In-Vehicle Displays: Driving Information Prioritization and Visualization

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Abstract—Systems developed to be operated in a vehicular environment have gradually begun to include further applications, which can be found in other mobile environments, such as smart phones and tablets. This continued growth could overwhelm the driver and affect road safety. Thus, it is crucial to ensure that these devices provide the type of information drivers need. This paper focuses on the presentation of in-vehicle information while driving. Function clusters and information prioritization for different modules in Driver Information Systems are primarily investigated through driver preferences analysis. Results are evaluated outlining implications for proper location of information on the in-vehicle displays.

I. INTRODUCTION

Driver Information Systems (DIS) are systems developed to be operated in a vehicular environment. The purpose of such in-vehicle systems is to assist drivers in the primary driving task without negative effects on traffic congestion, road safety, fuel consumption and driving performance [1]. Thus, it is crucial to ensure that these devices provide the type of information drivers need in the least distracting way possible. The continued increase in the use of such systems has gradually begun to include further applications, such as those found in other mobile environments (smart phones, tablets), which could overwhelm the driver. For this reason, some automobile manufacturers have begun to reorganize traditional vehicular spaces, such as the instrument panel or even the center console, sharing them with digital screens in order to cope with the limited space available inside a vehicle. Even the rear view mirror and the windshield are being used to display information through Head Up Displays (HUD).

Proper in-vehicle information visibility could facilitate driver interaction with device controls, assuring a smoother operation and reduction of distraction potential. Thus, it is imperative to examine the visual demand these devices require while driving. Relevant in-vehicle driving information should be able to be identified at a glance, ideally within 1 second. Additionally, the average number of glances required to access the information should be minimized [2].

Most DIS interfaces use screens as the information source. Following visual display location guidelines, these screens will be installed within the driver’s field of vision, providing sufficient visibility [3], [4]. Visibility can be enhanced through the proper placement of the in-vehicle functions, ensuring a user-friendly design which allows for user preferences and expectations. Both user experience and product satisfaction can be increased through a focus on user preferences: which, and where these functions should be located within a vehicle.

In this paper, we investigate whether preferences related to the location of information in the vehicle exist. Research questions such as: Where do drivers prefer to have important features located and Do drivers have differential preferences for the layout of DIS compared to existing ones? are examined in this paper. We rely on the Interactive Consumer Design and Evaluation (ICode) methodology to investigate user cognitive structures related to automotive functionalities [5]. Since user-centered designs can contribute to performance improvement through the reduction of user errors in the interaction with in-vehicle systems [6], [7], the results of this study will be of particular interest for the design of future in-vehicle systems.

The implications for the design and adaptation of displayed in-vehicle functions are outlined. The remainder of this paper is organized as follows:

The next section considers related work in the areas of in-vehicle information. Section III presents a detailed description of the methodology followed to acquire and filter data for this study. Section IV reports on the results of the data evaluation. Finally, Section V concludes the paper.

II. RELATED WORK

As distribution of information displayed in a vehicle can facilitate its identification at a glance, the prioritization of features and informational elements in in-vehicle systems has been studied in several previous works. For example, a scoring system was developed based on the impact of functions on road safety and traffic congestion, as well as on user experience in [8], [9]. A list of functions and features for driver information systems was identified. Traffic information systems, car phones, navigation systems, road hazard warnings, and vehicle monitoring systems were examined in detail to determine preferred display formats. The authors concluded that it is difficult for drivers to estimate desired features of...
products for which they have had no previous experience. In [1], traveler preferences toward in-vehicle traffic information systems were analyzed to quantify importance ratings of in-vehicle system information. The study showed that ratings depended on several user-determined factors, such as user socioeconomic level and attitude toward in-vehicle technologies. In a different study preferences in the functional use and priorities of infotainment systems, focusing on menu structure organization were investigated [10], [11]. The authors concluded that information organization within displays is an important factor in the design of information systems in a vehicular context.

In addition, driver preferences related to the visualization of traffic information on the freeway, were investigated in several other works, focusing on which types of information were most important to drivers, depending on traffic conditions. The study showed that information related to current accidents had the highest priority [12].

It is well known that the location of information inside a vehicle affects proper driving visibility. In this context, the authors of [13] studied the attentional demand of in-vehicle displays by means of driver glance duration and frequency to three in-vehicle displays (center console, HUD, instrument cluster) while driving. They showed that the location of in-vehicle displays affects driver glance behavior. Moreover, glance duration depends on the type of in-vehicle display.

The effect of vehicle display location on driving performance was also investigated in [14], [15], in which secondary tasks were projected onto a display at several possible locations. Authors concluded that the information position had a clear effect on lane-keeping performance. Moreover, the closer the display was positioned to the windshield (e.g. above the mid-console or dashboard), the more favorable effect on driving performance due to visual demand.

Another study by [16] developed a method to evaluate distractions caused by different display positions in five areas based on reaction times. It was concluded that frequently used displays should not be located in the center console of a vehicle.

Most existing studies pertaining to the assessment of in-vehicle visual demand address topics related to different modes of information presentation, or display locations. However, existing approaches do not sufficiently address how to convey information from complex information systems with several components to the driver, and which location is preferred for specific functions related to these components. In this paper, we investigate the heterogeneity of driver preferences by means of function location and further qualitative analysis. We intend to optimize in-vehicle display systems by analyzing user preferences in six different areas, in order to determine the best location to present user-determined information inside a vehicle.

III. DATA ACQUISITION AND FILTERING

An exploratory experiment (circa 90 minutes) was conducted to investigate possible preferences related to the location of driving in-vehicle information. A subset of individuals corresponding to lead users that had experienced needs that are unknown to other users was selected to estimate characteristics of the targeted user population; namely owners of a high-end car and thus, expected customers. Table I shows the sample distribution. With this method, a low-cost sampling and fast and accurate data collection were achieved.

After a previous screening made by phone, 21 subjects were recruited which fulfilled the requirements of having previous experience with smart phone applications; being in-vehicle technology aware; having as primary means of transportation a private vehicle, not older than 3 years, and being between the ages of 40 and 65.

A. Experimental Setting and Description

The goal of the experiment was to determine where in-vehicle functions or applications should be displayed for operation or visualization while driving. Participants were instructed to place cards depicting in-vehicle devices and functions into six different in-vehicle areas (5 displays and the center console) following the card sorting approach [17], thus creating their ideal in-vehicle information system. No other specific instructions were provided. These areas were located on a life size illustration of a vehicle, with the placement of the cards indicating preferred user location for the given information while driving. The in-vehicle displays were located and labeled as depicted in Figure 1. If participants ran out of space available in the preferred display, they were instructed to locate the desired cards on top of each other in that display area. Placement of all available cards was not required. The evaluator was available for questions concerning the meaning of the pictures on the cards during the experiment. After having sorted the cards, participants filled in a post-task questionnaire about several aspects concerning prioritization and reasoning for locating the displayed information as a control tool to evaluate data consistency. The post-task questionnaire included the following questions: Which in-vehicle functions or applications are the most important for you, and in what order?; Did you feel some applications of functions were missing in this experiment?; Do you consider all the displays used in the experiment to be useful or necessary?. Table II shows the list of information that was presented in the cards and could be selected, sorted by groups. Figure 2 shows the cards final disposition on the board after having performed an experiment.

B. Data Description and Evaluation

To interpret the card-sorting data, a quantitative and then qualitative analysis of the display categories that were selected by more than two subjects was performed. The sampling process was considered in order to acquire the data described in the previous section, and sample-based statistics were selected for evaluation. An analysis to sort out common patterns in the way subjects grouped the given in-vehicle functions or devices
Fig. 1. Predefined locations of the displays in the vehicle

<table>
<thead>
<tr>
<th>AGE CLASSES/GENDER</th>
<th>40-44 Years old</th>
<th>45-49 Years old</th>
<th>50-54 Years old</th>
<th>55-59 Years old</th>
<th>60-65 Years old</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female subjects</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Male subjects</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21</strong></td>
<td><strong>21</strong></td>
<td><strong>21</strong></td>
<td><strong>21</strong></td>
<td><strong>21</strong></td>
<td><strong>84</strong></td>
</tr>
</tbody>
</table>

**TABLE I**

Subjects sample distribution

was carried out, which tested a null hypothesis of no significant differences in the functions selected and the corresponding distribution in the displays. Frequency counts of functions locations in one or another display were compared. Significant differences between the samples were determined by p values. If the p value was smaller than the predefined significance level \( \alpha (\alpha = 0.05) \), the null hypothesis that said that no effect in the location of the in-vehicle information took place, was rejected and consequently the differences between samples were accepted as significant. Since we did not know beforehand if the location of the functions on one or another display had an effect at all, we performed a two-sided, paired parametric t-test to test statistical independency from each other and to assess the significance levels of the frequency counts of functions located on the predefined displays. Therefore, the factors to be tested were the in-vehicle areas. Multiple comparisons were subsequently corrected using the Bonferroni correction.

Function priority classification was performed in an exploratory way to find out which functions were considered to be the most important ones by the majority of the subjects. As the experiment did not require a selection of all available cards, the analysis was implemented as a control tool to proof data consistency by comparing the number of functions that were located in displays with the number of functions that were prioritized (from a priority of 1 (highest) to 6 (lowest)).

**IV. DATA EVALUATION RESULTS**

**A. Information Priority**

Within the signals that are mandatory by law, high priority (1) was given to the image card showing an “analog speedometer”, meaning 71% of subjects considered it to be the most important information in a vehicle. Additionally, 33% and 20% of subjects considered a “digital speedometer” and “analog fuel gauge”, respectively, to be of particular importance. The rest of the functions were not given any priority. Within the information corresponding to “Vehicle data”, 14% and 33% of the subjects ranked “clock digital” and “tachometer analog” with priority 1 or 2 respectively. “Radio digital”, in the “Entertainment” category, was given the same priority by 43% of subjects.

Within the “Driver Assistance Systems” category, 19% of subjects considered a “parking assistant” to be important. Additionally, between 19% and 24% classified the “sign assist”, “rear view camera”, “night vision”, and “collision warning” functions with priority 1 or 2.

The “climate” function was also considered to be important (priority of 1 or 2), by 35% of the subjects.

Within the categories “Communication” and “Navigation”, the functions “phone” and “map” were classified with the highest priorities by 38% and 57%, respectively. None of the applications were considered to be important. Only the calendar function was considered by 9% to have priority 1 or 2. In summary, the highest importance priority was given to the

**TABLE II**

Functions by module

<table>
<thead>
<tr>
<th>MANDATORY SIGNALS</th>
<th>VEHICLE DATA</th>
<th>ENTERTAINMENT</th>
<th>COMMUNICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speedometer analog</td>
<td>Tachometer analog</td>
<td>Radio analog</td>
<td>Phone</td>
</tr>
<tr>
<td>Speedometer digital</td>
<td>Tachometer digital</td>
<td>Radio digital</td>
<td>Contacts</td>
</tr>
<tr>
<td>Fuel gauge analog</td>
<td>Mileage</td>
<td>CD analog</td>
<td>E-mail</td>
</tr>
<tr>
<td>Fuel gauge digital</td>
<td>Clock analog</td>
<td>MP3</td>
<td>Internet</td>
</tr>
<tr>
<td>Turn signal left</td>
<td>Clock digital</td>
<td>TV</td>
<td>Office</td>
</tr>
<tr>
<td>Turn signal right</td>
<td>Warning lights</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE III**

Functions by module

<table>
<thead>
<tr>
<th>NAVIGATION</th>
<th>SETTINGS</th>
<th>DAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation</td>
<td>System status</td>
<td>Parking assistant symbol</td>
</tr>
<tr>
<td>Map</td>
<td>System status</td>
<td>Attention assistant</td>
</tr>
<tr>
<td>Navigation arrow</td>
<td>Water temperature</td>
<td>Lane keep assist</td>
</tr>
<tr>
<td>Route info</td>
<td>Gear recommendation</td>
<td>ACC Symbol</td>
</tr>
<tr>
<td>Board Computer</td>
<td>Temperature</td>
<td>Sign assistant</td>
</tr>
<tr>
<td></td>
<td>Start-Stop symbol</td>
<td>Rearview camera</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE IV**

Applications by module
following functions by the following percentage of subjects:

1) “speedometer analog”, 71%
2) “navigation map”, 57%
3) “radio digital”, 43%
4) “phone”, 38%
5) “climate”, 35%

The remaining functions and information sources were not considered to have priority, or were classified as important by a much lower percentage of subjects. Figure 3 shows a graphical overview of the most representative results.

B. Information Visualization

1) Quantitative Evaluation: The experiment results reflect specific information that users expected to have access to in a vehicular context, as well as the location of such information on the different displays. Each available card was selected at least once to be located on some display. Generally speaking, most of the functions that related to “Mandatory signals” by law, as well as to “Vehicle data” were preferred to be located on the display number 2, directly in the driver’s field of view.

Over 70% of subjects preferred almost all of the functions in the category ”Mandatory signals” to be located on display 2 as well. Only “speedometer digital” and “fuel gauge analog” were preferred by a lower percentage (30%) in the same category. Over 50% of subjects preferred almost all of the functions of the category “Vehicle Data” also to be located on display 2. Only “tachometer digital”, “clock”, “gear recommendation” and “start stop symbol” were preferred by less than 30% on this display. “Analog speedometer” and “warning lights” were located in the display 2 by the highest percentage of subjects, with 85% and 75% respectively.

Results also showed a tendency to locate functions related to “Entertainment”, “Communication”, “Navigation” and “Settings” on the display number 5. All the functions in these categories were preferred on display 5 by at least 20% of the subjects.

“Radio digital” and “MP3” were selected by the highest percentage of the participants to be on display 5, with 63% and 52% respectively. Only hardware devices such as radio (10% ) and “CD analog” (40%) were located on other areas, specifically the “Center Console”. “Car settings” and “map” were preferred by the highest percentage of subjects on display 5 with 51% and 41% respectively. Only “climate analog” and “navigation arrow” were selected to be located in different areas (60% in the “Center Console”, 30% on the
display number 1). The favorite location for “Applications” was also the display number 5, with “calendar”, “Internet”, “weather” and “Email” ranked highest (between 40% and 52%). Information related to Driver Assistance Systems was located preferentially on displays 1 and 3. “Night vision” was classified by the highest proportion of persons on display number 1 (38%) and “collision warning” on display number 3 (33%). The box plot in Figure 4 shows the frequency count of locations for each function category into the displays denoted with the numbers 1 to 5 and the center console (CC), including median, minimum and maximum. In summary, the categories “Mandatory signals” and “Vehicle data”, as well as information provided by Driver Assistance Systems and the “navigation arrow”, were preferred to be located directly in the driver’s field of view (display number 1, number 2 and number 3). Secondary information such as entertainment, navigation map, communication, settings and apps were sorted into the display number 5 or into the display number 4.

Table III shows the significant differences in the frequency count of categories location in one or another in-vehicle area. Statistical significance of the frequency count mean values is denoted by different letters in the p column. Information resulting from the data consistency analysis confirmed the validity of the data acquired since the number of functions that were located in displays correlated with the number of functions that were prioritized (p<.0001).

2) Subjective Evaluation: The post task questionnaire enabled the evaluation of subjective rating scales. Some subjects noted functions that were not included within the experiment. However, most of these functions were only missed by one person out of 21. The only functions missed by a total of 3-4 persons were “speed limit” and the “WhatsApp” communication tool.

Between 30% and 70% of subjects considered display number 4 to be useful. Advantages of this display were noted as clarity promotion as well as increased space to accommodate advertisements. Additionally, the significant reduction of distraction caused by placing information in this area was highlighted. Subjects that did not consider the display to be necessary argued that the information could also be integrated into other, existing large displays in the driver’s field of view (e.g. display number 3). As for the overall impression of the experiment, test subjects were asked to comment on the interaction with in-vehicle devices, and to explain why certain functions were selected or not. The most significant responses are listed:

- Applications and other functions that were not selected were considered to be distracting;
- Mileage should be shown only if desired;
- Voice-control should be available;
- Robust touch screens are desirable;
- Systems should synchronize with personal smart phones;
- TV should be available while driving (for passengers);
- Smart phones should be controlled via the main menu;

Additional comments referred to extra wishes in the design of In-Vehicle Information Systems, such as audio volume control as a haptic gauge or a single button to return to the main screen in the menus.

V. CONCLUSION AND FUTURE WORK

In this paper, we investigated differences related to the location of information on in-vehicle displays by means of an empirical experiment, following the findings of [8] related to the difficulty of identifying desired features for in-vehicle products that have not been experienced before, focusing on users that had previous experience with in-vehicle systems. The results presented in this paper show that the evaluation of in-vehicle displays between individuals can be very heterogeneous. However, the differences in the number of subjects that classified the information in different displays were statistically significant.

It can be concluded that subjects were inclined to locate in-vehicle information into areas where this information is currently presented in the vehicle. Important information was located on displays directly in the driver’s field of view, and additional, unnecessary information into the display number 5 (which traditionally contains information related to menus, settings, etc.). Applications normally found on mobile devices were located mostly on this display as well. Hardware devices such radio or climate control were preferred to be located in the “Center Console” area, where they are currently located in most of vehicles. This selection could be due to the
VI. ACKNOWLEDGMENTS

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