Development and Usability Evaluation of Fixed-base AHS Simulator

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Abstract

This study described the specification and configuration of developed fixed-base AHS (Automated Highway System) simulator for the human factors researches, and its usability evaluation results after riding 120, 140, and 160kph automated driving speed. As the results, this study suggested the subjects' preferences and opinions about simulator and AHS configurations that would help to establish the AHS R&D plan and driver-vehicle/road interface design guidelines as the basic researches of the AHS human factors.

Keywords : Automated Highway Systems, human factors, usability evaluation, driver-vehicle/road interface

1. Introduction

AHS-fully automated driving-aims to automate the operations of the vehicles on the highway to eliminate the problems of traffic flow caused by operations of vehicles by individual drivers. It means that AHS increases highway safety by reducing driver error, which causes a large share of motor vehicle crashes, because the performance of driving depends on how the following environments of driving are perceived and translated into specific decisions; they are the weather condition, highway geometric design, and traffic flow conditions. As the results, not only the traffic flow can be made uniform, but also the operations can be controlled such that the flow is optimized in terms of capacity, energy use and environmental impacts. Further, the individual drivers are relieved of the driving tasks leading to the reduction of fatigue and judgment errors [7].

Human factors considerations are the crucial issues for AHS design because human driver should be involved in automated driving, even if there is no need to control the steering and speed during automated driving mode. Because, for instance, drivers may be expected to instruct their vehicles and exit locations and destinations, take control in some emergency situations, and driving authority changes. Because of all roads will not be automated, drivers should control the vehicle manually before and after automated driving. Also, newly developed information systems essentially required to deliver the AHS, vehicle and traffic information, for example, head-up display, AHS flat panel display, in a vehicle. Considering these kinds of changed driving maneuvering and driver-vehicle interfaces, the driver's capabilities and limitations must be considered to ensure the successful and safe implementation of the AHS. Human factors has performed important roles to investigations of AHS driver physical, demographical, psychological characteristics to provide the basis for determining system configurations and features, and to develop the human factors design guidelines.

This study described the specification and configuration of developed fixed-base AHS driving simulator and its usability test results after riding 120, 140, and 160kph with 0.0625 sec. inter-vehicle gap. The results revealed the driver's opinions, feelings and their preferences about the AHS configuration and developed simulator.

2. Simulator Development

2.1. H/W and S/W Specifications

Simulator was constructed on a half-sized real vehicle cockpit module with 16 d.o.f. real vehicle dynamics model. Virtual driving environment was injected using beam projector (Sanyo Pro xtraX multimedia projector) on the 110-inch size of screen.

This simulator has 45°~55° field of view, and distance from projector and screen was 3.6m to present the real-size road environment and features with 800x600 32bits true color resolution through 40~60Hz refresh rate. 3D vehicle sound was generated through four speakers around the vehicle using integrated control box. Host computer was Pentium III 700Mhz capability that controlled by keyboard and mouse connected with integrated control box. Flat panel display was implemented on the 7-inch LCD-based portable client computer display using IPX protocol for the synchronization between vehicle status and information on the display. Table 1 describes the hardware and software specifications, and Figure 1 shows the overall functional diagram of this simulator.

2.2. Driver-Vehicle/Road Interface

Head-up display was implemented on the screen graphically, and the AHS flat panel display was implemented on the 7-inch LCD-based portable computer display. Head-up display presented the current vehicle position on the lanes, speed, driving mode (automated or manual driving), and rest time to destination, and driving status, for example, the changing the lane, entering the automated lane and so on. And, flat panel display presented the rest distance to destination, inter-vehicle distance, destination, and driving mode on the rightside of the cockpit.

Eight variable message signs were implemented for the driver's rapid and exact information acquisition and reactions just before each gate and in

Table 1. H/W and S/W Specifications

Hardware Specification	Software Specification
Computer System · main processor (CPU) : Pentium III 700Mhz · memory (RAM) : 256Mb · graphic card : Supports Open GL, AGP 32Mb, Riva TNT II G-Force (nVidia Co.) · sound card : 3D Sound, PCI · signal IO interface card (KITI IO Interface Card)	**Development Environment** · Microsoft Visual Studio (Visual C++ 6.0) · graphics library : Spectrum Ver. 1.5 (OpenGL-based Graphics Library) · client : Microsoft Foundation Class
Integrated Control Box · sound generation system · four 3D speaker and amplifier · input device : mouse and keyboard	**Software Modules** · interface processing module · calibration module · vehicle dynamics calculation module · check/inspection Module · display module · vehicle generation module · camera calculation module · communication module · menu module
Vehicle Module · Verna cockpit and automatic transmission module (Hyundai Motor Company) **Display System** · beam projector and screen	

front of 500m of each gate with young female voice instructions. Figure 2 shows the screenshot of AL (Automated Lane) driving on this simulator. Five functions keys were arranged on the instrument panel area for the calibration of vehicle calibration (function key 1~4), and for the CCB (Cruise Control Button) for automated driving (function key 5). By pressing the CCB, subjects could start the automated driving on the transition lane.

2.3. Road and Inter-Vehicle Configurations

Figure 2 shows the road configuration that implemented in this simulator that based on the shared space at-grade concept suggested by PATH (Partnerships for Advanced Transit and Highways) [15]. Among four kinds AHS road configurations of shared space at-grade concept, dedicated space at-concept, above-grade AHS concept, and below-grade AHS concept suggested by PATH, this concept is a low-cost minimum-changeable configuration for the implementation of Korean road situation through a transportation expert's review. This concept also, satisfies the principles governing the configuration of the AHS, and the maneuvers of vehicles below [6].

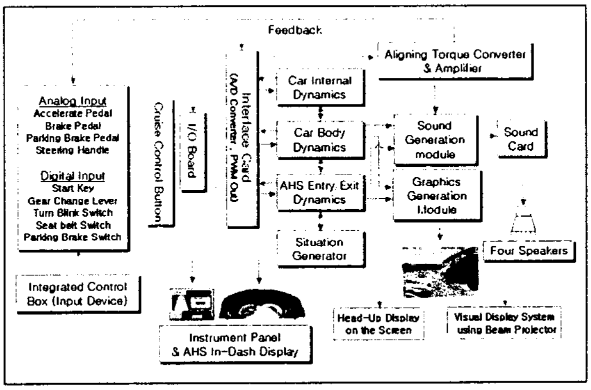

Figure 1. Functional Block Diagram of AHS Simulator

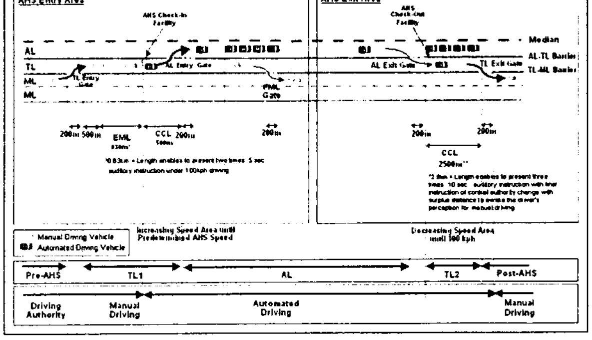

Figure 2. Road Configuration (Entry / Exit)

(1) Vehicles are organized into closely spaced platoons, which have an inherently low casualty rate
(2) There is a barrier (or divider) between the AL and ML (Manual Lane) on the rest of the right-of-way; vehicles must enter and exit through gates in the dividers
(3) Platoons do not join together (merge) at speed, either on the ALs or on the transition lane

To implement this concept on the virtual environment, graphic engineers modified recorded road scenes from Osan to Chonan. Barriers were used from Korean road facility standards [11], median (drawing number : II-15-2), AL-TL (Transition Lane) barrier and AL-TL barrier (drawing number : II-3-1) were used. And, road width was 3.5m that is the minimum requirements from Korean regulations of road structure and facility [12]. Figure 3 shows the cross road section of implemented shared-at grade concept implemented on the simulator, and Figure 4 does the implemented AL driving scene on the screen.

Human Factors Design Guideline of AHS (1998), suggest the inter-vehicle distance guideline that based on the Bloomfield *et al*'s experiment. Their experiments were based on the driver's preferences,

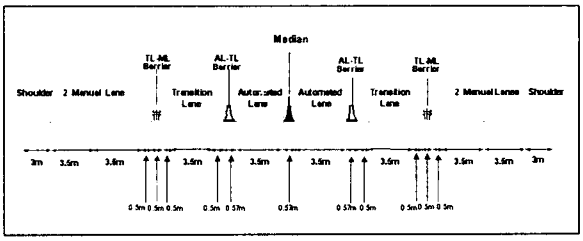

Figure 3. Cross Road Section

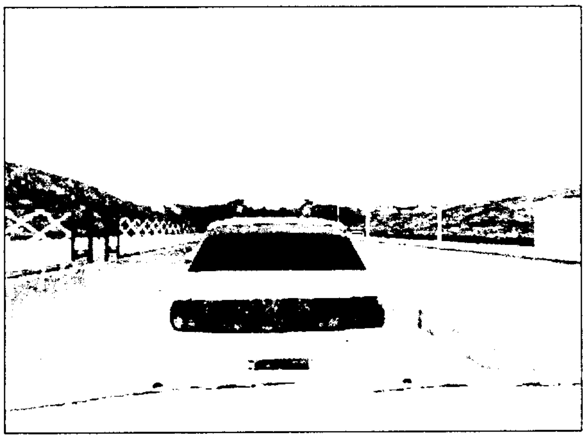

Figure 4. Implemented Road Environment

if there are string of vehicle on the automated lane, and the designed speed in that lane is 104.7kph, and provide gaps between vehicles within string of more than 0.0625 second [2].

Alicandris *et al*'s experiment investigated the basic driver and system attributes for the AHS design. They set at three levels of speed of 104.6, 128.8, and 152.9kph (65, 80, 95mi/h) with different three inter-vehicle gaps ranging 0.0625, 0.25, and 1.0 second (1.8 to 42.5m) [1].

Buck and Yenamendras's experiments investigated the human factors issues of drivers maneuvering for entering the automated lane. He insisted that the gap between successive platoons of car should be large enough to allow a safe entry to be made behind the last car in the passing string and so that the entering car could accelerate to the AHS design speed precisely as the first vehicle in the trailing string joins up 0.0625 second behind it. In this experiment, minimum inter-vehicle gap, 0.0625 second was used with three levels of vehicle speed of 104.6, 128.8, and 152.9kph (65, 80, 95mi/h), and inter-vehicle gap was 1.8, 2.2, and 2.7m, respectively [3].

And, at the San Diego demonstration (1997), 6m inter-vehicle gap was chosen as a compromise, considering technical, political and human factors considerations. Those vehicles were tested extensively at clearances of 4m, 4.5m, and 5m during the development of the demonstration. Before demonstration they also tested the 2m inter-vehicle gap, however, that time the technology on vehicles were not enough to implement the 2m gap safety more than 2 vehicles. In a long term, they will try to enhance the performance so that all the vehicles can run at 1 to 2m inter-vehicle gap all the time. It means that the inter-vehicle is maintained almost constant (within an accuracy of about 20cm), which gives the passengers the sensation of having a mechanical coupling between the cars even though the coupling is only electronic, as implemented by vehicle-follower control system. Also, the aerodynamic drag and system capacity benefits are close to the maximum and the safety should be good [13].

In this experiment, 0.0625 second inter-vehicle gap was used that fulfill the PATH's development plan, and also does the minimum inter-vehicle gap that have used prevalently. Therefore, designed inter-vehicle gap was 2.08m, 2.43m, and 2.78m for 120kph 140kph, 160kph, respectively.

3. Driving Scenario

In Figure 2, EML (Entry Maneuvering Length) is the area that the drivers press the CCB to start the automated driving and to check the vehicle state, CCL (Control Change Length) is for the driving authority transferring from vehicle to driver/driver to vehicle on the TL, and FML (Failure Maneuvering Length) gate is the exiting area in case of CCB press failures or vehicle malfunctions. During road sections, CCL length after exiting AL is long, because there is possibility that the driver fall into drowsiness and he or her should prepare the manual driving.

To complete a session of experiment, subject should drive the car by following orders; ML→TL→AL→TL→ML. When the subject enters the TL for AHS driving, vehicle control authority changed to the vehicle after pressing the CCB on the instrument panel. Then, the vehicle automatically enters the AL, increasing the vehicle velocity until the predetermined AHS speed at the end of platoon. In case of, the subject failed to push the CCB, they should driver the vehicle through the FML gate. At the end of automated driving on AL, vehicle also automatically moves to the gate at the end of TL to change to control authority to the driver. In this experiment, the length of pre- and post-AHS was 6.5km, and time on the AL driving was about 12.5, 10.7, and 9.4 minutes for each AHS speed.

Figure 5 shows the driver's maneuvering and vehicle operation procedures from entering to exiting

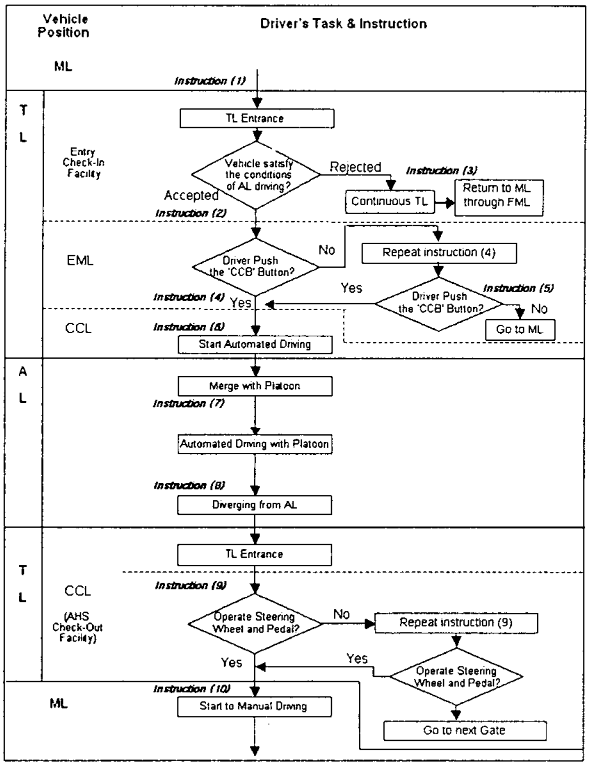

Figure 5. Driver's Maneuvering and Instructions for Entry and Exit of AL

the automated driving with following 10 kinds of voice instructions.

[INSTRUCTION 1] Please move to the transition lane in front of 500m, if you want to use the AHS

[INSTRUCTION 2] Maintain the transition lane, and go forward to the check-in system.

[INSTRUCTION 3] You have entered transition lane but you're not authorized to be in the AHS. Return to the manual lane through next FML.

[INSTRUCTION 4] You are success to be in the AHS. To engage the automated system, push the 'CCD' button.

[INSTRUCTION 5] You didn't push the 'CCD' button. If you want to use the automated system, please push 'CCB' button again. If not, return to manual lane through next FML.

[INSTRUCTION 6] From now on, your vehicle is controlled by AHS, and you will enter the automated lane 500m ahead.

[INSTRUCTION 7] Your vehicle joins completed with a platoon. Enjoy the automated driving!

[INSTRUCTION 8] You will leave the automated lane 500m ahead for the entrance of transition lane. When you get there, wait for further instructions

[INSTRUCTION 9] Your vehicle will enter the manual lane 500m ahead. To regain manual control of the vehicle, press the accelerator or brake pedal and put your hands on steering wheel.

[INSTRUCTION 10] You completed changed driving authority from automated to manual driving. From now on, control your vehicle safely. Enjoy your driving.

4. Participants and Experiment

28 male subjects (from 23 to 33 years olds, mean : 26.8), who had driver's license and without any physical and psychiatric diseases, were participated for simulator and AHS usability test after 120, 140, and 160kph AHS driving. Developed simulator and AHS usability were evaluated using 5-scale response alternatives that are frequently recommended by Dyer *et al* [4]. Each scale means following alternatives.

- 1 : very unacceptable (unsatisfactory, ineffective)
- 2 : unacceptable (unsatisfactory, ineffective)
- 3 : borderline
- 4 : acceptable (satisfactory, effective)
- 5 : very acceptable (very satisfactory, very effective)

Ranking order scale was also used to establish the hierarchical orders of their preferences and opinions.

5. Results

Table 2 describes the results of fidelity and usability of constructed simulator including the suitability as an AHS training/education facility. Subjects expressed their opinions of simulator fidelity from 3.01 to 3.1 points, however, many subjects expressed their opinions above borderline. Also, they suggested the opinions that this simulator could help to understanding the AHS, and then, they presented high acceptability for the use of the AHS training and education facility.

Table 2. Results Summary of Simulator Fidelity and Usability

Q#	Question	Average Points	% above borderline
1	Fidelity of simulator control	3.1	79%
2	Fidelity of road environment	3.5	87%
3	Fidelity of simulator sound	3.4	89%
4	Overall simulator reality	3.01	78%
5	Helps of understanding AHS and its operation	4.3	96%
6	Education needs of AHS operation and use	4.6	96%
7	Suitability for AHS training/education	3.7	89%

Table 3 shows the evaluation results of AHS configurations. Subjects strongly required the TL, barriers between TL and ML for driving safety. However, they suggested the opinions that 0.0625 seconds vehicle gap in a platoon was rather short, but they expressed the satisfactory opinions about vehicle control authority sequence.

Table 3. Result of Implemented Configurations

Q#	Question	Average Points	% above borderline
1	Inter-vehicle gap		
	120kph	2.9	61%
	140kph	2.9	72%
	160kph	3.1	68%
2	Satisfaction of driving scenario (ML→TL→AL→TL→ML)	4.1	100%
3	Necessity of TL	4.6	96%
4	Necessity of barrier between TL and ML	4.6	96%
5	Satisfaction of control authority transfer on this simulator	3.6	86%
6	Preference of control authority transfer sequence		
	Steering first	2.2	Rank order scale
	Speed first	1.9	
	Steering and speed simultaneously	2.1	

Table 4 shows the usability of information system and their contents that implemented on constructed simulator. Head-up display and voice instructions gained the high preference as the newly development vehicle information system, however, they also presented the high necessity for the usefulness of conventional vehicle instrument panel information. Current information and driving mode were importantly regarded than other information supplied by in-vehicle information facilities.

Table 4. Result Simulator Information Usability

Q#	Question	Average Points	% above borderline
1	Importance of head-up display information		
	Current vehicle speed	1.8	Rank order scale
	Driving mode	2.2	
	Remaining time to destination	2.9	
	Remaining distance to destination	3.2	
	Current lane position	3.6.	
2	Importance of AHS flat panel display		
	Current vehicle speed	1.8	Rank order scale
	Driving mode	2.8	
	Inter-vehicle gap	2.9	
	Remaining time to destination	3.4	
	Remaining distance to destination	3.8	
	Destination name	4.8	
	Current position on the road	4.9	
3	Utility of conservative IP information	3.7	85%
4	Usefulness of above three information		
	Head-up display	1.1	Rank order scale
	AHS flat panel display	2.9	
	Cluster information	2.3	
5	Usefulness of voice guidance	4.6	100%
6	Adequateness of voice guidance presentation timing (presented 500m before gates)	3.9	89%

Table 5 shows the general usability of the AHS after driving of constructed simulator. They highly presented the implementation of AHS, and 140kph platoon speed was preferred for their feeling of comfort and safety. During experiments, 3 subjects fell into sleep on AL and just after post-AHS manual lane. They said they felt the dull and monotonous driving environment during automated driving, and then became sleep. Therefore, they strongly required the drowsiness warning system for AHS implementation, and also expressed the necessity of road environments monitoring on the AL driving.

Table 5. AHS Usability

Q#	Question	Average Points	% above borderline
1	Implementation needs of AHS	4.1	93%
2	Road environments monitoring needs when driving automated road	4.0	93%
3	Intention of AHS use	YES : 89%	
4	AL speed preferences		
	120 kph	25%	
	140 kph	50%	
	160 kph	25%	
5	Intention to pay for AHS use	YES : 61%	
6	Mixed-flow platoon	3.0	61%
7	Feeling of drowsiness during automated driving	4.0	93%
8	Needs of drowsiness detection system	4.0	100%

6. Conclusion and Discussion

Korean Ministry of Construction and Transportation announced that they have established the plan to install the national-wide ITS until 2010, and also, they will develop and service the AHS until 2020 [8]. And, this study suggested the configurations and specifications of the AHS simulator as the basic tool of the human factors research and prototype for future extensions.

In this study, as the initial human factors works for AHS development, we described the developed fixed-base and low-cost AHS simulator for the research of AHS human factors that could be used very easily and conveniently with the various human factors equipments. Then, usability of simulator and AHS were performed to investigate the usability and preferences after their riding experiences of simulator.

Most of subjects agreed the needs of AHS and simulator for AHS training system, however, more researches of human factors about AHS configurations and driver-vehicle interface were remained for the future works.

The results of experiments using this simulator could assist the hardware and electronics engineers for the driver-vehicle interface design and evaluation by suggesting the human factors guidelines and to establish the R&D policy of AHS-related systems in Korea.

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