUD interface (red, large, lead vehicle symbol in the same lane). Similarly the other 11 users decided for their own reasons to disregard the “red level” warning. This unusual behaviour might be subject to further investigation by further driver psychology studies.

Still the collision speeds of these users were considerably lower than those without the HUD. Further examination of charts presents an interesting concentration of users (15) in the range of 10-30 seconds.

This HW magnitude can be achieved by maintaining an appropriate speed for motorway standards and at the same time a safe distance from the lead vehicles. Yet, this HW has predominantly derived from the HUD information as the lead vehicles at this distance can only been seen through the vehicular sensors of the vehicle.

Remarkably, with the assistance of the HUD interface, users managed to maintain an average headway of 11.7 seconds. Approximately double (7.7 seconds) than the suggested minimum safe TTC or HW (when the lead vehicle is stopped), which is 4 seconds according to [11]. This HW surplus of 7.7 seconds correlates with the time of the symbols’ appearance (250m for the lead vehicle symbols) when the user’s vehicle travels with approximately 100km/h [12].

The comparisons of these two charts highlight the significant difference between HUD and HDD interfaces. Particularly the difference of means between HUD and HDD (11.7- 6.8) is 4.9 secs. Interpreting the above, the proposed HUD interface offers an average of 4.9 seconds in excess to a HDD. This is due to the design and appearance timing of the symbolic representations that reconstruct rapidly, in real time, the external surroundings. The prompt notification of the neighbouring vehicles and other road elements, consequently enhance visually the driver. In turn, the visual enhancement forms a spatial understanding of the surrounding environment (i.e. motorway and traveling vehicles). By heightening spatial awareness, the driver is able to identify the potential collision hotspots or objects well in advance and adjust his/her driving according to the incoming traffic flow and road characteristics. This chain reaction concludes to faster driver’s responses in view of an imminent collision by maintaining in whole his/her situational awareness.

The results proved repeatedly HUD’s benefits for guidance in extreme weather conditions as presented in Chart 2 and 3.

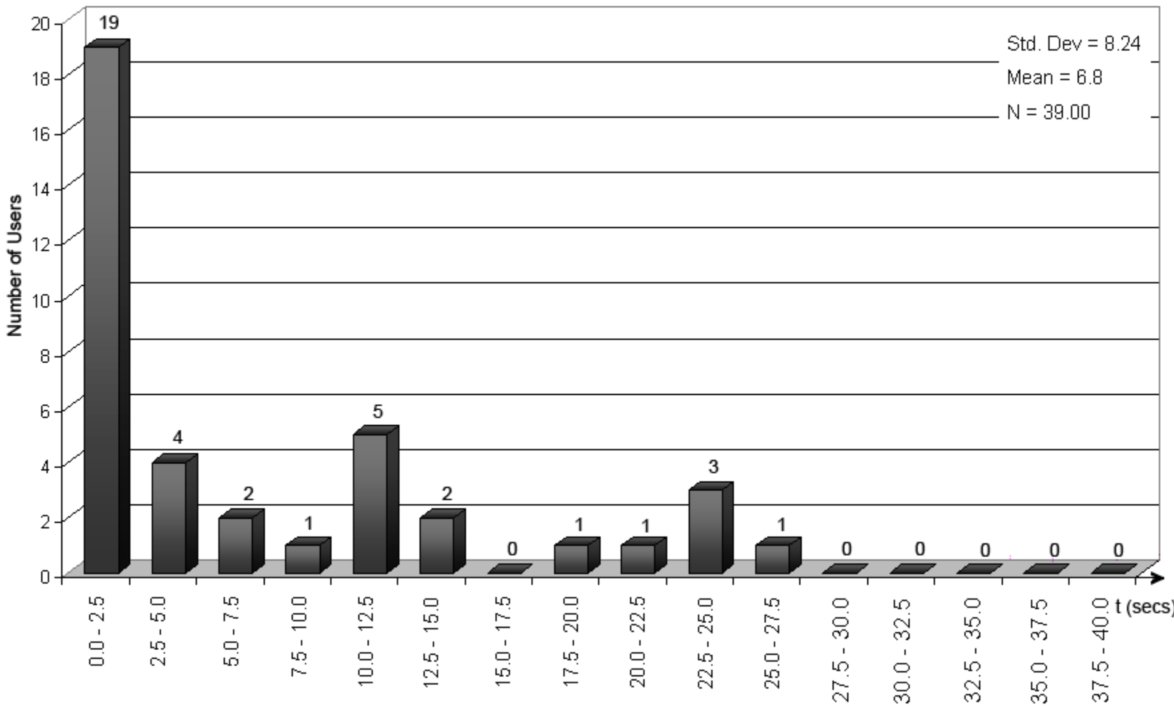


Chart 4: Headway Concentrations with HDD

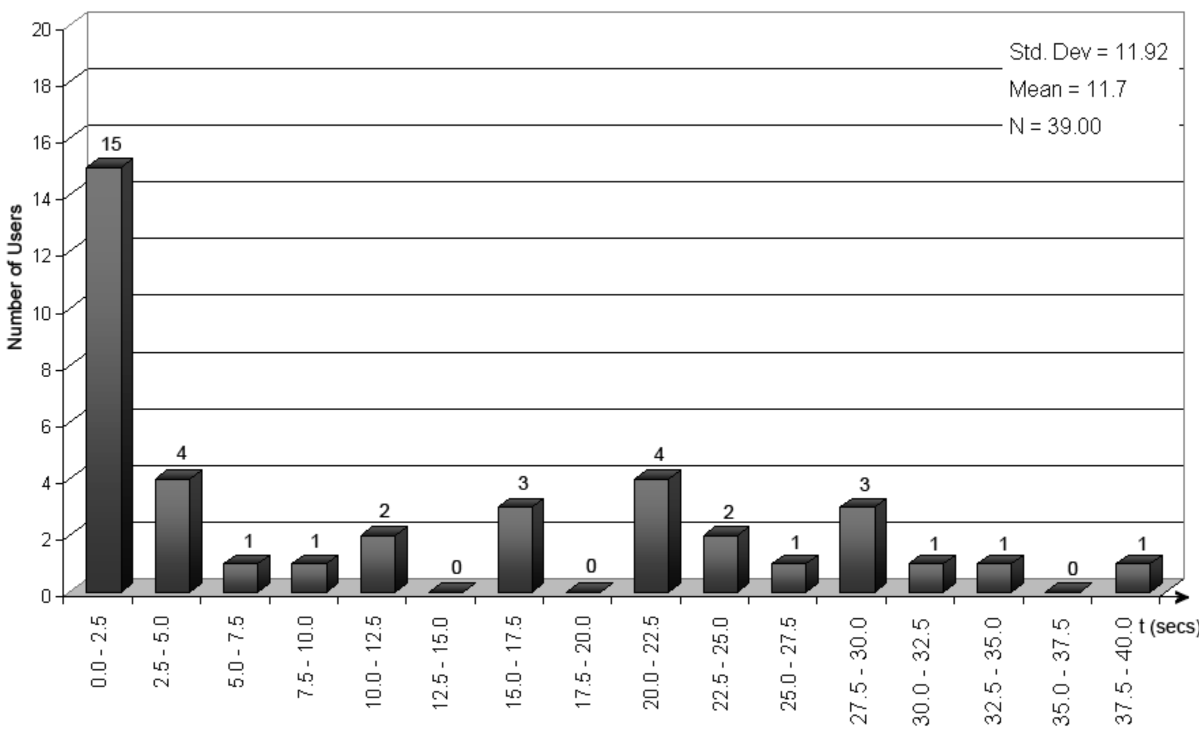


Chart 5: Headway Concentrations with HUD

CONCLUSION

In this paper we have presented an evaluation of a proposed novel HUD design, which aids driver awareness in low visibility conditions. To facilitate an appraisal of the system, user trials were conducted to compare the HUD design with a contemporary HDD interface (dashboard). The results indicated that drivers could navigate effectively, with the assistance of the HUD interface, through very demanding, “accident-prone” situations and under low visibility conditions. In contrast, the HDD interface was deemed inadequate in supporting the driver with the necessary information required to overcome imminent collision. The users seemed to regard the system positively and stated to be inclined to adopt it for every day use.

However, apart from engrafting the positive outcomes of the presented work, it is apparent that such a deployment (driving simulator) might not adequately highlight issues hidden in the simplifying assumptions of simulation or otherwise not included in present simulation techniques. Therefore we aim to improve our driving simulation to accommodate for real-life mechanical shortcomings such as false positive indications provided by vehicular sensors, which would trigger an erroneous visual cue. Finally, we are also working towards realising a fully functional HUD in an actual vehicle, which should allow us to evaluate its performance in a more realistic setting.

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