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Ergonomic Design of the Gauge Cluster Display for Commercial Trucks

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Objective: The purpose of this study is to determine the priority of information presentation and the effective menu type to be placed in the center of a gauge cluster display for commercial trucks and to present a set of ergonomic designs for the gauge cluster display.

Background: An effective ergonomic design is specifically needed for the development of the gauge cluster display for the commercial trucks, because more diverse and heavier information is delivered to truck drivers, compared to the information to passenger car drivers.

Method: First, all the information that must be shown on the commercial truck display was collected. Then, the severity, frequency of use, and display design parameters were evaluated for those information by commercial truck drivers. Next, an analysis on the information attributes and the heuristic evaluation utilizing the display design principles were carried out. According to the results, a design alternative of the main screen to be displayed was constructed by priority. A comparative analysis between the alternative and existing main screens was also conducted to see the efficacy of the designs. Lastly, we conducted an experiment for the selection of menu type. The experiment was conducted using the driving simulator with an eye-tracking device. The independent variables were four types of the menu reflecting the commercial truck characteristics such as grid type, icon type, list type, and flow type. We measured preference, total execution time, the total duration of fixation on the gauge cluster area, and the total number of fixation on the gauge cluster area as dependent variables.

Results: Four types of driver convenience information and six types of driver assistance information were selected as the information to be placed primarily on the main screen of the gauge cluster. The Grid type was the most effective among the menu types.

Conclusion: In this study, the information that appears on the main screen of the display, the division of the display and the design of the menu type for commercial truck drivers were suggested.

Application: This study is expected to be utilized as guidelines on the ergonomic design of a gauge cluster display for commercial trucks.

Keywords: Commercial truck, Gauge cluster display, Human machine interface, Menu type

1. Introduction

Displays within a vehicle are necessary to effectively convey various types of

information related with driving and vehicle status to the drivers. These displays can be core factors of HMI (Human Machine Interface) (Frost & Sullivan, 2006). Displays within a vehicle offer information from various positions including the gauge cluster, multi-function display on the center fascia and head-up display offered to the front windscreen. Among them, the gauge cluster display is the main information source that drivers receive most, while they drive (Nam et al., 2007).

For ergonomic study on such a vehicle cluster display, many sensibility ergonomics studies on the shape of gauge cluster, and number and color of gauges have been carried out (Tanoue et al., 1997; Jung et al., 2010). Recently, variable displays using a liquid display within the gauge cluster are introduced to indicate more information, as information within a vehicle increases. Also, studies on such a thing is conducted. Studies on the displays within gauge cluster have been performed from various perspectives including the design of display menus (Hong et al., 2010) and visual complexity of display (Yoon et al., 2015). However, these have researched passenger car's gauge clusters mostly.

Recently, however, the importance of gauge cluster display increases for commercial trucks requiring more information than passenger cars, and competition becomes more serious. Existing studies on passenger car displays are insufficient to reflect them to commercial trucks, of which information characteristics are different. Figure 1 shows the information displayed on the gauge cluster of a commercial truck. There are no common criteria for information type and placement shown on the first display screen, and also ergonomic design lacks. In this regard, ergonomic gauge cluster display design in a commercial truck is needed.

Consequently, this study presents ergonomic gauge cluster display design by identifying information to be placed in priority on the display and driver-centered display's major design variables for variable display's ergonomic design within commercial truck's gauge cluster.

Figure 1. Current gauge cluster displays of commercial trucks

2. Method

This study was carried out as follows: The study collected information revealed on the existing commercial trucks' gauge cluster displays, and selected information use frequency, importance and the major design variables of display through a questionnaire survey targeting commercial truck drivers. Through the analyses of information attributes and ergonomic guidelines, this study selected the information to be presented on the main screen of the gauge cluster display in priority. Through comparison between the alternatives of the selected information and the existing commercial trucks' information, this study selected the alternative with the highest preference. Also, this study presented ergonomic design on the display division and menu type selected with the major variables of displays through an experiment.

2.1 Information presented on the gauge cluster display of commercial trucks

Information shown in the commercial trucks' gauge cluster displays was collected in this study via investigation of domestic and international commercial trucks, and videos and photos research on gauge cluster display. Table 1 shows information displayed on the gauge cluster display, after verification through five commercial truck drivers. The career of the truck drivers, who participated in the verification, was 12 years on average (SD=3.2). This study excluded the functions offered as options to specific vehicles including the engine RPM indicator, speedometer, fuel gauge, cooling water temperature gauge, LDWS (Lane Departure Warning System) and TBT (Turn by Turn) that are revealed commonly in the commercial trucks' gauge cluster area.

Table 1. Information of commercial truck

Information	Function
Average fuel consumption	Indication of the fuel consumption as the amount of the consumption up to now for a distance
Instantaneous fuel consumption	Indication of the average of the fuel efficiency driving over a certain speed after start-up
Average velocity	Indication of the average speed of the current point in time
Driving time	Indication of the driving time of the current time
Fuel level (Travel distance)	Indication of the remaining amount of fuel and the travel distance
Total mileage	Indication of the total driving distance to date
Transmission	Indication of the transmission when the gear lever is changed
Outside temperature	Indication of the temperature outside of the Commercial truck
Clock	Indication of the current time
Total idle time	Indication of the total idle time of the Commercial truck
Urea gauge	Indication of the urea gauge
Oil pressure gauge	Indication of the engine oil pressure gauge
Brake pressure gauge	Indication of the air pressure gauge in the brake system
Voltage gauge	Indication of the voltage gauge in the electrical charging circuit system
Tire pressure gauge	Indication of the tire pressure and temperature
ECAS axle load	Indication of the total weight for all wheels connected to a given axle

Table 1. Information of commercial truck (Continued)

Information	Function
Front/Rear brake wear condition	Indication of the front and rear brake wear condition
Fault Diagnosis - Engine	Indication of the fault diagnosis for the engine
Fault Diagnosis - AMT/ATM	Indication of the fault diagnosis for the AMT/ATM
Fault Diagnosis - EBS	Indication of the fault diagnosis for the EBS
Fault Diagnosis - CMK/IMMO	Indication of the fault diagnosis for the CMK/IMMO
Fault Diagnosis - E-APU	Indication of the fault diagnosis for the E-APU
Fault Diagnosis - CM	Indication of the fault diagnosis for the CM
Fault Diagnosis - Smart Junction Box	Indication of the fault diagnosis for the smart junction box
Fault Diagnosis - CLUSTER	Indication of the fault diagnosis for the CLUSTER
Fault Diagnosis - RETARDER	Indication of the fault diagnosis for the RETARDER

2.2 Truck driver survey

2.2.1 Evaluation on the frequency and the importance of the information

This study evaluated frequency of use and importance on the information presented in Table 1 through a questionnaire survey targeting commercial truck drivers. The truck drivers participating in the questionnaire survey was 20 drivers and average age was 43.7 (SD=6.1), and average career was 15 years (SD-7.4). The frequency of use and importance were evaluated with 9-point Likert scale. As a result of ANOVA on the evaluated frequency of use and importance, significant differences were revealed at significance level of 0.05, respectively ($p<0.000$, $p<0.000$). As a result of S-N-K (Student Newman Keuls) post hoc analysis result

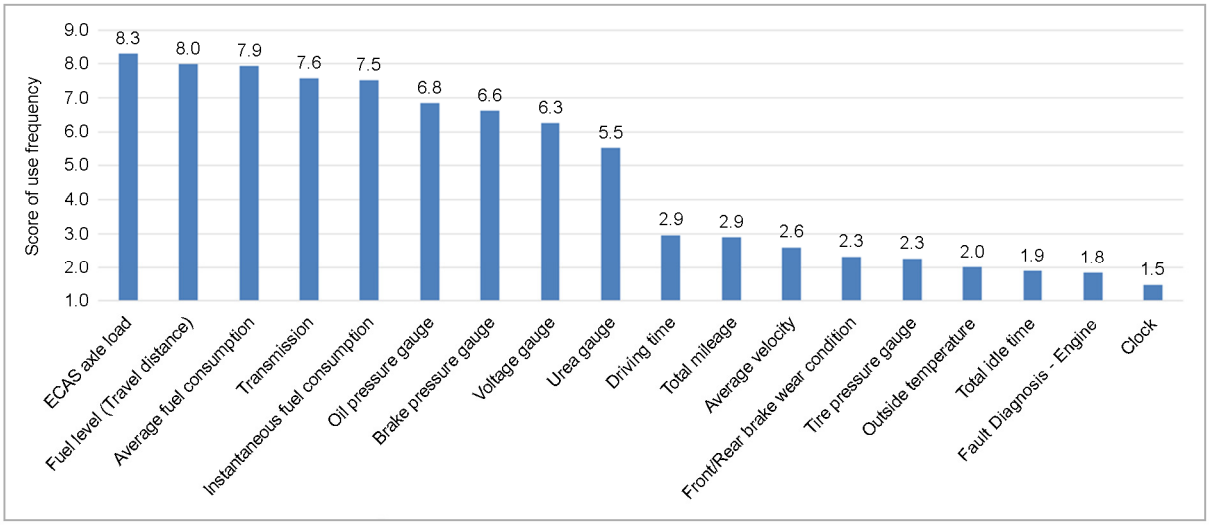

Figure 2. Frequency of use

on information use frequency, this study divided into three groups with higher than 7 points, 5~7 points and less than 5 points, respectively, and each was classified into High, Medium and Low levels.

In the frequency of use as shown in Figure 2, five such information as the axis/load, fuel level (Travel distance), average fuel consumption, indication of transmission speed and instantaneous fuel consumption were classified as High level. Four types of vehicle status gauge information were classified as Medium level, and the remaining nine types of information were classified as Low level.

In the importance as shown in Figure 3, 11 types of information were classified as High level, one type information of total mileage was classified as Medium level, and the remaining six types of information were classified as Low level.

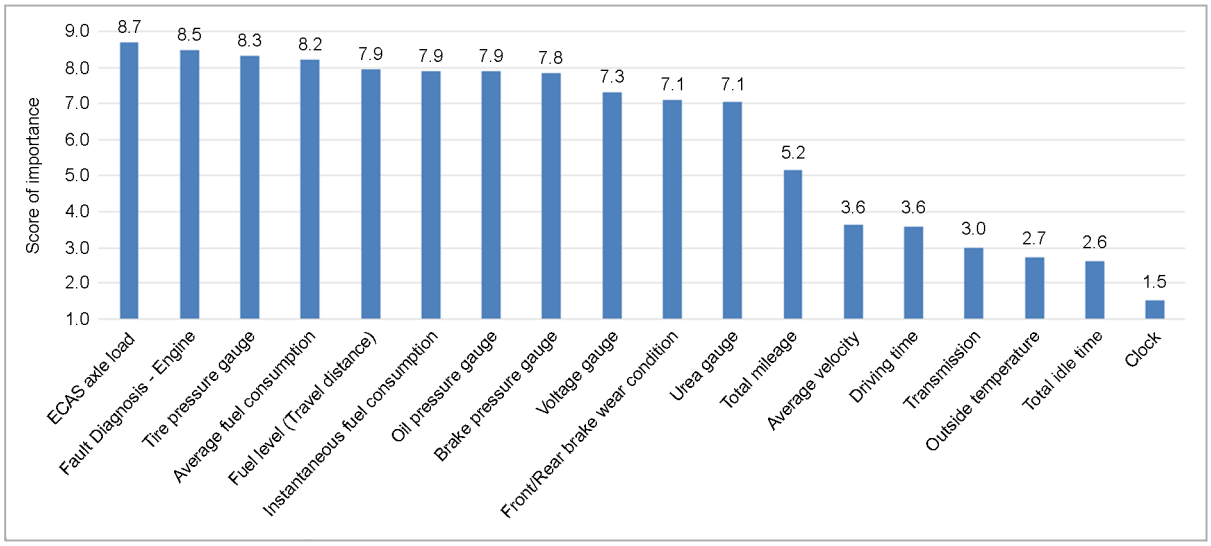

Figure 3. Importance

2.2.2 Variables selection related to the display design

This study selected the related variables upon the ergonomic design of gauge cluster display through literature study and FGI (Focus Group Interview) as shown in Table 2.

Table 2. Design variables related to the gauge cluster display

	Design variables	Definition
Display-related design variables	Color	Truer colors for the display
	Size	Font size for the display
	Font	Font for the display
	Ways of Information presenting	Level of expression according to the information

Table 2. Design variables related to the gauge cluster display (Continued)

	Design variables	Definition
Display-related design variables	Menu level	Level of menu according to the information
	Menu type	Level of menu type according to the information of the next depth
	Division	Visually presented divided area by lines
	Display location	Location of the display

This study carried out an importance evaluation questionnaire survey on the selected design variables as shown in Table 2. The drivers participating in the questionnaire survey were 19 people, and their average age was 45.7 (SD=8.1), and driving career was 17 years (SD=10.0). As for evaluation, the importance of design variables was evaluated with 9-point scale by looking at the gauge cluster display photos and videos of nine types of domestic and international commercial trucks. Consequently, this study selected division (seven points) and menu type (seven points) classified as the highest group in terms of importance as the study subjects.

2.3 Information attribute analysis

To select the information to be placed on the main screen in priority among the information presented on the commercial truck gauge cluster display, the qualitative, quantitative, dynamic, static and changing information (time) were used as the attributes of each information as shown in Table 3. And, this study analyzed the use of frequency and importance through a questionnaire survey on the drivers in section 2.2.1 above as shown in Table 4.

Table 3. Information attributes

Attribute	Definition
Qualitative	Information to read information and status changes
Quantitative	Information to read the exact value
Dynamic	Information of the status change in real-time
Static	Information in a fixed state
changing information	Immediately changing information after operation: High Changing information during running period of time: Medium Information indicating the special situation: Low
Frequency of use	Frequency level of using information while driving / not-driving
Importance	Level of importance of the information
Submitting time	Time when the information is submitted

2.4 Information selection

This study selected information to be placed in priority on the main screen of commercial truck gauge cluster display on the basis of attributes analysis and ergonomic guidelines. This study selected transmission information (No. of transmission speed) of which changing information (time) level was High level, according to Rapidly Changing Information Guidelines among the principles of

Table 4. Analysis of information attributes

	Qualitative	Quantitative	Dynamic	Static	Changing information	Frequency of use	Importance	Submitting time
Average fuel consumption		O		O	M	H	H	Driving
Instantaneous fuel consumption	O	O	O		M	H	H	Driving
Average velocity		O		O	M	L	L	Driving
Driving time		O		O	M	L	L	Driving
Fuel level (Travel distance)		O		O	M	H	H	Driving
Total mileage		O		O	M	L	M	Driving
Transmission	O			O	H	H	L	Driving
Total idle time		O		O	M	L	L	Driving
Outside temperature		O		O	M	L	L	Driving
Clock		O		O	M	L	L	Driving
Urea gauge	O	O	O		M	M	H	Driving + Specific time
Oil pressure gauge	O	O	O		M	M	H	Driving + Specific time
Brake pressure gauge	O	O	O		M	M	H	Driving + Specific time
Voltage gauge	O	O	O		M	M	H	Driving + Specific time
Tire pressure gauge	O	O	O		M	L	H	Specific time
ECAS axle load		O		O	M	H	H	Driving + Specific time
Front/Rear brake wear condition	O	O	O		M	L	H	Specific time
Fault Diagnosis - Engine	O			O	L	L	H	Specific time
Fault Diagnosis - AMT/ATM	O			O	L	L	H	Specific time
Fault Diagnosis - EBS	O			O	L	L	H	Specific time
Fault Diagnosis - CMK/IMMO	O			O	L	L	H	Specific time
Fault Diagnosis - E-APU	O			O	L	L	H	Specific time
Fault Diagnosis - CM	O			O	L	L	H	Specific time
Fault Diagnosis - Smart Junction Box	O			O	L	L	H	Specific time
Fault Diagnosis - CLUSTER	O			O	L	L	H	Specific time
Fault Diagnosis - RETARDER	O			O	L	L	H	Specific time

NUREG-0700 information indication that rapidly changing information should be continuously displayed (Green et al., 1993; USNRC, 2002). Regarding the Information presented to a specific situation, drivers behave by drawing proper rules form long-term memory, since they have not many experiences, and they experience difficulties in immediately understanding the meaning of information (Rasmussen, 1983). In this regard, the following information presented in specific situations, namely, fault diagnosis information, tire pressure mode indication and front/rear brake lining status were excluded from the information to be placed in priority on the main screen. Also, the information at Low level, such as use frequency and importance of information, were commonly excluded. Consequently, this study selected ten types of information to be placed on the main screen as shown in Table 5.

Table 5. Selected information for the main display

Average fuel consumption
Instantaneous fuel consumption
Fuel level (Travel distance)
Total mileage
Transmission
Urea gauge
Oil pressure gauge
Brake pressure gauge
Voltage gauge
Axle load gauge

2.5 Comparative experiment

To select the design plan of the main screen of commercial trucks' gauge cluster display, this study selected display alternatives indicting the information required for commercial truck drivers through comparative evaluation between design plan A presenting ten types of information selected above on the main screen, and design plan B presenting four types of information, of which use frequency and importance are High level, and five types of information including transmission on the main screen.

The information included in the four alternatives used in the comparative evaluation are alternative A in Table 5, alternative B in Table 6, alternative C in Table 7 and alternative D in Table 8. Alternatives C and D are the same as the displays of the currently sold commercial trucks. This study evaluated the four alternatives with 9-point scale on the information desired to be displayed on the main screen of the gauge cluster through a survey targeting commercial truck drivers. The number of truck drivers participating in the survey was 20, and their average age was 44.2 (SD=6.9), and average driving career was 14.1 years (SD=7.5). The survey on driver preference regarding the information displayed on the main screen, such as existing commercial trucks, is judged to reflect user needs on information priority, based on years of truck driving experience.

Table 9 shows ANOVA results of the preference for information presented on the main screen of gauge cluster display. Preference for alternatives was statistically significant at significance level of 0.05. Figure 4 reveals the S-N-K post hoc analysis results of information. Alternatives A and D belonged to different groups, and alternatives C and B belonged to the same group. As a result of comparison on average preference for each alternative, alternative A was selected as the display alternative presenting the information required for commercial truck drivers.

Table 6. Alternative B

Average fuel consumption
Instantaneous fuel consumption
Fuel level (Travel distance)
Transmission
Axle load gauge

Table 7. Company C

Average fuel consumption
Instantaneous fuel consumption
Total idle time
Fuel level (Travel distance)
Outside temperature
Clock
Transmission
Urea gauge
Oil pressure gauge
Brake pressure gauge

Table 8. Company D

Instantaneous fuel consumption
ECO function
Cruise function
Transmission
Clock

Table 9. ANOVA result of preference

Source of vriation	DF	SS	MS	F	*p*-value
Alternative	3	270.050	90.071	104.447	0.000*
Error	76	65.500	0.862		
Total	79	335.550			

*: significant at α=0.05 level

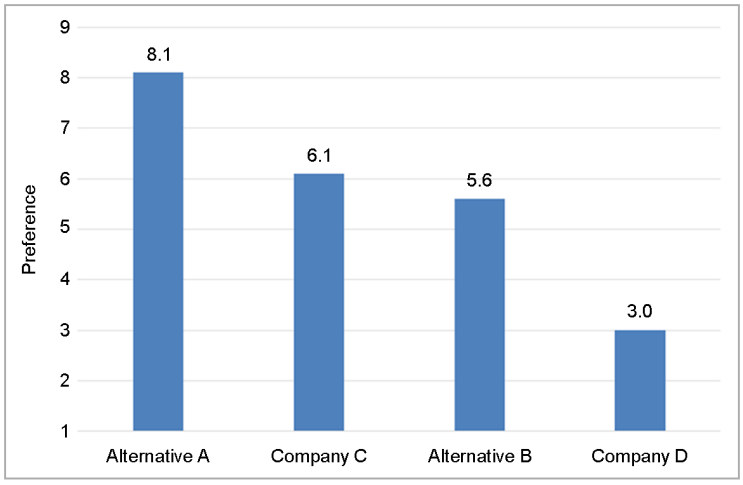

Figure 4. The results of S-N-K post hoc analysis

3. Display Design

This study presented a design plan on the division and menu type selected through a main design variables selection experiment

of display. This study targeted only variable displays within the gauge cluster. Therefore, engine RPM gauge, speedometer, fuel level gauge, cooling water temperature gauge were made the same. The size of display was based on 177.8mm (width) x 113.0mm (length), which is the size actually applied to commercial trucks. This study excluded design factors to the fullest.

3.1 Division

The division of display means the area division presented on the main screen, and this applies to all existing large trucks. And, division was preferred by the truck drivers. In this experiment, a grouping method presented by Neal et al. (1999) was applied to effectively indicate the alternative A's information selected in the information preference evaluation. Table 10 shows grouping of the information. To show grouped information on the display, the grouped information was placed with neighboring distance, and then divided. To assure legibility, letter size, and line gap were set to be 7mm and 5mm, respectively (Green et al., 1993). The information was presented on the display in consideration of the qualitative, quantitative, dynamic and static characteristics of the information. Precise values were presented in terms of static and quantitative information. With precise values using bars, the

Table 10. Information grouping

Driver convenience information	Trip computer information	Average fuel consumption
		Instantaneous fuel consumption
		Fuel level (Travel distance)
		Total idle time
Driver assistance information	Operation assistance information	Transmission
	Gauge information	Urea gauge
		Oil pressure gauge
		Brake pressure gauge
		Voltage gauge
	ECAS information	Indication of the axle load

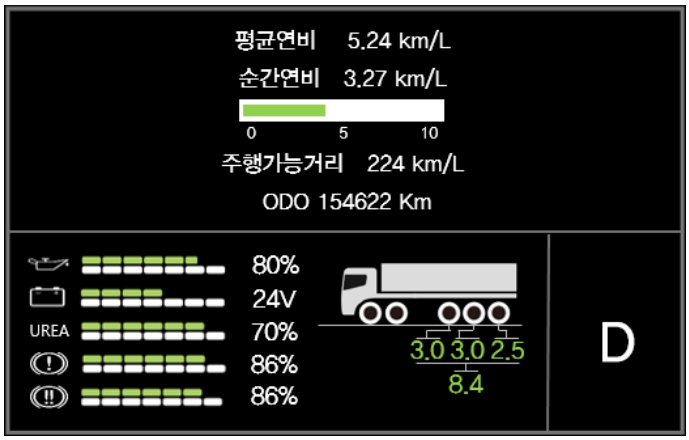

Figure 5. Display design

dynamic information containing both quantitative and qualitative information was presented. In this manner, the display was designed as shown in Figure 5.

3.2 Menu type

3.2.1 Experimental design

To select menu type for display manipulation, this study selected four menu types as comparative experiment subjects as shown in Figure 6 by applying the existing mobile phone type (Oh and Lee, 2007), IVIS menu type (Kim et al., 2013) and the menu type used in existing truck display.

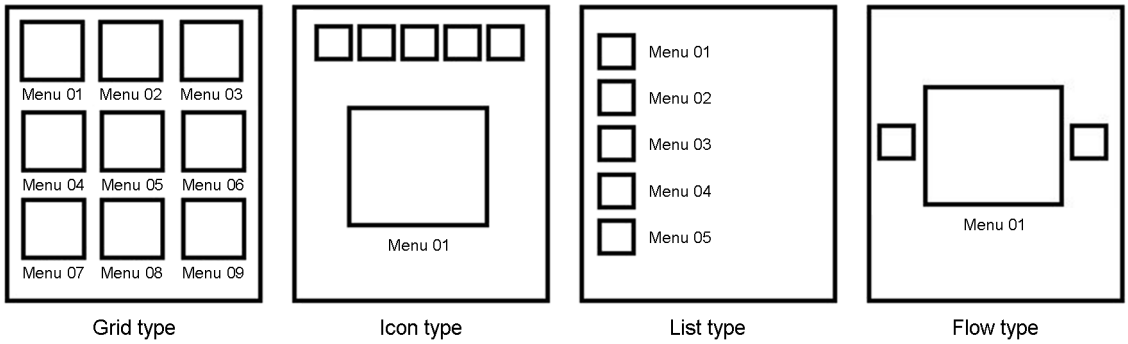

Figure 6. Menu type level

Each selected menu types are a grid type in which all menu clues are provided on the entire screen, an icon type in which menu clues are offered on the top part, a list type in which the clues are provided in the top-down mode, and a flow type in which clues of before and after menus are provided, and Figure 7 shows those menu types.

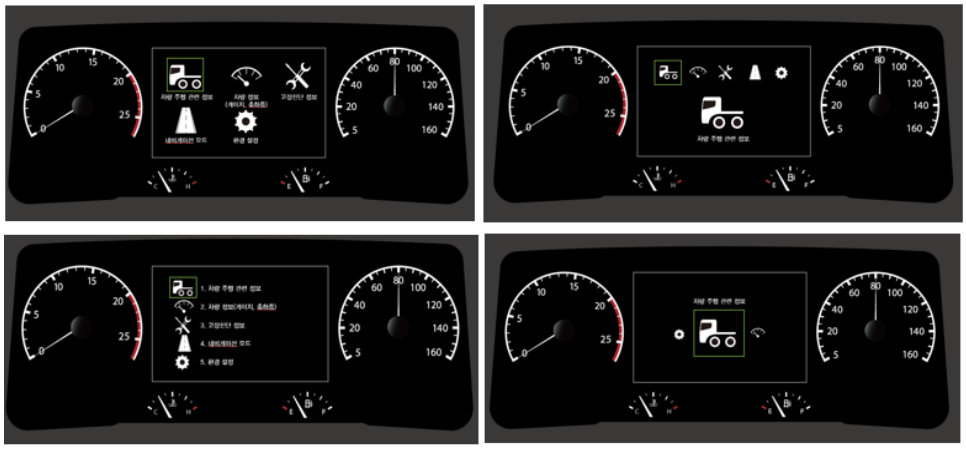

Figure 7. Menu type

For the evaluation of selected alternatives, an experiment was conducted to evaluate subjective preference, performance time, total duration of fixation, total number of fixation. Subjective performance was evaluated through a questionnaire survey after the experiment. The performance time, total duration of fixation and total number of the fixation of gauge cluster area were measured using an eye camera. Table 11 shows the selected independent and dependent variables.

Table 11. Experimental variables

Type	Variables	
Independent variable	Type of menu	Grid type
		Icon type
		List type
		Flow type
Dependent variable	Subjective measure	Preference (score)
	Objective measure	Performance time (sec)
		Total duration of the fixation (sec)
		Total number of the fixation (number)

The number of the experiment participants was 15, and average age was 43.5 (SD=5.3), and average driving career was 10.9 years (SD=4.5).

For experimental environment, the menu screen was produced with Adobe Flash CS6 using an LCD monitor. The experiment was carried out with Euro truck simulation driving by using the Logitech's G27 controller and a controller to manipulate menu type conversion. Figure 8 shows experimental environment.

Figure 8. Experimental environment

For eye camera, Dikablis eye tracker of Ergoneers Gmbh, and Marker Detector 2.1, D-Lab 2.1 software were used to analyze driver's eye (gaze). To minimize experiment participant's driving posture and discomfort, according to wearing of eye tracker, enough sitting time and wearing time were provided, and calibration was conducted through the preliminary test of eye tracking prior to the experiment.

To reduce the learning effect of the experiment, enough manipulation operation time of Euro truck simulation was offered, and the experiment was conducted by randomly composing the experiment sequence with Within Subject Design. A task checking fault diagnosis, after checking fault signal, was carried out, while performing the manipulation of driving simulation. Experiment measurement started as the experiment participant checks fault signal, when the signal was presented on the gauge cluster during the driving. The experiment was measured with the last task checking fault diagnosis information by manipulating the menu.

3.2.2 Result

Table 12 shows ANOVA results of the performance time. Statistically significant differences were not revealed among menu types at significance level of 0.05.

Table 12. ANOVA results of Performance time (unit: sec)

Source of variation	DF	SS	MS	F	*p*-value
Menu type	3	181.199	60.400	1.567	0.208
Error	56	2158.777	38.550		
Total	59	2339.975			

As shown in Figure 9, the average time of total duration of fixation was shown in the order of grid, list, flow and icon types. As shown in Table 13, statistically significant differences were shown at significance level of 0.05 in terms of the ANOVA results of the total duration of fixation. As for the S-N-K post hoc analysis result, grid type and the remaining list, flow and icon types were classified as different groups.

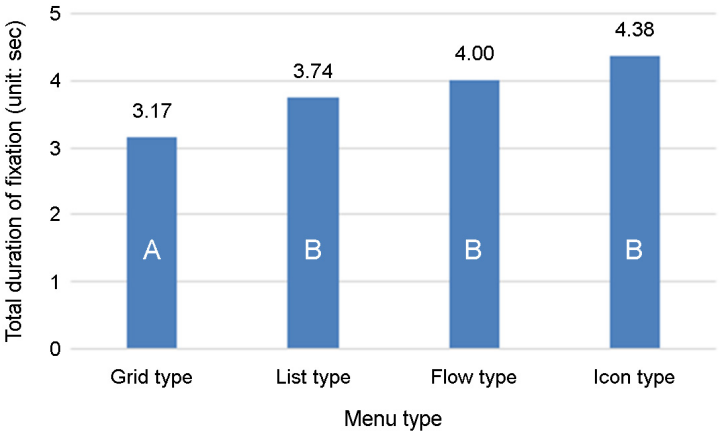

Figure 9. Post hoc analysis results of total duration of fixation

Table 13. ANOVA results of total duration of the fixation (unit: sec)

Source of variation	DF	SS	MS	F	*p*-value
Menu type	3	11.581	3.860	5.137	0.003*
Error	56	42.080	0.751		
Total	59	53.661			

*: significant at α=0.05 level

As shown in Figure 10, the total number of fixation results were shown in the order of grid, list, flow and icon types. Concerning the ANOVA results of the total number of fixation, statistically significant results were revealed at significance level of 0.05 as shown in Table 14. As for the S-N-K post hoc analysis result, the grid type and the remaining list, flow and icon types were classified into different groups mutually.

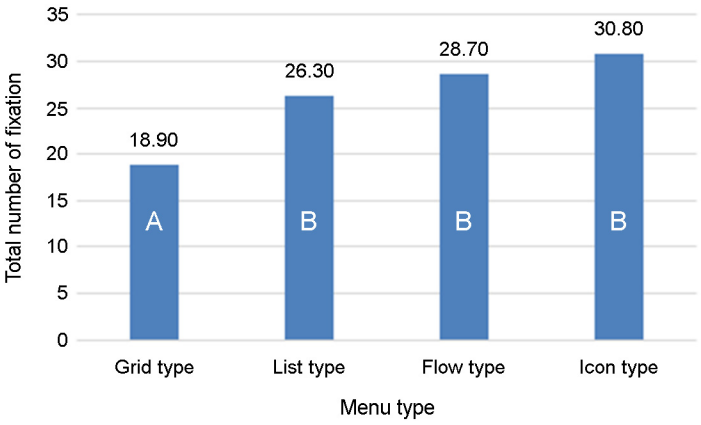

Figure 10. Post hoc analysis results of total number of fixation

Table 14. ANOVA results of total number of the fixation (unit: number)

Source of variation	DF	SS	MS	F	*p*-value
Menu type	3	1200.983	400.328	9.613	0.000*
Error	56	2332.000	41.643		
Total	59	3532.983			

*: significant at α=0.05 level

The results of preference were shown in the order of grid, list, icon and flow types as shown in Figure 11. Regarding ANOVA analysis results, statistically significant differences were shown at significance level of 0.05 as shown in Table 15. Concerning the S-N-K post hoc analysis results, the grid type was classified as A group, the list type as B group and the Icon and Flow types as the same C group.

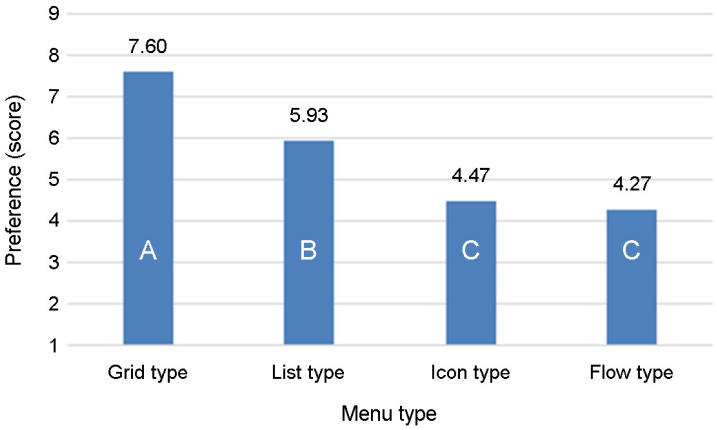

Figure 11. Post hoc analysis results of preference

Table 15. ANOVA results of subjective preference (unit: score)

Source of variation	DF	SS	MS	F	*p*-value
Menu type	3	107.533	35.844	48.721	0.000*
Error	56	41.200	0.736		
Total	59	148.733			

*: significant at α=0.05 level

4. Discussion and Conclusion

As gauge cluster within a vehicle gradually changes from analog display to digital display, and as the amount of information increases, the environment to solve the problems of driver's workload increase and attention decrease is needed. For the gauge cluster display of commercial trucks having more information than passenger cars, the design of display to deliver information efficiently to commercial truck drivers is required.

This study drew alternative A with high preference of information to be placed in priority on the gauge cluster display of commercial trucks. Such a result reveals the gauge information and vehicle's axis/load information, which is driver assistance information, is presented to main information, while existing gauge cluster display information consists of driver convenience information. Namely, it means drivers prefer information display, through which they can quickly detect vehicle's status information, and easily identify the current status of the vehicle.

Division among various design variables of display has been presented through ergonomic guidelines. This study also drew the grid type as the menu type satisfying recognition load and commercial truck drivers' preference most through the evaluation of preference, total performance time, and gauge cluster area's total duration of fixation and total number of fixation via driving simulation in terms of the four menu types. Especially, significant differences were shown in the gauge cluster areas' total duration of fixation, total number of fixation and preference, and the grid type was revealed to be more excellent than the other three types. Looking at objective indicators, they mean the drivers can concentrate on driving more with less performance time and frequency in the total duration of fixation and total number of fixation. By adopting the grid type that minimizes driver's eye

dispersion, when he/she processes commercial truck's information, driver's attention dispersion seems to be reduced. The reason is that driver's recognition on the information displayed on the gauge cluster was easy, and accessibility to driver-desired information was high. When the amount of information displayed on the gauge cluster display is presented within 7±2, which is human's short-term memory capacity, human's recognition is considered to become easier.

Although, the icon type was revealed as a good type from performance and preference aspects in a study of existing passenger cars (Kim et al., 2013), the grid type was shown as the better type in this study. This is the menu type that studies on passenger cars did not consider, and the grid type appears to be appropriate to present truck-related information. Although, the icon type was revealed to be the best in the studies on passenger cars, the icon and list types were shown to belong to the same group statistically. Therefore, the other types except the grid type seem to have similar tendency.

Based on the results of this study, this study presented the information and division (Figure 12) shown on the commercial truck drivers-centered display's main screen, and menu type design (Figure 13).

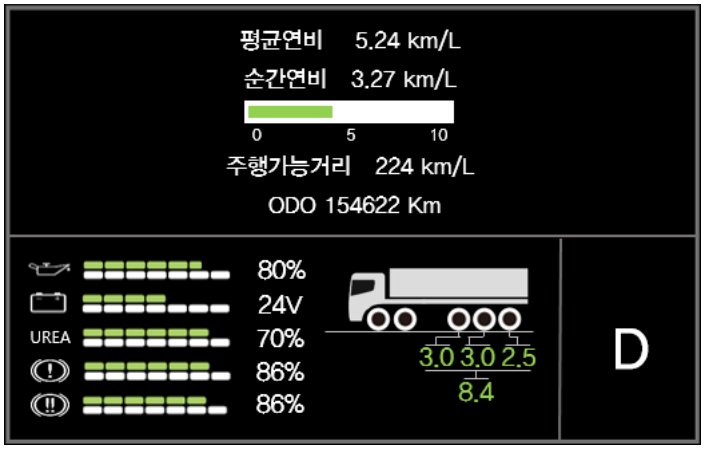

Figure 12. Division

Figure 13. Grid type

The display design plan presented as a result of this study is judged to offer safer driving situation by reducing driver's attention dispersion time. Although, commercial trucks require more diverse information than passenger cars, the study results are expected to be used as basic guideline for the ergonomic design of different commercial trucks' gauge cluster displays, according to truck type. The findings of this study are considered to be used as the basic data for standardization of information presented on the commercial trucks' gauge cluster.

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