Development of a Traffic Information System Driver Interface

Gretchen Paelke and Paul Green, Ph.D.
The University of Michigan Transportation Research Institute (UMTRI)

Abstract

Based on ideas from the literature and the project team, several reasonable interface options were prototyped using SuperCard (on a Macintosh computer). Some designs were eliminated after initial prototype attempts because critical details were not legible. Others were developed further and evaluated using human factors computational methods (GOMS, Tullis Display Analysis Program) and quick usability tests.

Five basic designs have been developed. For the designs where simple text displays show incidents and congestion, there are three ways to select the highway of interest: a bidirectional scrolling menu, a graphic of the highways, and a phone-style keypad. The graphic designs use a skeleton map of the metro Detroit highways, and represent traffic problems through color coding or explicit travel speeds.

An experiment was conducted at a motor vehicle licensing office to examine the understandability of and preferences for aspects of the five designs. From this it was determined that using orange to indicate slow moving traffic is ambiguous to drivers. Drivers preferred a color coding scheme which used green to indicate freely moving traffic (at or above speed limit), yellow to indicate slow traffic (30 - 54 mph), and red for stop and go traffic (0 - 29 mph). The results of this study were used to modify the interfaces for future testing in a driving simulator.

Introduction

The annual cost of traffic congestion in the United States is believed to be as much as 61 billion dollars [1, 2]. The implementation of Intelligent Vehicle-Highway Systems (IVHS) should help reduce this waste of money and the associated waste of time. One way to accomplish this is to provide motorists with current traffic information throughout their trip. Given the proper information, many drivers may be willing to modify their routes or departure times to avoid delays due to congestion or incidents [3]. Motorist information surveys have shown that the most important factor in route choice for daily commuters is travel time [3, 4, 5]. For the average daily commute of 30-35 minutes, a delay of 16 - 18 minutes [3, 6] would cause drivers to divert to an alternate route.

Although the potential benefits of providing traffic information have been established, the most effective and safe methods for providing the information to drivers have not. For a traffic information system to be effective, it must be easy for drivers to understand and use while driving. To address usability concerns, traffic information system interfaces were developed using rapid prototyping software and evaluated by potential users. This effort is part of a large project funded by the U.S. Department of Transportation to develop human factors guidelines and methods for testing the safety and ease of use of future driver information systems. A model predicting human performance with these systems is also being produced. An overview of the project is described in [7].

This project has several unique aspects. First has been the application of the iterative design approach [8] commonly used for user-computer interface development, to automotive design. Second, analytic methods used to evaluate user-computer interfaces such as GOMS and the Tullis Display Analysis Program have also been applied for the first time in the automotive domain.

Throughout the development of the systems, design decisions have been recorded. This has led to the generation of human factors design guidelines for traffic information systems, which reflect the chronology of design. Some of the design guidelines for displaying traffic information on Variable Message Signs (VMS) [9], an outside the vehicle application, have been useful in developing in-vehicle traffic information displays. The VMS guidelines for traffic state descriptor messages, incident descriptors, and lane blockage indicators were particularly helpful.

Identification of Information Elements

To develop a driver interface, one must first establish what information should be shown to the driver. Here, the focus was on a traffic information system for the near future. Four sources of information were used initially: 1) technical literature, 2) concept cars, 3) industrial liaisons, and 4) in-house expertise. These sources were supplemented by information drawn from Focus Group studies of driver information systems [10]. The relevant features for traffic information displays included: congestion, construction, freeway management, parking, traffic rules, vehicle access, and weather [1,2]. The criticality of these features was evaluated based on three scoring dimensions: 1) effect on accidents, 2) impact on traffic operations, and 3) driver needs. From those data, utility scores were computed. (For further details of this analysis see references [1,2].)

According to the criticality scores, the following information elements were highly ranked and considered for the traffic information system driver interfaces:

Distance to blockage
Location of congestion
Location where speed decreases
Congestion level
Travel speed (through problem)
Length/area of congestion
Lane blockage

All of the elements did not appear independently, as it was sometimes possible to aggregate elements. For example, by providing the specific location of the congestion by its beginning and end points, the length/area of the congestion was also provided. Also, showing the travel speed through an area was similar to providing a congestion level (which would correspond to various speeds).

Development of Potential Interfaces

In designing traffic information systems two issues were addressed:

1. How should drivers retrieve information?

2. How should traffic information be presented once drivers retrieve it?

Based on input from the research team members and the related literature, several retrieval methods and presentation schemes were identified. In considering the selection of interfaces for further development, emphasis was placed on examining a wide range of possibilities since a key aspect of this project is developing a human performance model. For many of the retrieval procedures on display formats of interest, there are no existing in-simulator or on-the-road human performance data.

Several candidates were eliminated upon initial development attempts because they could not be presented in an easy or straight-forward manner. For example, thought was given to representing the level of congestion on a road by the width of a line on a road map. But to show 3 readily discriminable line widths (for 3 traffic levels) made the widest line so wide that few map details could be shown, so this idea was abandoned. Similarly, showing the traffic speed on road segment by having graphic elements move also proved infeasible because of the large area required to show several moving elements (dashed lines, car icons, etc.) Most of the decisions were fairly obvious when the images were drawn on a small computer screen.

One of the project goals is to develop a display which would be legible. This meant that letters should be 1/4 inch high. This value is only slightly larger than required by the Bond Rule, a human factors rule of thumb for computing character heights [11]. In situations such as those found inside a car, where viewing time is limited, there are significant penalties in response time when display sizes are set based on free viewing conditions [12]. Further, there was particular concern for making the display readable by older drivers.

To reduce the problem domain and facilitate implementation, only visual information presentation schemes were considered, either text- or graphic- based. Three methods are being examined to retrieve text-based traffic information, all which assume a touchscreen. Drivers can access information by pressing the desired highway on a static map graphic (Figure 1). Other text-based approaches include a scrolling menu somewhat similar to that in the TravTek interface (Figure 2) [13] and a phone-style keypad (Figure 3). In the text-based versions, a single information screen summarized each traffic problem (Figure 4).

The graphic interfaces used a skeleton map of the metro Detroit highways, on which drivers pressed the area of interest to increase the level of detail viewed (Figure 5). Areas with traffic problems were indicated using color coding (Figure 6), showing specific travel speeds (Figure 7), or combinations of both. The Detroit area highways (as opposed to a hypothetical network) were selected in order to examine the response of drivers who are familiar with the roads and traffic information being tested.

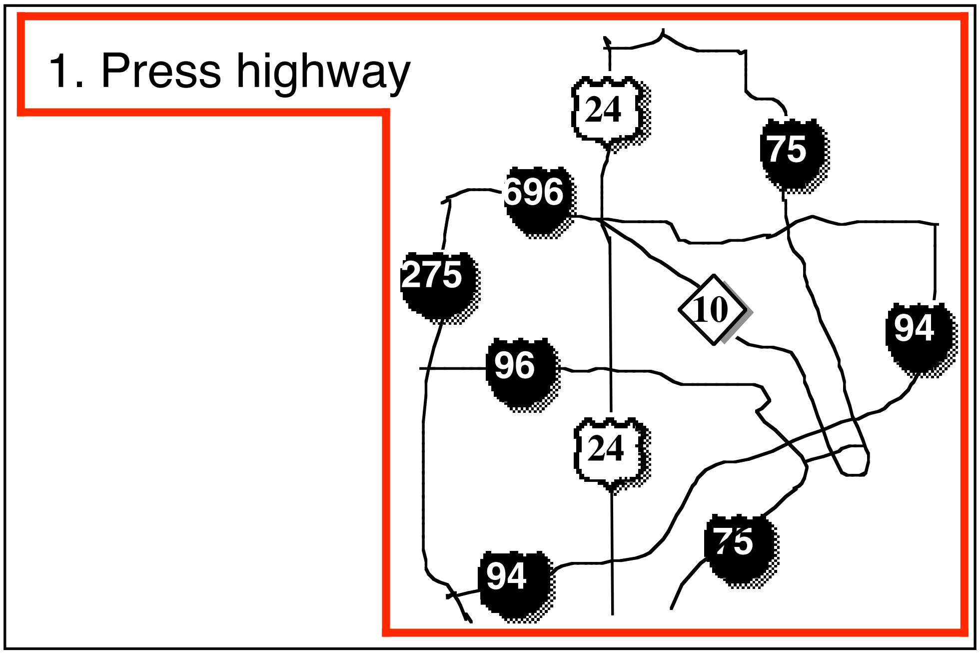

Figure 1. Text-based system with static graphic map retrieval method

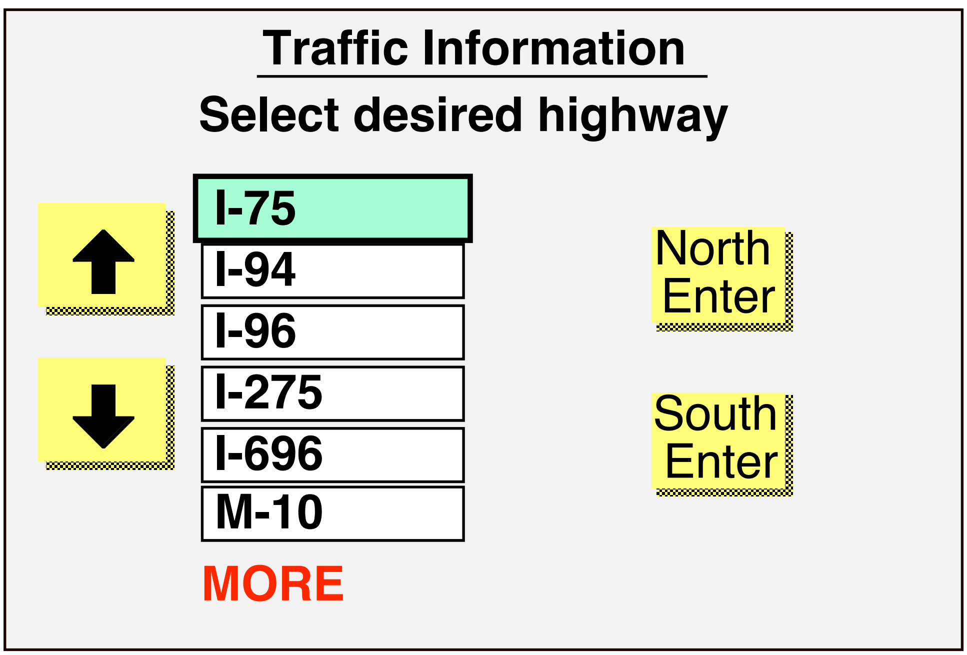

Figure 2. Text-based system with bidirectional scrolling menu

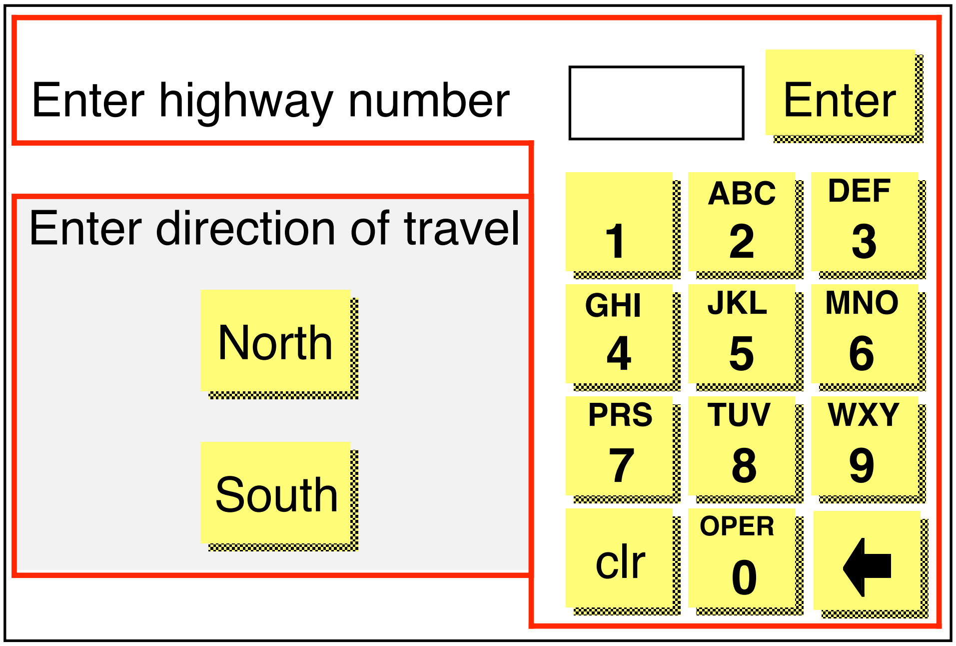

Figure 3. Text-based keypad retrieval method

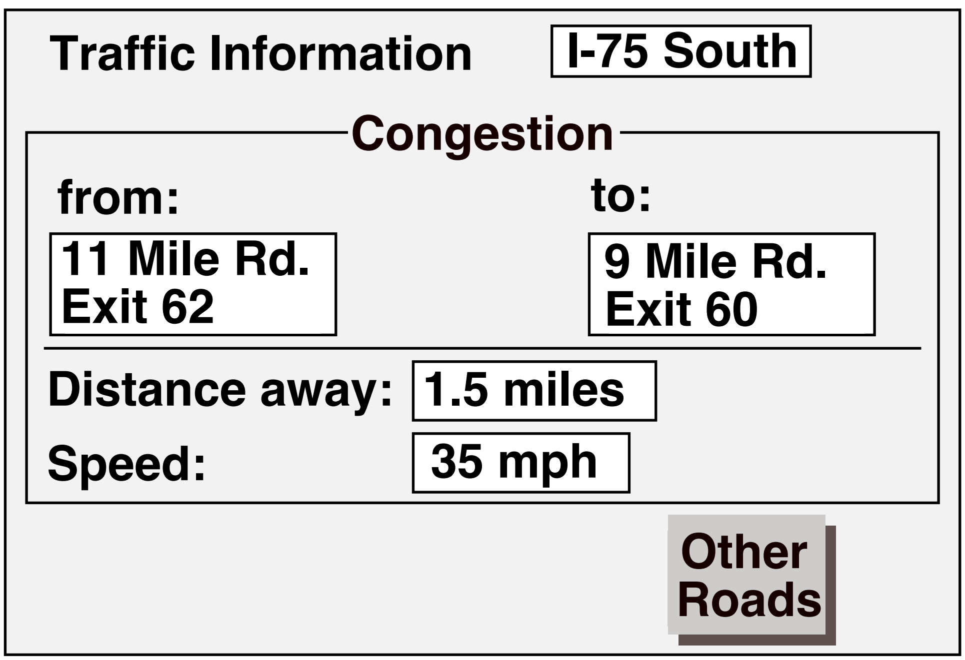

Figure 4. Preliminary text-based information screen

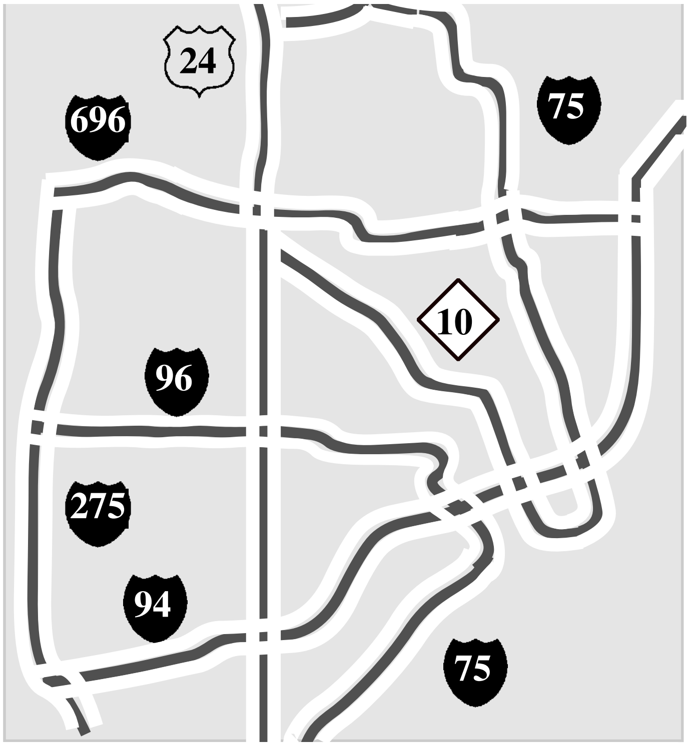

Figure 5. Skeleton map of the metro Detroit highways

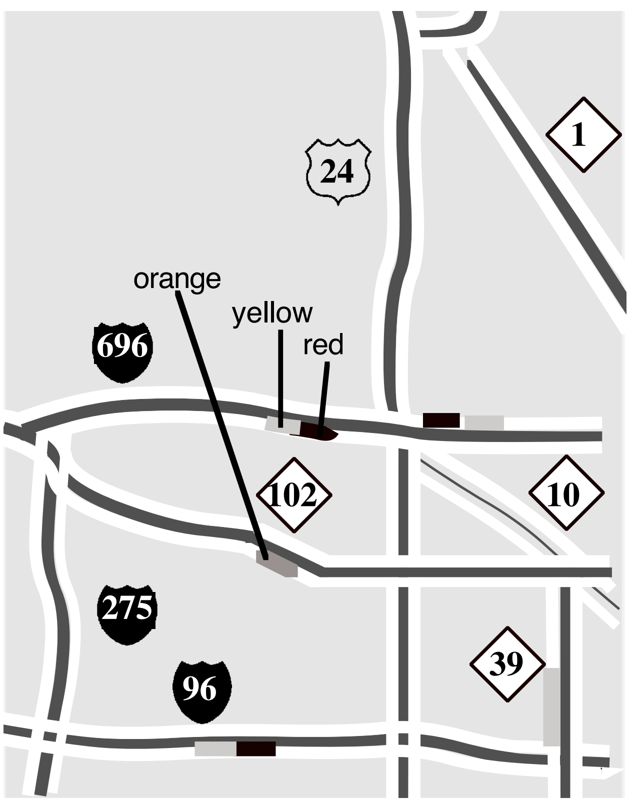

Figure 6. Graphic-based system showing next level of detail

Application of Human Factors Methods from Human-Computer Interaction

To predict human performance with computer systems (such as using alternative editing methods), scientists at Xerox (and elsewhere) have developed a class of models known as GOMS, an acronym for Goals, Operators, Methods, and Selection rules [14]. In this approach an analyst identifies

1. the goals and subgoals (e.g., goal=see if the path to work is congested; subgoal=see if the first part (I-94W) is congested),

2. the operators to achieve a goal (e.g., get next task, use push and hold method to reach menu item, etc.),

3. the method or sequence of operators for accomplishing a task, and

4. the rules for carrying out the task (e.g., to get more detailed information using the graphic system, press on the desired highway).

From this class of models two specific models have emerged, the Model Human Processor and the Keystroke Model [14]. Using the Keystroke Model, the Goals, Operators, Methods, and Selection rules for each Traffic Information System task were identified along with time estimates for the completion of each task. A sample of the output from that analysis (for moving the selection box in the scrolling menu interface) is shown in Table 1. The operators involved are mental operations (M), pointing (P), and keypresses (K). A comparison of predicted times for using the text-based systems and the costs of correcting an initial wrong highway selection are given in Table 2. The execution time differences between the unidirectional and bidirectional scrolling menus result from the additional mental operations (M) needed to determine if the up or down arrow should be pressed.

Table 1. Sample of GOMS analysis

Goal: Select the desired road		
	Method: Move box directly to desired road	
Time (secs)	Element	Steps
1.2	M	1. Think of direction you want box to move
1.1	P	2. Point to arrow corresponding to box movement direction
0.28	K	3. Press arrow button
		4. Report goal accomplished

Table 2. Comparison of selection and error times using GOMS model (Preliminary analysis)

Interface	Time to select highway (sec)	Cost of an error (sec) (selecting wrong highway)
Unidirectional Scrolling*	9.96+3.78(x-1)	3.78(n-1)
Bidirectional Scrolling (Fig. 2)	11.2+4.98(x-1)	4.98
Highway Graphic (Fig 1)	7.56	3.78-6.2
Keypad (Fig 3)	5.68+d(3.78)	7.48(c)

where x = position of desired highway in list (1st, 2nd, etc.)
n = number of highways in list
d = number of digits in highway
c = number of digit corrections to make
* unidirectional scrolling menu was not evaluated in further testing

The GOMS model data for task times was drawn primarily from the psychological and computer-human interaction literature. In some cases for the psychological data there is an implication these tasks were performed as quickly and accurately as possible, not at a "normal" pace. Another complication was that the GOMS models were developed for single-task performance. However, the use of a traffic information system while driving will require time sharing between multiple tasks. While some work on time sharing has been done [15], the tasks have been discrete, not the continuous task of steering a car.

Despite these complications, the GOMS model has potential for usability assessments of driver information system interfaces. One of its strengths was in comparing the cost of an error among each of the text-based interfaces being developed. This comparison helped eliminate a unidirectional scrolling menu interface from further consideration because of the time required to correct a highway selection error (Table 2). To fully utilize the GOMS model, the values assigned to the model variables must be calibrated to better approximate the human reaction times for a driver information system. An upcoming laboratory simulation will help collect the data necessary to assign appropriate values for button presses and mental response times for traffic information interfaces.

The screens for presenting traffic information to drivers were initially evaluated using the Tullis Display Analysis Program [16]. This is a PC-based program in which a display is entered as a text file and evaluated for its ease of scanning by the viewer. It was originally developed for CRTs showing fixed pitch characters on a 24-line by 80-column display. The text is assumed to be structured or form-like (e.g., columns listing airlines, flights, departure times, and gates). Hence, key attributes include justification, capitalization, and spacing of text. Unfortunately, this model does not consider the effects of color or highlighted text. Also, it could not accommodate graphical enhancements such as lines or boxes which were used to organize the information on the traffic information screens. As a consequence, differences between screens were small and not informative. However, in subjective evaluations of the initial screen designs, knowledge of the model parameters was useful.

Quick Usability Tests

Most of the initial refinements of the interfaces were identified through quick usability tests performed continually throughout the development of the systems. The purpose of these tests was to determine if people understood a certain aspect of the interface operation or information format, before it was completely developed into the prototype. This type of input was typically obtained from a few people in the building (UMTRI) who were unaffiliated with IVHS research and development (e.g., clerks and secretaries from other departments).

For example, when determining the format for the text-based information screens, five layouts (similar content, but with different justification, word highlight, and graphic enhancements) were shown to seven people. The participants were told that the screens were for a traffic information system, and were asked to describe what the screens were telling them. After identifying the content of the screens, the participants' preferences and suggestions for improvement were recorded. In general, people preferred displays which used highlighted text to identify the main information points. Also, they tended to prefer screens which had graphic enhancements (lines and boxes to separate different information types).

A similar quick experiment was conducted to determine what gestures people used for changing the level of detail on a graphic display with a touchscreen without buttons. An issue was the gestures for zooming in and out. People were shown a map similar to Figure 5 and a second more detailed map and asked what motion they would make to get the second (pushing the highway, pushing the highway sign, pushing the general area of interest, etc.). Due to the absence of a gesture stereotype, it was decided to run the experiment again with a grid superimposed over the map (dividing the map into 4 quarters). When this display was shown, all subjects pressed within the grid area. It was therefore determined to provide a grid on the global level map, to avoid ambiguities for zoom-in commands. For the zoom-out command, no gestures were indicated (people said they wanted a button instead). Consequently, the idea of a gesture-based interface was eliminated.

Other quick usability tests were conducted to determine how well people could understand the graphic representations of traffic information. This helped refine the color coded and travel speed screens, and eventually eliminated the coding methods of line widths, colored arrows, and dots to represent traffic congestion.

The main advantage to the quick usability approach was the immediate feedback gained on whether people understood the designs. Also, it was easy to obtain subjects because the only real criteria for selection was that they be unfamiliar with advanced driver information systems. However, there were also disadvantages to this approach in that the small sample size provided no quantitative performance data on which to base decisions. For the kinds of decisions to be made, the informal testing carried out was quick, inexpensive, and very appropriate.

Secretary of State Testing

Once the interfaces were developed and refined to a suitable level of functionality, they were taken to a Michigan Secretary of State Office (where driver licensing, vehicle registration and similar activities are conducted) to receive input from a wide variety of licensed drivers. The purpose was to gain insight on the understandability of each interface and drivers' preferences for the display of traffic information, specifically:

- Can drivers understand the use of traffic coding schemes on maps?
- How do drivers interpret various color coding schemes?
- What method(s) of showing traffic information on electronic maps do drivers prefer?
- What commands would drivers use to access greater/lesser levels of traffic information detail on electronic maps?
- Do drivers understand text-based methods of selecting highways for receiving traffic information?
- What text-based method for selecting highways do drivers prefer?

Twenty drivers (8 male and 12 female) waiting in line at the Pittsfield Township (Michigan) Secretary of State Office participated. The drivers ranged in age from 20-59 years, with an average age of 36. Twelve of the participants had at least a college degree. Most of the drivers were native English speakers.

Color copies of computer screens were shown to subjects as they waited in line at the Secretary of State Office. The experiment took between 12 - 15 minutes to complete. The screens were developed on an Apple Macintosh using SuperCard or Canvas software.

Testing of the graphic-based interfaces was conducted first. The experimenter showed the subject a map of the major highways in the metro Detroit area, with a scale of 8 miles/inch. (See Figure 5). Subjects were given a hypothetical driving situation (e.g., "You are travelling west on I-696 toward I-275") and asked how they would access more detailed information.

Next, the understandability of different schemes for graphically showing traffic information was tested. For each of the schemes shown in Table 3, the subjects were asked what information the screen was giving them and where they felt traffic was the worst. They were also asked what they thought each color meant, and the approximate travel speed they would expect in each colored area. All of the screens shown were for the northwest portion of metro Detroit highways (scale = 4 miles/inch). Screens were shown involving only color coded information (Figure 6), only travel speed information (Figure 7), and both travel speed and color coded information.

Table 3. Schemes tested for the graphic display of traffic information

Design	Speed Shown	Color Coding
1	no	*color scheme I* yellow = slower than normal (41-54 mph) orange = much slower (16 - 40 mph) red = stopped/crawling (0-15 mph) (white = "normal" traffic)
2	no	*color scheme II* green = above speed limit yellow = slow (31 mph - speed limit) red = very slow (0 - 30 mph) (white = "normal" traffic)
3	yes	none
4	yes	color scheme I
5	yes	color scheme II

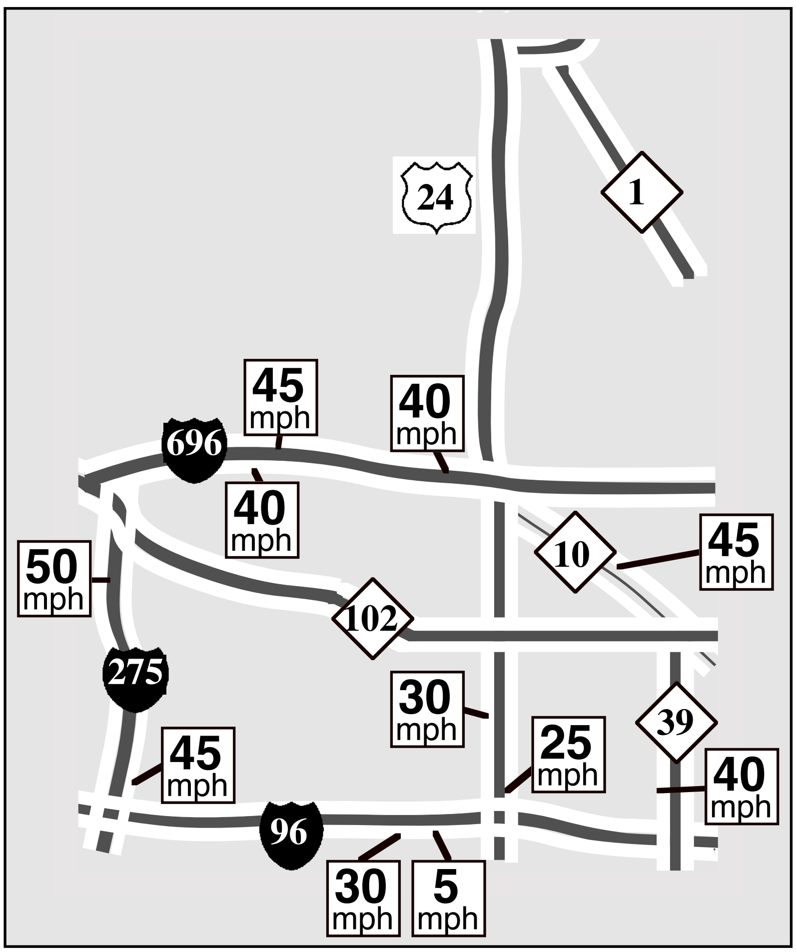

Figure 7. Graphic-based system with travel speeds

After subjects gave their interpretation of all five schemes, they were asked to rank them in order of their preference. Next, they were asked how they would access more detailed information for a specific traffic problem shown on the display. They were then shown the most detailed level of information, which gave specific locations of the problem based on nearby exits (Figure 8). After interpreting this screen, they were asked how they would tell the system to show them the earlier screen. (This was done by showing them the screens in order to avoid biasing their language selection.) Subjects chose from commands provided or suggested their own.

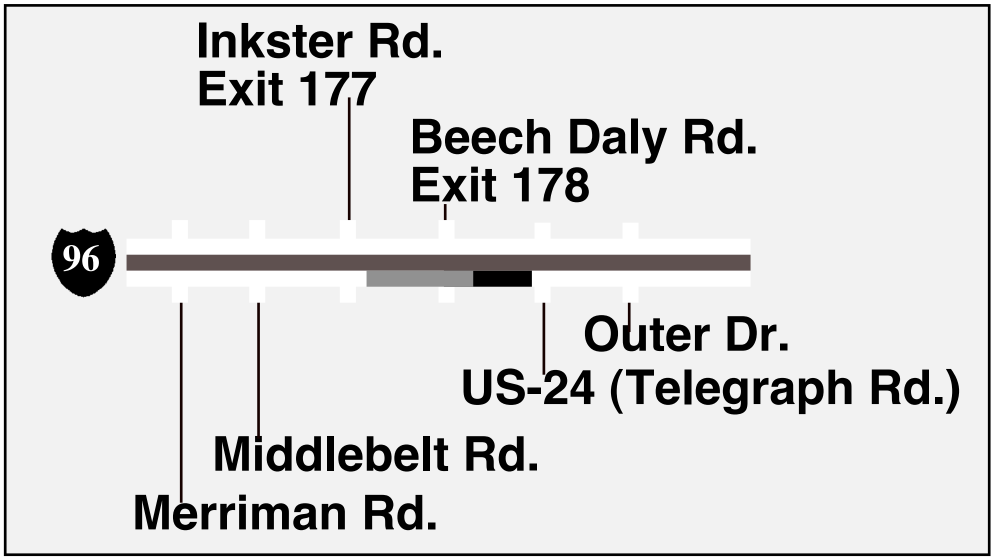

Figure 8. Graphic-based system at most detailed level

The testing of textual displays for traffic information was less extensive at the Secretary of State Office, due to the dynamic nature of these displays that could not be captured on paper. (The shaded areas in Figures 1 and 3 appear only after the highway is entered.) Subjects were shown input screens for three potential text-based systems: A scrolling menu (Figure 2), graphic of the highways (Figure 1), and phone-style keypad (Figure 3). The displays shown to subjects were in color. Subjects were asked how they would select a highway using each system, and then ranked the three systems based on their preferences.

Results of the Secretary of State Testing

Both color schemes were understood by most of the participants, as shown in Table 4. The orange coding in the first color scheme was unclear to 35% of the drivers (they either had no idea, or thought it explicitly indicated a construction area). The second color scheme was more consistently understood. In general, the implication of red = stop and yellow = caution was quickly assumed by the drivers tested.

Table 4, Understandability of color schemes for representing traffic information.

Scheme	Understandability color	speed
Color I		
yellow (40-50 mph)	90%	85%
orange (20-39 mph)	65%	60%
red (0-19 mph)	95%	80%
Color II		
green (over 55 mph)	75%	85%
yellow (25-50 mph)	90%	85%
red (0-24 mph)	90%	90%
*note: in both schemes, white indicated "normal" traffic		

The understandability of each graphic display was measured by whether the participants gave the intended interpretation of the color and estimated speed. Multiple answers were accepted, as long as they conveyed the general idea (e.g., yellow=slow, caution; red=stopped, heavy, jammed). Responses that were different from the intended meaning implied that the driver did not understand the coding scheme (e.g, orange=bus routes; green=lawn crew, etc.).

Subjects preferred the the second color scheme (Green-Yellow-Red). The most preferred graphic interface was that which showed both color coded congestion and actual travel speeds on problematic links, as indicated in Table 5. According to a Kruskal-Wallis test of ranks, the differences among them was significant (H(4)=37.8, p<.001). It should be noted that to determine their interpretation of the color coding, a key was not provided on the map. This may have led to their preference of having the travel speeds included on the display. In the next phase of laboratory testing, a key will be provided.

Table 5. Preferences for showing graphic traffic information

	mean rank	Scheme	Design
best	1.90	Green-Yellow-Red with speeds	5
	2.35	Yellow-Orange-Red with speeds	4
	2.75	Green-Yellow-Red	2
	3.75	Yellow-Orange-Red	1
worst	4.25	Speeds	3

The results of the text based systems indicated that drivers preferred the interface with the graphic showing the metro highways (Kruskal-Wallis H(2)=24.9, p<.001). Unfortunately, the methods they used to input the highway of interest varied. The majority (55%) pressed the highway sign (I-275) followed by the desired direction (south enter). Preferences of the remaining subjects were split between four methods of input: pressing south enter, pressing south enter and then the highway sign, pressing west enter, and pressing on the lower (south) portion of the line representing the highway. The interpreted use of the scrolling menu was much more consistent, with only 15% suggesting something other than using the arrows to scroll along the menu. The keypad entry interface was least preferred but had consistent results. Most (85%) would press only the numbers corresponding to the highway, while 15% would press the letter ("I" for Interstate) followed by the highway number.

Dynamic Testing of the Interfaces

The results of the static tests of the traffic information interfaces from the Secretary of State office will be used to further develop the prototypes for upcoming laboratory testing. For the graphic interfaces, it was determined that a revised color coding scheme could be used (Green = freely moving traffic at or above the speed limit, Yellow = slower traffic 30 mph - 54 mph, and Red = very slow/stopped traffic 0 - 29 mph.) The use of white roads for “normal” traffic was eliminated by using green for all traffic at or above the speed limit. The prototypes for two graphic systems are being refined, one which shows traffic information by only using the color coding (including a key), and the other by using the color coding combined with actual travel speeds on congested links. All three text-based systems (scrolling menu, graphic of highways, and keypad) are being developed further.

This study will be conducted using the UMTRI Instrument Panel Test Facility. This simulator shows a single-lane road at night without traffic or other details. Subjects will operate the UMTRI driving simulator while using the proposed traffic information system interfaces. The PC-based driving simulator with projection video is connected to a 1985 Plymouth Laser. The traffic information systems are programmed in SuperCard on an Apple Macintosh II series computer. An LCD color display with a touch screen will be located on the upper-middle area of the console.

While subjects drive in the UMTRI simulator, they will be asked if there are any traffic problems on a specific highway. They will use the traffic information system to determine if traffic problems exist on the route of interest. Each subject will use all five traffic information interfaces. Subjects will only interact with one interface at a time.

The experimental software will record the response times of all button presses made by subjects. A few drivers will also be videotaped with one camera aimed at their face and a second showing the interior and the road scene, to collect eye-fixation data. The following issues will be addressed:

1. Will drivers be able to use traffic information systems effectively to determine upcoming traffic problems?
2. Which type of interface (graphic or text) is easier for drivers to understand? (look at overall task time)
3. Which type of interface (graphic or text) has the best response time? (look at system use time)
4. Of the graphic formats, is it best to use color coding with a key, or color coding with approximate travel speeds?
5. Of the text formats, which is best?
6. Do drivers prefer a text-based or graphics-based traffic information system?
7. What is the pattern and duration of eye fixations?
8. What are the appropriate values for elements of the GOMS model?

Conclusions

The methods described in this paper have been useful for developing prototype interfaces to test the usability of traffic information systems. It should be noted that the rapid prototyping tools used (SuperCard on a Macintosh IIsi) resulted in traffic information interfaces that operated very slowly. This problem intensified when a video board with NTSC output was used to display the screens on the 6-inch LCD monitor. Although accelerator boards have been acquired to help alleviate this problem, frustrations with the slowness of SuperCard remain. As improved hardware and software are released over the next 2-3 years, this problem will diminish. Also, as the emphasis shifts from developing the initial interface, to modifying existing ones, development time will be sharply reduced. Despite its slowness, SuperCard has provided an easy-to-use graphic environment for developing the interfaces and it will be used in future phases.

The use of quick usability tests were quite helpful for developing the traffic interfaces from scratch. The continuous line of feedback helped ensure that people other than engineers could understand and use the systems. It was helpful to eliminate confusing or cumbersome interfaces (such as line widths and dynamic icons) early on, so that efforts could be directed toward interfaces which were more understandable (such as color coding or travel speeds). Clearly, the method of testing and the sample sizes was not traditional. If one shows an interface to 5 reasonably typical drivers and they cannot understand it at a first glance (and the design specifications say they should), then there is no need to test another 95 drivers to arrive at a commonly accepted sample size and confirm the problem.

Interviewing drivers at the Secretary of State Office was also beneficial. The subjects helped identify items that were confusing (e.g., the orange color coding), and often gave ideas of other things they would like to include on the interfaces (e.g., color keys, alternate routes). The results of this phase of testing indicated that drivers could easily understood three levels of traffic indicators. For color coding, red (for stop or hazard), yellow (for slow or caution), and green (for freely moving or go) were quickly understood by drivers. Using orange to indicate a traffic level between yellow (slow) and red (stopped) was ambiguous to over a third of the drivers, and is therefore not recommended.

The goal of this research program is not just to collect collect data on different interface designs, but to examine the efficacy of human factors models and methods (such as GOMS and rapid prototyping) from non-automotive contexts for solving automotive problems. This paper represents one step in that direction.

Acknowledgements

Several people have contributed to the research described in this paper. Of key importance are Marie Williams and Colleen Serafin, members of the UMTRI Human Factors Division research team involved with this project. Also, Daryll Hasse of the local Secretary of State Office (Pittsfield Township, Michigan) was extremely helpful in allowing us to spend numerous lunches and afternoons interviewing people while they waited in line. Finally, the authors would like to thank King Roberts of FHWA who has ably served as a contract technical monitor.

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