Usage of a Driving Simulator in the Design Process of new HMI concepts for eco-driving Applications (eCoMove project)

Eva García, Rosa Blanco, Abel Nogueira , Moisés Rial
CTAG (Centro Tecnológico de Automoción de Galicia)
Porriño (Pontevedra)
Spain

Abstract

In the framework of the eCoMove project, CTAG has carried out a study in its Dynamic Driving Simulator focused in analyses the most suitable way to present speed and gear recommendations to the driver. The aim of this study was to provide useful recommendations based on the results obtained during the development of the new concepts of ecoHMI carried out within the project. In order to analyse the best way to display the recommendations three different options to display the information were compared. The experimental design defined was a within-subject experiment where 24 participants drove through all the experimental conditions. With the purpose to evaluate the perceptions and opinions that the participants had about the system, different subjective measures were collected and in order to evaluate workload the DALI subjective tool was also used. After a general introduction of the eCoMove project and the purpose of the study, this paper will describe the methodology defined to carry out the experiment and the main results and conclusions obtained in terms of speed and gear recommendations for an eco-driving support system.

Introduction

eCoMove project aims to reduce fuel consumption (and therefore CO2 emissions) by applying the latest vehicle-to-infrastructure and vehicle-to-vehicle communication technologies. The project will create an integrated solution comprising eco-driving support and eco-traffic management to tackle the main sources of energy waste by passenger and goods vehicles having the target of the 20% reduction of fuel consumption (CO2 emmissions).

Within the project, one important aspect is the HMI development as it is a key factor for the acceptation and usage of the system by the drivers, especially for the on-trip advices. For this reason, the design process of the HMI was done interactively and focussing on a user centred design approach, including a previous study based in surveys and empirical studies in driving simulators, previously conducted to develop the final concepts.

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Main objective of this study was the analysis, during the development phase, of different aspects related with the HMI for the systems developed in eCoMove project, aiming to clarify and solve some design concerns:

- Disposition of information on the screen.
- How to present the gear and speed recommendations (position of icons, clarity, colours…).
- Analysing distraction and driver workload in terms of graphical design.
- Estimation of time for the information in the display.

The study was performed using a general HMI designed in the previous phases of the project and allowing the testing in the driving simulator. This concept was designed taking into account the main results of one pre-study (survey) carried out in the previous steps.

Method

The tests were carried out in the CTAG's Dynamic Driving Simulator. This simulator is composed of the following subsystems: the movement platform with 6 DOF and 4000 Kg payload, the visual system (180º cylindrical screen and 3 rear view displays), the acquisition and control systems and the SCANeR© II (release 2.24) software, which builds a realistic virtual environment.

The instrumented vehicle inside the cabin is a commercial vehicle, in which the only changes done in the car were the replacement of the steering-wheel by the Active Steering Wheel System and the sensors mounted in pedals, gear stick, etc. The vehicle has an automatic gear change, but, for this experiment, the manual mode was used. A 7" screen was placed on the up side of the IPC in order to display the graphical information to the driver.

Figure 1. CTAG Dynamic Driving Simulator

Scenarios and test routes

The road network selected for the study was placed in a rural area, without many buildings. The road was composed of straight sections, curves and intersections (including roundabouts). All the roads used for testing had one lane in each direction. There were different values for the speed limit. These values varied between 50 and 90 Km/h, and the traffic density could be light or medium.

Figure 2. Image from the scenario

Three different routes were selected to test each option for HMI. The routes have very similar characteristics and they are located in the same areas of the scenario and the length was the same for all three routes, around 4 kilometres and 500 meters.

Description of HMI

The HMI proposed for the study was based in a screen located on the up side of the central screen of the vehicle (right side of the driver), three different graphical proposals for displaying the information were developed, changing the position and the order of the information presentation (i.e. recommended gear and speed).

Figure 3. Position of the display in the vehicle

In general, the layout proposed for the screen was divided into five different areas (1, 2, 3, MAPs and Reserved areas):

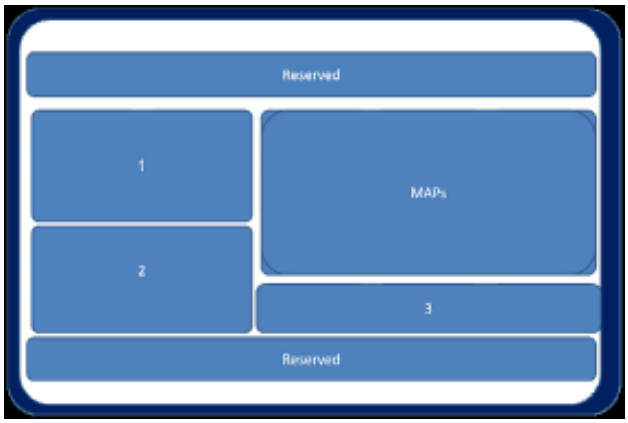

Figure 4. Layout of the Screen

- The upper and lower areas are reserved.
- The left side is the main driving information area (numbers 1 and 2 in the image), in which the recommended and current speed and gear information will be located.
- The right side is separated into two areas. The upper area shows the route information (map) and the lower area shows the ecoInformation advices (use of energy consumers inside the vehicle, maintenance information and load).

The proposals A and B differed only in the position of the gear and speed information: in proposal A the gear is shown in the position 1 and speed in position 2. In the proposal B, the location of the information is just the opposite (speed is in position 1 and the gear in position 2).

Figure 5. Proposal A (left) and proposal B (right)

In the proposal C, the areas 1 and 2 were treated as only one area where speed or gear information is displayed at a time (no simultaneous recommendation of speed and gear). This information was provided automatically and alternatively every 5 seconds (areas 1+2).

In all proposals (A, B and C) the ways in which the map information (see area 'MAPs') and the ecoInformation advices (see area 3 in the Layout) are displayed do not change. The map area and the ecoInformation area (position 3 in the layout) work as a simulated system, without real data.

System description and use

Below, it is explained how the speed and gear recommendations were given to the driver.

Gear information presentation

While the participants were driving, the current gear that the driver has engaged from 1 to 6 is displayed in the screen (simultaneously with speed information in proposals A and B and intermittent with the speed information in proposal C).

When the revolutions are below 1800 rpm's the system suggests to the driver a gear change to a lower gear by means of a face down green triangle blinking. Until the adequate gear position is reached, the triangle blinks. The system suggests a change in the gear where it should be engaged.

Figure 6. Gear down suggested

In the opposite side, driving in a high level of revolutions, above 3200 rpm's, the system suggests to engage a higher position of gear. In this case, the green triangle blinking in the upper side of the current gear is displayed.

As in the previous case, until the adequate position of the gear is reached (taking into account the rpm) the triangle continues blinking.

Driving in the range of 1800 – 3200 rpms, the system does not show any recommendation of change, only the current gear.

Speed information presentation

The current speed is displayed in the centre of an oval, where different colours showed if the speed is the 'eco' speed (green section) or not.

The oval around the speed will illuminate a number of sections depending of the percentage value of the current speed with respect to the recommended value

(always in the centre of green zone). Three different colours indicated if the speed is the recommended one (green section of the oval), not recommended at all (red section of the oval) and a transition zone between the not recommended speed and the recommended one (orange section of the oval).

Figure 7. Speed zones

System implementation in the Driving Simulator

For the implementation of the system in the driving simulator, a screen was placed on the up side of the central screen of the vehicle (right side of the driver), where the information was displayed. A dedicated PC controls the information displayed in this screen. This PC was connected to the driving simulator network and it received information from a specific software module (called 'HMI server'), developed specifically for the communication between the driving simulator software (SCANeR© II) and the HMI.

Subjective measures

For analyzing the participant's feedback (perceptions and opinions) about the HMI concept, five different questionnaires were used: general questionnaire, DALI (Pauzié & Pachiaudi, 1997), HMI General Evaluation, Pre-Trip and Post-Trip information, perceived HMI distracticton evaluation (Andreone et al., 2011).

Experimental Design

A within-subject experimental design was defined: each person drove three times and each time tested a different HMI proposal (A, B or C). Furthermore, it was necessary to control the order effect of the displays presentation using complete counterbalance. 6 groups of participants (4 persons in each group) were defined, depending on the order of presentation of the three displays. All of them had to drive through three different routes (one for each chosen display) into the same scenario.

Table 1. Configuration of groups

	Groups Screen Presentation Order			Nº participants
Group A	Proposal A	Proposal B	Proposal C	4 persons
Group B	Proposal A	Proposal C	Proposal B	4 persons
Group C	Proposal B	Proposal A	Proposal C	4 persons
Group D	Proposal B	Proposal C	Proposal A	4 persons
Group E	Proposal C	Proposal A	Proposal B	4 persons
Group F	Proposal C	Proposal B	Proposal A	4 persons
			Total:	24 persons

Experimental Procedure

Each participant drove a single session lasting approximately 1 hour, following the indications given to them. Before starting the session, general information was provided to them. The sessions were recorded (audio and video) in order to be used during the data analyses. The collection of information was done maintaining and protecting the privacy of participants.

Participants

The total sample was composed by 24 persons that were assigned randomly to the 6 experimental groups.The recruitment of them was done using the CTAG's database.The total sample is composed by 24 participants (M=27.29; SD= 3.483) with a range of age between 22 and 37 years old. Two thirds of the sample were male, meanwhile one third were female (Women = 8; Men = 16).

Results

In this section results from DALI questionnaire, evaluation of the graphical interfaces and distraction are presented. Furthermore, results from general questions about pre-trip and posttrip items are analyzed from a qualitative perspective.

DALI results

Five factors from the DALI questionnaire (Driving Activity Load Index), were analyzed for the three options presented to the participants: Global attention demand, visual demand, temporal demand, interference and stress. As it can be appreciated in Figure 13 the highest values are for the dimension 'Visual demand'. The median value for this variable is in a range between 2.46 for Option A and 3.00 for Option C.

Moreover, the option C presented the most negative results; in fact, the highest media values in all the factors evaluated are assigned to this option as it is shown in Table 2. The results of the Friedman Test indicated that there were a statistically significant different in all the factors except for the temporal demand.

A Wilcoxon Signed Rank Test indicated that there was a statistically significant difference between Option A and C regarding Global attention (Option A presents a lower value than Option C), $z=-1.992$, $p<.05$, with a medium effect size ($r=.30$) (Cohen, 1988). Regarding the Visual Demand, there was also a statistically significant difference between Option A and C ($z=-2.056$, $p<.05$), and Option B and C ($z=-2.044$, $p<.05$) in both the effect size was medium ($r=.30$). Finally, regarding the stress, a Wilcoxon Signed Rank Test revealed a statistically significant increase concerning option A ($Md=1.00$) and option B ($Md=2.00$), with $z=-2.285$, $p<.05$, with a medium effect size ($r=.33$).

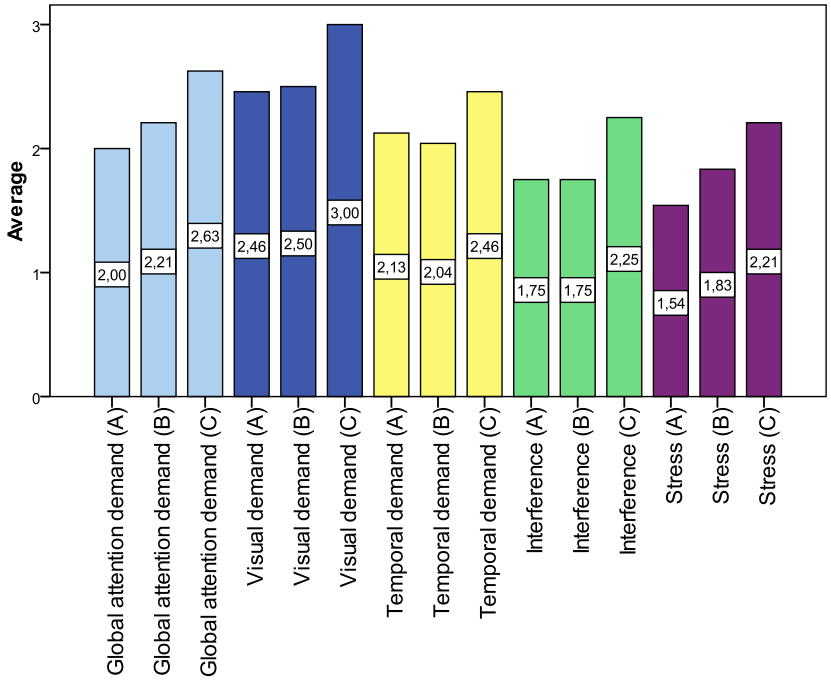

Figure 8. Average scores for the DALI factors

Table 2. Friedman Test Results (DALI questionnaire) (p < 0.05)*

Friedman Test	*Option A*	*Option B*	*Option C*
Global attention	Median *2.00*	Median *2.00*	Median *2.50*
		*χ(2,24)=7.015**	
Visual demand	Median *2.00*	Median *2.00*	Median *3.00*
		*χ(2,24)=8.784**	
Temporal demand	Median *1.00*	Median *1.25*	Median *2.00*
		χ(2,24)=3.205	
Interference	Median *1.00*	Median *1.50*	Median *2.00*
		*χ(2,24)=6.127**	
Stress	Median *1.00*	Median *2.00*	Median *2.00*
		*χ(2,24)=7.508**	

HMI evaluation results

For the different items included in this questionnaire the scores obtained are in general positive. The mean for all of them is over 5 points (except for degree of distraction and degree of driver annoyance, but in this case, values lower than 5 points are positive). The different values are better in option A and B than in option C. It seems that option C is the less pleasant option for the participants.

Friedman test results show statistically significant differences only for degree of utility, ease of learning and global value (see Table 3). The results of the Friedman Test indicated that there was a statistically significant difference in degree of utility scores for the three options (option A, B and C), $\chi(2,24)=8.955$, $p<.05$.

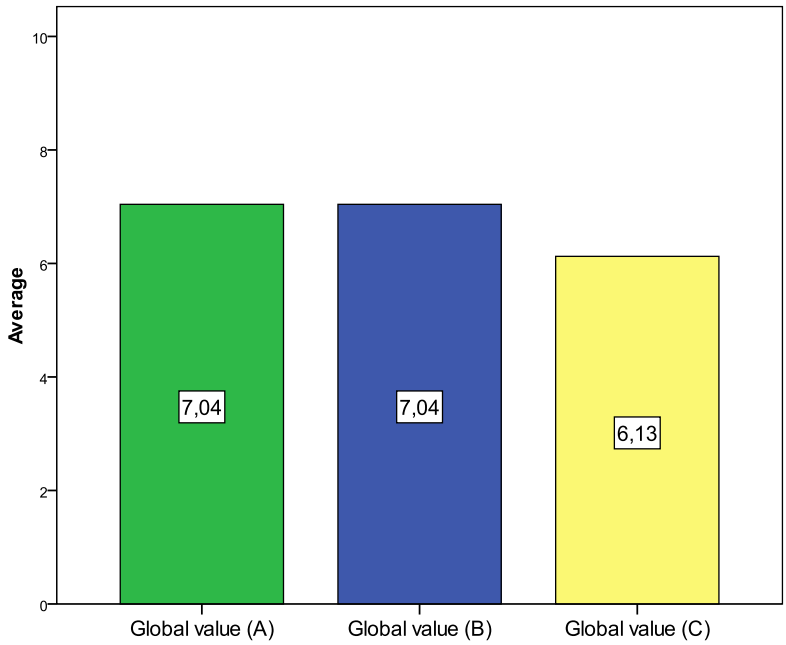

Figure 9. Average scores for global HMI evaluation

The analyses of the median values shown a decrease in degree of utility scores from option A and B (Md=7.00) to option C (Md=6.00). A Wilcoxon Signed Rank Test shown a statistically significant reduction in degree of utility scores concerning option A and C ($z=-2.275$,$p<0.05$. with a medium effect size ($r=.30$)), and concerning option B and C ($z=-2.265$,$p<0.05$. again with a medium effect size ($r=.30$)).

A trend similar to the one found in degree of utility can be observed in the ease of learning analyses: options A and B (Md=8.00) present the highest value (option C: Md=7.00) and the differences are statistically significant: $\chi(2,24)=7.524$, $p<.025$. A Wilcoxon Signed Rank test revealed a statistically significant reduction in easy of learning values concerning option A and option C, $z=-1.997$, $p<.05$, with a small effect ($r=.28$).

Table 3. Friedman Test Results (HMI Evaluation) (* p < 0.05)

Friedman Test	*Option A*		*Option B*		*Option C*	
Degree of utility	*Median*	*7.00*	*Median*	*7.00*	*Median*	*6.00*
			*χ(2,24)=8.9**			
Ease of learning	*Median*	*8.00*	*Median*	*8.00*	*Median*	*7.00*
			*χ(2,24)=7.52**			
Global value	*Median*	*7.00*	*Median*	*7.00*	*Median*	*6.00*
			*χ(2,24)=16.44**			

Finally, the results of the Friedman Test for the Global value were significantly different, the median values showed a decrease ($\chi(2,24)=16.444$, $p<.001$) in Global value scores from option A and B (Md=7.00) to option C (Md=6.00). Once again, a Wilcoxon Signed Rank Test indicated a statistically significant reduction in degree of utility scores between option A and C, $z=-2.811, p\leq 0.005$ with a medium effect size (r=.40), and between option B and C, z=-3.581, <0.000 again with a large effect size (r=.51).

Distraction evaluation

Concerning distraction evaluation, option C presented the highest value (M=5.22). Option A and B showed similar mean scores (Mean for A=4.46 and for B=4.58). But statistical differences among the three options were not found. These results are in accordance with the data obtained in HMI results about degree of distraction for the three proposals.

Duration of information in the screen for option C

Regarding the estimation of time the information is in the screen for option C, the average value was 4.04 seconds (SD=2.56). 66.6% of the participants undervalue the time giving a value under 5 seconds (the actual time the information is maintained in the screen). Only 16.7% estimates it correctly.

Focusing on the comments from the participants, part of the sample considered the duration to be adequate: the time is considered enough to see the information without being distracted. In addition, they suggested that if the duration is lower, this situation would generate stress and, on the contrary, if the time were higher, they thought they would be worried about the change (waiting it) and the number of times they'd look to the screen would be increased.

Those who estimated that the duration should increase (25% of the sample), claimed that it should increase with 1, 2, 5, 7 or 10 seconds, and those who thought the duration should decrease (12.5% of the sample) suggested to decrease by 1, 3 or 5 seconds

Some participants commented that the time the information is presented in the screen should depend on the characteristics of the road and it should be presented in the screen while the recommendation is applying to the driving situation.

Preference of screens

The option A was the first choice for 54.17%, while 41.67% of the participants chose option B. For the second choice, the percentages were similar: 45.83% chose option A as second option and 50% chose option B. Option C was the least selected option for first and second choice, option C was the most preferred as third choice.

The participants who choose option A commented that for them the most appreciated characteristic of this option is the position the gear indicator on the top because it is easier to see it, it is easier to understand and it is more intuitive.

Regarding to option B, the participants who selected it justified their selection because they found it easy to understand the information, easy to see the gear information and the position is more intuitive, also the position of gear information is associated with the position of gear shift in the vehicle.

Not all participants valued option B positively, mainly because they think that it is complicated to see the gear in this position (below the speed information).

Option C had the most negative values. The participants commented that they did not like the alternation of the information in the screen because this change distracts them. Those who liked this option commented that, as the information is not displayed simultaneously, when they look at the display they need only to understand one advice and not both of them at the same time.

Qualitative results

Most of the participants that made a comment suggested that the indicator (the arrow) that recommended changing the gear and the area that shows the eco-driving should be more visible. Furthermore, an important part of the sample thought that it would be recommendable to show the speed and gear indicators together only in those cases in which that would coincide.

Some subjects thought that the amount of information displayed in the screen is quite high and the presentation mode causes distraction. As an alternative, they suggested to use sound for some cases or to reduce the arc of colour (it involves a lot of workload).

Regarding the oval shape and the arc of colours designed for the speed recommendations, some participants considered it complicated to make a quick association between colours and eco driving. They judged that the use of colour levels in both sides is not needed. Nevertheless, other part of the sample believed that the arc of colours is very intuitive and comfortable.

Finally, many of participants would place the display in the dashboard and some subjects considered the system to be useful, but dispensable.

Pre-trip

The kind of information that drivers would like to provide at the begin of the trip is the following destination, driving efficiently (mode), consumption, load, route, meteorology, selection of efficient road (mode), etc.

Moreover, participants answered (using a 0 to 100 points scale) to the question: in which degree do you like the system will help you? The mean value of the answers was of 24.17 points with a standard deviation of 31.31. The scores given by 30% of the sample were below 50 points. The other part of the participants provided higher values (25% of them gave 100 points).

Post-trip

Participants were also asked about what information they would like the system to provide at the end of the trip. The information that participants demanded by to end the trip was the following: Fuel Consumption and Average consumption, time eco-driving, percentage of fuel consumption, difference between eco-driving and real driving, percentage of time the gear position is correct, time eco-driving, driving cost, time eco-driving, a graph with the sections in which the fuel consumption was higher, etc.

Second option

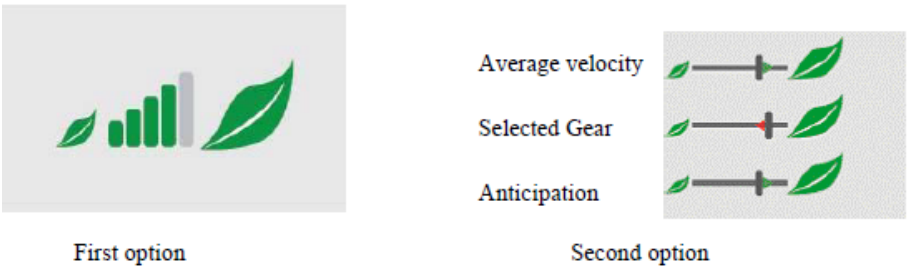

Figure 10. Proposal of presentation of information

Summarizing, the general result is that the participants preferred the first option as a default mode and the second option as an advanced mode in which more information is displayed.

Discussion

Added to the general evaluation of the graphical interface, the study has focused on analyzing the best way to give the gear and speed recommendations. Taking as a reference other studies in which the design and evaluation of different interfaces was done using simulated driving situations (Chalmé et al. 1999), an experiment in a dynamic driving simulator was carried out in order to do the subjective evaluation of three different graphic modes designed for presentation of the on-trip information.

The workload was evaluated using the DALI questionnaire (excluding only the auditory demand item not needed for this evaluation). This questionnaire is broadly used for evaluating workload in drivers (Pauzié & Pachiaudi, 1997). In this study, the visual demand plays an important role (presentation of information only in visual mode) so it has sense the highest values of the DALI were assigned to this factor. In any case, the presentation of the information does not annoy to drive. In this sense, it was important to take into account the use of visual information to maintain an ecological driving. Fricke (2007) found that "in general, visual information presentation is best where the presented information need to be persistent because one cannot immediately respond to it".

When the results of the DALI questionnaire were compared for the three options, option A presents a lower value for Global attention demand than option C (significantly different with medium effect size). Focusing in the Visual demand, there was also a statistically significant difference between Option A and C and between Option B and C (lowest values for A and B). Regarding the stress, a statistically significant increase was appreciated concerning option A and B. Looking at these results, it seems that option A presents better results in terms of Global attention, Visual Demand and Stress and option C present the worst ones.

The differences between options A, B and C are also reflected in the answers to the questionnaires. The differences between option A and B are minimum, but there is a clear difference with option C: drivers preferred the combination of the information instead of the presentation in an alternative way. A change in the presentation mode was irritating for them in general (Fricke, 2007). Then, when information is presented alternatively (Option C) the drivers do not feel comfortable. In fact, the participants agreed that they did not like changeable information and this fact caused distraction.

Moreover, participants expressed that the HMI evaluation was positive for all screens. Once more, the alternative presentation of information has the worst values (statistical significant differences were found in 'degree of usefulness', 'easy of use' and 'global score'). In general, the results are supporting the conclusion about the preference of the drivers for the presentation of gear and speed information combined at the same time.

On the other side, no significant results were found regarding the distraction, but, once again, option C presents the highest values.

Regarding the duration of information, after this study it is not clear that the subjects are good in estimating the duration of information. These analyses should be taken into account in further studies.

The analyses of the qualitative results show that, in general, the drivers appreciated the help offered by an eco-driving support system and they were willing to provide clues to improve it. Focusing on the post-trip application, when only a general evaluation of the driving is given, the drivers considered this as a default mode meanwhile when more descriptive information is provided, they perceive that this

mode should be an advanced option. This is related to the fact that "several new approaches to assisting the driver in dealing with the complex task of the driving situation are being develop with the aim to give support in the secondary task and at the same time facilitate the primary driving task" (Fricke, 2007). From this study it could be understood that the fact of providing aid to green driving is a secondary task that would help drivers in their primary driving task.

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