The Effects of Interface Design for Head-Up Display on Driver Behavior

Cheng-Hung Huang[1], Chun-Wen Chao[2*], Tienwei Tsai[3], Ming-Hui Hung[4]

[1]Department of Industrial Design, Tatung University, Taipei 106, Taiwan
[2]Ph.D. Program of Design Science, Tatung University, Taipei 106, Taiwan
[3]Department of Multimedia Design, Chihlee Institute of Technology, Taipei County 220, Taiwan
[4] M.A. Program of Design Science, Tatung University, Taipei 106, Taiwan
[*]Corresponding author, email:joanne@mail.chihlee.edu.tw

Abstract: In recent years In-Vehicle Information System (IVIS) related devices provide too much information to the drivers. Therefore, the interface for information access has become ever more complex and confusing, which might decrease the driving performance. The Head-up Display (HUD) technology is among one of the Human Machine Interface (HMI) solutions, which is expected to help reduce driver workload by minimizing the driver's eye movement. The purpose of this study is to provide a framework of guidelines for HUD devices in battling distracted driving. We first investigate the importance of various types of driving information, as well as elements and background transparency of HUDs in the current market. Then, a driving simulator is used to explore design principles for a suitable interface of a HUD that displays only the important information. The survey on vehicle information found that drivers considered car speed related information to be necessary, which is consistent with the fact that all car HUDs currently in the market display car speed. The experiment variables involved in the driving simulation are speedometer color (green, orange, blue, and white), type of quantitative display (round, level, digital, and round & digital), and figure type of speed limit (solid, outline). In the study on drivers responding to the change of speed limit, the shortest response time can be achieved when the HUD is displayed with a green, level, outline and high-transparency speedometer. Moreover, the best operation stability can be achieved when the HUD is displayed with a white, round, outline, and low-transparency speedometer. Color is another important issue for HUD and conflicting colors could prevent drivers from clearly seeing information and reduce driver workload. It is also show that the experiment technique used in this study is suitable to analyze the HUD problems. The results can be a guideline for automobile manufacturers in designing the HUD to prevent distracted driving and improve driving safety.

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1. Introduction

In recent years, vehicle industry has begun introducing advanced computerized systems for relaying information to the drivers. These systems involve touch screens, head up displays (HUDs) and other information displays. Nowadays, the number of functions combined with the amount of information that the driver has to handle increases with every new model(Horrey, W. J., 2003).For example, the introduction of GPS-navigation and the broadening of the media systems are flooding the driver environment. However, using those in-vehicle technologiescan also be sources of distracted driving.

The problem with in-vehicle information systems is that most drivers are required to take their eyes off the road for a few seconds when operating the system. Therefore, some scholars claimed that the longer you take your eyes off the road when driving, the higher the possibility that a traffic accident will occur (Caird, J.K., 2008., Liu, Y.C., 2004, Wittmann, M.,2005, Jamson, A. H.,2005).There are 16% of fatalities and 20% of injuries in the U.S. involved driver distraction according to the U.S. National Highway Traffic Safety Administration (NHTSA, 2010). The analysis of eye glance behavior indicated that eyes-off-the-road durations of greater than two seconds significantly increased the risk of crashes and near-crashes.

To reduce distracted driving, the technology ofHUDfor aircrafts is applied to automobiles.HUD technology is among one of the Human Machine Interface (HMI) solutions, whichdirectly projects driving information onto the windshield. As all information that drivers needed would be directly displayed on the windshield in front of them, this would allow them to always focus on their main mission, and would no longer need to lower their heads.HUD is reducing distractions and increasing driving safety, and is estimated to contribute lower vehicle crashes up to 25percent (Hibberd, D. L., 2010).

The HUD variant had a low impact on mental load and scored highest in user satisfaction, and therefore appears to be the most viable target for future study (Weinberg, G.,2011,Yau, Y. J.,2008). Intuitively, using more colors on HUD makes it easier to differentiate between general driving information like speed limits, navigation directions and urgent warning signals (Konrad, B.,2001).In addition, driving informationon HUD can be numerical (quantitative) or consist of words, images or elements (qualitative).How to make the interface design of such information in a way which issupporting instead of distracting drivers still needs a lot of research(Blanco, M.,2006, Horberry, T., 2006).The purpose of this study is to explore the effects of driving information and elements of HUD on driver behavior. These factors include colors of speedometer information (green, blue, orange, and white), different speedometer types (round, level, digital, and round & digital) and different symbols of speed limit (solid and outline). The experiment result gives a goodsolution to display data on HUD.

2. Research Approach

To explore the effects of driving information and elements of HUD on drivers, a micro projector is used to simulate information on a HUD, and a driving simulator is used to simulate actual driving situations. We first conduct a questionnaire on the importance of various types of driving information, as well as elements and background transparency of HUDs that are in the market. In the survey, drivers score each type of information from 1 point “Completely disagree” to 7 points “Completely agree.” Results indicate that the five most important types of information are: speed, reverse collision warning, speed limit of speed-measuring device, forward collision warning and road speed limit.

Next, we use a driving simulator to explore design principles for a suitable interface of a HUD combined with driving information decided by the previous stage. Subjects in this experiment are at least 20 years old and have a vision value greater than 0.9 after vision correction, which ensures that subjects have normal field of vision and reading ability, as well as a driver’s license and driving experience.

To establish a driving simulator, the driving scenariosare created using the 3D virtual reality technology, in which NEC LT380 is used to project a 1024×768 image on a 120-inch (243-cm) screen at the frame rate of 60 Hz to make the scenarios more realistic. The driver sits in the driving simulator and faces the screen, viewing the screen from 60 degrees off the horizontal line. Contents of the HUD are projected by a micro projector 3M MPro120 onto a 120-inch (243-cm) screen (image dimensions are 34 cm×14.5cm with the resolution of 1024×768). The position of the projected image is 9 degrees off the driver’s line of sight; the upper boundary of contents is 8 degrees off the horizontal line and the lower boundary of contents is 11.8 degrees off the horizontal line, as shown in Figure 1.

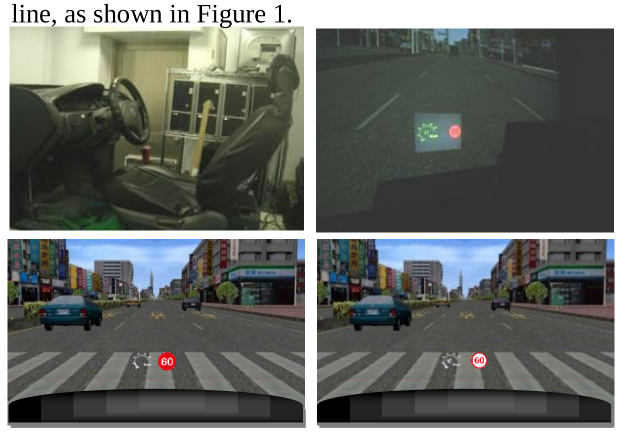


Figure 1. Experiment scenario

At this stage, the Taguchi method is applied to determine design variables, aiming to use minimal experiment data to construct the most precise experiment model. It is an improvement of the conventional experiment design method, using the “Taguchi orthogonal array” and “additive model” to enhance experiment efficiency. In this method the signal-to-noise (S/N) is used to represent quality characteristic and the largest S/N ratio is demanded. Usually, there are three types of quality characteristics, i.e. the-target-the-better, the-larger-the-betterand the-smaller-the-better:

(1) The-target-the-better

$$S/N = -10\log\left(\frac{1}{nS}\sum_{i=1}^{n} y_i^2\right) = -10\log\left(\frac{\bar{y}^2}{S^2}\right), \qquad (1)$$

(2) The-larger-the-better

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right), \text{ and} \qquad (2)$$

(3) The-smaller-the-better

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) = -10\log\left(\bar{y}^2\right), \qquad (3)$$

where S is the standard deviation, y_i is the measured property, and n corresponds to the number of samples in each test trial.

2.1 Experiment Parameters

Though car HUDs currently in the market provide somewhat different information, car speed is one type of information that can be found in all products, indicating that manufacturers consider car speed to be important information to drivers, which is consistent with survey results of this study. In this study, four types ofspeedometer are investigated, including round, level, digital, and round & digital. The colors used to display car speed include green, orange, blue and white. Furthermore, speed warning information is displayed outline or solid shape in red color.

L16 orthogonal array is used to find combinations offactors (i.e., variables), includingHUD background transparency: (1) high (2) low; speed limit symbols: (1) solid (2)outline; speedometercolors: (1)green(2)blue(3)orange(4) white; speedometer types: (1) digital(2)level(3)round(4)round&digital. Interactive effects between factors are not considered, meaning that any two factors do not affect each other. Based on the L16 orthogonal array, 12 samples generated by Illustrator and Flashare used for the subsequent experiments, aiming to improvethe HUD interface design.

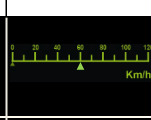
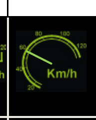
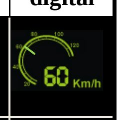
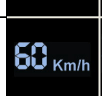
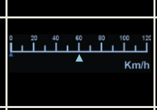
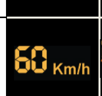
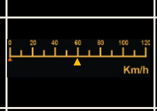
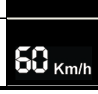
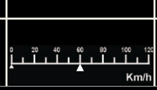
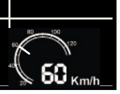
2.2 Speedometer color and type

For each of those factors stated above, 2 or 4 levels are defined. Table 1 shows different combinations of these factors.Speedometer type is divided into “digital,” “level,” “round” and “round & digital”; speedometer color is divided into “green,” “blue,” “orange” and “white”; speed limit symbol is divided into “solid figure” with contrast boundary and “outline figure” with simple line boundary;HUD background transparency is divided into “high” and “low.”Note that colors are expressed in the RGB color model.

Table 1. Experiment factors and levels for each factor

factors		(A) HUD background transparency	(B) speed limit symbol	(C) speedo-meterColor	(D) Speedometer type
level	1	high	Solidfigure	green	digital
	2	low	outline figure	blue	level
	3			orange	round
	4			white	round&digital

Table 2.Four different types of speedometers with green, blue, orange and white colors

Type / Color	digital	level	round	round & digital
Green (R143 G195 B31)				
Blue (R139 G188 B229)				
Orange (R248 G182 B45)				
White (R255 G255 B255)				

Four different types of speedometers with green, blue, orange and whitecolors are illustrated in Table 2. To indicate the current speed, the digital speedometer displays speed in digits while the level speedometer increases from left to right with a moving triangle underneath it; the round speedometer points the valuewith a needle,increasing the value by rotating it from the lower left to the upper rightclock wisely; the round&digital speedometer combines the digital and round speedometers in the same instrument.

2.3 Road speed limit symbols on HUD

Two kinds of speed limit symbols,i.e., solid and outline, are examined to see which one achieves better display effects on HUD, as depicted in Figure2.

Figure 2. Two speed limit symbols: solid and outline

2.4 HUD background transparency

Based on the findings of static experiments, higher contrast between interface information and background provides better visibility; therefore,background transparency is furtherstudiedto improve the visibility of interface information. In the Flash software all three values of RGB at 0 represents high transparency and all three values of RGB at 102 represents low transparency. Figure 3illustrates different transparencies projected by a micro projector; the figure on top is high transparency while the figure on bottom is low transparency.

Figure3.An illustrated example of HUD background transparency and road visibility

3.Experiment Procedures

3.1Participants

Subjects in the experiment included 22 male subjects and 10 female subjects where 17 were in the ages 21-25 (53.13%), 81.25% had at least one year driving experience, 56.25% drove at least once a month, more than half heard of HUD, but relatively few used HUD before (78.13%).

3.2 Procedures

The experiment is divided into two stages.

Thefirst stageaims to investigate requirementsof users, how drivers perceive car HUD as a driving assistance, the percentage of drivers that used car HUD before, and the opinions and willingness to use HUDs for driving information. At this stage, subjects look at static pictures and fill in questionnaires based on their perceptions and cognitions on HUD.Results can be used as reference for interface design of the car HUD at the second stage.

After collecting opinions of users, the next step was to design a driving simulator by which we can test and evaluate HUDs.The driving scenariosare created using the 3D virtual reality technology.Before conducting the second stage, subjects were given a briefdescription of each road scenario. Subjects werealso required to be familiar with the operational procedures of the driving simulator, as well as HUD applications in cars.

4. Statistical Analysis

4.1 HUD questionnaire Analysis

The assessment questionnaire of car HUD that provides driving information adopts a 7-point Likert scalewhich is used to allow the subjects to express how much they agree or disagree with a particular statement(Flynn, 2004). For example,subjects can rate how important they think the speed information provided by HUD for safe driving, with 1 being "completely disagree"and 7 being "Completely agree".The analysis gives us a picture of what the subjects expect from HUD. Results show that subjects hadmore positive opinions (e.g., improves, helps, useful and wise) than negative opinions (e.g., don't need, unnecessary, endangers driving safety)for presenting information on HUD. Subjects hadother similar opinions towards HUD, such as interested, wise, positive opinion, willing to use, and willing to recommend, etc., showing their positive attitude towards this new technology.

In the questionnaire, most subjects heard of HUD (62.5%), but only 34.7% of subjects used HUD before. The main reason for subjectsto use HUD was because HUD was pre-installed in it when they purchased the car (60%).It means that many car manufacturers have listed HUD asbasic appliance or equipment. Though more modern cars offer multi-media information systems inorder to enhance the passengers' comfort, the drivers still show their positive attitude toward the use of HUD for driving assistance. This questionnaire further found that although subjects who never used HUD before had an overall lower opinion of HUD compared with subjects who used HUD before, they were equally willing to use HUD. This implies that subjects who never used HUD had high expectations for HUD but were also afraid that they wouldget disappointed.

Finally, whether or not subjects used HUD before, they all had more positive opinions than negative opinions. In the comparison between the opinions of ordinary drivers and professional drivers (e.g.,taxi drivers), professional driversgave HUD slightly higher scores than ordinary drivers did. However, independent sample T-test resultsshow that the difference did not reach level of statistical significance. Therefore, in the following simulation experiment, subjects were not limited to professional drivers, but withdriving experience instead.

4. 2 HUD Interface FigurePerformance Analysis

The performance analysis of HUD interface in this study is mainly divided into two parts: the response time and operation stability of subjects to the images displayed on the HUD, which are discussed in the following two subsections.Response time refers to the time it takes for subjects responding to the change of the displayed speed limit.It is used to evaluate the effectiveness of image that is presented on HUD. The operation stability of actions is used to evaluate the subject's stability in speed control and lane keeping. Figure 4 shows the response time and stability that the subject responds to the change of the speed limit.

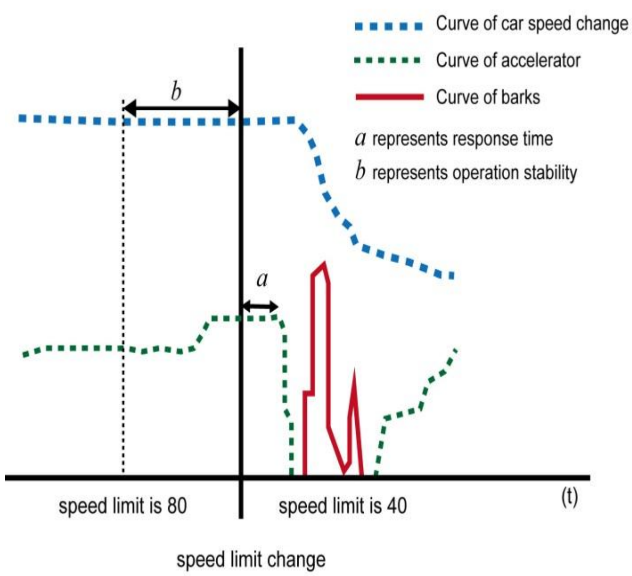


Figure 4. Response time and operation stability to the changes of speed limit

4.3Response Time of Subjects to the Change of Speed Limit

Response time of subjectson various factors, including HUD background transparency, speed limit symbols, speedometer colors and typesare next examined. The experimental resultson 16 groupsare given in Table 3, where each group is generated by the combination of factors and levels.

Table 3. Response time on various factors

Group No.	(A) HUD background transparency	(B) speed limit symbol	(C) speedo-meter Color	(D) speedo-meter type	Mean	Standard deviation	S/N ratio
	Factor levels						
1	1	1	1	1	2.65	1.46	-9.62
2	1	1	2	1	2.86	2.10	-11.02
3	1	1	3	3	3.06	1.60	-10.76
4	1	1	4	3	2.97	2.18	-11.32
5	1	2	1	2	2.35	1.23	**-8.47**
6	1	2	2	2	2.42	1.28	-8.75
7	2	1	3	4	3.84	3.64	**-14.47**
8	1	2	4	4	2.37	1.20	-8.50
9	2	1	1	4	3.05	2.34	-11.70
10	2	1	2	4	3.15	2.69	-12.33
11	2	1	3	2	2.90	2.00	-10.94
12	2	1	4	2	2.96	1.59	-10.53
13	2	2	1	3	2.68	1.39	-9.59
14	2	2	2	3	3.30	2.33	-12.13
15	2	2	3	1	2.99	1.68	-10.70
16	2	2	4	1	2.64	1.56	-9.73
				Average	2.89	1.89	-10.66

To find an optimal combination of parameters for driver response time, the average response time of each group is converted into signal-to-noise (S/N) ratioas an indicator of quality where shorter response time to changes in speed limit implies better performance. The S/N ratio is used to make the factor-response table, which is next used to draw the factor-response chart for observation on trends of individual factors.

The mean S/N ratio for each factor and level is calculated. For example, the S/N ratio of A1 is calculated as follows:

The S/N ratio of

A1=((-9.62)+(-11.02)+(-10.76)+(-11.32)+(-8.47)+(-8.75)+(-14.47)+(-8.5))/8=-10.283

Afterwards, the factor-response chart and factor-response table can be constructed, as shown in Table 4 and Figure 5.

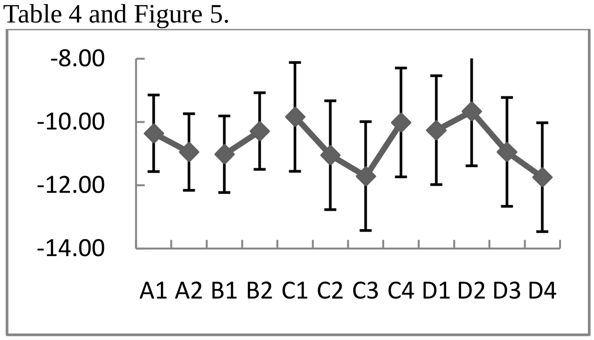


Figure5. S/N chart of subjects' response time to each parameter with a 95% error margin

Table 4. S/N value of subjects' response time to changes in speed limit with a 95% error margin

level	(A) HUD background transparency	(B) speed limit symbol	(C) speedo-meter Color	(D) speedo-meter type
	Factor form			
1	-10.36	-11.03	-9.85	-10.27
2	-10.96	-10.29	-11.06	-9.67
3			-11.72	-10.95
4			-10.02	-11.75
95% Error	1.21	1.21	1.72	1.72
Optimal combination	A1	B2	C1	D2

From Table 3, Table 4 and Figure 5, it is shown that group 5(Table 3) had the shortest average response time of 2.35 seconds with the combinationsof A1 (high transparency), B2 (outline speed limit), C1 (green speedometer) and D2 (level speedometer). Group 7(Table 3) had the longest average response time of 3.84 seconds with combinations of A2 (low transparency), B1 (solid speed limit), C3 (orange speedometer) and D4 (round&digital speedometer).Figure 6 shows the best display result based on optimal combination of parameters.

Figure6.The best display result of response timebased on optimal combination of parameters. (high transparency HUD, outline speed limit, green and level speedometer).

Next, the analysis of variation and the F-test are applied to evaluate the confidence level of each parameter. The purpose of the analysis of variance is to quantify the influence of each factor on response time; in other words, it aims to find the contribution degree of each factor. On the other hand, the F-test is used to understand whether or not each factor has significant influence on response time with confidence level at 90% or below. All results are shown in Table 5.

Table 5.The analysis of variance and the F-test on response time

Factor	SS	DOF	Var	F-test	Confidence	Contribution
(A) HUD Background transparency	1.40	1	1.40	0.66	55.67%	3.75%
(B) speed limitsymbol	2.15	1	2.15	1.01	65.23%	5.75%
(C) speedometer Color	9.37	3	3.12	1.47	69.69%	25.02%
(D) speedometer type	9.64	3	3.21	1.51	70.69%	25.75%
Error	14.88	7	2.13	S=1.46		39.74%
Total	37.45	15				100.00%

Results of the analysis of variance in Table 5 indicate that speedometer type contributesthe most to the response time with contribution ratio of 25.75%, followed by color of speed with contribution ratio of 25.02%, speed limit figures with contribution ratio of 5.75%, and finally background transparency with contribution ratio of 3.75%. The F-test results indicate that factors do not reach level of significance with confidence level at 90%, which means background transparency, speed limit figures, color of speed and speedometer types do not have significant effect on response time.

4.4Operation Stability of Subjects to the Change of Speed Limit

To investigate the operation stability of subjects to the change ofspeed limit, the same factors are considered as those in the response time. Experimental results are shown in Table 6:

Table 6. Subjects' speed operation stability

NO.	Factor levels						
	(A) HUD Background transparency	(B) speed limit symbol	(C) Speedo-meter color	(D) Speedo-meter type	Mean	Standard deviation	S/N ratio
1	1	1	1	1	0.86	0.98	-2.31
2	1	1	2	1	0.85	0.58	-0.22
3	1	1	3	3	0.72	0.66	0.25
4	1	1	4	3	0.99	0.91	-2.58
5	1	2	1	2	0.77	0.65	-0.12
6	1	2	2	2	0.83	1.14	-2.97
7	1	1	3	4	1.02	1.78	-6.24
8	1	2	4	4	0.69	0.72	0.02
9	2	1	1	4	0.80	0.68	-0.40
10	2	1	2	4	0.84	0.77	-1.15
11	2	1	3	2	0.93	0.90	-2.25
12	2	1	4	2	0.67	0.52	1.44
13	2	2	1	3	0.81	0.77	-0.97
14	2	2	4	3	0.59	0.36	**3.24**
15	2	2	3	1	0.75	0.59	0.43
16	2	2	4	1	0.59	0.54	1.89
Average					0.79	0.79	-0.75

To find an optimal combination of parameters for driver stability, the average stability of each group is converted into signal-to-noise (S/N) ratioas an indicator of quality wheresmaller operation stability to changes in speed limit implies better performance. The S/N ratio is used to make the factor-response table, which is next used to draw the factor-response chart for observation of trends of individual factors (Table 7 and Figure7).

Table 7. S/N values of speedometer operation stability with 95% error margin

Level	Factor form			
	(A) HUD background transparency	(B) speed limit symbol	(C) speedo-meter Color	(D) speedo-meter type
1	-1.77	-0.90	-0.95	-0.05
2	0.28	-0.59	-0.27	-0.98
3			-1.95	-1.94
4			0.19	-0.02
95% Error	1.93	1.93	2.73	2.73
Optimal combination	A2	B2	C4	D3

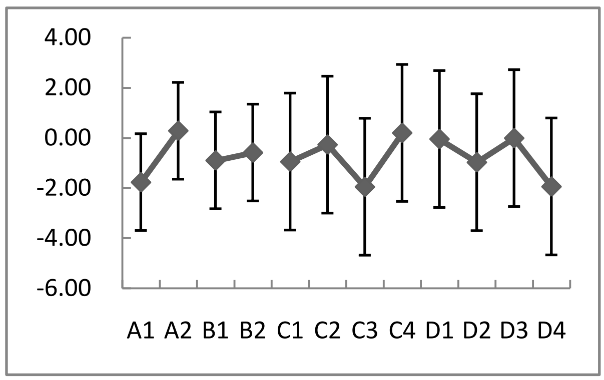


Figure7.S/N chart of subjects' stability with 95% error margin

Figure8. The best display result of operation stability for speed control based on optimal combination of parameters.(low transparency HUD, outline speed limit, white and round speedometer)

Similarly, the analysis of variation and the F-test are applied to evaluate the confidence level of each parameter. Results are shown in Table 8.

Table 8.The analysis of variance and the F-test onoperation stability

Factor	SS	DOF	Var	F-test	Confidence	Contribution
(A)HUD Background transparency	16.79	1	16.79	3.16	88.11%	22.44%
(B)speed limitsymbol	0.39	1	0.39	0.07	20.51%	0.52%
(C)speedo-metercolor	10.42	3	3.47	0.65	39.40%	13.92%
(D)speedo-meter type	10.01	3	3.34	0.63	38.00%	13.37%
Error	37.24	7	5.32	S=2.31		49.75%
Total	*74.84*	*15*				*100.00%*

Results of the analysis of variance in Table 8 indicate that background transparency contributesthe most to the operation stability over speed control with contribution ratio of 22.44%, followed by color of speed with contribution ratio of 13.92%, speedometer type with contribution ratio of 13.37%, and finally speed limit figures with contribution ratio of 0.52%. The F-test results indicate that factors do not reach level of significance with confidence level at 90%, which meansall factors do not have significant effect on stability.

It is shown that the best average stability of speedometers was achieved in group 14 (Table 6) with the combination of A2 (low transparency), B2 (outline speed limit), C4 (white speedometer) and D3 (round speedometer). Figure 8 shows the best display result of operation stability for speed control based on optimal combination of parameters. The worst average stability was in group 7 with the combination of A1 (high transparency), B1 (solid speed limit), C3 (orange speedometer) and D4 (round& digital speedometer).

5.Experimental Results

To explore the effects of driving information and elements of HUD on drivers,we divide our study into two stages. At the first stage, a questionnaire survey is conducted to understand the perception and cognition of HUD users,as well as the relationship of background transparency and text color with visibility. The preliminary results of the study are highlighted as follows:

(1)Most subjects heard of HUD (62.5%), but only 34.7% of subjects used HUD before. The main reason for subjectsto use HUD was because HUD was pre-installed in it when they purchased the car (60%).

(2) Most subjects held a positive attitude towards the integration of HUD with vehicle information and were very willing to use the technology(92%).

(3) The HUD users have an overall higher opinion of HUD compared with those who never used HUD before(94%).

(4)Car speed related information, such as current speed and speed limit are the most important driving information in the survey.

(5)90% of subjects thought higher contrast between interface information and background provides better visibility.

(6) Analysis results of the Taguchi Experiment show that the optimal combination for response time is high background transparency, outline speed limit symbol, green and level speedometer. Thecombinationsindicate that users had better short reaction time to control speed when speed limit is changed.

(7) Analysis of the Taguchi Experiment found the optimal combination for operation stability was low background transparency, outline road speed limit symbol, white and round speedometer. The combinationsindicate that users had better performancein speed control and lane keeping when speed limit is changed.

(8) Analysis of the Taguchi Experiment found the users hadbad performance to operationthe speed and had longer response time forsolid road speed limit symbol, orange and round & digital speedometer on HUD.

6.Discussion and conclusion

Most visual conditions of traffic signs can be perceived with the road luminance levels which are lower than the recommended today (Chao, C.W., 2013). To solve this problem, HUD may help to capture the traffic signs for the drivers. One of the key factors contributing to the market of HUD growth is the increasing focus on improving safety and convenience for drivers/pilots of various vehicles according to Global Heads-up Display Market 2012-2016 (Infiniti Research, 2013). Among top concerns of driving safety, car speed is probablythe most importantone and should be carefully consideredand wisely controlled by drivers.The speed control is self-regulating and it can affect driver behavior andimprove traffic flow management. Minimum speed limits have also been shown to reduce dangerous overtaking andaccident rates.Our survey on vehicle information found that drivers considered car speed related information to be necessary, which is consistent with the fact that all car HUDs currently in the market display car speed. This shows the importance of car speed information to drivers.

The interface design of HUDin the experiment promises to be a highly effective and easily implemented technology thatcan dramatically improve safety margins by recommending drivers an appropriate travel speedbased on current road conditions. This modification of driver behavior will most likely keep thespeed within the recommended limits and lead tofewer and less severe crashes. Inourstudy of HUD display related to speed, the users had poor performance when responding to the speed change and had longer response time for the round & digital speedometer on HUD. It revealed the fact that the frequent speed change will cause eye fatigue though digital speedometer provides accurate car speed. The purpose of displaying car speed is to tell the driver an approximate speed, not an exact one which might hold the driver's attention and thus cause considerable stress. Therefore, it is suggested that to avoid stress while driving, only static information is suitable to be displayed on HUD.

Color is another important issue for HUD. Since HUD information is displayed on the windshield in front, the background of the information is relatively complex. Though HUD is designed to provide aid to drivers, conflicting colors could prevent drivers from clearly seeing information and result in an accident instead. In our study on color, the best average stability was achieved with a low transparency, outlined speed limit, white & round speedometer on HUD. Some speedometers in the market present information in white during the daytime and orange at nighttime. The result in the Taguchi experiment matches the trend of the current HUD product. In summary, the results of our study can be a guideline for automobile manufacturers in designing the HUD to prevent distracted driving and improve driving safety. Our future studies include finding the best color combination of HUD at night to further reduce eye fatigue and workload, developing an eye tracking system to further explore driving behavior, etc.

***Correspondence:**
Chun-Wen Chao,
Ph.D. Program of Design Science, Tatung University, Taipei 106, Taiwan.
joanne@mail.chihlee.edu.tw.
C.W. Chao is currently an assistant professor at Chihlee Institute of Technology.

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