In-Vehicle Information:  
Design of Driver Interfaces for Route Guidance

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ABSTRACT

This paper provides an overview of design guidelines for the development of safe and easy to use navigation systems. Specifically, this paper considers route guidance aspects of the driver interface. The information presented summarizes the UMTRI Interface Design Guidelines (Green, Levison, Paelke, and Serafin, 1993) along with other recent UMTRI human factors research. Recommendations concern how to tell drivers where to turn (use turn displays with voice), text size (6.4 mm characters), intersection display design details (use plan or aerial views, show maps heading up, show landmarks, show distances to nearest 0.1 mi, etc.), and the speed-dependent
timing of voice messages. It is particularly important that in-vehicle information be compatible with roadside information.

INTRODUCTION

The purpose of this paper is to identify some key questions relating to the design of in-vehicle navigation systems, along with answers to those questions. These questions have grown in importance as navigation systems become more commonplace. In-vehicle navigation systems are quite prevalent in Japan, are available for a limited number of cars in Europe, and are beginning to be mass marketed in the U.S. Sales in all regions of the globe are likely to expand.

It is important, however, to consider geographic dissimilarities. The need for such systems varies both by region of the world and by user type (travelers renting cars, commuters going to work, consumers going shopping). Regional differences in need are quite profound. For example, in Japan many streets do not have names, the main streets are not in a grid pattern (except in Kyoto), and buildings are numbered in their order of construction, not based on their location on a street. Hence, directions are often given using maps, with major buildings serving as landmarks. In contrast, in the U.S. directions are given with regard to traffic lights and stop signs ("go to the second traffic light, turn right and go to the first stop sign"), and are often presented as text. Further, travel involving any significant distance in the U.S. invariably involves a freeway. In contrast, in Japan almost all of the high speed roads involve tolls (so showing toll booths and fees is important) and there are relatively few expressways. Congestion is common and avoiding it is of great interest to Japanese drivers. The European traffic network is more like the U.S. than Japan, though many major cities have traffic circles, an intersection geometry quite rare elsewhere.

Hence, the need for navigation interfaces and how information should be presented to meet user needs can vary quite widely. This paper describes how driver interfaces to
navigation systems should be designed to meet some of those needs for the U.S. market, focusing on a recently completed set of design guidelines (Green, Levison, Paelke, and Serafin, 1993) and other recently-completed research at UMTRI (e.g., Green and George, 1995) and elsewhere (e.g., Schraagen, 1993).

What, then, are the user needs? Using a navigation system involves four categories of tasks:

1. Entering and retrieving destinations
2. Following the route guidance information
3. Retrieving other (but navigation-related) information
4. Calibrating/setting the system.

This paper focuses on the second task, route following. Of the remaining tasks, destination designation is the only one to have received much attention in the literature. While many methods have been developed for entering and retrieving destinations--entering the destination name (if it is in the data base), entering the street address or the nearest pair of cross streets, selecting a nearby point of interest in the data base, entering the phone number of the destination (if such a data base exists), pointing to the location on a map, and entering the longitude and latitude of the destination--there is no consensus as to which is best and when. Further, at the present time, there are no data on the frequency of use of each method. Of course, the frequency of use will depend on how well a method was implemented for a particular interface and the alternatives available. Readers interested in research concerning destination selection should review Coleman, Loring, and Wiklund, 1991; Marics, 1990; and Paelke, 1992.

**HOW SHOULD DRIVERS BE TOLD WHERE TO TURN?**
This is the most commonly asked question by designers of navigation systems. Turn information can be provided by showing highlighted routes on maps, on a turn-by-turn display, by voice guidance, by a list of text instructions, or using combinations of methods. Two studies bear directly upon this question. In an experiment conducted at UMTRI (Green, Williams, Hoekstra, George, and Wen, 1993) drivers were asked to drive a 19-turn route guided by a navigation system. Guidance modes included an instrument panel (IP) turn-by-turn display, the same information presented on a Head Up Display (HUD), and voice guidance. Shown in Figure 1 are examples of the turn-by-turn displays. Table 1 shows the number of turn errors for each display type. Notice that while performance with visual displays was slightly better than the voice display, the differences were very slight.
Figure 1. Example Turn Displays from UMTRI Research

Table 1. Turn Errors

<table>
<thead>
<tr>
<th>Route guidance system interface</th>
<th># Execution errors</th>
<th># Near miss errors</th>
<th>Total # errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td>5</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>IP</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>HUD</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

Note: Execution errors are instances where drivers turned too soon or missed a turn. Near miss errors are situations where they almost turned at the wrong place, but corrected their mistake.
Similar data (e.g., Figure 2) appear in reports on the TravTek project (Hulse, Dingus, McGehee, and Fleischman, 1995). The turn-by-turn displays in the TravTek project resembled those in the UMTRI experiments. Notice the large differences in attentional demand of the alternative display formats, with navigation systems providing voice guidance requiring less attention (fewer glances) than those without it. Also note that turn-by-turn displays required fewer glances than route map displays.

![Figure 2. Eye Glance Data from the TravTek Project](image)
As a whole these studies suggested that guidance should be provided by turn-by-turn displays with voice guidance, though differences due to format may depend upon the quality of the implementation. Of the potential locations for a turn-by-turn display, a HUD location appears to be the best.

HOW BIG SHOULD THE TEXT BE?

Probably no topic has gotten more attention in the human factors literature than the required size for text. The most commonly accepted method for estimating required character height is the James Bond Rule (the visual angle should be greater than or equal to .007 radians). For a standard instrument panel viewing distance (28 inches), this translates into a required character height of approximately 1/4 inch (6.4 mm). However, the Bond Rule is for static reading, not the situation found in vehicles where drivers, accommodated to optical infinity (the road scene), must quickly glance inside their vehicle to read a display. In an UMTRI experiment involving reading numeric speedometers (Boreczky, Green, Bos, and Kerst, 1988), reductions in reading times were found for characters up to 19 mm high, the largest size examined. Hence, 6.4 mm should be considered a minimum size.

HOW SHOULD INTERSECTION DISPLAYS BE DESIGNED?

During the UMTRI project, decisions regarding display design could often be made based on design principles. Two of them (1. Be consistent. 2. Keep the interface simple.) were commonly cited (Green, 1995). However, since the original research on ERGS (Experimental Route Guidance System) interface (Rothery, Thompson, and von Buseck, 1968), there has been little research on the design of turn-by-turn displays.

Critical to designing easy to read turn-by-turn displays is keeping the display simple and providing landmarks. As was noted previously, in the U.S. the most useful landmarks are traffic lights and stop signs. At present, this information is not in any of
the commercial data bases of the U.S. used for in-vehicle navigation systems (e.g., Etak, Navitech), though landmarks are shown in a system found in Toyota cars sold in Japan. While navigation data base developers are focusing their efforts on improving the coverage of their data bases, they are encouraged to reallocate some effort into adding landmarks to their data bases, especially for the more heavily traveled areas.

The table that follows identifies the major design characteristics of turn-by-turn displays for the U.S. market. As noted previously, differences in the road network and driver experience with maps may lead to different interfaces for different regions of the world.

Table 2. Selected Turn-by-Turn Display Design Characteristics

<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Rationale and Comments</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show plan or aerial (bird's eye) view, not perspective</td>
<td>While perspective view matches the driver's view of the world, the details of the upcoming intersection geometry are too obscured.</td>
<td>Green and Williams, 1992</td>
</tr>
<tr>
<td>Roads should be solid lines, not lines for edges</td>
<td>Using solid lines makes the roads more prominent.</td>
<td>Green and Williams, 1992</td>
</tr>
<tr>
<td>Show landmarks (stop signs and traffic lights) at intersections</td>
<td>In the U.S. (and elsewhere), drivers naturally use landmarks for guidance.</td>
<td>design experience in UMTRI project, Alm, 1990</td>
</tr>
<tr>
<td>Required information includes the road being driven, the road for the next turn, the direction and approximate angle of the turn, and the distance to the turn</td>
<td>These are the basic elements of a turn display.</td>
<td></td>
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<tr>
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</tr>
<tr>
<td>For complex choice points, show all roads and ramps</td>
<td>The navigation display should match the world driven.</td>
<td>Design experience from TravTek project (Fleischman)</td>
</tr>
<tr>
<td>Design Requirement</td>
<td>Rationale and Comments</td>
<td>Source</td>
</tr>
<tr>
<td>--------------------</td>
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</tr>
<tr>
<td>For close proximity turns (within 0.1 miles), show both maneuvers at one time.</td>
<td>Successive turns are planned as a single maneuver sequence and drivers need all of the information before the first turn to successfully plan the sequence. Further, there may not be time in the middle of the sequence to look at the display for guidance for the second turn.</td>
<td>design experience from TravTek project (Fleischman)</td>
</tr>
<tr>
<td>Omit count down bars if the distance to the turn is highly legible.</td>
<td>In the first on-road version of the UMTRI interface, count down bars were provided. Some subjects did not know what they were. When omitted from later designs, the interface was simpler and navigation performance did not suffer.</td>
<td>Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993</td>
</tr>
<tr>
<td>For expressway exits, give both the route name and city.</td>
<td>Information on the navigation display should match that appearing on highway signs.</td>
<td>design experience from TravTek project (Fleischman)</td>
</tr>
<tr>
<td>Displays should be heading up while driving, north up while planning.</td>
<td>The display should be compatible with the real world. It is commonly observed that drivers rotate paper maps when following routes, even if that means the printing is inverted.</td>
<td>compatibility principle</td>
</tr>
<tr>
<td>Distances should be given to the nearest 0.1 miles.</td>
<td>This is the accuracy used by the odometer and by highway signs.</td>
<td>consistency</td>
</tr>
<tr>
<td>Rotating displays during turns is not required</td>
<td>Drivers generally do not look at a turn display in the middle of turns. Having the display change during a turn can be distracting to drivers.</td>
<td>experience during the UMTRI project</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------bose in the middle of turns. Having the display change during a turn can be distracting to drivers.</td>
<td>experience during the UMTRI project</td>
</tr>
<tr>
<td>Turn displays should emphasize local geometry.</td>
<td>Example: If a turn appears to be 90 degrees at low resolution, but in fact consists of a 30 degree bend and then a 60 degree turn, both turns should be shown.</td>
<td>experience during the UMTRI project</td>
</tr>
<tr>
<td>Omit longitude and latitude.</td>
<td>Except for off-road use and where used for destination entry, these coordinates are difficult for typical U.S. drivers to use.</td>
<td>general design experience</td>
</tr>
</tbody>
</table>

Note: Fleischman refers to ongoing discussions (in 1990-1993) with Rebecca Fleischman of General Motors, a key participant in the design of the TravTek driver interface. The UMTRI project refers to the navigation interface UMTRI design as part of a DOT-sponsored project (Green, 1993).

**WHEN SHOULD VOICE MESSAGES BE PRESENTED?**

Voice guidance systems generally provide a series of messages indicating when drivers should turn. (See Davis, 1989, for a discussion.) Most interfaces contain at least one advance message. ("In 2 miles, at the traffic light, turn right on Main Street.") When the driver approaches the choice point, the "at turn message" is presented. ("Turn right.") If the "at turn" message is presented too soon, then drivers might turn onto the wrong street. If "at turn" message is presented too late, then drivers may decelerate too quickly, increasing the chance of being struck in the rear by a following motorist.
According to Green and George (1995), "at turn" messages should be presented well in advance of arriving at the desired intersection. The distance is predicted by the following equation:

Distance (ft) = \(-389 + 119 \text{ (Age.code)} - 113 \text{ (Sex.code)} + 95 \text{ (Turn.code)} + 15 \text{ (Speed)} + 21 \text{ (Number of Vehicles)}\).

where:
- Age.code 1= young, 2= middle, 3= older
- Sex.code 1= women, 2= men
- Turn.code 1= right, 2= left
- Speed (mi/h)
- Number of Vehicles (vehicles ahead)

According to this equation, messages should be provided approximately 450 feet from an intersection when traveling at 40 mi/hr. Similar results appear in a report describing work done in the U.K. as part of the DRIVE program (Ross, Nicolle, and Brade, 1994).

WHAT SHOULD VOICE MESSAGES SAY?

In addition to timing, voice message content is important. Table 3 provides a few example design requirements. The constraints on the number of phrases presented and wording of the "at turn" message are quite important.
### Table 3. Selected Design Requirements for Voice Messages

<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Rationale and Comments</th>
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</tr>
</thead>
<tbody>
<tr>
<td>The final turn message should use the word &quot;approaching&quot; or other words to avoid being a command.</td>
<td>If drivers are told &quot;turn right&quot; instead of &quot;approaching ___, turn right,&quot; they may believe the vehicle knows everything and turn, even if a traffic light or one way sign indicates otherwise.</td>
<td>design experience in UMTRI project</td>
</tr>
<tr>
<td>Time messages to coincide with advance notice signs on expressways.</td>
<td>Auditory and visual information should agree.</td>
<td>Ito, 1994</td>
</tr>
<tr>
<td>Limit the number of prepositional phrases in a message generally to no more the 4, preferably 3.</td>
<td>If there is too much too remember, short term memory will be overloaded.</td>
<td>Gatling, 1975, 1976, 1977</td>
</tr>
</tbody>
</table>

### CLOSING THOUGHTS

Engineers should realize that there is now a considerable body of specific engineering data on how to design navigation interfaces, particularly guidance displays. Some of those recommendations are summarized in the UMTRI driver interface guidelines (Gould and Lewis, 1985; Green, Levison, Paelke, and Serafin, 1993), as well as in subsequent research. In addition to specific guidance, it must be emphasized that general principles (especially consistency) can often be used as a basis for interface design decisions where specific research data are absent. Consistency is achieved by using the same format for information in different places but used in the same manner (in the vehicle versus the roadside environment, in different parts of the in-vehicle interface). Consistency is also achieved by using the same entry methods for similar tasks that are in different parts of the interface.
In designing an easy to use interface, complying with a set of design requirements is not enough. It is critical that every interface development program include rapid prototyping of interfaces and iterative testing and redesign (Green, Boreczky, and Kim, 1990). Without such feedback from users, an easy to use interface may not emerge, even if the requirements are applied by a human factors expert.

Application of general principles, the design guidelines, in conjunction with rapid prototyping techniques and testing, should lead to safe and ease to use navigation interfaces.

REFERENCES


