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Entry of Destinations into Route Guidance Systems: A Human Factors Evaluation

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16. Abstract <p>This research examined four touchscreen methods for entering a destination into a route guidance system. Three of the interfaces were character entry-based, including 1) a method using a sequence of two buttons for each alphanumeric entry (referred to as doublepress), 2) a Qwerty-style keypad layout, and 3) a Phone-based keypad where letters were entered using their corresponding number key. The fourth interface provided an alphabetic list through which a user scrolled to select a city or street name.</p> <p>Sixteen subjects used each of the interfaces to enter destinations in a laboratory experiment while "parked" and while driving a simulator. The entry methods were evaluated based on entry time, driving performance, errors, preferences, and perceived difficulty. Overall, address entry times were shortest for the phonepad (43 seconds) and Qwerty (45 seconds) methods, followed by the scrolling list (56 seconds) and doublepress (75 seconds) methods. Entry time was significantly affected by driver age, with older drivers taking about 20 percent more time. Driving performance (deviation of lane position) was significantly worse when entering a destination as compared with baseline driving performance. Participants rated the difficulty of destination entry only slightly greater than that of conventional driving tasks. According to the subjective data, there was no preferred entry method.</p>					
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Introduction

One component of Intelligent Vehicle-Highway Systems (IVHS) likely to see early large-scale introduction in the U.S. is electronic navigation/route guidance systems. With a route-guidance system, a driver could receive step-by-step instructions on how to reach a destination. This would reduce the need to look away from the road to a paper map or handwritten directions, and to search for street names while driving. This could make driving safer. A route guidance system would provide efficient directions between the origin and destination, reducing the vehicle mileage traveled by lost drivers or those using less than optimal routes. For these potential benefits to be experienced, the route-guidance system must be easy to understand and use while driving.

Only a few navigation or route-guidance systems have been marketed or tested in the U.S. The Etak navigation system (the first on the market) has been the subject of several recent human factors evaluations, particularly by researchers at Virginia Polytechnic Institute and State University (Antin, Dingus, Hulse, and Wierwille, 1986; Dingus, Antin, Hulse, and Wierwille, 1988). A commercial route-guidance system, Navmate, was recently developed by Zexel. These systems use the Global Positioning System (GPS), dead-reckoning, and/or map-matching for locating and navigating the vehicle. The Ali-Scout system, developed by Siemens, obtains local navigation data from infrared beacons to guide equipped vehicles to their destinations.

Route-guidance systems have also been developed as part of IVHS Operational Field Tests (Federal Highway Administration, 1992). The TravTek (Travel Technology) program (involving General Motors, American Automobile Association (AAA), Federal Highway Administration (FHWA), and others) in Orlando, Florida is one example. This recently completed demonstration project provided information on traffic congestion, route guidance, motorist services, and tourism to drivers of 100 specially equipped vehicles (Krage, 1991). Development of the ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) program is underway. This will be the first, large-scale dynamic route guidance system in the United States, involving up to 5000 vehicles in the northwestern suburbs of Chicago. Vehicles will be equipped with navigation and route guidance systems, and will also serve as probes that provide real-time traffic data. Evaluations of the route guidance systems used in these studies were not available at the time this report was being drafted.

The emphasis of the human factors evaluations of these interfaces has been on route following. Human factors evaluations of the Etak Navigator were conducted to address the visual attentional demand of the system, as well as its overall effectiveness (Dingus, Antin, Hulse, and Wierwille, 1988). In the study, 32 participants drove an instrumented 1985 Cadillac, which was equipped with an Etak Navigator. Eye-glance data were collected using a rearward-

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looking video camera aimed at the driver. Participants performed several tasks while driving, some of which involved the Navigator, and others which were conventional driving tasks. The resulting total glance times to the display for the tasks are shown in Table 1 in order of increasing time. Italicized items indicate tasks that involved the navigation system.

Table 1. Display glance times for conventional and navigation (*italics*) tasks
(Source: Dingus, et. al, 1988)

Task	Mean Time (sec)	Standard Deviation (sec)
Speed	0.78	0.65
Following Traffic	0.98	0.60
Time	1.04	0.56
Vent	1.13	0.99
<i>Destination Direction</i>	<i>1.57</i>	<i>0.94</i>
Remaining Fuel	1.58	0.95
Tone Controls	1.59	1.03
Info. Lights	1.75	0.93
<i>Destination Distance</i>	<i>1.83</i>	<i>1.09</i>
Fan	1.95	1.29
Balance Volume	2.23	1.50
Sentinel	2.38	1.71
Defrost	2.86	1.59
Fuel Economy	2.87	1.09
<i>Correct Direction</i>	<i>2.96</i>	<i>1.86</i>
Fuel Range	3.00	1.43
Temperature	3.50	1.73
Cassette Tape	3.23	1.55
<i>Heading</i>	<i>3.58</i>	<i>2.23</i>
<i>Zoom Level</i>	<i>4.00</i>	<i>2.17</i>
Cruise Control	4.82	3.80
Power Mirror	5.71	2.78
Tune Radio	7.60	3.41
<i>Cross Street</i>	<i>8.63</i>	<i>4.86</i>
<i>Roadway Distance</i>	<i>8.84</i>	<i>5.20</i>
<i>Roadway Name</i>	<i>10.63</i>	<i>5.80</i>

A few of the navigation-related tasks required much longer than average glance times. The glance times for the high-visual-demand navigation tasks (cross street, roadway distance, and roadway name) were attributed in part to the need to zoom in/out (requiring additional button presses) in order to access the information. If zooming was not required (the information was already available on the screen), the glance times were much lower (4.05 seconds for cross street, 6.77 seconds for roadway distance, and 4.61 seconds for roadway name).

A subsequent study (Wierwille, Hulse, Fischer, and Dingus, 1988) examined variations in the visual attentional demand of the driving task to determine whether drivers modified their visual attention while using the Etak Navigator. Visual attentional demand of the road was determined based on the sight distance, curvature, lane restrictions (the distance of the closest

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obstruction to the road), and width of the road. Objective and subjective measures were obtained from 24 subjects who drove the same vehicle used in the previous study. Regression analyses indicated that drivers adapted to high, anticipated, attentional demand by increasing the proportion of time devoted to looking at the driving scene (and related tasks), and decreasing the proportion devoted to the navigation display. In particular, drivers focused more on the center of the road when anticipated demand increased. Glance times to the navigation display decreased in length when anticipated demand increased, however times increased when the drivers needed to reorient themselves.

Drivers also increased the proportion of time spent looking at the driving scene when faced with unanticipated attentional demands (high traffic and incident situations). The glance length times to the road scene were the highest for incident situations. This study suggested that drivers are able to adapt their behavior to accommodate the changing demands of driving.

Most studies of navigation systems (Fleischman, Carpenter, Dingus, Szczublewski, Krage, and Means, 1991; Walker, Alicandri, Sedney, and Roberts, 1991) have focused primarily on the use and understanding of the navigation information, which is the key component of such a system (Green, 1992). However, the first step in using a navigation or route-guidance system is to tell the system where the driver wants to go, the focus of this report. Specifically, this report examines four methods for entering a destination into a navigation/route-guidance system. The actual tasks of following the route guidance instructions are not part of this evaluation.

There are few studies in the literature examining destination entry. Coleman, Loring, and Wiklund (1991) examined the use of three, small, touchscreen, alphanumeric keypads. Twenty participants used a traditional Qwerty arrangement, revised matrix Qwerty arrangement, and alphabetical arrangement. Participants completed 15 tasks on each keypad arrangement, including alphabetic strings, numeric strings, and alphanumeric strings. The keypad arrangements were evaluated based on the average keystroke times. The matrix Qwerty arrangement had the briefest keystroke time (0.54 seconds), followed by the traditional Qwerty (0.56 seconds) and the alphabetical arrangement (0.73 seconds). There were no significant differences in error rates between arrangements. The majority of subjects preferred the traditional Qwerty arrangement, but disliked its small button size. That study did not look at potential arrangements that used something other than a full alphanumeric keypad.

Related research, a usability evaluation of various "pre-drive" functions, is described by Dingus, Hulse, Krage, and Szczublewski (1991). ("Pre-drive" refers to the more complicated functions for which the car must be stopped before a driver could perform them.) In that experiment 72 drivers were asked to enter a new address, select a stored address, determine where traffic was congested, select voice messaging options, and perform other tasks using a simulated interface. Destination-related tasks took between 50 and 160 seconds to complete.

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This laboratory study indicated that drivers were able to use TravTek's destination entry system. There was no comparison of their performance with other potential methods.

Beyond the literature, product demonstrations at the 1992 IVHS America meeting served as stimuli for this research. There were three destination input interface designs of which the authors were aware. Most involved entering the letters and digits of the destination address using a keypad. The method used by TravTek and Etak required two buttons to be pressed in order to enter a letter or number (using a touchscreen for TravTek and softkeys for Etak). A hierarchical format was used where several characters were grouped onto main or master buttons. After the main button was pressed, the individual letters appeared (with corresponding buttons) and could then be selected.

A proposed interface for the ADVANCE route-guidance system used a standard Qwerty keyboard layout. This enabled only one button press per letter entry, but used much smaller buttons (as a compromise). A non-letter entry method was used by the Zexel Navmate and an RDS (Radio Data System) prototype in Europe. With this method, drivers would scroll through a list of city or street names to make their selections. With the Zexel system, drivers could jump letter-by-letter through the alphabet, and name-by-name, using different buttons on a touchscreen. A page up/page down feature was recently added to allow faster movement within a particular letter.

Although each system may be tested individually as part of a demonstration project or independent research, comparisons of different entry methods have not been described in the open literature. The current study was therefore conducted. Prototypes of four destination input interface designs were developed and tested in a laboratory experiment. The prototypes were designed to represent the input methods of several of the current navigation systems, but were by no means exact duplications. The prototypes were used only to enter unfamiliar addresses (those that were not preprogrammed into the system).

As part of their examination of the four entry methods, the authors utilized a human performance model to predict entry-time performance prior to collecting data. The GOMS model (Card, Moran, and Newell, 1983) was adapted from the human-computer interaction literature for use in this study. The GOMS model identifies the goals, operators, methods, and selection rules used to accomplish tasks.

Also examined in this study was whether destination entry should be restricted to a "pre-drive" activity, or whether access to this activity while driving should be unrestricted. To address this issue, destination entries in this experiment were made while "parked" (only using the system) and while driving a simulator.

Specifically, the following issues were addressed:

- How do the destination input interface methods compare with regard to the entry time?

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- Do GOMS model predictions of the destination entry task time agree with actual performance data?
- How do the destination input interface methods compare regarding errors?
- Was steering performance in a simulator affected by concurrent entry of destinations?
- Which interface method do drivers prefer?
- How difficult do drivers perceive the destination input task to be while driving, as compared with other conventional in-vehicle tasks?

Test Plan

Test Participants

A total of 16 drivers (8 women and 8 men) participated in the study. Half of the participants (the young group) were students at the University of Michigan ranging in age from 21 to 27 years. The eight older subjects ranged in age from 59 to 71 years. (The mean age was 64.) The subjects were paid \$20 for their time.

Only one subject had driven a car with a navigation system before. Most (69 percent) had used a touchscreen prior to the experiment. All but one of the younger subjects used a computer every day. Only two of the older subjects used computers every day (the others were evenly divided between using a computer a few times a month, less than once a month, or never). All young subjects were very comfortable using a standard (Qwerty) keyboard or typewriter, except for one who was neutral (neither comfortable nor uncomfortable). The older subjects ranged from neutral to very comfortable in their feelings toward keyboard use. Based on a Landolt C vision test, all but one of the younger subjects had at least 20/20 vision (one had 20/22). Half of the older subjects had 20/25 vision (the others had 20/50, 20/30, 20/22 and 20/18 vision). Hand and finger anthropometry was not recorded.

Test Materials and Equipment

Four methods for entering a destination into a navigation system were examined in this experiment. Three of the designs were based on the interfaces of systems currently being marketed or tested in U.S. operational field tests. Prototypes of the four potential interface designs were developed using SuperCard on an Apple Macintosh IIsx. For the three existing designs, the prototypes were intended to represent the general method by which a destination would be entered.

The interface prototypes were shown on a 13-inch Macintosh display mounted in the instrument panel console of a vehicle mockup described in detail later in this section. Input to the system was made through an Edmark Touchwindow touchscreen. All of the "buttons" on the interfaces were programmed to record response times. Only a 5-inch diagonal section of the display was visible to participants (through a cutout in a cover). This size was identical to that of the touchscreen CRT in the Oldsmobile Toronado, the only car manufactured in the U.S. equipped with a CRT at the time this research was conducted. Screens of this approximate size are likely to be used for upcoming navigation products.

Within the constraints of the display size and entry methods, the interfaces were developed using human factors engineering principles. An effort was made to ensure that the different designs were comparable from a human factors standpoint. A legible character size

(minimum of 4 to 5 mm.) was used on all designs. Where possible, large touchscreen buttons were provided (2 cm x 1.5 cm on all but one interface). Regularly used buttons (e.g., "Done") were placed in consistent locations between screens and interfaces. Because of the small size of navigation system displays, usability tradeoffs and compromises were made between button size, the number of button presses required for an entry, and feedback. Each of the prototypes developed represented at least one of these tradeoff issues. A description of each interface follows (the figures shown are the actual size of the prototype).

For brevity, names were assigned to the interface designs (doublepress, Qwerty, phone pad, scrolling list). For the first three interface designs described, a destination was entered to the system by entering the individual letters and numbers of the address. A description of each interface follows. The figures shown are the actual size of the prototype.

Doublepress Interface

This interface (Figure 1) required that two on-screen buttons be pressed for a letter to appear (hence the name). It was similar to the interface developed by General Motors for the TravTek project in Orlando, Florida. Letters and numbers were arranged on ten main buttons, typically with four letters/numbers grouped on one main button.

To enter a letter, a driver would first press the main (four-letter) button, which contained the desired letter in the group. Upon pressing the main letter button, individual buttons for each corresponding letter would appear at the bottom of the display (E, F, G, H, in Figure 1). A driver would then press the individual letter desired. The letter or number would then appear in a display window near the center-top area. This process was repeated for each character (letter or number) entered. Letters could be deleted by pressing the "<--" button. When the desired letters or numbers were displayed, the user would press the "Done" key.

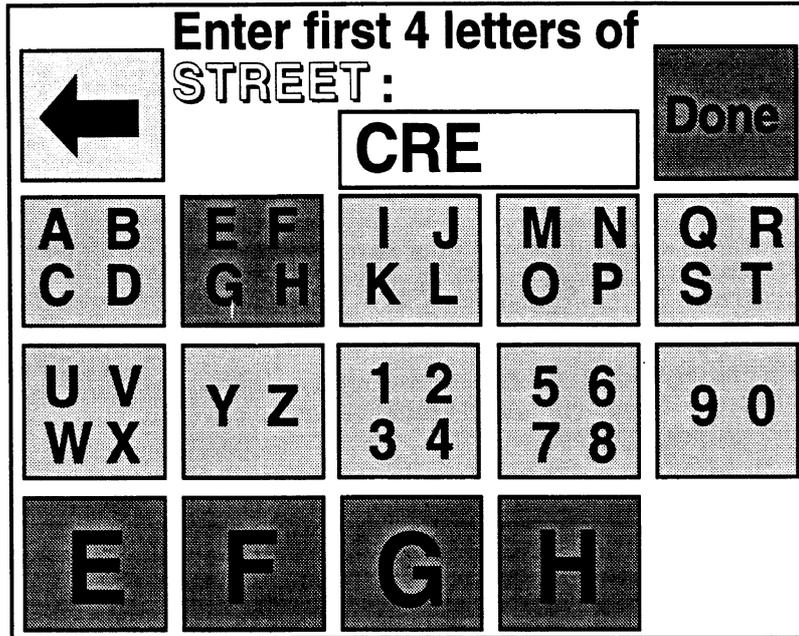


Figure 1. "Doublepress" interface design

Qwerty Keypad Interface

The layout of this interface was similar to a typical keyboard or typewriter. However, only the alphanumeric keys were included. (See Figure 2.) A similar destination input method was being considered by Motorola for the ADVANCE operational test in the Chicago area. To enter a letter or number, the driver would press the touchscreen button for that individual letter or number, causing it to appear in the display window in the top-center portion of the screen. This was repeated for each desired character. When the desired letters or numbers were displayed, the user would press the "Done" key. The delete key ("Del") was used to erase the last character in the display.

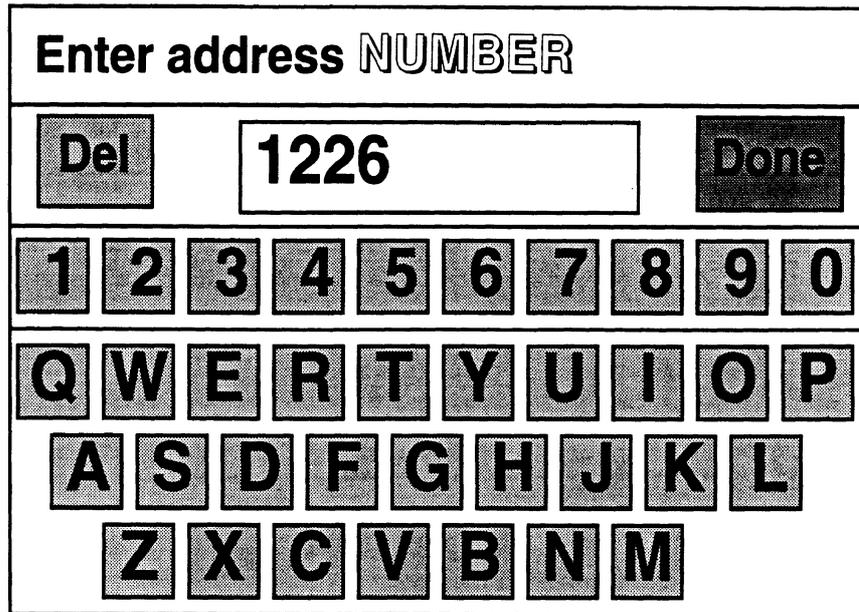


Figure 2. Qwerty-style keypad interface design

Phonepad Interface

This layout was similar to a touch-tone phone. (See Figure 3.) The conventional assignment of letters to numbers was followed. The addition of "Q" and "Z" to the "1" button was made after consulting a long-distance telephone company. (Plans are currently underway to add the letters to the existing phonepad layout). Address number entries were made by pressing the button corresponding to the desired number. Letters of the city and street name were actually entered as the numbers that had the corresponding letter grouped with them. For example, to enter "DOG," a person would enter "364." The city and street names actually appeared as a number in the display window. When the desired numbers were entered, the "Done" button was pressed. A delete key (represented by a left-pointing arrow) was available to erase the last character from the display. Since this method often did not lead to a uniquely matching city or street name, a scrolling list (described below) was used to complete selection of the desired entry.

City/Street Selection Screens for the Three Letter Entry Interfaces

In general, for the three interfaces described, it was not necessary to enter every letter of a city or street name. Based on conversations with a navigation system developer (Borcherts, 1992), the first four letters would typically provide a sufficient link to the desired name in the database. After pressing the "Done" button, a search of the database for the letters entered was made. In some cases, there may have been more than one name with the same first four letters. Therefore, a screen showing the individual names beginning with the letters entered appeared. (See Figure 4.) If the desired name was not highlighted, the user could scroll up or down the list

until the desired city or street was selected. Once selected (highlighted), the user would press the "Done" button. The system then prompted the user for the next entry.

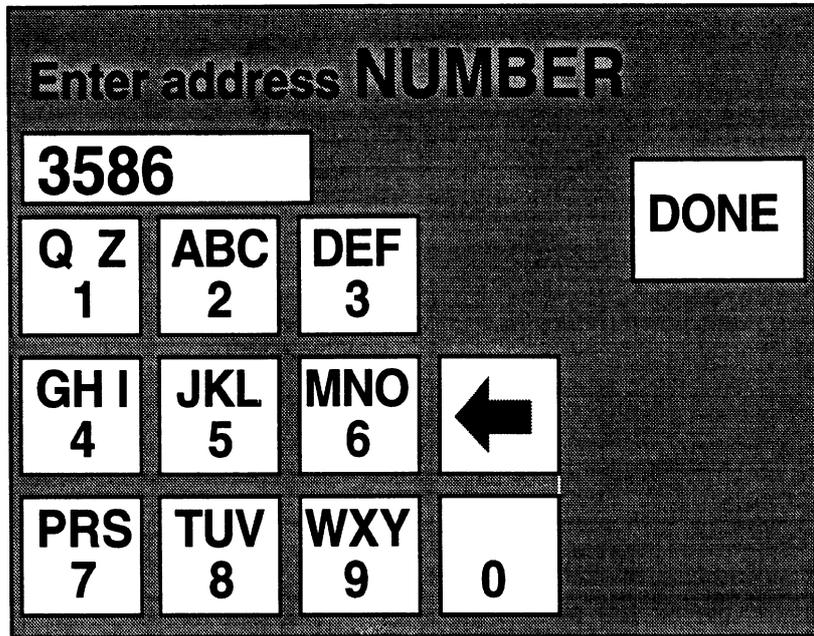


Figure 3. Phone-style keypad entry method

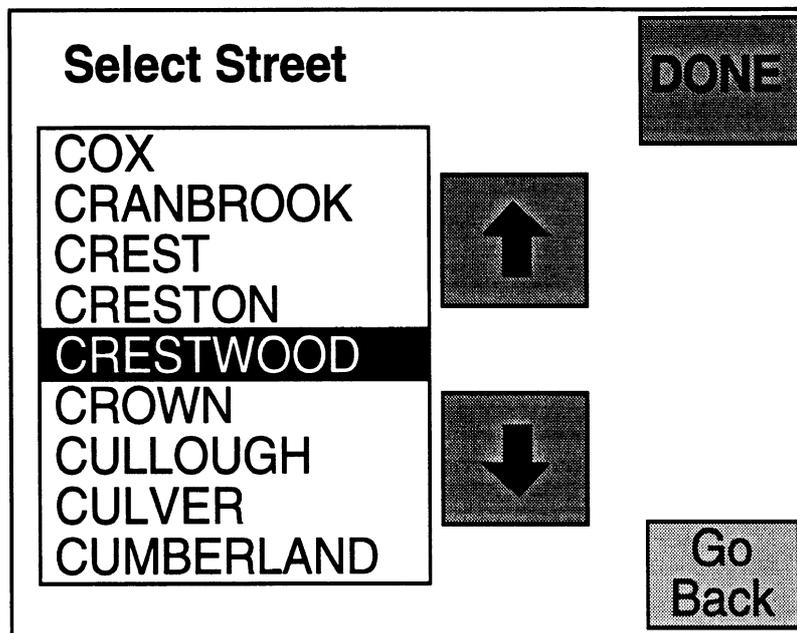


Figure 4. Selection screen for doublepress and Qwerty name selection

For the phonepad system, the selection screen only showed the names that matched the four-number entry code. (See Figure 5.) Other than this difference, it functioned similarly to the selection screen for the doublepress and Qwerty interfaces.

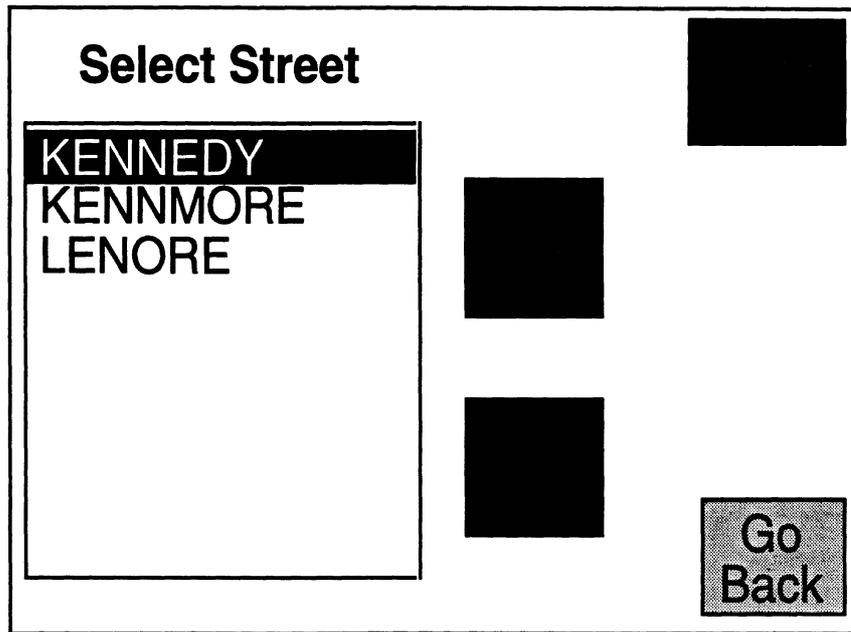


Figure 5. Selection screen for phonepad name selection (the entry prior to this screen was "5366").

Scrolling List Interface

Unlike the first three interfaces described, this interface did not involve entering specific letters to select the city or street name. Similar to the Navmate system by Zexel, a driver selected the desired name by scrolling through a complete list. There were two scrolling options. As shown in Figure 6, there were buttons above the list labeled "<A" and ">Z". These buttons advanced through the first letter of the names alphabetically. Pressing the ">Z" button moved to the next letter toward the end of the alphabet, while pressing the "<A" moved toward the beginning. (A user could scroll backwards from the beginning of the alphabet (A) to the end (Z) by pressing the "<A" button.) The general concept was to use the "<A" and ">Z" buttons to get close to the name (near other names starting with the same first letter) and then to use the up and down arrows to scroll line by line. When the desired name was highlighted, the "Done" button was pressed. To enter an address number, a phone-style keypad was used (similar to Figure 3, however buttons were labeled only with the numbers).

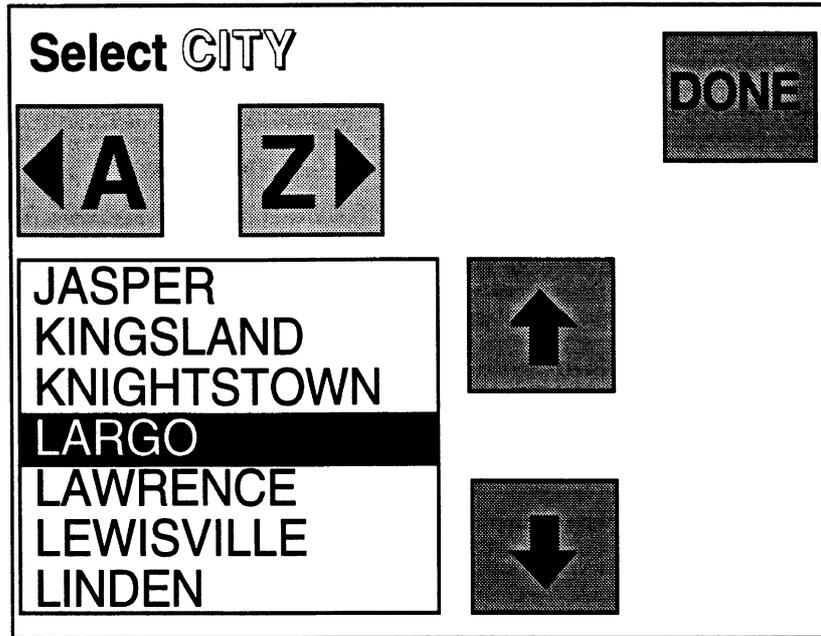


Figure 6. Scrolling list interface design

Destinations

The destinations utilized in all four interface designs were fictitious. The cities chosen as the destinations were taken from a map of Indiana (probably unfamiliar to most Ann Arbor, Michigan, drivers). The street names were based on streets in the greater Lansing, Michigan, area. This metro area was chosen because the street names were generic and had little regional influence. Street names that were common in the Ann Arbor, Michigan, area (where most participants lived) were not used, to help assure that the set of destination addresses was unfamiliar to all participants.

A total of 81 cities appeared in the list (less than half of these were actually used as destinations). There were 883 street names in the database for all systems except the scrolling list. The number of streets in the scrolling list interface was reduced to improve the speed of the system. (The SuperCard programs were inherently slow. Reduction of street data base size was the easiest way to make the scrolling list prototype reasonably functional.) A list of the city and street names appears in Appendix A.

The destinations to be entered were laser-printed on three-by-five inch index cards on a self-supporting stand. The cards were illuminated by a high-intensity desk lamp and were clearly legible. The destination addresses were created using the lists of cities and streets. Most of the street names used contained two syllables, to keep the cognitive demands constant between addresses.

Driving Simulator

The experiment was conducted in the UMTRI human factors laboratory. Participants sat in an A-to-B-pillar 1985 Plymouth Laser mockup throughout the study. The destination input systems appeared on a 13-inch Macintosh display mounted in a fixed location in the console of the mockup. A Macintosh IIsi equipped with a Daystar 40 MHz accelerator, was placed in the back of the mockup, and ran the system prototypes. The setup inside the vehicle mockup is represented in Figure 7.

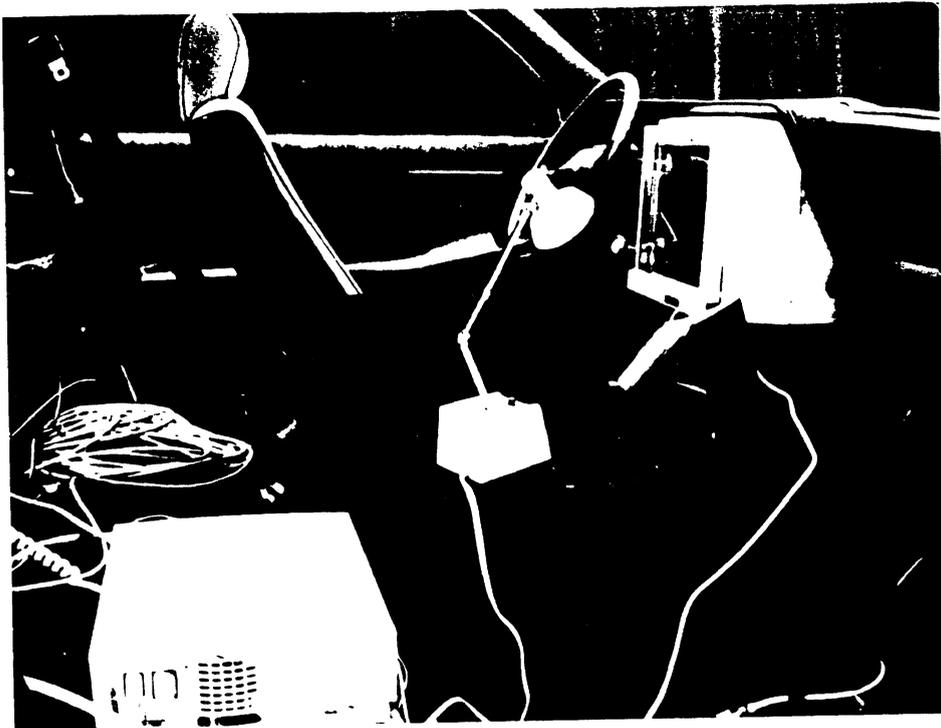


Figure 7. Test equipment in the vehicle mockup - Macintosh IIsi, light, stand with address cards, and monitor with touchscreen.

During half of the trials, the participants used a driving simulator while entering the destinations. The simulator (Green and Olson, 1986) ran on an NCR PC-8 80286 computer, and was displayed by a NEC video projector onto a screen in front of the driver. The room lights were off at all times. The equipment used in the experiment is shown in Figure 8. The driving scene appeared as a single-lane road at night (similar to Figure 9), on which the driver was instructed to keep the vehicle centered. The velocity of simulator was constant, as if driving while using cruise control, so the driver's task was to properly steer while using the destination input systems. The simulator did not provide any auditory cues for speed or skidding.

Test Plan

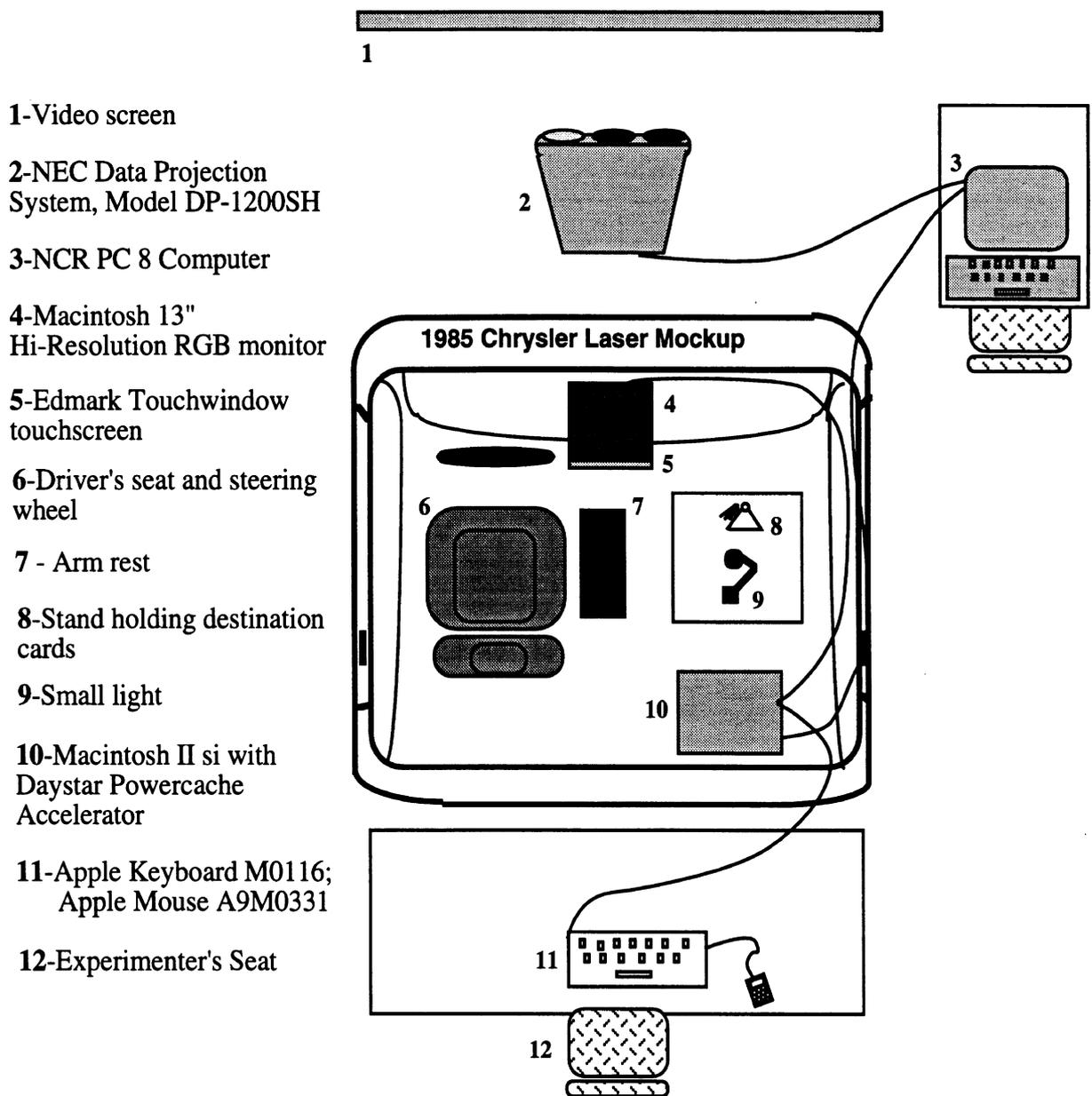


Figure 8. Sketch of the laboratory setup.

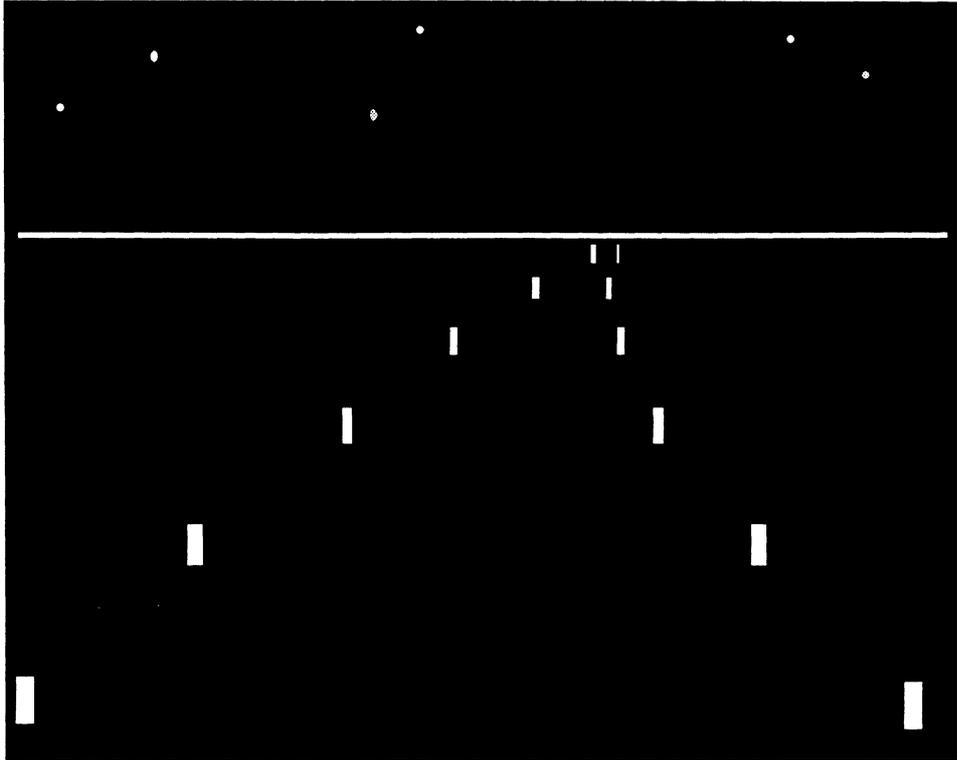


Figure 9. Sample of the nighttime driving simulator scene.

A serial port communication was made between the Macintosh running the prototypes and the PC running the driving simulator. This allowed flags to be sent to the driving simulator output files identifying the tasks (pushing specific buttons on the prototypes) occurring while driving.

At the end of the experiment, a brief questionnaire was given to participants to measure drivers' perceived difficulty of entering a destination (using each system) while driving. The survey was modeled after research by Kames (1978) that examined the difficulty of using a mobile phone while driving. Baseline tasks not related to a navigation system (e.g., tuning a radio, adjusting climate control, etc.) were examined for comparison. This survey also identified drivers' preferences for destination input method. A copy of the survey appears in Appendix C.

Test Method

The experimenter briefly described the experiment to the participants before getting their consent and collecting biographic data. The biographic and consent forms are provided in Appendices D and E. Participants were then seated in the vehicle mockup and the experimenter explained the experiment in detail using the instructions sheet provided in Appendix F. Subjects then practiced using the driving simulator. Baseline driving data for a two-minute period were collected.

Test Plan

Participants were then told that they would be entering several destinations into four different systems. Their attention was directed to the stack of address cards, and the layout of each was explained. The top line of the address cards identified the city, and the bottom line gave the number and street. (See Figure 10). Participants were told that they would always enter the parts of the destination in the same order: City name first, then the street name, and finally the address number. Throughout the explanation, participants were frequently asked if they had any questions about the procedure or systems.

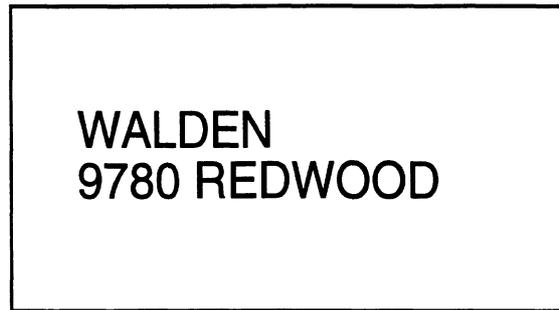


Figure 10. Sample destination address card (not shown to scale)

For the letter/digit entry systems, the complexity of the city or street selection depended on whether a name's first four letters were unique. If more than one name had a specific first-four-letter combination, it may have been necessary to scroll through the list of candidates to select the desired name. To maintain scrolling consistency among interface designs, the addresses were categorized based on the number of first-four-letter matches for each city and street name. For each category, destinations were randomly assigned to the interface designs. Similar first-four-letter-match combinations were used for the driving and non-driving trials. A list of the destinations used for each interface is provided in Appendix B.

Each individual destination input method was described to a participant as he or she was about to use it. While the system appeared on the display, the experimenter explained how it functioned. (In many cases, the participants guessed how it would work before being told.) After the explanation, participants entered a practice address without experimenter interaction. They were then asked if they wanted to try another practice entry. (Most people felt that they were ready to begin the experiment after the initial practice entry.)

For each interface method, there were eight destination trials. The first four destinations were entered while "parked," while the participant was not involved in any task except entering the destination. During the last four trials of a system, the participant drove the simulator while entering the destinations. These were considered the driving trials. Figure 11 shows a participant entering a destination during a driving trial.



Figure 11. Older driver entering a destination (using the doublepress method) during a driving simulator trial.

Each participant used all four systems. The order of system use was counterbalanced. Each interface design had one set of addresses that was consistently used. As noted earlier, the difficulty of the destination entry (based on alphabetic uniqueness) was constant between interfaces.

After all four interface designs were used, the participant exited the mockup and was asked to complete a short survey aimed at determining the perceived difficulty of performing the destination-entry tasks while driving. First, participants were asked to rate the difficulty (from 1 to 10, where 1 = not at all difficult, and 10 = extremely difficult) of several conventional tasks that may occur while driving. They then completed a separate page with questions regarding each interface design (a picture of the interface was shown on each). The pages were arranged in the same order that the interfaces were used during the experiment. The difficulty of similar entry tasks for each system were rated. Finally, participants were asked to rank the systems in order of their preference.

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How did the destination input interface methods compare with regard to the entry time?

The button response-time data collected from the SuperCard prototypes were used to calculate the destination entry times. Entry times were computed for each component of the destination (city, street name, and number). There were 128 values (data points) for each component of the destination. The times that involved character entry errors (where use of the delete key was necessary) were not included in the analysis. Entries with minor errors such as scrolling too far up or down a list were included in the analysis.

An analysis of variance was conducted for each potential effect. Gender did not have a significant main or interacting effect, so it was excluded from subsequent analyses. The ANOVA for all effects (except gender) is shown in Table 2.

Table 2. Analysis of variance for the effects of variables on entry time

Source	Sum-Of-Squares	DF	Mean Square	F-Ratio	p
System	27498.07	3	9166.02	177.75	< 0.001
Entry	37535.61	2	18767.80	363.96	< 0.001
Status	7315.99	1	7315.99	141.88	< 0.001
Age	4303.25	1	4303.25	83.45	< 0.001
System*Entry	6583.92	6	1097.32	21.28	< 0.001
System*Status	133.68	3	44.56	0.86	0.459
System*Age	1927.83	3	642.61	12.46	< 0.001
Entry*Status	236.27	2	118.13	2.29	0.102
Entry*Age	1882.43	2	941.22	18.25	< 0.001
Status*Age	123.65	1	123.65	2.40	0.122
System*Entry*Status	1488.00	6	248.00	4.81	< 0.001
System*Entry*Age	787.47	6	131.25	2.55	0.019
System*Status*Age	24.70	3	8.23	0.16	0.923
Entry*Status*Age	3.07	2	1.54	0.03	0.971
Sys.*Entry*Status*Age	142.85	6	23.81	0.46	0.837
Error	72037.97	1397	51.57		

In general, the average time required to enter a complete destination was 43.0 to 75.6 seconds, depending on the interface design. Figure 12 shows the mean entry time for each portion of the destination (city, street, and number). These values represent both age groups and both states of operation (parked and driving the simulator). The phonepad and Qwerty interface designs allowed for the fastest destination entry (43.0 and 44.2 seconds, respectively). Both of these systems required only one button press per character entry.

The doublepress method required the longest mean entry time (75.6 seconds), mainly because it required twice as many button presses for each character entry. It should be noted that the longer times for this method may have been exaggerated by the speed of the prototype. The

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design was more complicated and required greater manipulation of graphics on the display, and hence the display system response time was somewhat longer than for the phonepad or Qwerty interfaces. Regardless of the slight system time increase, it is logical that the entry time would be much longer than in interfaces for which only one button press was needed because more driver actions are required.

The address number was the fastest part of the destination to enter. The scrolling interface, which used a basic number pad (telephone orientation), had the fastest number entry time (7.8 seconds). Number entry times using the Qwerty (9.5 seconds) and phonepad (9.3 seconds) interfaces were similar. The doublepress method required a much greater time for number entry (20.7 seconds), again due to the requirement of two button presses, and possibly an increased challenge of finding the appropriate buttons. The other three interfaces used conventional number layouts (telephone or horizontal layout), with which people were familiar. The layout of the doublepress buttons was probably unfamiliar to participants.

In general, it took longer to enter the city and street names (than the number) because of the need to scroll to the specific name. (City and street names were randomly scattered throughout the alphabet.) This additional step was more time consuming for the street names than for the city, because there were more street names than cities in the database. Therefore, the likelihood of duplicate first-four-letter combinations was greater for street name entries than for the cities. This was particularly evident in the scrolling list interface, where the time to enter the destination was highly dependent on the location of the names in the list. Although the method was identical, the time to find the street name (29.1 seconds) was much greater than the time for the city (18.2 seconds), because there were many more street names through which to maneuver. The speed of the scrolling list interface prototype may have been slower than an actual production system, due to the limitations of the hardware and software available.

The difficulty of scrolling through long lists was further exhibited when performing the task while driving the simulator. Figure 13 shows the time to enter a street name using the scrolling system was much greater while driving (34.7 seconds) than while parked (23.8 seconds). The effect of driving on entry time for the other systems was less noticeable; however, an analysis of variance indicated that driving status had a significant effect ($p < .0001$) on mean entry time.

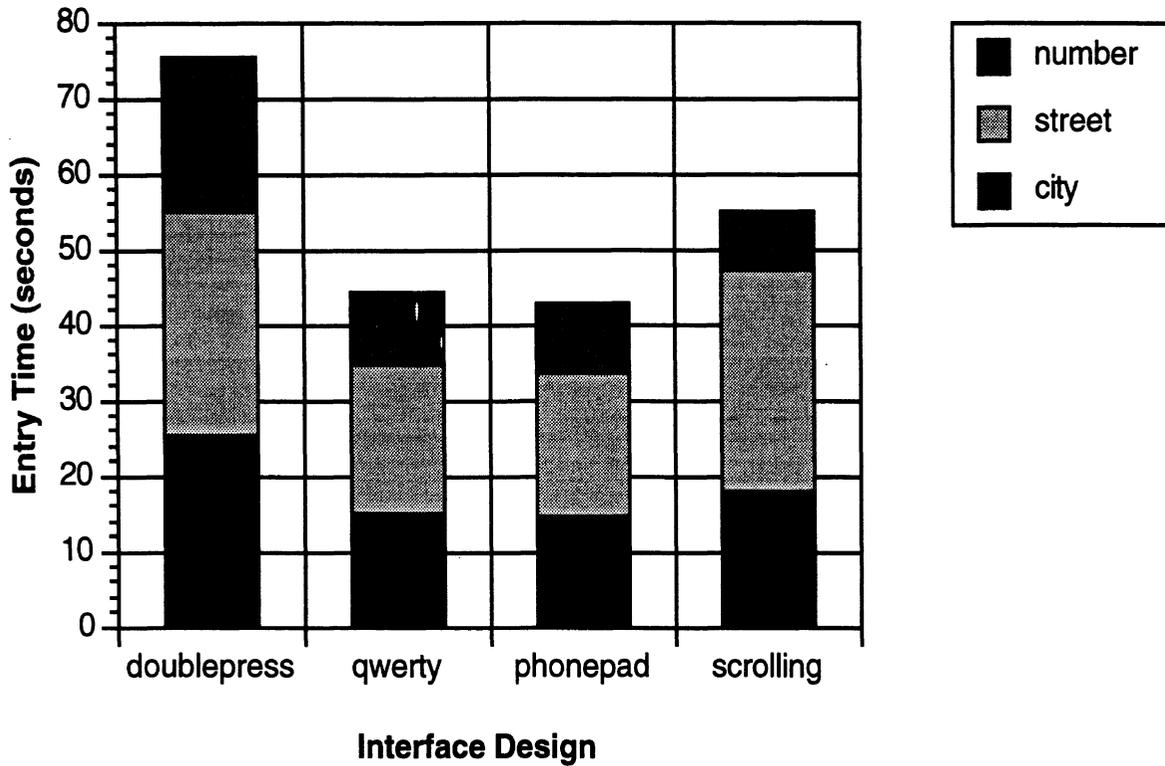


Figure 12. Mean destination entry times

The impact of driving on scrolling list entry time may have indicated that long scrolling activities were more demanding. The degradation in performance suggested that the long scrolling task was more difficult when time-sharing between system use and driving was required.

An analysis of variance indicated a highly significant effect of age ($p < .0001$) on destination entry time. The effect of age was least evident for the doublepress method, as shown in Figure 14. The entry times for the Qwerty and phonepad methods were affected similarly by driver age. The most extreme difference in entry time was seen when using the scrolling interface, particularly when scrolling through a long list (e.g., selecting a street name). When using the scrolling list interface, younger participants took 15.5 seconds to enter a city while older participants took 21.0 seconds. For entering a street name (which typically required more scrolling), younger participants took 22.4 seconds, while older participants needed 35.9 seconds to make the same entry.

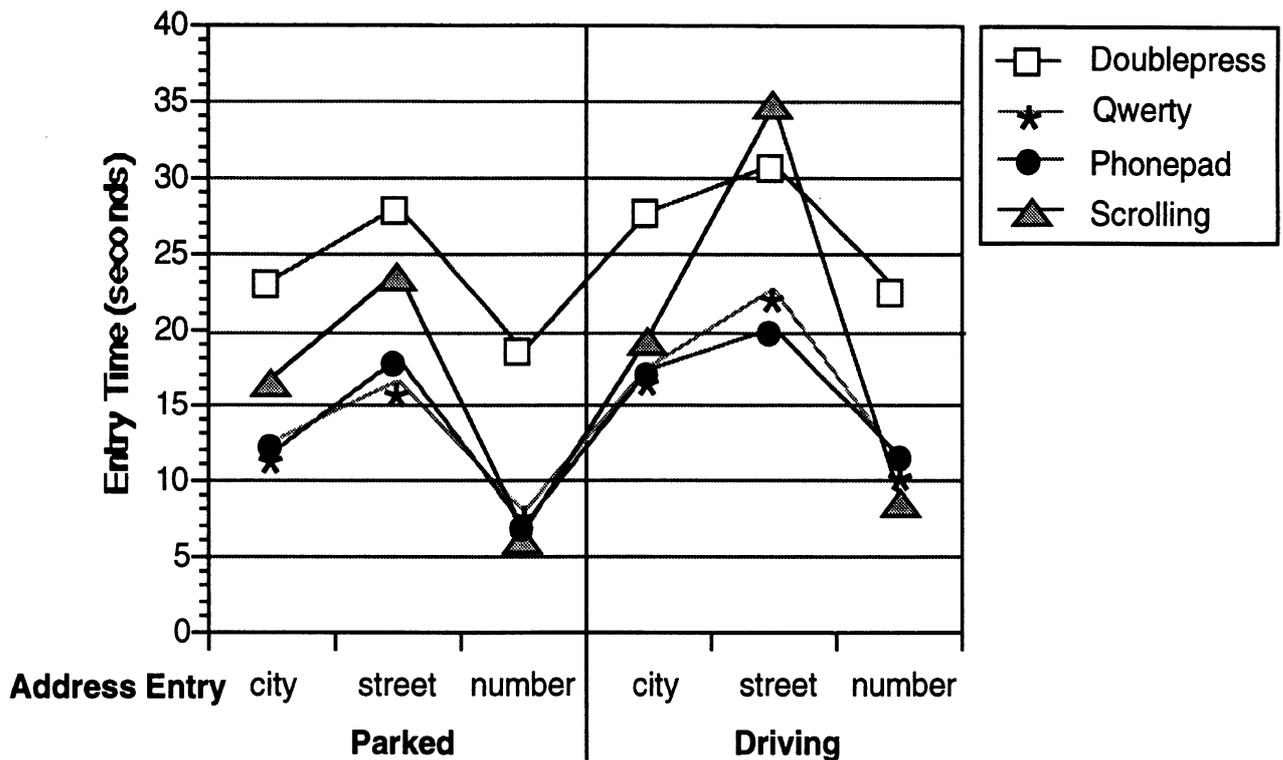


Figure 13. Destination entry times when parked and driving.

A possible reason for the extreme differences in entry times between age groups could be that the correct approach for entering a name using the scrolling list was less obvious than with the other three character entry systems. Efficient use of the scrolling list interface required a strategy before beginning. First, a driver must determine whether to scroll forward or backward in the alphabet (e.g., is the name closer to the beginning or the end). For longer lists (such as the street names), it should also be determined whether the name is near the beginning or end of its particular letter group (for example, Summer Street would be at the end of the Ss, therefore it would be most efficient to scroll backward to the Ts, and then use the up button to reach “Summer” (the desired street name).) From the experimenter's observations, many of the older participants did not take an optimal approach to selecting names from the list.

Several different approaches were used by participants with the scrolling list interface. In contrast, the character entry interfaces were specifically defined. The only approach that could be used was to enter each letter individually, in the correct order. Perhaps, since this method was more straight-forward, there was less potential for variability based on the minimal decision making required.

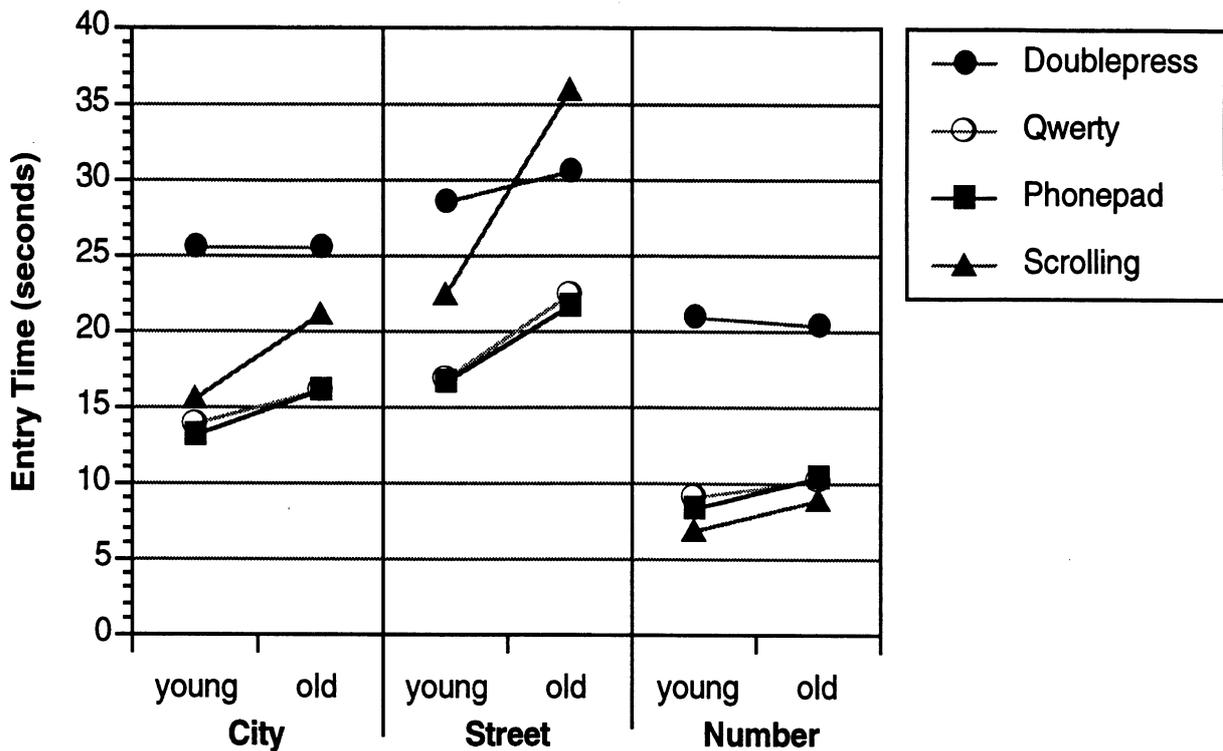


Figure 14. Entry times for each method based on driver age.

Did GOMS model predictions of the destination entry task time agree with actual performance data?

The GOMS model (Card, Moran, and Newell, 1983) defines a person's cognitive structure as having four components: (1) a set of goals, (2) a set of operators, (3) a set of methods for achieving the goals, and (4) a set of selection rules for choosing among competing methods for goals. GOMS was originally developed for human-computer interaction analyses in office settings, particularly for evaluating graphical user interfaces. Kieras (1988) described a GOMS analysis as a representation of the "how to do it" knowledge required by a system in order to accomplish the intended task. The top-down approach of constructing a GOMS model is believed to provide a useful tool of analysis throughout system development.

The GOMS model was applied to each of the four destination input methods tested in this study in order to estimate task performance time. The estimated times for various elements of the GOMS analysis were based on estimates provided in Olson and Olson (1990), or derived from operations (based on Hicks' Law and Fitts' Law) described in the Model Human Processor (Card, Moran, and Newell, 1983). The GOMS models developed for each method are provided in Appendix G.

As shown in Table 3, the GOMS model was not very accurate at predicting the times for the character entry systems. Data on actual system response time may have improved the accuracy of the GOMS predictions. Although the time estimates were not exact, the GOMS

model was able to correctly rank the character entry methods in order of their entry speed. This could be helpful for initial design evaluations.

The GOMS prediction for the scrolling-list-method entry time was excessively high, probably resulting from an overly generous estimation of the mental time required to press a scrolling button. Also, it was difficult to estimate an average time for the scrolling method, because the entry time depended on the location of the name in the list.

Table 3. Comparison of GOMS predictions and prototype execution times

Interface	GOMS Prediction (sec.)	GOMS Rank	Prototype test (sec.)	Time Rank	Difference (sec.)	Difference (%)
Phonepad	49.8	1	42.9	1	6.9	16.08
Qwerty	54.2	2	44.1	2	10.1	22.90
Doublepress	63.1	3	75.6	4	-12.5	16.53
Scrolling	82.5	4	55.1	3	27.4	49.73

Was steering performance in a simulator affected by concurrent entry of destinations?

The driving performance was measured by the standard deviation of the steering error (deviation from the center of the lane). Steering-error data were given in the form of pixels. The road lane image was 305 pixels wide at the point where drivers were supposed to focus. Assuming an average lane width of 10 feet, this corresponds to approximately 30 pixels per foot as the lane-deviation conversion factor.

The baseline driving data were collected during a two minute trial at the beginning of the experiment. Figure 15 illustrates that the standard deviation of steering error was much greater when using the destination entry systems than when driving only. There were significant main effects on driving performance due to age and system (the baseline condition was considered one of the systems). This difference was particularly evident for the Qwerty system. The standard deviation of the steering error was 37 pixels (an average deviation of more than a foot beyond the lane boundary) for older drivers, but only 21 pixels for younger drivers. The older driver error was partly attributable to the small size (1 cm x 1 cm) of the letter/number buttons. Some of the older drivers experienced difficulty using the smaller touchscreen buttons (sometimes they didn't have their fingers correctly positioned on the button). (The difference in Qwerty entry time between older and younger drivers was relatively small compared to the other interfaces.) Therefore, it appears that identifying and pressing the smaller, closely spaced buttons was more demanding for older drivers. To compensate for this difficulty, more attention was devoted to the destination entry task, and driving performance suffered.

While it varies with the task, the standard deviation of lateral position is typically one foot or less in actual driving. In this experiment, values exceeded one foot in several cases. This

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may be attributable to the lack of auditory feedback provided by the driving simulator. Perhaps auditory cues (the sound of squealing tires, rumble strips, etc.) indicating major lane deviations would have helped drivers realize their lane status and inspired them to pay more attention to the driving task. Since there was no penalty for driving off the road, drivers probably focused more of their attention on the destination entry system than would likely be the case if they were actually driving in traffic.

Overall, there was no significant main effect on driving performance due to the interface type (excluding the baseline driving condition). The only significant difference between interfaces was for the Qwerty versus the phonepad (Fisher PLSD, $p=.046$), and this resulted from the effect of the older drivers. In general, participants drove much worse on the simulator when they were concurrently using the destination input interface than when the only task was driving.

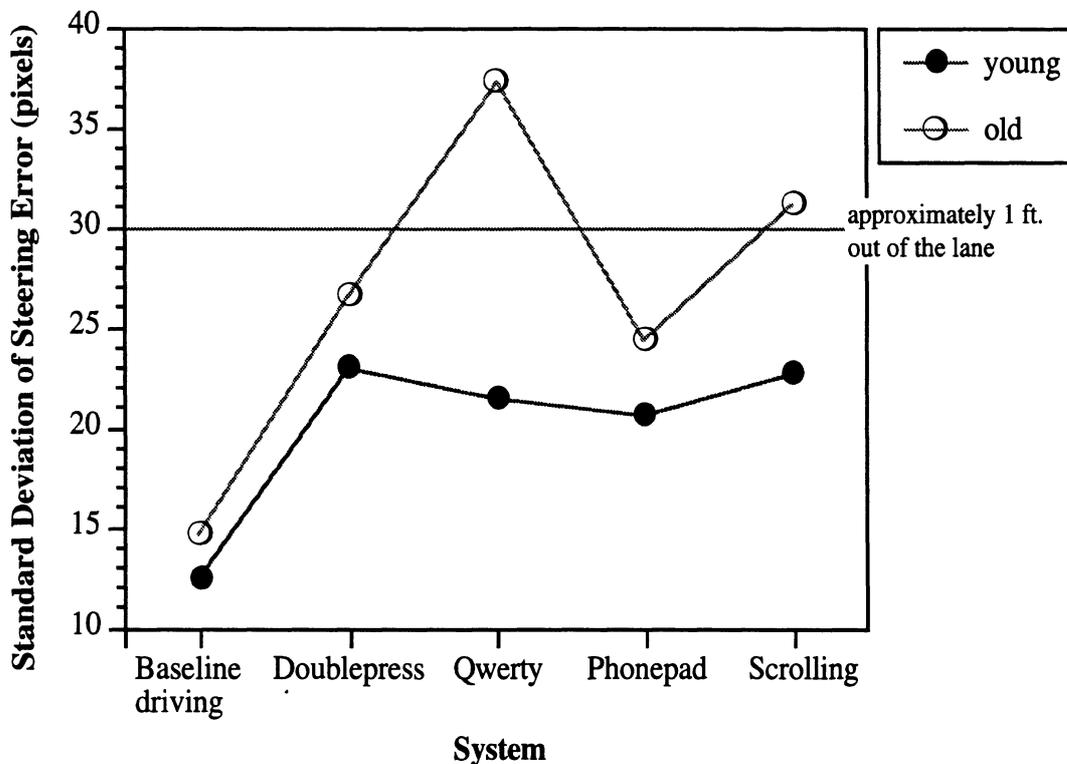


Figure 15 Driving simulator performance based on the average variance of steering error.

How did the destination input interface methods compare regarding errors?

There were a variety of common errors made by participants when using the destination input systems. For each system, a total of 384 entries (each component of a destination) were made. Errors made using the character entry methods were classified into three categories. (See Table 4.) The percentage of errors was determined by the number of destination components in which an error was made. Entering the wrong character (letter or number) was the most common error. This typically resulted in the need to use the delete key. As noted earlier, the trials during

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which letters were deleted were excluded from performance time analysis. Efforts were made to preserve as much of the data as possible. In some cases, after making a mistake, participants deleted everything and started from the beginning of the address entry. If a full, correct entry was made following an error, it was included in the analysis. Errors were occasionally made where the wrong item of the destination was entered. This should not be considered a factor of the interface design, because the destination presentation and entry order was identical for all four systems. The final error type involved the scrolling screen for name selection (when a duplicate four-letter combination was entered). Occasionally, participants went too far in the list or scrolled in the wrong direction.

Wrong-character-errors were highest (34 errors, affecting 8.9 percent of component entries) for the doublepress method. Errors could result from pressing the wrong main button, or pressing the wrong individual button. The Qwerty method resulted in 28 errors. Based on the experimenter's observations, these typically occurred from the accidental activation of adjacent buttons due to the small button size (for example, inadvertently pressing the "Q" instead of the "A"). The phonepad interface had the least number of wrong character errors (21).

The scrolling-direction errors should have been similar for the doublepress and Qwerty methods because the screen content and layout was the same. However, the doublepress had twice as many errors (14) as the Qwerty interface. Scrolling-direction errors with the phonepad system were slightly fewer (6), which was reasonable because participants were only given the names that matched the four-number code that they entered, and therefore had fewer from which to choose.

Table 4. Errors made using the character entry methods.

	Doublepress			Qwerty			Phonepad		
	wrong character	wrong item	scrolled too far	wrong character	wrong item	scrolled too far	wrong character	wrong item	scrolled too far
Young	20	4	1	12	3	7	13	0	2
Old	14	0	6	16	0	7	8	0	4
Total	34	4	7	28	3	14	21	0	6
# entries	384	384	256	384	384	256	384	384	256
% error	8.85 %	1.04 %	2.73 %	7.29 %	0.78 %	5.47 %	5.47 %	0	2.34 %

Errors made using the scrolling list system were not directly comparable to the character entry systems. Participants used many different approaches for selecting the correct name, therefore it was difficult to classify errors, since everyone eventually found the correct place in the list and selected the correct name. An error with the scrolling list system was defined as a counterproductive movement (going too far forward or backward or up or down, and then having to retrace the activity back to the desired location).

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The counterproductive movements are listed in Table 5. Errors in moving forward or backward alphabetically are indicated as "A-Z" errors. Up or down errors are those resulting from scrolling line by line using the arrow buttons (see Figure 6). Nearly 24 percent of the name entries were affected by alphabetic scrolling (going forward or backward) errors. Older participants were more prone to this (37 errors) than younger participants (24 errors) and this may have led to the longer entry times of older participants when using the scrolling list system. Errors in scrolling up and down (line by line) were less frequent (12.5 percent). Only two errors were made when entering the address number.

Table 5. Errors made using the scrolling list method

	A-Z button error	up/down button error	wrong digit
Young	24	14	1
Old	37	18	1
Total	61	32	2
# entries	256	256	128
% error	23.83 %	12.50 %	1.56%

Which interface design did drivers prefer?

There was no significant preference for a particular destination input method. (See Table 6.) The phonepad interface received the most first choice rankings (7 out of 16). However, it had a bimodal distribution. Five participants ranked it as their last choice. It is apparent that preference data from a much larger pool of subjects would be necessary before significant preference inferences could be made.

Table 6. Ranked preferences for the destination input methods (n = 16 drivers)

System	Rank 1 (best)	Rank 2	Rank 3	Rank 4 (worst)	Mean rank
Phonepad	7	2	2	5	2.4
Scrolling list	4	7	1	4	2.4
Qwerty	3	4	7	2	2.5
Doublepress	2	3	6	5	2.9

How difficult did drivers perceive the destination input task to be?

The mean difficulty ratings for the normal driving tasks and destination input tasks are shown in Figure 15. The difficulty ratings range from 1 (not at all difficult while driving) to 10 (extremely difficult to do while driving). For a complete description of the questions for which the ratings were given, see Appendix C. The average difficulty for a conventional task was 3.9. The most difficult of the tasks examined was reading a map while driving. This was also rated higher in difficulty than any of the destination input related tasks. There was no significant difference in perceived difficulty between the destination input methods. (See Figure 15.) On

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average, the doublepress method was rated slightly higher in difficulty (4.8) than the phonepad (4.4), scrolling (4.4), or Qwerty (4.2) methods.

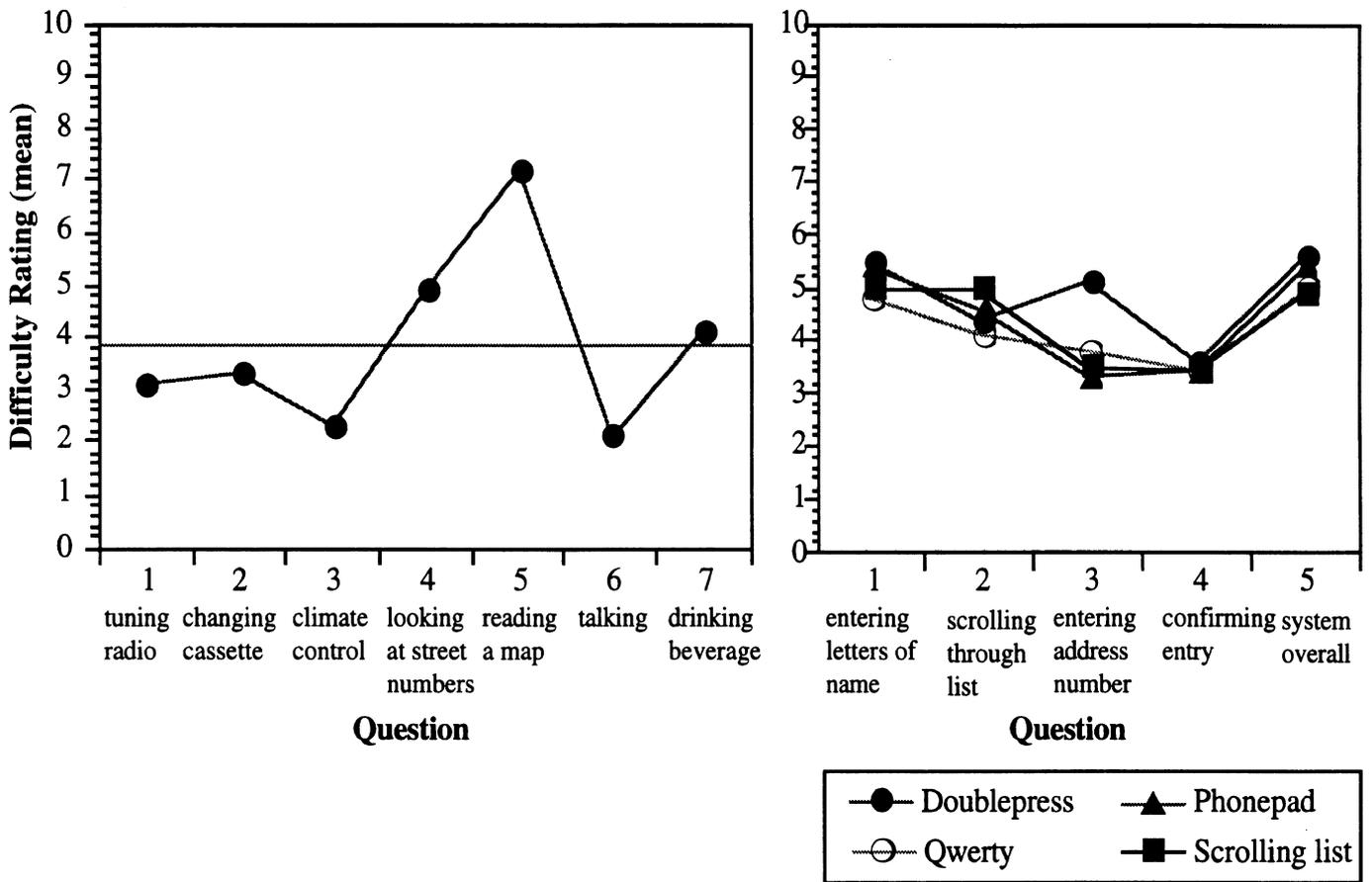


Figure 15. Difficulty ratings for various conventional and destination input tasks while driving.

Conclusions

This experiment demonstrated that drivers could effectively use four different methods for entering a destination into a navigation/route-guidance system. Response times recorded by the prototypes indicated that the doublepress system for destination entry would require the longest entry time. The Qwerty and phonepad interfaces (both single button character entry systems) would result in the quickest destination entry.

For the estimation of general, destination-entry times, the GOMS model predictions were moderately effective. The GOMS model was able to predict the rank order for times involving the character entry interface. The model may also serve as an effective tool for evaluating the effects of button size, location, and quantity on destination-entry time (based on modifications to the Find and Point elements). This could be helpful for preliminary interface evaluations. Unfortunately, the GOMS model is intended for single-task activities, and would be less applicable to estimating times for systems used while driving.

There were several factors that affected destination-entry time. The driving status (whether parked or driving while using the system) had an effect on entry time. The increased time needed to enter a destination while driving was particularly evident when using the scrolling list method to select a city or street name. The age of drivers also affected the destination-entry time. Older drivers required much more time than younger drivers to enter a name from a long list using the scrolling method. The doublepress system was least affected by the age of a driver, as well as the driving status during entry.

Errors using the character-entry interfaces were the lowest for the phonepad method, followed by Qwerty, and highest using the doublepress method. Errors for the scrolling list method were defined differently, and indicated that counterproductive movements were made in nearly one-fourth of the entries. Although learning and practice effects were not examined in this experiment, it appeared that the learning procedure for the scrolling list interface would likely be different than that for the character entry systems, as many strategies could be used to eventually reach and enter the desired name using the scrolling list method. In order to efficiently use the scrolling list interface, a driver must adopt a strategy for reaching a desired name from a potentially long list of candidates. This activity appeared to be more difficult for older drivers. In contrast, the strategy for using the character entry interfaces was more defined. It would be interesting to see how drivers interact with the different systems after using them over a longer period of time.

Participants were more likely to drive out of a lane on a driving simulator when entering a destination than when actually driving. Older drivers experienced large lane deviations when using the Qwerty destination interface while driving the simulator. This was believed to result

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partly from the smaller button sizes and greater number of individual buttons from which to choose. The lane deviations recorded by the driving simulator demonstrate that the destination entry task distracts from driving attention. To gain more reliable data, an enhanced simulator should be used. Auditory cues signaling lane deviations would probably help keep drivers' attention on the driving task and better represent their behavior in an actual driving environment. An incentive system may also help inspire participants to more realistically devote attention to the driving task (Allen, Stein, Rosenthal, Ziedman, Torres, and Halati, 1991).

Although the simulator used in this experiment ultimately functioned more as a tracking device, it was still apparent that using the destination input systems while driving required attention that was taken away from the driving task. A more realistic simulator or field studies would better indicate whether drivers are capable of effectively shifting their attention based on the demand of the driving situation. Wierwille et. al, (1989) reported that for the navigation task itself, drivers were capable of properly focusing their attention on the driving task when it became more demanding. The destination input task is considered one of the "pre-drive" tasks by the TravTek project, which implies that it is more demanding than using the basic navigation information while driving. The lack of consensus on what, if any, tasks should be limited to "pre-drive" activities suggests that laboratory and field tests should be conducted to further address this issue. Based on this study, it appears that entering a destination while driving would negatively affect driving performance.

Participants in the study perceived the destination-entry task to be only moderately difficult. On a 10-point scale (with 10 being extremely difficult), the average difficulty of the related activities of the entry task was given a rating of less than 5. The perceived difficulty ratings for entering a destination while driving were only slightly higher, on average, than for several tasks sometimes performed while driving. The limited number of participants in this study did not express a clear preference for either of the four destination input methods tested.

The comparison of the four destination interface methods identified several human factors issues that were compromised depending on the interface design. For the character entry methods, entry time was shortest for the methods that required only one button press per letter entry. This was supported by both the actual data and the GOMS analysis. Unfortunately, the use of a single button press required compromising other human factors principles. For the Qwerty method, the button sizes (1 cm x 1 cm) were much smaller, due to the need to fit 36 buttons onto the small screen. The reduced button size was particularly a problem for older drivers (especially while driving the simulator).

The phonepad design had a moderate button size, but provided less direct feedback regarding the city and street name entries, because entries were actually made as numbers. In contrast, the doublepress method provided good feedback and button sizes, but required twice as

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many button presses, resulting in a much longer time required for destination entry. The effective use of the phonepad method demonstrated a potential interface option that could be used in after-market systems that lack a touchscreen. Additional tests to examine the control of other features of a navigation/route-guidance system would be necessary before considering this option further.

It was difficult to make a recommendation for one particular destination input method based on this study, given the tradeoffs previously mentioned. An interesting point to consider when determining an input method is the ability (or inability) of older drivers to use the system. Older drivers had a particularly difficult time using the Qwerty method while driving, most likely due to its small button size. They also had a difficult time deciding how to efficiently use the scrolling list method.

This experiment only examined entry methods utilizing a touchscreen as the input device. Furthermore, the effects of wearing gloves and variations in vehicle dynamics (e.g., cars versus trucks) on touchscreen usability were not examined. Control of the system through other methods may be more effective. This study showed that all four of the methods examined were usable by drivers. Efforts should be made to have a destination entry method that is easy and convenient to use, to encourage frequent use of a navigation/route-guidance system. If the destination input method is too complicated or inconvenient, the entire system may go unused and the potential benefits will not be realized.

Conclusions

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Appendix A - List of City and Street Names

Cities

ALBANY
ALLENDALE
ANDREWS
ATHENS
AUGUSTA
AURORA
BEDFORD
BENNETT
BENTON
BLOOMFIELD
BOSWELL
BREMEN
BRIDGEPORT
BRIMFIELD
BURROWS
CAMBRIDGE
CARMEL
CARWOOD
COLLINS
DALE
DANVILLE
DUGGER
EDGEWOOD
ELMWOOD
ELROD
FAIRMOUNT
FARMLAND
FOWLER
FRANKLIN
FRANKTON
FREMONT
GREENDALE
GREENFIELD
GREENTOWN
GREENWOOD
HAMILTON
HAMMOND
HARTSVILLE
HIGHLAND
JAMESTOWN
JASPER
KINGSLAND
KNISGHTSTOWN
LARGO
LAWRENCE

LEWISVILLE
LINDEN
MIDDLEBURY
MITCHELL
MOORESVILLE
MURRAY
NEWBURG
NEWMAN
NEWPORT
OSGOOD
OSSIAN
PARAGON
PARKER
PIKEVILLE
PITTSBURG
PORTAGE
RAMSEY
REMINGTON
RICHMOND
ROCKVILLE
SALEM
SEYMOUR
SHELburn
SPENCER
SULLIVAN
THORNTOWN
TREATY
UNDERWOOD
UPLAND
VERNON
WALLACE
WALTON
WATERFORD
WHEELING
WILLIAMS
WILLIAMSBURG

Streets

ABBOTT
ABERDEEN
ABINGTON
ADA
ADAMS
ALDRICH
ALFRED
ALGER

ALGOMA
ALGONQUIN
ALSDORF
ALTON
AMAERST
AMBER
ANDERSON
ANDREA
ANDREW
ANN
APACHE
APOLLO
APPLE RIDGE
APPLE TREE
APPLEWOOD
ARBOR
ARCADIA
ARC
ARDEN
ARLENE
ARLINGTON
ARROWHEAD
ASH
ASHLEY
ASTOR
ATLANTA
ATTWOOD
AUDUBON
AVERILL
AVON
BABBIT
BAILY
BAKER
BALDWIN
BALFOUR
BALLARD
BALZER
BANCROFT
BANGHART
BARCLAY
BARKER
BARNARD
BARON
BARTON
BASS
BASSET
BATES
BAYSHORE

Appendix A - List of Cities and Streets Used In Database

BAYVIEW	BROOK	CLARK
BAYWOOD	BROOKFIELD	CLAYBORN
BEAL	BROOKLAND	CLAYTON
BEAUMONT	BRUCE	CLEO
BEAVER	BURCHAM	CLEVELAND
BEDFORD	BURCHFIELD	CLIFFORD
BEECH	BURGUNDY	CLIFTON
BEECH RIDGE	BURNING	CLINTON
BEFORD	BUTLER	CLIPPERT
BELMONT	BUTTERFIELD	COLBY
BENJAMIN	BUTTERNUT	COLEMAN
BENNETT	BYRNES	COLLEGE
BENNINGTON	CABOT	COLLINGWOOD
BENSON	CADE	COLLINS
BERKLEY	CADILLAC	COLONY
BERKSIRE	CADY	COLORADO
BERRY	CAHILL	COLUMBINE
BERWICK	CAMBRIDGE N.	COMMUNITY
BEULAH	CAMBRIDGE S.	CONCORD
BIBER	CAMELOT	CONGRESS
BILLWOOD	CAMEO	CONNERS
BILTMORE	CAMP	CONRAD
BIRCH	CAPITOL	CORNELL
BIRCH ROW	CARDIFF	COTTAGE
BIRCHWOOD	CAREY	COVINGTON
BISHOP	CARLTON	COWLEY
BLACK	CASE	COX
BLACKBERRY	CATHERINE	CRANBROOK
BLAKE	CAVANAUGH	CREST
BLANCHE	CAWOOD	CRESTON
BLOOMFIELD	CEDAR	CRESTWOOD
BLOSSOM	CEDARBROK	CROWN
BLUE RIDGE	CEDARHILL	CULLOUGH
BLUE RIVER	CENTER	CULVER
BOGART	CHARLES	CUMBERLAND
BOGUE	CHARLESTON	CURRY
BOLLEY	CHARLOTTE	CYNWOOD
BONITA	CHERRY	CYPRESS
BONNET	CHERRY HILL	DAFT
BOSTON	CHERRYLAND	DAGGOTT
BRAD	CHERRYWOOD	DAHLIA
BRADFORD	CHESTER	DAISY
BRADLY	CHIPPEWA	DAKIN
BRAEBURN	CHRIS	DANVURT
BRAMAN	CHRISTANCY	DARBY
BRAMBLE	CIRCLE E.	DARLINGTON
BRETTON	CIRCLE W.	DARRON
BRIARCLIFF	CLARE	DAVID
BRIGHTON	CLAREDON	DAVIDSON

Appendix A - List of Cities and Streets Used In Database

DELL	EMERAL	GENESEE N.
DELLRIDGE	EMERSON	GENESEE S.
DEL MAR	EMILY	GEORGE
DELOFF	EUREKA	GILBERT
DELRAY	EVERETT	GINGER
DELTA	EVERTTDALE	GLASGOW
DEPOT	EVERGREEN	GLENBROOK
DESNDER	EXECUTIVE	BLENBURGNE
DETROIT	FAIRFAX	GLENCREST
DEVONSHIRE	FAIRFIELD	GLENDALE
DEXTER	FAIRLANE	GLENDEN
DIBBLE	FAIRVIEW	GLENMOOR
DOBIE	FAIRWAY	GOODRICH
DONALD	FAMINGO	GORDON
DONEGAL	FAUNA	GOSSARD
DONNA	FELT	GOULD
DONOVAN	FELTON	GRACE
DORNET	FENTON	GRAND
DOROTHY	FERGUSON	GRANDELL
DORRANCE	FERNWOOD	GRAND RIVER
DOUGLAS	FERROL	GRANDVIEW
DOVELLE	FIDELITY	GRANGER
DOVER	FIELDCREST	GRANITE
DOWNER	FIELDING	GRANT
DURANT	FLAGSTONE	GRANTSBURG
DURWELL	FLETCHER	GRAY
DWIGHT	FLORENCE	GREEN
EARL	FORBES	GREENBELT
EAST	FOREBANKS	GREENBRIAR
EAST CHESTER	FOREST	GREENCLIFF
EASTFIELD	FOREST HILLS	GREENCREST
EAST GATE	FORREST GLEN	GREENCROFT
EASTLAWN	FOSTER	GREENLAWN
EASTWOOD	FOUNTAIN	GREENMAN
EATON	FRANKLIN	GREENOAK
ECHO	FRANKLYNN	GREENVIEW
EDDIE	FREDFREDERICK	GREENWAY
EDGEBROOK	FULLER	GREENWOOD
EDGEMONT	FULTON	GRISWOLD
EDGEWOOD	FAGE	GROSEBECK
EDISON	GAINSBOROUGH	GUENTHER
EIFERT	GALGARY	GULL
EIGHT	GALWAY E.	GUNSTON
ELIZABETH	GALWAY W.	HACO
ELEN	GARDEN	HADEMEN
ELM	GARFIELD	HAGADORN
ELMORE	GARLAND	HALL
ELMWOOD	GARY	HALLEDALE
ELVIN	GATEWOOD	HALLOWAY

Appendix A - List of Cities and Streets Used In Database

HAMELON
HAMILTON
HAMMOND
HANNAH
HANOVER
HARDING
HARDY
HARRIS
HARRISON
HART
HARTON
HARVARD
HARVEST
HARVEY
HATCH
HATHAWAY
HAVEN
HAVERHILL
HAZEL
HAZELWOOD
HEATHER
HEIGHTS
HERITAGE
HERRICK
HERRON
HESS
HIGH E.
HIGH N.
HIGHGATE
HIGHLAND
HILL
HILLCREST
HILLSIDE
HILLTOP
HOLIDAY
HOLLYWAY
HOLLYWOOD
HOMES
HORTON
HOWARD
HOWE
HUGHES
HUNT
HUNTINGTON
HUNTER
HURON
HYLAND
INDIANA
INDIAN HILLS

INGERSOLL
INNER
IRIS
IROQUIOS
IRVINTON
ISBELL
ISLAND
JACKSON
JAMES
JAY
JENISON
JEWEL
JOHN
JOHN R.
JOHNSON
JOLLY
JONES
JULIA
JULIAN
JUNE
JUSTICE
KAISER
KALAMAZOO
KANSAS
KAPLIN
KELSEY
KENBERRY
KENBROOK
KENDALWOOD
KENDON
KENNEDY
KENNMORE
KENSINGTON
KENT
KENTFIELD
KENWAY
KENWICK
KENWOOD
KESSLER
KEYSTONE
KILBORN
KING
KINGSLEY
KINSWOOD
KRIBY
KIRKWOOD
KNOLL
KNOLLWOOD
LA BELLE

LAFAYETTE
LAGOON
LAKE
LAKEVIEW
LAMONT
LAND
LONDON
LANSDOWN
LANSING
LANTERN HILL
LARCH
LATHAM
LATHROP
LAURIE
LAWLER
LAWN
LEAWOOD
LEDGE
LEE
LELAND
LENORE
LERNER
LESHER
LESLIE
LEWTON
LEXINGTON
LIBBY
LINDEN
LINDY
LINLAWN
LINVAL
LOCKMORE
LOGAN
LOGAN ACCESS
LONGFELLOW
LOWELL
LUCIE
LUWANNA
LYMAN
LYNDHURST
LYNWOOD
LYONS
MAC
MACDOUGAL
MACK
MADON
MADISON
MAIN
MAJESTIC

Appendix A - List of Cities and Streets Used In Database

MALIBU	MULLET	OTTO
MALL	MUNSON	OVERLEA
MANITOU	MUREL	OWEN
MANOR	MURPHY	OXFORD
MANSFIELD	NAKOMA	PACIFIC
MAPLE	NAUBINGWAY	PACKARD
MAPLEHILL	NAVAHO	PALMER
MAPLEWOOD	NELLER	PARIS
MARBLE	NESTOR	PARK
MARGUERITE	NEWPORT	PARKDALE
MARIGOLD	NORBURN	PARKER
MARION	NORMAN	PARK LAKE
MARSH	NORTH	PARK LANE
MARSHALL	NORTHAMTON	PARKVALE
MARTIN	NORTH CEDAR	PARKVIEW
MARTINUS	NORTHCREST	PARKWAY
MARY	NORTHDAL	PARKWEST
MARYLAND	NORTHGATE	PARKWOOD
MAUMEE	NORTHRUP	PEARL
MAX	NORTHVIEW	PEBBLEBROOK
MAY	NORTHWARD	PEBBLESTONE
MAYBEL	NORTHWEST	PERCH
MAYCROFT	NORTH WIND	PERCKINS
MAYFAIR	NORTHWOOD	PERRY
MAYFIELD	NORWICH	PERSHING
MAYLAND	NOTTINGHAM	PERSON
MC KINLEY	NUGGET	PETTIS
MEADOW	OAK	PHEASANT
MEADOWBROOK	OAKCLIFF	PHILLIPS
MEADOWDALE	OAKCREST	PICARDY
MEADOWLANE	OAKHILL	PIERCE
MEADOWLEDGE	OAKLAND	PIERSON
MEADOWVIEW	OAKLANE	PIKE
MELODY	OAKLAWN	PINE
MELVIN	OAKRIDGE	PINECREST
MERRILL	OAKWOOD	PINE DELL
MERRITT	OCHA	PINE FOREST
MERRY	OLD CANTON	PINEHURST
MIDWAY	OLD HICKORY	PINE RIDGE
MIDWOOD	OLD MILL	PINE TREE
MILL	OLD RIVER	PINEWOOD
MILLER	OLDS	PINGREE
MILLET	OLIN	PIONEER
MOHICAN	ONTARIO	PLAINFOED
MONROE	ORCHARD	PLEASANT GROVE
MOORE	ORLANDO	PLEASANT VIEW
MOORES RIVER	OSBORN	PLYMOUTH
MORELA	OTIS	POLLARD
MORGAN	OTTAWA	PONTIAC

Appendix A - List of Cities and Streets Used In Database

PORTER
POTTER
POWELL
PRINCETON
PROSPECT
QUADRILLE
QUAIL
QUEEN
QUENTIN
QUINCY
RABY
RACE
RADFORD
RALEIGH
RALPH
RANGER
RAVENSWOOD
RAY
RAYBORN
RAYMOND
RAYNELL
REASONER
RED CEDAR
RED LEAF
REDNER
REDWING
REDWOOD
REGENT
RESEARCH
REVERE
REYNOLDS
RICE
RICHARD
RICHARDS
RICHARDSON
RICHMOND
RICKARD
RIDGE
RIDGEFIELD
RIDGELINE
RIDGEWAY
RIVER
RIVERIA
RIVER RIDGE
RIVERSHIELL
RIVERSIDE
RIVERVIEW
RIVERWOOD
ROANOKE

ROBBINS
ROBERT
ROBERTS
ROBERTSON
ROBINSON
ROCKFORD
ROE
ROSE
ROSEDALE
ROSELAND
ROSELAWN
ROSEMARY
ROSEMONT
ROSEWOOD
ROYALE
RUSSEL
RUTGERS
RUTH
RUTHERFORD
SALINE
SAGINAW
SANDERS
SANDHILL
SANDHURST
SANDLYN
SAND PIPER
SANFORD
SCHAEFER
SCHOOL
SCHULTS
SCIENCE
SCOTT
SENATE
SENECA
SEYMOUR
SHAKER
SHANNON
SHAW N.
SHAW S.
SHAW LANE
SHAWNEE
SHEFFER
SHEFFIELD
SHELDON
SHERIDON
SHERWOD
SHIAWASSEE
SIDNEY
SKYE

SKYLINE
SKYWAY
SMITH
SMITHFIELD
SOMERSET
SORAN
SOUTH
SOUTHBROOK
SOUTHFIELD
SOUGHTGATE
SOUTHLAND
SOUTHWOOD
SPARROW
SPRUCEWOOD
STABLER
STADIUM
STAFFORD
STARWICK
STILLMAN
STILLVALLEY
SILLWELL
STIRLING
STONECRAFT
STONEGATE
STONELEIGH
STONERIDGE
STONEWOOD
STRATFORD
SUMMerville
SUMMIT
SUNSET
SUPERIOR
SUSSEX
SWEET
SYCAMORE
SYLVESTER
TACOMA
TAFT
TAHOE
TAMARACK
TANGLEWOOD
TAYLOR
TECUMSEH
TEMPLE
THEO
THEODORE
THOMAS E.
THOMAS W.
THOMPSON

Appendix A - List of Cities and Streets Used In Database

TORRANCE	WESTWOOD
TOURAINÉ	WEYMOUTH
TOWER	WHISTLER
TOWNER	WHITE HILLS
TOWNSEND	WHITE OAK
TROWBRIDGE	WHITE POND
TULANE	WHITMAN
TULIP	WILDWOOD
TURNER	WILLARD
UNIVERSITY	WILLIAM
UPTON	WILLIAMS
VALLEY	WILLIAMSBURG
VALLEYVIEW	WILLIAMSON
VANCE	WILLOW
VASSAR	WINDSOR
VERMONT	WINSTON
VICTOR	WINTER CREST
VIKING	WISCONSIN
VINE	WOOD
VIRGINIA	WOODBINE
WABASH	WOODBURY
WABEEK	WOODCRAFT
WADSWORTH N.	WOODCREEK
WADSWORTH S.	WOODGATE
WAGNER	WOODHAVEN
WALNUT	WOODINGHAM
WALNUT HEIGHTS	WOOD ISLAND
WALSH	WOODLAND
WALTON	WOODLAND PASS
WARDCLIFF	WOODLAWN
WARDELL	WOODMER
WARREN	WOODROW
WASHTENAW	WOODRUFF
WAVERLY	WOODVIEW
WAYBURN	WOODVILLE
WAYCROSS	WOODWORTH
WEGER	WORDEN
WELLINGTON	WYCKHAM
WESLEY	YORK
WEST	YORKLEIGH
WESTBURY	YORKTOWN
WESTCHESTER	YOUNG
WESTERN	YUNKER
WESTFIELD	
WESTGATE	
WESTMORELAND	
WESTMOUNT	
WESTON	
WESTVIEW	

Appendix B - Destinations Entered by Participants

Doublepress

MITCHELL
2865 LEXINGTON

HAMMOND
1180 SEYMOUR

VERNON
2297 WESTGATE

ROCKVILLE
2290 DOVER

ATHENS
1329 ROSELAND

BEDFORD
3580 LOGAN

RICHMOND
3170 MEADOWLANE

FAIRMOUNT
7245 BROOKFIELD

LEWISVILLE
5268 CRESTWOOD

Qwerty

CARMEL
2350 GREENBRIAR

NEWMAN
1658 BENNETT

PORTAGE
5378 GRANGER

EDGEWOOD
2895 BERKSIRE

FOWLER
1427 BIRCHWOOD

LINDEN
7795 ARBOR

SPENCER
2289 STONEWOOD

JAMESTOWN
6290 ANDREW

MITCHELL
1226 FAIRLANE

(Practice trials are
shown in italics.)

A - Z SCROLL

NEWPORT
7754 KENMORE

DANVILLE
4692 BABBIT

FRANKTON
5529 RADFORD

HARTSVILLE
1988 SOUTHWOOD

LAWRENCE
2865 COLLINS

RAMSEY
1490 FLETCHER

PIKEVILLE
5673 FAIRVIEW

NEWBURG
2389 MILLER

CARWOOD
4385 MAPLEWOOD

Phonepad

WALDEN
9780 MAPLEWOOD

ELROD
2243 MAPLE

DUGGER
8755 NORTHDALE

BOSWELL
1694 KENWICK

COLLINS
9744 GREENCLIFF

HIGHLAND
3761 ANDERSON

GREENWOOD
6489 SCHOOL

ELMWOOD
5348 BIRCH ROW

UPLAND
3586 THOMPSON

Appendix B - Destinations Entered by Participants

Appendix C - Difficulty Survey

Appendix D - Biographical Data Form

University of Michigan Transportation Research Institute Human Factors Division		Subject: <input style="width: 80px;" type="text"/>
Biographical Form		Date: <input style="width: 80px;" type="text"/>
Name: _____		
Male	Female (circle one)	Age: _____
Occupation: _____		
Education (circle highest level completed):		
	some high school	high school degree
	some trade/tech school	trade/tech school degree
	some college	college degree
	some graduate school	graduate school degree
Other: _____		
(If retired or student, note it and your former occupation or major)		

What kind of car do you drive the most?
Year: _____ Make: _____ Model: _____
Annual mileage: _____

Have you ever driven a vehicle with a navigation system? yes no					
How comfortable are you using maps?					
<table style="width: 100%; border: none;"> <tr> <td style="text-align: center;">very comfortable</td> <td style="text-align: center;">moderately comfortable</td> <td style="text-align: center;">neutral</td> <td style="text-align: center;">moderately uncomfortable</td> <td style="text-align: center;">very uncomfortable</td> </tr> </table>	very comfortable	moderately comfortable	neutral	moderately uncomfortable	very uncomfortable
very comfortable	moderately comfortable	neutral	moderately uncomfortable	very uncomfortable	
Have you ever used a touchscreen? yes no					
How often do you use a computer?					
<table style="width: 100%; border: none;"> <tr> <td style="text-align: center;">never</td> <td style="text-align: center;">less than once a month</td> <td style="text-align: center;">a few times a month</td> <td style="text-align: center;">a few times a week</td> <td style="text-align: center;">every day</td> </tr> </table>	never	less than once a month	a few times a month	a few times a week	every day
never	less than once a month	a few times a month	a few times a week	every day	
How comfortable are you typing (on a standard typewriter or computer keyboard)?					
<table style="width: 100%; border: none;"> <tr> <td style="text-align: center;">very comfortable</td> <td style="text-align: center;">moderately comfortable</td> <td style="text-align: center;">neutral</td> <td style="text-align: center;">moderately uncomfortable</td> <td style="text-align: center;">very uncomfortable</td> </tr> </table>	very comfortable	moderately comfortable	neutral	moderately uncomfortable	very uncomfortable
very comfortable	moderately comfortable	neutral	moderately uncomfortable	very uncomfortable	

TITMUS VISION: (Landolt Rings)													
1	2	3	4	5	6	7	8	9	10	11	12	13	14
T	R	R	L	T	B	L	R	L	B	R	B	T	R
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13

Appendix D - Biographical Form

Appendix E - Consent Form

Evaluation of Destination Input Methods Participant Consent Form

In cars of the future, you may have a navigation system which would tell you how to reach your destination. In order to use it, you'll need to tell the system where you want to go. We are looking at different methods for providing this destination information (city, street name, and address number) to the navigation system. Responses from typical drivers such as you, will help identify the best way to input this information to a system.

While sitting in a vehicle mockup, you will respond to a touchscreen display located inside the car. This display will provide buttons that you can use to enter your destination. A computer will record how long it takes you to enter the destination. We may videotape this session, but only if you allow us. We will not release any identifying information, so your responses will remain confidential.

The experiment takes about 1-1/2 hours for which you will be paid \$20. You may take a short break between system testing if you like. If you have any problems completing this experiment, you can withdraw at any time. You will be paid regardless.

I have read and understand the information above.

Print your name

Date

Sign your name

Witness (experimenter)

It is OK to videotape me: yes no (circle one)

Appendix E - Consent Form

Appendix F - Subject Instructions

Destination Input Method Study Subject Instructions

Make sure there are blank consent forms, bio forms, support voucher, and money for payment.

When participant arrives:

Are you ____? Hello, my name is _____ and I am one of the experimenters working on the traffic information study. Before we get going I would like to note this experiment takes approximately 1 1/2 hours and you will be paid 15 dollars for your time. If you would like to visit the rest room, now would be a good time to do so. Also smoking is prohibited in this building, so please refrain from doing so.

Go into lab. Flip "Experiment in Progress" sign over.

In this study, we're looking at ways for you to tell your car where you want to go. Specifically, pretend that you have a navigation system in your car. This system would give you directions to your destination—but first you have to tell it where that destination is. The purpose of this experiment is to determine the best way for drivers to input their destination into a navigation system. You may be doing this while you're stopped in your car, or perhaps while you're driving. Therefore, we want the system to be easy-to-use so it won't distract or frustrate you. The results of this study may be used for designing navigation systems in future vehicles. Since you will be driving those vehicles, your opinion is important.

Before we start, there is some paperwork to complete. First, you need to sign this official consent form, which basically repeats in writing what I just said.

Have participant sign consent form.

Also, we need to know a little more about you.

Fill out bio form with subject.

Test subjects vision. Make sure both eye switches are on.

Have participant sit in buck.

You'll be sitting in this car throughout the study. Half of the time you will use the system while you're "parked" and the other half you will be driving the UMTRI driving simulator as you input the destinations. Please position yourself as if you were driving. Are you comfortable? Would you like the seat moved at all?

Adjust seat if necessary.

I am going to turn off the lights now and show you what the driving scene will look like.

Turn out lights.

Appendix F - Subject Instructions

The driving scene is similar to nighttime where you'll see road markers on the edge of the lanes. The road scene looks like this (turn on simulator). Try to stay in the middle of the road at all times. Please try driving on it for a little while and let me know when you feel comfortable with it.

Run Driving Simulator for 2 minutes. Ask if comfortable driving the simulator

OK, now I'd like you to drive the simulator for 2 minutes just to get some basic driving data.

Run Simulator for 2 minutes and save as S#.BASE

Great, now I'll turn the lights on and explain the rest of the study. As I mentioned before, in this study you'll be telling a navigation system where you want to go. There are four different methods or systems that you will use. All of the systems will appear on this display (point). They will use a touchscreen, so all you have to do is press on the "buttons" that appear on the display.

Have you ever used a touchscreen before?

Refer to bridal registry and other examples

Here is a short practice session so you can see how the touchscreen works. Do you have any questions

Answer questions.

Run touchscreen tutorial

Here is a book that you will use during the study. On each card there is a different destination. Every card is arranged the same. The top line has the city that your destination is in. You will enter that first. The bottom line gives the street address that you are trying to reach. This is the number (point) and this is the streetname (point). You will enter the streetname next, and then the address number last. The system will tell you which item to enter.

When you hear a voice say "next destination" please flip to the next card and enter that destination. For each system, you will enter the first 5 destinations while "parked" (so you won't have to drive or do anything else). Then you will enter the last 5 destinations while you drive the simulator. When "driving", please remember that it is important to stay in the middle of the lane even while you are entering the destination.

I will explain each system to you before you use it, and give you a chance to practice. Do you have any questions?

Start recording videotape

Appendix F - Subject Instructions

CHECKLISTS FOR EXPLAINING EACH SYSTEM TO SUBJECTS

Doublepress

For this system, you need to press a sequence of two buttons to enter a letter or number. Each of the main buttons have 2 or 4 letters assigned to them. When you press a main button, individual buttons for each of the letters or numbers appear down here. (point) You can press the individual letter you want here to enter it in the display.

To be consistent, please enter only the first four letters of each city or streetname. When the first four letters appear in the display, press the "Done" button. This will tell the system to search for the street or city and ask you to verify which one you wanted. If for some reason you'd like to re-enter the first four letters, press the "Go Back" button and it will take you back to the previous screen. Please note that you may have to scroll up or down to find the exact name you're looking for. When the name is highlighted in black, press the "Done" button. Now you'll enter the streetname in a similar manner. When you've entered and selected the streetname, enter the digits in the address number, and press "Done". This completes the entry of the destination. You can then ignore the system until you're asked to enter the "next" destination.

Do you have any questions? Here's a practice destination for you to try. Do you feel comfortable using the system? OK, let's begin. When you hear the "enter destination" cue, flip to the next destination and press the "enter destination" button.

QWERTY

This system uses a keyboard-style arrangement of buttons which is similar to a typewriter or computer keyboard. Press the key that corresponds to the letter or number you want to appear in the display.

To be consistent, please enter only the first four letters of each city or streetname. When the first four letters appear in the display, press the "Done" button. This will tell the system to search for the street or city and ask you to verify which one you wanted. If for some reason you'd like to re-enter the first four letters, press the "Go Back" button and it will take you back to the previous screen. Please note that you may have to scroll up or down to find the exact name you're looking for. When the name is highlighted in black, press the "Done" button. Now you'll enter the streetname in a similar manner. When you've entered and selected the streetname, enter the digits in the address number, and press "Done". This completes the entry of the

Appendix F - Subject Instructions

destination. You can then ignore the system until you're asked to enter the "next" destination.

Do you have any questions? Here's a practice destination for you to try. Do you feel comfortable using the system? OK, let's begin. When you hear the "next destination" cue, flip to the next destination and press the "enter destination" button.

PHONEPAD

With this system, you'll use a keypad similar to that of a telephone to enter the city, street, and number of the destination. To enter the city and street names, use the number button that corresponds to the letter you want to type. For example, to type DOG, you would press 364. When you type the letter, you will see only the corresponding number in the display. For this system, it is very important that you type ONLY the first 4 letters of the name (no more and no less). You can use the delete key if you make a mistake or want to change something. When the first 4 letters are entered and appear in the display, press "DONE" This will search the database and will show all of the names that correspond to the 4 digit code you entered. Use the up and down arrow buttons to highlight the particular name you're interested in. When that name is highlighted, press "DONE". You will enter the city name and street name in this manner. After you have done both, enter the address number by using the numbers on the keypad. When the correct number appears in the display, press "DONE" and continue driving until the "next destination" cue.

Remember -- enter the city name first, the street name second, and the address number last.

Do you have any questions? Here's a practice destination for you to try. Do you feel comfortable using the system? OK, let's begin. When you hear the "next destination" cue, flip to the next destination and press the "enter destination" button.

A-Z

With this system, you select the city or street name by advancing letter by letter in the alphabet. All of the names are listed in alphabetic order. Use these buttons (point to A and Z) to move toward the beginning or end of the alphabet. When you reach the first letter of the name, use these buttons (point to arrows) to move up and down within the letter so you can highlight the correct name. Once the correct city or street name is highlighted, press "DONE". You will use this method to select the city and street of your destination. You will enter the address number using a number pad that is similar to that on a

Appendix F - Subject Instructions

telephone. When the correct number appears in the display, press the "DONE" button and continue driving until you hear the "next destination" cue.

Do you have any questions? Here's a practice destination for you to try. Do you feel comfortable using the system? OK, let's begin. When you hear the "next destination" cue, flip to the next destination and press the "enter destination" button.

OK, you're done using the systems now. Before you leave, I'd like to find out which system you prefer. Here are pictures of each of the four systems you used.

Show them the preference ranking sheet

Please rank them in the order that you would like them with 1 being best and 4 being worst.

Thank you for your help. Pay them \$20.

Appendix F - Subject Instructions

Appendix G - GOMS Model Analysis

Operators used in GOMS models

<i>Olson & Olson (1990)</i>			
button press	K	0.28	(estimate for keystroke)
move hands to display	H	0.4	(estimate from mouse to keyboard)
mental operation	M	1.35	(LTM, WM retrieval)
<i>Derived from Card, Moran, and Newell (1983)</i>			
Interface	finding button (F)	pointing (moving) finger to button (P)	
Doublepress			
main button	.52		.15
individual	.35		.15
Qwerty	.78		.23
Phone	.50		.14
Scrolling list			
letter	.24		.16
number	.50		.14
Eye movement (look) L = .23 seconds (all interface designs)			

Calculations from Model Human Processor

Find times (F)

Uncertainty principle. Decision time T increases with uncertainty about the judgment or decision to be made

$$T = I_c H$$

$$I_c = 150 \text{ msec/bit}$$

$$H = \log_2(n+1)$$

n = the number of alphanumeric buttons on the interface

Doublepress

main letter/number button $T = 150 * \log_2(10+1) = 518.9 \text{ msec}$

individual letter button $T = 150 * \log_2(4+1) = 348.3 \text{ msec}$

Qwerty

$$T = 150 * \log_2(36+1) = 781.4 \text{ msec}$$

Phonepad

$$T = 150 * \log_2(9+1) = 498.3 \text{ msec}$$

Scrolling list

$$T = 150 * \log_2(2+1) = 237.7 \text{ msec}$$

Point times (P)

Fitt's Law. The time T_{pos} to move the hand to a target of size S which lies a distance D away is given by

$$T_{pos} = I_m * \log_2(D/S+0.5)$$

$$I_m = 100 \text{ msec/bit}$$

Doublepress: The average movement distance between buttons is 4.5 cm. Buttons are 2 cm wide

$$T_{pos} = 100 * \log_2(4.5/2+0.5) = 145.9 \text{ msec}$$

Qwerty: The average distance (within and between rows) is 4.5 cm. Buttons are 1 cm wide.

$$T_{pos} = 100 * \log_2(4.5/1+0.5) = 232.2 \text{ msec}$$

Phonepad: The average movement distance over all possible movement combinations is 3.3 cm. The buttons are 1.6 cm wide.

$$T_{pos} = 100 * \log_2(3.3/1.6+0.5) = 135.0 \text{ msec}$$

Scrolling list: The average movement between the four scrolling buttons is 5 cm. The buttons are 2 cm wide.

$$T_{pos} = 100 * \log_2(5/2+0.5) = 158.5 \text{ msec}$$

Appendix G - Doublepress GOMS Analysis

operator	oper. time	goal time	# of times exec	Total time	# of NGOMSL statements	Description
M	1.35					Method to accomplish goal of entering destination Step 1. Get address information Step 2. Accomplish the goal of entering address item
		1.35	1	1.35	3	
						Selection rule for the goal of entering address item If the task is entering the City then Accomplish the goal of entering the City If the task is entering the Street name then Accomplish the goal of entering the Street If the task is entering the address Number then Accomplish the goal of entering the address Number Report goal accomplished
					8	
M	1.35					Method to accomplish the goal of entering the City Step 1. Accomplish the goal of getting an item (CITY) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the Street name Step 1. Accomplish the goal of getting an item (STREET) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the address Number Step 1. Accomplish the goal of getting an item (NUMBER) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Report goal accomplished
		1.35	1	1.35	4	
L	0.23					Method to accomplish the goal of getting an item from the address card Step 1. Look at address card
M	1.35					Step 2. Commit first four letters of item to memory
L	0.23					Step 3. Look at display
						Step 4. Report goal accomplished
		1.81	3	5.43	15	

Appendix G - Doublepress GOMS Analysis

operator	oper. time	goal time	# of times exec	Total time	# of NGOMSL statements	Description	
H	0.4					<p>Method to accomplish the goal of entering an address item</p> <p>Step 1. Move hand to display</p> <p>Step 2. Accomplish the goal of entering a letter/digit</p> <p>Step 3. Accomplish the goal of entering a letter/digit</p> <p>Step 4. Accomplish the goal of entering a letter/digit</p> <p>Step 5. Accomplish the goal of entering a letter/digit</p> <p>Step 6. Confirm that first four letters of item appear in the display</p> <p>Step 7. Move finger to "Done" button</p> <p>Step 8. Press "Done" button</p> <p>Step 9. Report goal accomplished</p>	
M	1.35						
PD	0.18						
K	0.28						
		2.21	3	6.63	30		
L	0.23						<p>Method to accomplish the goal of selecting correct name</p> <p>Step 1. Look at highlight bar</p> <p>Step 2. Accomplish the goal of scrolling to correct name</p> <p>Step 3. Move finger to "Done" button</p> <p>Step 4. Press "Done" button</p> <p>Step 5. Report goal accomplished</p>
PD	0.18						
K	0.28						
		0.69	2	1.38	12		
F(m)	0.52						
P	0.15					<p>Method to accomplish the goal of entering a letter/digit</p> <p>Step 1. Find main letter button</p> <p>Step 2. Move finger to main letter button</p> <p>Step 3. Press main letter button</p> <p>Step 4. Find individual letter button</p> <p>Step 5. Move finger to individual letter button</p> <p>Step 6. Press individual letter button</p> <p>Step 7. Report goal accomplished</p>	
K	0.28						
F(i)	0.35						
P	0.15						
K	0.28						
		1.73	12	20.8	96		
L	0.23						<p>Method to accomplish the goal of scrolling to correct name</p> <p>Step 1. Look at highlight bar</p> <p>Step 2. Determine if desired name is highlighted</p> <p>Step 3. If desired name is NOT highlighted then</p> <p>Step 3.1 Move finger to down arrow</p> <p>Step 3.2 Press down arrow</p> <p>Step 3.3 Goto Step 2</p> <p>Step 4. Report goal accomplished</p>
M	1.35						
PD	0.18						
K	0.28						
		2.04	2	4.08	16		
				43.7		total Operator times	
				19.4		NGOMSL statement time	
				63.1		Total estimated time (not including system time)	

Appendix G - Qwerty GOMS Analysis

oper- ators	oper. time	goal time	# of times exec	total time	# of NGOMSL statements	Description
M	1.35					Method to accomplish goal of entering destination Step 1. Get address information Step 2. Accomplish the goal of entering address item
		1.35	1	1.35	3	
						Selection rule for the goal of entering address item If the task is entering the City then Accomplish the goal of entering the City If the task is entering the Street name then Accomplish the goal of entering the Street If the task is entering the address Number then Accomplish the goal of entering the address Number Report goal accomplished
					8	
M	1.35					Method to accomplish the goal of entering the City Step 1. Accomplish the goal of getting an item (CITY) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the Street name Step 1. Accomplish the goal of getting an item (STREET) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the address Number Step 1. Accomplish the goal of getting an item (NUMBER) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Report goal accomplished
		1.35	1	1.35	4	
L	0.23					Method to accomplish the goal of getting an item from the address card Step 1. Look at address card
M	1.35					Step 2. Commit first four letters of item to memory
L	0.23					Step 3. Look at display
						Step 4. Report goal accomplished
		1.81	3	5.43	15	

Appendix G - Qwerty GOMS Analysis

oper- ators	oper. time	goal time	# of times exec	total time	# of NGOMSL statements	Description
H	0.4					Method to accomplish the goal of entering an address item Step 1. Move hand to display Step 2. Accomplish the goal of entering a letter/digit Step 3. Accomplish the goal of entering a letter/digit Step 4. Accomplish the goal of entering a letter/digit Step 5. Accomplish the goal of entering a letter/digit Step 6. Confirm that first four letters of item appear in the display Step 7. Move finger to "Done" button Step 8. Press "Done" button Step 9. Report goal accomplished
M	1.35					
PD	0.18					
K	0.28					
		2.21	3	6.63	30	
L	0.23					Method to accomplish the goal of selecting correct name Step 1. Look at highlight bar Step 2. Accomplish the goal of scrolling to correct name Step 3. Move finger to "Done" button Step 4. Press "Done" button Step 5. Report goal accomplished
PD	0.18					
K	0.28					
		0.69	2	1.38	12	
F	0.78					Method to accomplish the goal of entering a letter/digit Step 1. Find letter/number button Step 2. Move finger to letter/number button Step 3. Press letter/number button Step 4. Report goal accomplished
P	0.23					
K	0.28					
		1.29	12	15.48	60	
L	0.23					Method to accomplish the goal of scrolling to correct name Step 1. Look at highlight bar Step 2. Determine if desired name is highlighted Step 3. If desired name is NOT highlighted then Step 3.1 Move finger to down arrow Step 3.2 Press down arrow Step 3.3 Goto Step 2 Step 4. Report goal accomplished
M	1.35					
PD	0.18					
K	0.28					
		2.04	2	4.08	16	
				38.4		total Operator times
				15.8		NGOMSL statement time
				54.2		Total estimated time (not including system time)

Appendix G - Phonepad GOMS Analysis

operator	oper. time	goal time	# of times exec	total time	# of NGOMSL statements	Description
M	1.35					Method to accomplish goal of entering destination Step 1. Get address information Step 2. Accomplish the goal of entering address item
		1.35	1	1.35	3	
						Selection rule for the goal of entering address item If the task is entering the City then Accomplish the goal of entering the City If the task is entering the Street name then Accomplish the goal of entering the Street If the task is entering the address Number then Accomplish the goal of entering the address Number Report goal accomplished
					8	
M	1.35					Method to accomplish the goal of entering the City Step 1. Accomplish the goal of getting an item (CITY) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the Street name Step 1. Accomplish the goal of getting an item (STREET) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.35					Method to accomplish the goal of entering the address Number Step 1. Accomplish the goal of getting an item (NUMBER) from the address card Step 2. Accomplish the goal of entering an address item Step 3. Report goal accomplished
		1.35	1	1.35	4	
L	0.23					Method to accomplish the goal of getting an item from the address card Step 1. Look at address card
M	1.35					Step 2. Commit first four letters of item to memory
L	0.23					Step 3. Look at display
						Step 4. Report goal accomplished
		1.81	3	5.43	15	

Appendix G - Phonepad GOMS Analysis

operator	oper. time	goal time	# of times exec	total time	# of NGOMSL statements	Description
H	0.4					<p>Method to accomplish the goal of entering an address item</p> <p>Step 1. Move hand to display</p> <p>Step 2. Accomplish the goal of entering a letter/digit</p> <p>Step 3. Accomplish the goal of entering a letter/digit</p> <p>Step 4. Accomplish the goal of entering a letter/digit</p> <p>Step 5. Accomplish the goal of entering a letter/digit</p> <p>Step 6. Confirm that first four letters of item appear in the display</p> <p>Step 7. Move finger to "Done" button</p> <p>Step 8. Press "Done" button</p> <p>Step 9. Report goal accomplished</p>
M	1.35					
PD	0.18					
K	0.28					
		2.21	3	6.63	30	
L	0.23					<p>Method to accomplish the goal of selecting correct name</p> <p>Step 1. Look at highlight bar</p> <p>Step 2. Accomplish the goal of scrolling to correct name</p> <p>Step 3. Move finger to "Done" button</p> <p>Step 4. Press "Done" button</p> <p>Step 5. Report goal accomplished</p>
PD	0.18					
K	0.28					
		0.69	2	1.38	12	
F	0.5					
P	0.14					
K	0.28					
		0.92	12	11.04	60	
L	0.23					<p>Method to accomplish the goal of scrolling to correct name</p> <p>Step 1. Look at highlight bar</p> <p>Step 2. Determine if desired name is highlighted</p> <p>Step 3. If desired name is NOT highlighted then</p> <p>Step 3.1 Move finger to down arrow</p> <p>Step 3.2 Press down arrow</p> <p>Step 3.3 Goto Step 2</p> <p>Step 4. Report goal accomplished</p>
M	1.35					
PD	0.18					
K	0.28					
		2.04	2	4.08	16	
				33.96		total Operator times
				15.8		NGOMSL statement time
				49.76		Total estimated time (not including system time)

Appendix G - Scrolling List GOMS Analysis

operator	oper time	goal time	# of times exec.	total time	# of NGOMSL statements	Description
M	1.4					Method to accomplish goal of entering destination Step 1. Get address information Step 2. Accomplish the goal of entering address item
		1.35	1	1.35	3	
						Selection rule for the goal of entering address item If the task is entering the City then Accomplish the goal of entering the City If the task is entering the Street name then Accomplish the goal of entering the Street If the task is entering the address Number then Accomplish the goal of entering the address Number Report goal accomplished
					8	
M	1.4					Method to accomplish the goal of entering the City Step 1. Accomplish the goal of getting an item (CITY) from the address card Step 2. Accomplish the goal of entering an address name Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.4					Method to accomplish the goal of entering the Street name Step 1. Accomplish the goal of getting an item (STREET) from the address card Step 2. Accomplish the goal of entering an address name Step 3. Accomplish the goal of selecting correct name Step 4. Report goal accomplished
		1.35	1	1.35	5	
M	1.4					Method to accomplish the goal of entering the address Number Step 1. Accomplish the goal of getting an item (NUMBER) from the address card Step 2. Accomplish the goal of entering an address number Step 3. Report goal accomplished
		1.35	1	1.35	4	
L	0.2					Method to accomplish the goal of getting an item from the address card Step 1. Look at address card
M	1.4					Step 2. Commit first four letters of item to memory
L	0.2					Step 3. Look at display
		1.81	3	5.43	15	Step 4. Report goal accomplished

Appendix G - Scrolling List GOMS Analysis

operator	oper time	goal time	# of times exec.	total time	# of NGOMSL statements	Description
H	0.4					Method to accomplish the goal of entering an address number Step 1. Move hand to display Step 2. Accomplish the goal of entering a digit Step 3. Accomplish the goal of entering a digit Step 4. Accomplish the goal of entering a digit Step 5. Accomplish the goal of entering a digit
M	1.4					Step 6. Confirm that first four letters of item appear in the display
PD	0.2					Step 7. Move finger to "Done" button
K	0.3					Step 8. Press "Done" button Step 9. Report goal accomplished
		2.21	1	2.21	10	
L	0.2					Method to accomplish the goal of entering an address name Step 1. Look at highlight bar Step 2. Accomplish the goal of scrolling to correct first letter Step 3. Accomplish the goal of scrolling to correct name
PD	0.2					Step 3. Move finger to "Done" button
K	0.3					Step 4. Press "Done" button Step 5. Report goal accomplished
		0.69	2	1.38	12	
F	0.5					Method to accomplish the goal of entering a digit Step 1. Find letter/number button Step 2. Move finger to letter/number button Step 3. Press letter/number button Step 4. Report goal accomplished
P	0.1					
K	0.3					
		0.92	4	3.68	20	
L	0.2					Method to accomplish the goal of scrolling to correct first letter Step 1. Look at highlight bar Step 2. Determine if it is near the desired first letter Step 3. If it is NOT in the desired area then Step 3.1 Accomplish the goal of scrolling through the alphabet Step 4. Report goal accomplished
M	1.4					
		1.58	2	3.16	12	
M	1.4					Method to accomplish the goal of scrolling through the alphabet Step 1. Decide if name is near beginning or end of alphabet Step 2. Recall that if near beginning use ">Z" as the button, if near end use "<A" Step 3. Move finger to the button
M	1.4					
P	0.2					
		2.94	2	2.94	10	
K	0.3					Step 4. Press the button
M	1.4					Step 5. If the highlight bar is NOT in correct area of the alphabet then Goto Step 4. Step 6. Report goal accomplished
		1.63	14	22.8	28	

Appendix G - Scrolling List GOMS Analysis

operator	oper time	goal time	# of times exec.	total time	# of NGOMSL statements	Description
M	1.4					Method to accomplish the goal of scrolling to correct name
M	1.4					Step 1. Look at highlight bar
P	0.2					Step 2. Recall that if name is earlier in alphabet use up as the button, if later use down
		2.94	2	2.94	10	Step 3. Move finger to the button
K	0.3					Step 4. Press the button
M	1.4					Step 5. If the highlight bar is NOT on the correct name then Goto Step 4.
						Step 6. Report goal accomplished
		1.63	10	16.3	20	
				66.3		total Operator times
				16.2		NGOMSL statement time
				82.5		Total estimated time (not including system time)