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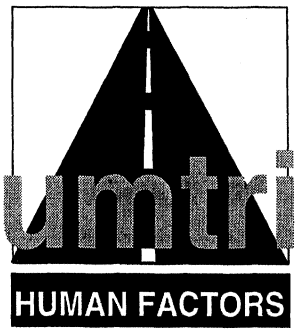
Navigation System Data Entry: Estimation of Task Times

Paul Green



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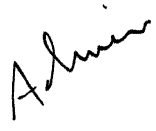

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16. Abstract

This report proposes a method (for SAE Recommended Practice J2365) to estimate in-vehicle task times and reviews the related human factors literature. This method will be used to evaluate alternative driver interface designs and to check compliance with the 15-second task time limit specified in SAE Recommended Practice J2364 (Navigation Function Access While Driving). Application of this method will enhance the safety and usability of driver information systems.

A review of the human factors literature (Kurokawa's dissertation, Levison's Integrated Driver Model, the NASA MIDAS software, the Integrated Performance Modeling Environment, etc.) revealed that there was no personal computer software available or hand calculation methods tailored for this purpose.

Therefore, the approach taken was to extend the Keystroke-Level Model (popular in human-computer interaction) using data from automotive navigation studies for calibration. The resulting 11-step calculation procedure begins with identifying all major goals (e.g., obtain guidance) and subgoals for each task the user performs along with identifying the method used (e.g., the street address method without short cuts). Exactly how each step is carried out is then described using pseudocode. Next, the associated elemental tasks (reaching for a device, keying (cursor, letter, space, enter), mental activity, searching, etc.) and their times are determined. Those times are adjusted for driver age, and entered into a spreadsheet where they are totaled. Finally, times are checked for reasonableness and the task sequences are adjusted as needed.

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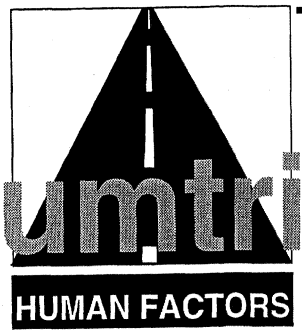

Navigation System Data Entry: Estimation of Task Times

UMTRI Technical Report 99-17
Paul Green

University of Michigan
Ann Arbor, Michigan, USA
July, 1999

PURPOSE

- provide information to enhance the safety and usability of driver interfaces
- provide background material to help develop SAE Recommended Practice J2365 (Calculating the Time to Complete In-Vehicle Navigation and Route Guidance Tasks)
- propose a computational method for J2365

LITERATURE SUMMARY

Study	Findings and Comments
Kurokawa (1990)	• dissertation with extensive data from on-road and simulator studies of control and display use • emphasis on conventional systems • HyperCard program to predict task times, hand-off-wheel time, number of glances and total glance time to the instrument panel, number of glances to road • requires extensive data for predictions (driver age, workload, exact location of device, size and luminance of labels, etc.) • software is not publicly available • being incorporated into model being developed for FHWA
Levison (1993), Levison and Corker (1995)	• development of Integrated Driver Model • includes optimal control model for steering and procedures model for in-vehicle tasks • software is not publicly available • software requires modification for each application • being incorporated in FHWA Integrated Highway Safety Design Model
NASA MIDAS	• used to model aircraft cockpit tasks and control rooms • requires Silicon Graphics workstation • key elements are Jack anthropometric software, Legibility Modeling Tool, and Cockpit Design Editor • no automotive applications to date
HOS and Integrated Human Performance Modeling Environment	• commercial software used by human factors professionals • Monte Carlo simulation software for discrete tasks • no automotive applications

PROPOSED METHOD (based on Keystroke-Level Model and UMTRI data)

1. Obtain a working model or step-by-step operational description of the device.

2 Identify the major user operational goals (and 3, subgoals).

4. Identify the methods used to achieve all goals and subgoals

5. Generate pseudocode for all methods.

6. Identify the assumptions (users' knowledge of methods, extent to which switch operation and cognitive activities occur in parallel, the use of shortcuts, etc.).

7. Determine the appropriate mental, keystroke, and other operators for each step. Mental times are 2.2 s. Search times are 2.29 s.

	Keystroke		
Key Category	1st	2nd	>2nd
Cursor	1.71	0.69	0.47
Enter	1.55		
Letters	1.54	0.99	
Numbers	1.15	0.47	
Shift	1.46		
Space	0.60		

8. Enter the times for each operator.

9. Add up the execution times for each operator using a spreadsheet.

10. Adjust the keystroke times using the age multiplier (1.4 for drivers ages 40-55, 2.2 for drivers over 65.

11. Verify that the times are reasonable and adjust as needed.

KEY REFERENCES

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- Society of Automotive Engineers (1998). SAE Recommended Practice for Calculating the Time to Complete In-Vehicle Navigation and Route Guidance Tasks (SAE J2365), Committee Draft of November 23, Warrendale, PA: Society of Automotive Engineers.

- Society of Automotive Engineers (1999). SAE Recommended Practice for Navigation and Route Guidance Function Accessibility While Driving (SAE 2364), Committee Draft of June 8, Warrendale, PA: Society of Automotive Engineers.

PREFACE

This report was produced for the Navigation Subcommittee (Jim Foley, chair) of the Society of Automotive Engineers (SAE) Intelligent Transportation Systems (ITS) Safety and Human Factors Committee (Gene Farber, chair). The report and other related activities were funded by the Society of Automotive Engineers as part of a U.S. Department of Transportation program to support the development of ITS standards. The content and wording of this report were determined by the author and represent his views.

This report is a working document written to provide the background for the development of SAE J2365 (Recommended Practice for Calculating the Time to Complete In-Vehicle Navigation and Route Guidance Tasks). This Recommended Practice serves as a design guide for SAE J2364 (SAE Recommended Practice for Navigation and Route Guidance Function Accessibility While Driving) in that it provides a means to estimate compliance with SAE J2364. SAE J2364 states that in-vehicle tasks, when measured staticly, should not take more than 15 seconds to complete ("The 15-Second Rule"). SAE J2364 provides an experimental procedure for testing interfaces to determine compliance. The unstated focus of J2364 is on data entry tasks, the tasks of greatest concern in a moving vehicle. The procedure specified here provides a quick means to estimate compliance, one that can be applied in the conceptual stage when the interface is still easy to modify. This will support iterative design, leading to safer and easier-to-use driver interfaces for navigation systems.

In parallel SAE efforts, a standard is being contemplated by the International Standards Organization (ISO) for the same purpose. In the interests of international harmonization, the two standards should be identical. At the time this report was being written, the ISO document was not yet a preliminary work item.

The author would like to thank Dr. Jim Foley of Visteon for serving as the technical monitor for SAE for this project and for review of this report. The patience shown by the SAE ITS Safety and Human Factors Committee while this thorough effort was conducted is greatly appreciated.

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INTRODUCTION

This is the second of two reports describing the research relating to in-vehicle navigation system use. The first report (Green, 1999c) addressed 11 questions that provided a basis for the development of SAE Recommended Practice J2364 (Navigation and Route Guidance Function Accessibility While Driving). Those questions are listed in Table 1.

Table 1. Questions to be Addressed

Topic	#	Question
Crashes	1	Is there statistical evidence that crashes are more likely when a navigation system is used, in particular during destination input?
	2	Are there cases in which navigation system use was the cause of a crash?
Visual Demand and Crashes	3	What is the relationship between visual demand and crashes?
Destination Designation and Driving Performance	4	Does the input and retrieval of destinations significantly degrade driving performance?
	5	How long do input-related navigation system tasks take to complete and how do they compare with existing tasks?
Preferences and Free Glance Behavior	6	How often and for how long do drivers prefer to look inside a vehicle and how safe/comfortable do drivers feel they are when they do such?
Ratings of Glance Comfort and Safety	7	What is the relationship between actual glance duration and ratings of comfort and safety?
Typical Glance Data	8	How much time do drivers actually spend glancing at existing vehicle controls and displays and, during entry tasks, navigation displays?
Prediction of Lane Departures	9	How often do lane departures occur for in-vehicle tasks?
	10	What is the relationship between task completion time, the mean number of glances, mean glance time, total glance time, and lane departures for existing controls and displays?
Guidelines and Regulations	11	What do existing guidelines require concerning the use of navigation systems in a moving vehicle?

Based on the evidence in that report and ITS Navigation Subcommittee discussions, a consensus was developed to use static task time as the performance measure (Green, 1999b). In addition, an experimental procedure for measuring task time was developed, and from this effort, a draft SAE Recommended Practice has emerged, SAE J2364 (Society of Automotive Engineers, 1999). In brief, SAE J2364 specifies that in-vehicle tasks, when measured staticly, should not take more than 15 seconds to complete ("The 15-Second Rule").

SAE J2364 relies upon an experimental procedure to determine compliance. A drawback of that approach is that testing requires a working prototype for compliance verification, something that often is not available until late in the development process, often too late to make changes. Therefore, to compare concepts, a design and evaluation aid is necessary for use early in development. The iterative cycle of design, calculate, and redesign is the manner in which most engineering occurs. Efforts to promote safety and usability that are consistent with common engineering practice are likely to be used by engineers.

In the early stages of this SAE project, the need for two SAE documents was envisioned. Initially, the thinking was that the second document would provide guidelines of some sort, for example, specifying the number of items that could be in menus, the types of controls appropriate for particular tasks, etc. However, it was clear to the author and others that what was really needed were calculation methods to assess alternative interface configurations. Such methods have proven to be extremely useful to those developing user interfaces to computer systems. Further, since navigation-system interfaces are evolving rapidly, there was the possibility of focusing on interface characteristics that were obsolete. In fact, at the time of this report, task completion times for interface elements (e.g., menu selection time as a function of menu length) did not exist for automotive-navigation interfaces. For these and other reasons, the second effort in this project emphasized a computational method.

Accordingly, the purpose of this report is to (1) review the data and methods in the literature that have potential use for predicting data-entry task-completion times with navigation systems, and (2) to propose a method for calculating those times. Each of those goals is treated separately. It is important to realize that the literature on human performance modeling is significant, and that within the framework of this project, the resources for a comprehensive review do not exist. The report scope has been set accordingly.

In parallel with the development of this report, a draft Recommended Practice (SAE J2365, Society of Automotive Engineers, 1998) has been developed and submitted to the Navigation Subcommittee. At the time of this report, SAE J2365 had not been discussed as the Subcommittee has focused on SAE J2364. In addition, a paper summarizing the calculation method has been written (Green, 1999b). Given the number of changes that occurred during the development of J2364, J2365 is unlikely to be implemented exactly as described in this report. However, the report should provide a solid foundation for the development of J2365.

TASK TIME MODELS FOR DRIVER INTERFACES

Tasks times can be (1) predicted directly or (2) based on task characteristics such as the number of glances, estimated using the equations in Green (1999). Direct computation is more likely to provide the most accurate estimates. Three topics related to task times are covered in this report: (1) software for the evaluation of interfaces, (2) GOMS (Goals, Operators, Methods, and Selection Rules) models, and (3) model extensions to display evaluation. Related research that considers the characteristics of control and display systems, the work of Applied Psychological

Services, is covered in Appendix A, and fundamental research on control use appears in Green (1979) and Faerber and Faerber (1988). Other, more current work of Faerber of the University of the Armed Forces (Munich) is not included in this review as English translations of his research were not available to the author, though it is known that evaluation software that runs on Silicon Graphics hardware has been developed. (See a forthcoming publication, Farber and Muller (1999), for a summary.)

Software for Interface Evaluation

Kurokawa (1990)

Kurokawa's dissertation (Kurokawa, 1990) contains extensive data from both on the road and in a driving simulator on the time to complete tasks such as selecting a button from an array while driving. (See also Hayes, Kurokawa, and Wierwille, 1989; Kurokawa and Wierwille, 1990.) The primary emphasis was conventional controls and displays. The HyperCard program developed is extremely complex and has numerous adjustment factors as shown in Table 2. The model computes task time, the desired measure, and presumably could be tailored to predict task performance in navigation-data-entry tasks. However, the model is so detailed that it is not readily amenable to hand calculation and the software is not publicly available at this time. However, development is ongoing (Wierwille, Dingus, and Hanowski, 1999), so the software could be available at some future date. The report (Kurokawa, 1990) describing the development and implementation of this model is quite comprehensive, so reconstructing the model is a time-consuming possibility.

Table 2. Selected Data Utilized by Kurokawa's Model

Category	Characteristics	Comment
output - performance	• task completion time • hand-off-wheel time • number of glances to the instrument panel • total glance time to the instrument panel • mean number of glances to the road • mean eye-transition time	
output - figures of merit	• visual • manual • overall • frequency of use adjusted figure	• visual = 40 * (mean IP glance time)^^2 + 3 * (# IP glances)^^2/3 • manual = 11 * (hand.off.wheel time) • overall = 0.7 * visual + 0.3 * manual • adjusted = overall * frequency.of.use/hr / 10

Category	Characteristics	Comment
driver	• age (18-24, 25-49, 55+, all) • sex (men, women, both) • workload (low, medium, high, all levels)	• low workload = low traffic density, straight and level roads, no unusual events • medium = moderate traffic or road curvature, or substantial up or down grade • high = high traffic density, unanticipated events requiring frequent monitoring, extreme curvature, minimal forward view
instrument panel location	• horizontal and vertical distance between line of sight and center of panel • horizontal angle • vertical angle • distance between eye and center of panel • panel tip back angle • instrument coordinates	
control label factors	• label character size (minutes of arc) • label luminance (high, low) • degree of driver reliance on labels	
control task type	primarily visual, primarily manual, complex manipulation, complex cognitive, auditory feedback, continuous control, discrete control, discrete control and display	For each task, additional details are generally required.
visual task type	check reading (label, odometer, fuel, speedometer), detection (which mirror	For each task, additional details are generally required. For example, for check reading, the character color, luminance, and size are needed.

Levison's Work

Levison (1993) and Levison and Corker (1995) describe the development of the Integrated Driver Model (IDM). This model is the combination of a submodel for driver completion of in-vehicle task procedures and an optimal control model used to predict steering performance. The emphasis of the model was on predicting task-switching behavior and providing a precise description of when steering corrections would occur. Some work was done to calibrate the model to predict performance when timesharing between tracking and dialing a phone. However, the model required use of a particular unique combination of hardware present at Bolt, Beranek and Newman and considerable tailoring for each application. Hence, the primary value of the work is in describing how a model should be developed for automotive applications rather

than as ready-to-run software. At one time, work on this model was continuing as one of the modules in the Federal Highway Administration Interactive Highway Safety Design Model (IHSDM). (See http://www.tfhrc.gov/.) The driver performance module will consist of 6 major functional components: (1) perception, (2) speed decision, (3) path decision, (4) speed control, (5) path control, and (6) attention.

MIDAS

The MIDAS project is run by the Computational Human Engineering Research Office of the Aviation Operations Branch of the NASA Ames Research Center (Anonymous, 1999; Corker and Smith, 1999). The purpose of the project is to produce software tools and methods to improve the human-engineering design process for advanced-technology crew workstations. MIDAS is a 3-D prototyping and task analysis environment. It allows designers to ask "what-if" questions about crew performance. MIDAS contains routines to describe the operating environment, equipment, and goals of operators. The software contains detailed models of human anthropometry, vision, memory, and decision making. Key elements include the Jack human figure model, the Legibility Modeling Tool, and the Cockpit Design Editor. The software runs on Silicon Graphics equipment. Applications of MIDAS include several aircraft applications (taxing, clearance to land, tilt rotor, flight suits, high speed civil transport) and two control room applications (nuclear power plant, 911 center). There have been no automotive applications.

Integrated Performance Modeling Environment

The Integrated Performance Modeling Environment (http://www.maad.com/ipme.html), a product of Micro Analysis and Design, is a collection of UNIX-based software tools to answer human-performance questions. The primary applications of the Integrated Performance Moceling Environment has been toward military problems. Tool elements include the environment modeling capabilities (temperature, time of day, etc.) operator characteristics (e.g., fatigue, ability), performance-shaping factors (e.g., task time limits), the Human Operator Simulator (HOS), and the MicroSaint application package. The HOS elements of this environement have the capability to allow for the specification of physical workspaces. Micro models of human behavior, such as reading rate, are key features of HOS.

MicroSaint is a discrete-event Monte Carlo simulator engine that uses a graphic interface to define a task network. MicroSaint allows for the distribution of task times to be specified along with distribution parameters, sequential dependencies, and other task characteristics. Within the human factors profession, the MicroSaint portion of that environment is the most commonly used simulation package.

GOMS Family of Models

The most commonly applied approach for determining task completion time for tasks that are highly cognitive, especially in human-computer interaction is the GOMS family of models (Card, Moran, and Newell, 1983; Kieras, 1988; Gray, John, and Atwood, 1993; John, 1995; Beard, Smith, and Denelsbeck, 1996; John and Kieras, 1996). GOMS is a group of models developed by Card and his colleagues at Xerox to predict

the time required to complete routine cognitive activities using a computer system. The model is intended to provide engineering approximations of task times. The model set assumes the user is reasonably familiar with the task of interest (hence the term routine) and that primary human limitations are cognitive (thinking), not physiological (aerobic capacity, muscle strength, etc.). Also, it is important to note that GOMS was designed for single tasks, and not timesharing as in the automotive case, though there is no reason why timesharing extensions could not be developed.

The key to a GOMS analysis is task decomposition. For example, suppose the task was to change the time on a car clock. Typically, this might involve pressing the set button, then pressing the hour or minute button, either separately or in conjunction with set button, to advance the time. In this case, the top-level goal is to "set the clock" with subgoals of "entering the set mode" and "advancing the hour." For each low level goal, operators and methods ("push the set button to enter the set mode') are created. Selection rules determine the sequence chosen when more than one alternative exists.

There are four commonly cited implementations of the GOMS concept: (1) Card, Moran, and Newell GOMS (CMN-GOMS), (2) the Keystroke-Level Model, (3) New GOMS Statement Language (NGOMSL), and (4) Critical-Path Method GOMS (CPM-GOMS, John and Kieras, 1996). CMN-GOMS, sometimes called the Model Human Processor, is the original version of GOMS as implemented by Card, Moran, and Newell (1983). The Keystroke-Level Model is a simplified version of GOMS. NGOMSL is a rigorous version of GOMS written in pseudocode. NGOMSL contains numerous applications rules. CPM-GOMS is a modification of the basic GOMS approach designed to handle parallel activities. CMN-GOMS and the Keystroke-Level Model are described in greater detail in the sections that follow. Finally, for the sake of completeness, readers should be alerted to Quick and Dirty GOMS (QGOMS), a calculation application developed to run under Windows (Beard, Smith, and Denelsbeck, 1996).

Model Human Processor

The Model Human Processor is a computer-system representation of the human thought process consisting of three memory systems and four processors. These components are organized into three subsystems (perceptual, cognitive, motor). Processors (Table 3) have one parameter, cycle time. Memories (Table 4) have three parameters: storage capacity, storage code, and decay time. For each parameter, three values are given: middleman, slowman, and fastman. Middleman is the most typical value. Slowman and fastman represent reasonable minima and maxima. The model also includes eye-fixation times. The choice of the value depends upon the prediction needed—best case, worst case, or typical. For most automotive tasks, using the Model Human Processor to predict the entire task may be more detailed than is needed as times of elements are on the order of 100 ms.

Table 3. Processor Cycle Times (ms)

Processor	fastperson	middleperson	slowperson
perceptual	50	100	200
cognitive	25	70	170
motor	30	70	100

Table 4. Memory Capacity

Memory	Parameter	Description	fastperson	middleperson	slowperson
visual image store	delta	decay 1/2 life (ms)	70	200	1000
	mu	capacity (letters)	7	17	17
	kappa	storage code		physical	
auditory image store	delta	decay 1/2 life (ms)	900	1500	3500
	mu	capacity (letters)	4.4	5	6.2
	kappa	storage code		physical	
long-term memory	delta	decay 1/2 life (ms)	infinite	infinite	infinite
	mu	capacity (letters)	infinite	infinite	infinite
	kappa	storage code	semantic	semantic	semantic
working memory, 3 chunks	delta	decay 1/2 life (ms)	5	7	34
	mu	capacity (letters)	5	7	9
	kappa	storage code		acoustic or visual	

Keystroke-Level Model

The Keystroke-Level Model (Card, Moran, and Newell, 1983; Chi and Chung, 1996) may be a more appropriate implementation for automotive tasks. Table 5 shows the commonly used values. These values emerged from research at Xerox on the time to complete tasks involving use of a CRT, keyboard, and a mouse. It is important to note that times for typing are for touch typing, a situation that does not occur in present-day vehicles. Also note the wide range of values (0.50 to 1.2 s) to choose from for the K (keystroke) parameter, especially when the material is complex or unfamiliar, or the user is unskilled, conditions that could occur for automotive-navigation data-entry tasks.

Table 5. Keystroke-Level Model Parameters

Parameter	Symbol	Comment	Time (s)
Pointing	P	point with a mouse to a target on a display	1.1
Homing	H	home hand(s) to keyboard or to device	0.4
Draw	D	draw N straight lines of length L cm	.9N + .15L
Mental	M	mentally prepare	1.35
System Response	R	context-specific response time, empirically determined	t
Keystroke	K	best typist (135 wpm)	0.08
		good typist (90 wpm)	0.12
		average skilled typist (55 wpm)	0.20
		average nonsecretary typist (40 wpm)	0.28
		typing random letters	0.50
		Typing complex codes	0.75
		worst typist (unfamiliar with keyboard)	1.20

Since this original set of values were obtained, other element time estimates have appeared in the literature. Olson and Nilsen (1987-1988) from their work on spreadsheet use estimate M to be 1.62 s and K to be 0.36 s. In addition, they also added a parameter to the set S (2.29 s), the time to scan a row to find an item in a matrix.

UMTRI Work on Keystroke-Level Models

Two sets of studies have been conducted for the purpose of validating the use of the GOMS approach for predicting task times in motor vehicles. Paelke (1993) had drivers enter destinations using four different interfaces. Table 6 shows the results obtained using NGOMSL. Although the rank order for the predictions agreed quite well with the actual task-completion times, there were substantial differences between the model and actual times, with the GOMS times being somewhat larger than the actual times. The reason for this is unclear. Nonetheless, this did establish that GOMS models have practical value for automotive-interface evaluation.

Table 6. Paelke's Comparison of Keystroke-Level Predictions and Prototype Execution Times

Interface	GOMS Prediction (s)	GOMS Rank	Prototype Test (s)	Time Rank	Difference (s)	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

Manes, Green, and Hunter (1996) describe an extension of the research by Steinfeld, Manes, Green, and Hunter (1996) in which Keystroke-Level Models were used to predict entry and retrieval times for the Ali-Scout navigation system. The experiment

conducted involved 36 subjects from three age groups (18-30, 40-55, and over 65), all of whom were licensed drivers but unfamiliar with navigation systems (as called for by J2364). Subjects watched a videotape on using the interface, and then practiced entering and retrieving five destinations, exactly the amount of practice envisioned in SAE J2364. In the test segment, subjects entered and retrieved five other sets of destinations three times (one using a touch screen simulation, and twice using real interfaces, both for simulated dusk and night conditions).

Entering and retrieving destinations involved typing in text, entering numeric strings (destination longitudes and latitudes), and scrolling through alphabetized lists, sequences common to many destination-entry tasks. Admittedly, the Ali-Scout interface had very small keys with poor feedback and the entry scheme was confusing, so elemental times could overestimate times for more typical interfaces. However, the additional test trials in the experiment should have caused subjects to reach a level of performance consistent with J2365. Hence, use of that data set as an initial basis for J2365 is reasonable.

To determine how well task performance could be predicted, Manes, Green, and Hunter (1996) provide an Excel spreadsheet that describes each step in the Keystroke-Level Model of the entry and retrieval tasks for each of the 15 destinations evaluated. Only the data for the real interfaces (not the touch-screen simulation) were included in the analysis as the lack of tactile feedback for the touch screen elevated task times by several percent.

Based on a regression analysis, linear equations based on pure Keystroke-Level Models accounted for 41 (all subjects) to 78 percent (young subjects only) of the variance of retrieval times but only 12 to 39 percent of the entry times. Retrieval tasks took about 10 s while entry tasks took about a minute. For tailored Keystroke-Level Models (with experimentally based values for keystroke times, and adjustments for age and lighting) the variance accounted for was 58 and 83 percent (all subjects and young subjects, respectively) for retrieval, and 47 and 49 percent for entry. Use of linear equations and tailored models significantly reduced the size of prediction errors, making the predictions useful for engineering evaluations of alternative interfaces. Table 7 shows the full set of predictions. The author has no theory-based explanation for why these corrections were needed.

Table 7. Regression Equations and Correlations for Various Keystroke-Level Models. Y is the actual time, X is the prediction.

Retrieval	Young		All Subjects	
	Equation	R2	Equation	R2
standard Keystroke-Level Model (K=1.2, M=1.35)	Y=-2.381 + 1.380 X	0.78	Y=-1.839 + 1.759 X	0.41
modified keystroke model (K=1.5, M=2.2)	Y=-2.381 + 1.104 X	0.78	Y=-1.839 + 1.407 X	0.41
standard model (K=1.2, M=1.35) with age adjustment (young=1, mid=1.4, old=2.2)			Y=-0.352 + 0.935 X	0.54
tailored model (various K's, M=2.2, lighting values, no age adjustments)			Y=-0.853 + 1.851 X	0.44
tailored model (various K's, M=2.2, lighting values, age adjustments)	Y=-1.585 + 1.447 X	0.83	Y=0.039 + 1.054 X	0.58
Entry				
standard Keystroke-Level Model (K=1.2, M=1.35)	Y=-17.057 + 1.613 X	0.39	Y=-12.962 + 1.851 X	0.12
modified keystroke model (K=1.5, M=2.2)	Y=-18.379 + 1.290 X	0.39	Y=-14.479 + 1.480 X	0.12
standard model (K=1.2, M=1.35) with age adjustment (young=1, mid=1.4, old=2.2)			Y=13.57 + 0.692 X	0.45
tailored model (various K's, M=2.2, lighting values, no age adjustments)			Y= -7.689 + 1.498 X	0.12
tailored model (various K's, M=2.2, lighting values, age adjustments)	Y=-17.494 + 1.445 X	0.49	Y=12.288 + 0.644 X	0.47

Based on these results, Manes, Green, and Hunter (1996) suggest a process similar to what follows for predicting entry and retrieval times. Although not formally stated, prior to computations, the goals and methods for each task and subtask must be identified, and from that information a detailed pseudocode description of all user actions must be created. This initial effort, in fact, is expanded elsewhere in this report into a series of steps. Completing this initial effort requires some experience in task analysis, an activity well suited to a human factors engineer. The time required for the initial effort is a significant fraction of the time for the complete analysis.

Step 1: Based on the pseudocode listing, select the base keystroke time from Table 8.

Table 8. Keystroke times for young drivers.

	Keystroke		
Key Category	1st	2nd	>2nd
Cursor	1.71	0.69	0.47
Enter	1.55		
Letters	1.54	0.99	
Numbers	1.15	0.47	
Shift	1.46		
Space	0.60		

Note: The standard Keystroke Level Model assumes that times for all keystrokes are equal. In this case, the differences between categories may be unique to the Ali-Scout keyboard, so these differences warrant further experimental investigation. However, more importantly, notice that the times for repeated keystrokes are much less than single or initial keystrokes. In navigation data entry, repeated keystrokes (scrolling though a list, repeated numbers or letters in an address) are common.

Step 2: Adjust for the lighting conditions.

Increase the time by 6 percent for night conditions. Decrease the time by 6 percent for dusk conditions. Since this effect is relatively small, this step can be omitted if quick calculations are needed.

Step 3: Adjust for age.

Multiply the time by 1.4 for middle-aged drivers (40-55), 2.2 for older drivers (over 65). If other age groups are to be the test group, use regression analysis to develop a multiplier for that age group. For older drivers, the times for shift and enter will be underestimated. Since there is usually only one enter keystroke and few shifts, if any, in a typical sequence, underestimating the time of one or two keystrokes leads to minimal errors.

Step 4: Use 2.22 s for mental time.

Step 5: Compute total time.

Insert the appropriate values for K, M, and other parameters in the Keystroke-Level Model and compute the total task time.

Step 6. Use the regression equations that follow to adjust the time estimates. For tasks on the order of 10 s, use the retrieval corrections. For tasks on the order of 1 minute, use the corrections for entry times.

An expansion of this approach, the method proposed for SAE Recommended Practice J2365, appears in Appendix B along with a detailed example of obtaining guidance using the street-address entry method for the Magellan PathMaster. The steps

identified represent a combination of the ideas found in the literature with insights gained when applying this approach to the analysis of real interfaces.

Extensions to Display Evaluation

The emphasis of most computational models (especially the keystroke model) is on tasks where manipulating controls is significant. However, there are trends towards expanding the information content presented to drivers. As that occurs, methods are needed to predict task times for visual tasks. Although aspects of the Keystroke-Level Model allow for such, models and methods tailored towards automotive applications are likely to be required. The psychological and human factors literature on display design, evaluation, and user performance is huge, and there is no way it can be comprehensively reviewed here. However, there are two approaches in the literature that have already shown potential value for automotive-display evaluation: Namba's Method and the computational methods suggested by Evans and Stevens.

Namba's Method

Namba's method is an attempt to predict the time necessary to view a display based on information theory. Namba (1980) asserts that since there are 46 kana (basic Japanese) characters, each kana contains 5.5 bits of information ($\log_2 46$), assuming all kana are equally likely (not true, but a reasonable first assumption). However, as Namba points out, treating voiced sound symbols and long vowels as equivalent to kana, there are actually 106 characters, so each contains 6.7 bits of information. As a compromise, Namba considered each kana to be 6.0 bits. Given there are approximately 1850 common kanji (Chinese ideographic characters), each kanji contains 10.85 bits of information. (For related information on this approach, see Fukuda, 1992a,b.)

To determine acceptable presentation rates, Namba examined three sources of data on reading text, two from the popular visual media (text on TV, film subtitles), and one from a reading experiment he conducted. For text shown on TV newscasts, he assumed that since the public was able to read them, the duration should be acceptable. Assuming human-channel capacity to be 50 bits/s, the typical rate was about 1/4 of that (12.5 bits/s) with most displays falling between 1/8 and 1/2 of channel capacity. All of the data points were above 1/12 of channel capacity. (See Namba's 1980 paper for a listing of the sources of information used to determine channel capacity and the programs from which text was obtained.)

In the experiment he conducted, 30 subjects were shown a variety of text displays. Subjects either (1) read (and recognized) the characters, or (2) transcribed them. The reading rate was between channel capacity and half of it (depending on the subject). The transcription rate was between 1/8 and 1/12 of channel capacity.

Finally, Namba examined the text presentation rates normally used for subtitles in film and dubbed speech. Interestingly, the subtitle rate was 1/2 that of dubbed speech. His assumption was that these rates were selected to assure reasonably high rates of comprehension by most viewers, but the rates would not be so slow as to lead to boredom.

As a whole, these data sets suggest a range of acceptable presentation rates of text.

Kamiya, Nakamura, and Matsumoto (1994) describe the application of Namba's method to display times for in-vehicle information based on data collected in the VICS project, a project conducted in Japan concerning the presentation of navigation and traffic information. (See also Ito, 1996.) Drivers were asked nine questions (Table 9) in the context of city and highway driving three times each, for a total of 54 responses. Regression analysis indicated the amount of information (for text) was equal to 44.26(bit/s) * eyes-off-road-time -15.74(bits). If channel capacity is 50 bits/s, and 1.49 s is required to process 50 bits, the difference, 0.49 s is the time required to look from the road to inside the vehicle, refocus, and then look back to the road. This is reasonably close to an estimate based on 200 ms to transition in each direction. For objects, the amount of information (again from regression analysis) was equal to 49.67 * eyes-off-road time - 18.56. In all cases, time is measured in seconds.

Table 9. Experimental Displays in VICS Experiment

#	display
1	text: 10 letter
2	deformed traffic-congestion display (schematic)
3	traffic-congestion display #1
4	text: 28 letters
5	parking-lot display
6	traffic-congestion display #2
7	text: 40 letters
8	traffic-congestion display #3
9	traffic-congestion display #4

Based on Kamiya, Nakamura, and Matsumoto (1994), the information content of an image is computed as follows:

1. Identify all elements in the display. Assign 2.2 bits to each letter, 6.0 bits to each kana, 10.85 to each kanji, and 14 bits to each object.

2. Identify the information that is relevant to the driver's decision. This includes all street, city, and district names, all major roads intersecting with the current position, roads onto which the driver might turn, and other graphical elements such as arrows and the current location icon. It is not apparent if this general description is sufficient for determining which elements to include in the calculations, an issue that deserves further exploration.

3. Compute the recognition time using the appropriate equation:
   for text: Information in image = 44.26 * time - 15.74
   or time = (information - 15.74) / 44.26
   where information is in bits, time is in seconds

   for graphics: information in image = 49.67 * time - 18.56
   or time = (information - 18.56) / 49.67

This method appears to be a reasonable first approximation for estimating display task completion time. However, it must be recognized that one must not only consider the graphical elements of interest, but also how they are manipulated. For example, finding a particular street relative to one's location (find the second cross street, a counting task) is quite different from identifying where a particular street is on a map. Identifying the steps required to compute information content for specific tasks for specific example maps (both in English and in Japanese) could provide useful clarification.

Evans and Stevens (1996)

This paper describes research to develop measures of graphical complexity for maps and map like images (Table 10). Evans and Stevens (1996) had 10 subjects rate three types of stimuli (navigation displays, route guidance displays, and text) on a 1 to 5 scale of complexity and also had subjects press a key when they had finished reading those displays in a dual-task context. In addition, they also examined the number of bytes required to represent the displays using various compression algorithms, though the description of them and the rationale for their selection is brief. Although this method is computationally efficient, a theory to explain which characteristics are important and why is desired.

Table 10. Measures of Graphical Complexity from Evans and Stevens (1996)

Measure	Description
total count of discrete features	total number of line segments contained within an arrow plus the number of roads that intersect the arrow, any lane markers, and any other features. In counting, each segment of an arrow is a separate feature.
weighted count of discrete features	certain features (such as the number of side roads that had to be passed before an exit was reached) are given more weight. A reproducible method for such is not described.
mean local density	the display is divided into 8 squares, and the number of features is counted
maximum local density	the number of features in the cell with the highest count
critical local density	the number of features within two degrees of the vehicle location icon expressed as the percentage of total features

Table 11 shows the results. This paper should be viewed as a source of ideas as to how the complexity of navigation displays might be predicted rather than as a definitive source of predictions. Further details on this research should be forthcoming.

Table 11. Results from Evans and Stevens (1996)

Stimulus type	Measure	Correlation	p
navigation	maximum local density	0.53	.039
route guidance	weighted count	0.73	.002
route guidance	subjective ratings	0.78	.001
route guidance	RLE compression	0.52	.034
route guidance	PACK compression	-0.75	.001

Summary

1. There at least five major efforts to model human performance in complex, time-sharing situations that duplicate or are similar to driving a motor vehicle; (1) Kurokawa, (2) Levison, (3) MIDAS, (4) the Integrated Performance Modeling Environment (a HOS-derivative), and (5) Faerber's work. Because it is written in German, little is known about Faerber's research in the U.S.

2. Kurokawa's method has been validated for conventional instrument panel tasks, but not for navigation tasks that require considerable cognitive input. However, his software, a HyperCard program, is not publicly available and recreation of his software would be expensive. Enhancements of his method may become available in the future.

3. Levison's work concerned the coordinated development of optimal control models to predict steering performance and a procedural model to predict in-vehicle system use. The resulting software has been demonstrated to provide good predictions of path maintenance and task interruptions. However, the software runs on unique hardware and is not widely accessible. Development of this model continues under FHWA sponsorship.

4. The NASA MIDAS software has been used recently for several high-technology applications, primarily related to aircraft. However, this application requires an Silicon Graphics workstation. There are no known automotive uses of MIDAS.

5. The HOS-based tools are well structured for predicting human task performance in that micro models for many tasks are a part of the software. The software is readily available and is the most commonly used simulation package by human factors professionals. However, the software, being a Monte Carlo simulation, was not intended to support continuous-control tasks (e.g., steering).

6. For human-computer-interaction problems quite similar to automotive data entry, the use of the GOMS family of models is preferred for task-time estimation. Of the models in the GOMS family, the Keystroke-Level Model is most appropriate for use, though the parameter values need to be adjusted to fit the UMTRI data. Those estimates should give reasonable engineering estimates for task-completion times.

7. This report proposes an 11-step method (presented in Appendix B) to estimate in-vehicle task times. Those steps are:

1. Obtain a working model or step-by-step description of device operation.

2 Identify the major user goals relating to device operation.

3. Identify the major user goals and subgoals relating to device operation.

4. For each particular goal or subgoal, identify the methods used to achieve them.

5. Convert the word/sentence-based description of the methods into pseudocode.

6. Identify the assumptions with regard to test-users' knowledge of various methods of task completion, such as the extent to which switch operation and cognitive activities are completed in parallel, the use of shortcuts, etc.

7. Determine the appropriate mental, keystroke, and other operators for each step.

8. Enter the times for each operator.

9. Add up the execution times for each operator. This is easiest to do using a spreadsheet.

10. Adjust the keystroke times using the age multiplier.

11. Verify that the times make sense and revise as needed.

8. Further development and validation to the procedure described in this report is desired. The only examples of navigation data-entry task-time estimates are the UMTRI work on the Ali-Scout cited earlier and the street-address-entry case for the PathMaster in the appendix to this report.

9. Several authors (Evans and Stevens, Namba) have proposed methods for computing the information demands of displays, and they should be considered for addition to future versions of task-time calculations. Several individuals in Japan have found Namba's method to be of practical value. These two methods do not consider control operation.

10. Finally, two methods described in the appendix provide figures of merit for user interfaces (Display Evaluation Index, Analytic Profile System). Although these methods are not used in contemporary practice, the underlying characteristics in these models should be considered as the calculation model is enhanced to improved the predictions for display tasks.

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APPENDIX A - RESEARCH AT APPLIED PSYCHOLOGICAL SERVICES

Siegel and his colleagues developed two methods for evaluating displays using figures of merit, the Display Evaluation Index (DEI) and the Analytic Profile System (APS). Although these methods do not strictly predict task time, the parameters that affect task time are the same as those that influence the figures of merit.

DEI is the weighted product of several factors, with each factor varying from 0 to 1 (perfect), as well as the product of those factors (Siegel, Miehle, and Federman, 1964). The implication of the multiplicative combination is that "a chain is only as strong as its weakest link." The factors in DEI include complexity, directness, data transfer, encoding, time, match, and critical links (Table 12). Siegel, Miehle, and Federman (1964) report that DEI ratings of various radar and radio units were in higher agreement with the mean ratings of human factors experts than the individual experts with each other. There are no published automotive examples of DEI use.

Table 12. Factors in DEI

Factor	Explanation
complexity	To compute this factor, links are established between displays and controls in accordance with the probability of successful information transfer. (See Siegel, Miehle, and Federman, 1963.)
directness	Ideally, there is only one link between each display and each control. Although redundancy can reduce the likelihood of a user error, multiple links are not desired. Redundancy is the sum of the number of controls and display squared divided by 2 times the number of information and instruction links times the sum of the number of controls and displays.
data transfer	This represents the extent to which information is in a ready-to-use form. To compute the data transfer factor, the interface must first be represented as an analog circuit or a logical equivalent. The factor is equal to 2 divided by the number of control and display elements times the number of gate, mixer, and computation boxes in the diagram.
encoding	The encoding factor only applies to controls and displays with 12 or more independent states and are controlled by binary devices (e.g., toggle switches). Siegel, Miehle, and Federman (1964) provide a nomogram to determine this factor.
time	This is the relationship between the time required to complete the task (estimated using information theory) and the time available to complete it. The estimated time is equal to 0.15 + 0.49 times the number of digits. The factor is equal to the number of digits divided by 16, with that expression multiplied by the cube of the time available divided by the actual time. Where the time available exceeds the actual time an additional complex value is added to the cube ratio term.
match	The match factor considers if the amount of information presented is adequate to complete the intended act. Usually it is 0.
critical links	The critical-link factor, represents the extent to which transfers, if not completed correctly, cannot be repeated and will result in a task failure.

In the Analytic Profile System raters score a display interface on seven dimensions (stimulus numerosity, primary coding, contextual discrimination, structure scanning, critical relationships, cue integration, cognitive processing activity) by responding to a series of questions for each dimension (Siegel, Fischl, and Macpherson, 1975). For example, the stimulus numerosity dimension, a sample question might be "At first glance, the interface seems to be relatively uncluttered." The values from the seven dimensions are combined to form a total score. See Table 13. Although Siegel, Fischl and Macpherson (1975) present an example of an automobile instrument-panel evaluation, no other automotive applications of this method have appeared in the literature.

Table 13. Example Questions for the Analytic Profile System

Dimension	Example item
stimulus numerosity	At first glance the interface seems to be relatively uncluttered.
primary coding	The overall format of this display seems to be a natural and proper one.
contextual discrimination	The things presented seem to fall into natural groupings.
structure scanning	The information seems well presented for the decisions which have to be made.
critical relationships	The influence that most displayed items have on other displayed items is reasonably apparent.
cue integration	The way the information is presented seems quite conducive to user integration of this information.
cognitive processing activity	Considerable intermediate information processing is required of the user.

APPENDIX B - EXAMPLE CALCULATION

4.0 Calculation Method

4.1 Overview

The basic approach involves top-down, successive decomposition of a task. That is, the analyst takes a task performed by the driver and breaks the task down into steps, and for each step identifies the human and device task operators. As a matter of practice, analysts sometimes get stuck using this approach because they are not sure how to decompose a subtask. In those cases, utilizing a bottom-up approach may overcome such roadblocks.

The original approach assumes error-free performance, well-learned tasks, and particular locations of controls, assumptions all violated in motor vehicles. Accordingly, compensations have been included in the method described here. The original method is described in some detail in Card, Moran, and Newell (1980), though modifications have been made (e.g., Kieras, 1998) to improve the accuracy of the method and modify the parameters to more closely approximate the time in motor vehicles.

More specifically, the general process is:

1. Obtain a working model of the device, a simulation of it, a videotape of someone using it, or a step-by-step operational description along with all supporting documentation (quick reference card, user manual). Also needed is the city and street database used, as well as any other data the system might access (e.g., dynamic traffic information). Have those items in hand while calculating estimates.

2. Identify the major operational goals (for example, obtain guidance).

3. For each major goal, identify the associated subgoals. Subgoals may be at multiple levels.

4. For each particular goal or subgoal, identify the methods used to achieve each goal or subgoal. Use words to describe the methods.

   For this step, camcorder-quality records of a few typical users operating the interface can be helpful in identifying where users may choose to pause to make decisions. Videotapes provide a useful record of screen actions and example screens serve to document the interface for analysis. When recording, be sure the camcorder is almost perpendicular to the test screen and blockage due to the user's hand is minimized. Slight departures from normality combined with painting the sides of switches contrasting colors makes the depression of short-throw switches easier to see on the recording. Also make sure the image is closely cropped around the display so the change of single characters is readily apparent on the recording.

5. Convert the word/sentence-based description of the methods into a computer-program-like format (pseudocode).

6. Identify the assumptions with regard to the knowledge of test users of various methods of task completion, the extent to which switch operation and cognitive activities are completed in parallel, the use of shortcuts, etc. Table 14 shows some of the basic assumptions. For actions performed in parallel, use the completion time of the most time consuming of the parallel actions to estimate total task-completion time.

Table 14. Computational Assumptions

Assumption	Comments	Adjustment
error-free performance	The computational method assumes drivers do not make any mistakes in obtaining and entering information. In fact, errors can be quite high, ranging from 10 to 50 % of the trials.	Rather than attempting to determine the probability of each error and the time to correct it, an overall correction penalty may be included in the estimate.
routine cognitive task	The method assumes that drivers know what to do at each step. In fact, navigation system use is not a highly learned task and drivers sometimes forget what to do.	Model estimates are improved by including additional mental operations where forgetting is likely to occur. Adjustments for this are made by using parameters from in-vehicle tasks rather than office tasks.
automotive context (The original model was developed for predicting task times in an office.)	The position of a mouse varies from movement to movement but automotive controls do not. However, automotive controls may require greater reach accuracy. In addition, vehicle motion may elevate times to reach for controls slightly	Utilize automotive-specific estimates of reach and movement time. Evaluators may wish to develop their own operator value or correction factors, as well as additional application rules to improve estimates.
warm start	For most tasks, the navigation is assumed to be on and the disclaimer screen is cleared.	Assume starting from the "main menu."
use only visible, noncognitively loading shortcuts	Many of the goals can be achieved using more than one method. Some shortcuts, while visible, are not simple. For example, if the goal was to scroll to a name starting with the letter "u" and the initial point was the letter "a," in some systems, the optimal method to get there would be to scroll backwards in the alphabet (a->z, z -> y, y -> x, x -> w, w -> v). See note 1.	Ignore methods of which only experts would be aware, or that are cognitively loading (such as reciting the alphabet backwards). Data on the frequency of use of shortcuts is needed.

include system response time (except for computationally interrupted tasks	Delays occur as systems scroll lists, update maps, and so forth.	Since the individual waits for these updates, system response time should be included in the task time.
Perfect knowledge of the address	Likely problems include (1) incomplete knowledge of the city of the destination (is the street address in Ann Arbor or Ann Arbor Township), (2) missing compass headings for streets (N 1st St vs. S 1st St), and missing street descriptors (Allen Drive vs. Allen Road). Normally people try to enter destinations, and only when they get to the last step of entering an address can they determine if the address is the desired one, or even if it is in the data base. Correctness is often determined by having a route computed and then looking at a map for the destination.	For ease of computation, assume the complete address is known.

Note 1: By observation, only expert users make use of alphabetic entry combined with backwards scrolling to retrieve city and street names. For example, the quickest way to select the city "Aurora" in the Great Lakes data base for the PathMaster navigation system (a scrolling list interface) is to use the alphabetic advance (right arrow key) to go from Aida (1st "A" entry) directly to Bannockburn (1st "B" entry) and then scroll backwards one entry, rather than pressing the down arrow 11 times (Aida, Addison, Algonquin, Allen Park, Alsip, Alto, Ann Arbor, Antioch, Arlington Heights, Auburn Hills, Aurora).

7. Determine the appropriate mental, keystroke, and other operators for each step. Entry into a spreadsheet is recommended.

   The most challenging aspect of this step is to decide where to include mental operators. Suggested rules for where to include them follow.

   a. Provide at least one mental operator when a menu must be read or a major decision needs to be made.

   b. If a decision can be fully anticipated because all of the information needed is visible well in advance of the sequence, a mental operator is not included in the sequence. So, when scrolling through a list entry-by-entry (assuming the entries are shown on a display), the sequence of operators would be "cursor, cursor, cursor," not "mental, cursor, mental, cursor, mental, cursor" because the user could think about what needed to be done next in parallel with pressing a cursor key. However, if the cursor action clears the screen (e.g., in alphabetic advance), then a mental operator would be included because the user needs to read the display.

The sequence would be "mental, next screen, mental, next screen," etc. There are times, such as when scrolling well into the alphabet, that this exception needs to be modified, such as when scrolling to the middle of the alphabet (and some of the mental operators are omitted). This situation will be covered in future revisions of this document.

c. When scrolling through long lists, a mental operator occurs just before pressing the enter key to confirm the correct item is to be selected.

8. Enter the times for each operator.

9. Add up the execution times for each operator. This is easiest to do using a spreadsheet.

10. Adjust the keystroke times using the age multiplier.

11. Verify that the times make sense and revise as needed. Where to include mental operators needs particular attention. This may also be a useful time to review a videotape of a typical user interacting with the system. When played back at slow speed on a frame-accurate VCR (such as a Panasonic AG550), those tapes can be used to provide rough estimates of screen update and calculation times. Review of Tijerina's (Tijerina, Parmer, and Goodman, 1998; Tijerina, 1999) and UMTRI's research (Manes, Green, and Hunter, 1998) may prove to be useful.

    One quick method to verify the time estimates is to have a colleague, most likely a young engineer who has some familiarity with the interface, perform the task in question without using shortcuts only an expert would know. The colleague's time will serve as a ballpark estimate of the total task time for young drivers, though the colleague's familiarity with the interface may lead to some mental operators being omitted.

Annex 1 - Calculation Example

Following is an example of entering Paul Green's office address (2901 Baxter Road, Ann Arbor, Michigan) into a Rockwell Pathmaster/Hertz Neverlost, Magellan Pathmaster (software version 3.31) with the Great Lakes data base (version 30J.0372.01) loaded. Readers should note that the data base is fluid, so that some short cuts may be available depending upon the recent driving history. The example that follows uses the street address method. It assumes that the address has not been recently visited (so it is not on the guidance history list) nor has Ann Arbor (so the city is not on the city shortcuts list).

1. Obtain a working model of the device and the software. Figure 1 shows the driver interface of the Magellan PathMaster, the example case.

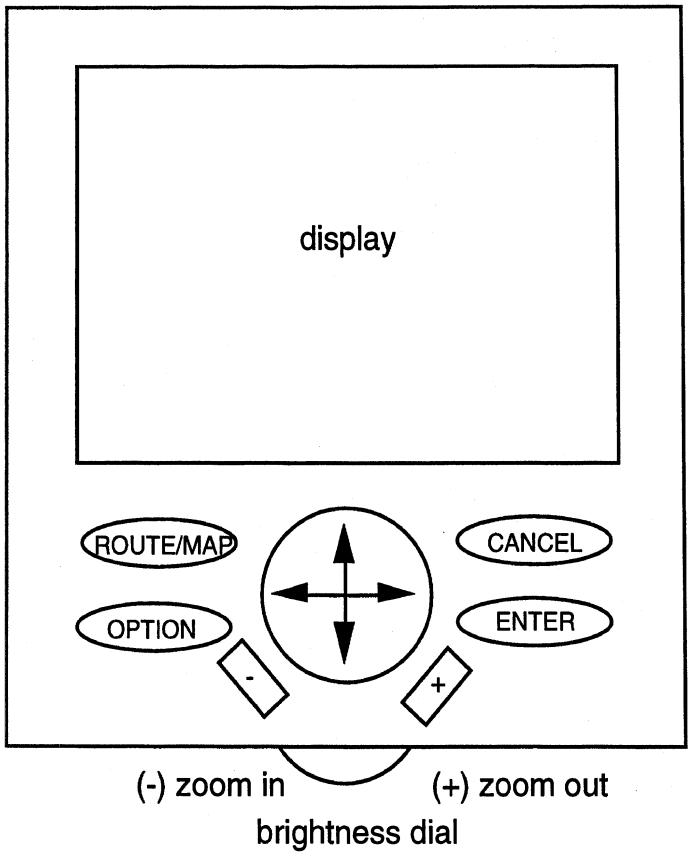


Figure 1. PathMaster user interface

2. Identify the major operational goals (enter a street address, enter an intersection).

3. For each major goal, identify the associated subgoals. Subgoals may be at multiple levels.

In this example, the goal is to enter an address using the street-address method. Below are the major subgoals.

Assumption: The starting point is the destination-method selection screen. After the title screen clears (by itself) and the driver clears the disclaimer screen, this screen appears.

Goal: Enter the destination using the street-address method.
- Goal 0: Move a hand to the device.
- Goal 1: Select destination entry via street-address mode.
- Goal 2: Select a city.
- Goal 3: Select a street.
- Goal 4: Select a street address.
- Goal 5: Select route criteria.

4. For each particular goal or subgoal, identify the methods used to achieve each goal or subgoal.

Goal 0: Move a hand to the device.
Reach for the navigation device.

Goal 1: Select destination entry via street-address mode.
Find the destination entry item on the initial menu and select it.

Goal 2: Select a city.

Scroll through the list of cities until the desired city is found. If the first letter of the city name does not match the first letter for the desired name, use the up and down arrow keys until a matching first letter is found. Then use the right and left arrows to scroll through the list of cities one city at a time. When a match is found, select it. Shortcut: If the city was recently visited, it appears on the recent list at the beginning of the city list. Use the up arrow keys to scroll to a possibly matching name. In all cases, when a match is found, select it.

Goal 3: Select a street.

This procedure is similar to that for selecting a city, except that a street name is being matched, not a city name.

Goal 4: Select a street address.

Compare the first column of the desired street address with the display address. If the columns values match, move to the next column (using the right and left arrow keys). If they do not match, then use the up and down arrow keys to increase or decrease the displayed value to match the desired address. When all the values match, select the address (by hitting enter).

Goal 5: Select route criteria.
Select the desired criteria from the list of three shown.

5. **Convert the word/sentence-based description of the methods into a computer-program-like format.**

. **Identify the calculations assumptions with regard to knowledge of various methods, the extent to which switch operation and cognitive activities are completed in parallel, etc. Table 14 shows some of the basic assumptions.**

Goal 0: Move a hand to the device.
Reach for the device.

Goal 1: Get to the desired destination entry mode.
Find the destination entry item on the initial menu and select it.

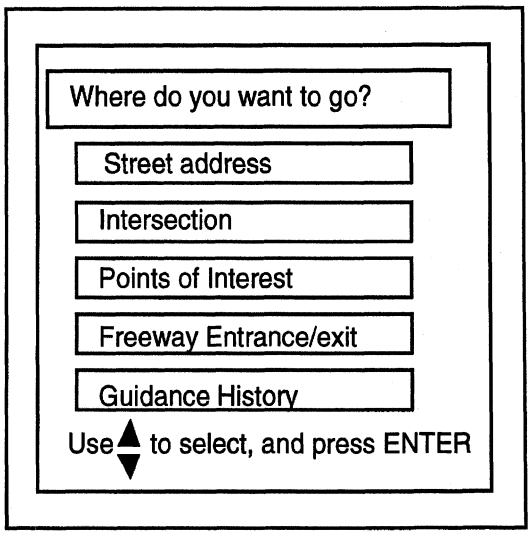


Figure 2. Route Criteria Screen

Read the "destination mode" (where) screen and search for "street address" Press the enter key to select the first entry.

Assumption: The normal process of selecting an item from a list is:
1: Read the list and find the desired item.
2. Scroll down to the desired item.
3. Confirm the desired item is highlighted.
4. Select the item by pressing the enter key.

However, when the desired item is the first item in the list, steps 2 and 3 are omitted. For long lists, the process of pressing keys (to scroll) down and reading the list appear to occur in parallel, with the keypress times determining the scrolling completion time. The final confirmation, however, still occurs.

Goal 2: Select a city.

After the city menu has appeared, scroll through the list of cities until the desired city is found. (See Figure 3.) If the first letter of the city name does not match the first letter for the desired name, use the up and down arrow keys until a match of the first

letter is found. Then use the right and left arrows to scroll through the list of cities one city at a time. When a match is found, select it. Shortcut: If the city was recently visited, it appears on the recent list at the beginning of the city list. Use the up arrow keys to scroll to a possibly matching name. In all cases, when a match is found, select it. How often this shortcut is possible is unknown.

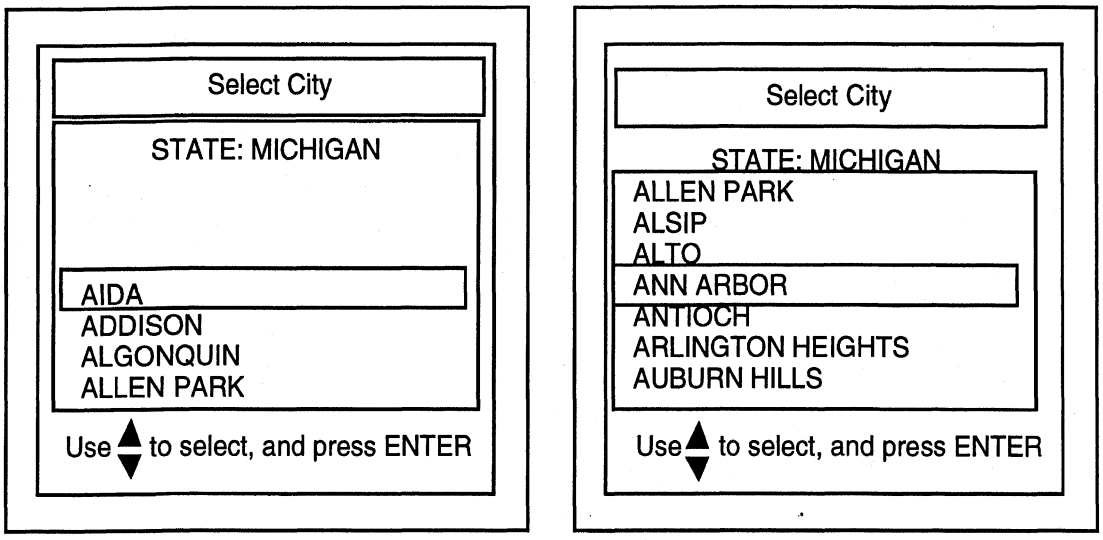


Figure 3. City screens

Method for goal: find matching entry in alphabetized list using scrolling method

wait for the beginning of the city listing to appear
1: read highlighted item and decide if 1st letter of current entry matches desired city
2: if first pass, then select method (pure or alpha scroll)
    if not matching 1st letter
        press bottom of round switch (4-way cursor) to go to next letter
        go to step 1 (decide if match, note: reading occurred earlier)
    if matching 1st letter
        current letter = second letter
        compare current letter of highlighted item with spelling of desired city
        2.1 if current letter matches and last letter
            confirm correct entry
            hit enter
            go to exit: next goal
        if current letter matches and not last letter
            increment current letter
            go to 2.1 (compare current letter)
        if current letter does not match
            press key to scroll down 1 entry (see note 1)
            go to 2.1
exit: next goal

Note 1: As noted above, when scrolling long lists for in-vehicle systems, observation has shown that reading text and pressing keys to scroll the list appear to occur in parallel. The predominant times are for keypresses.

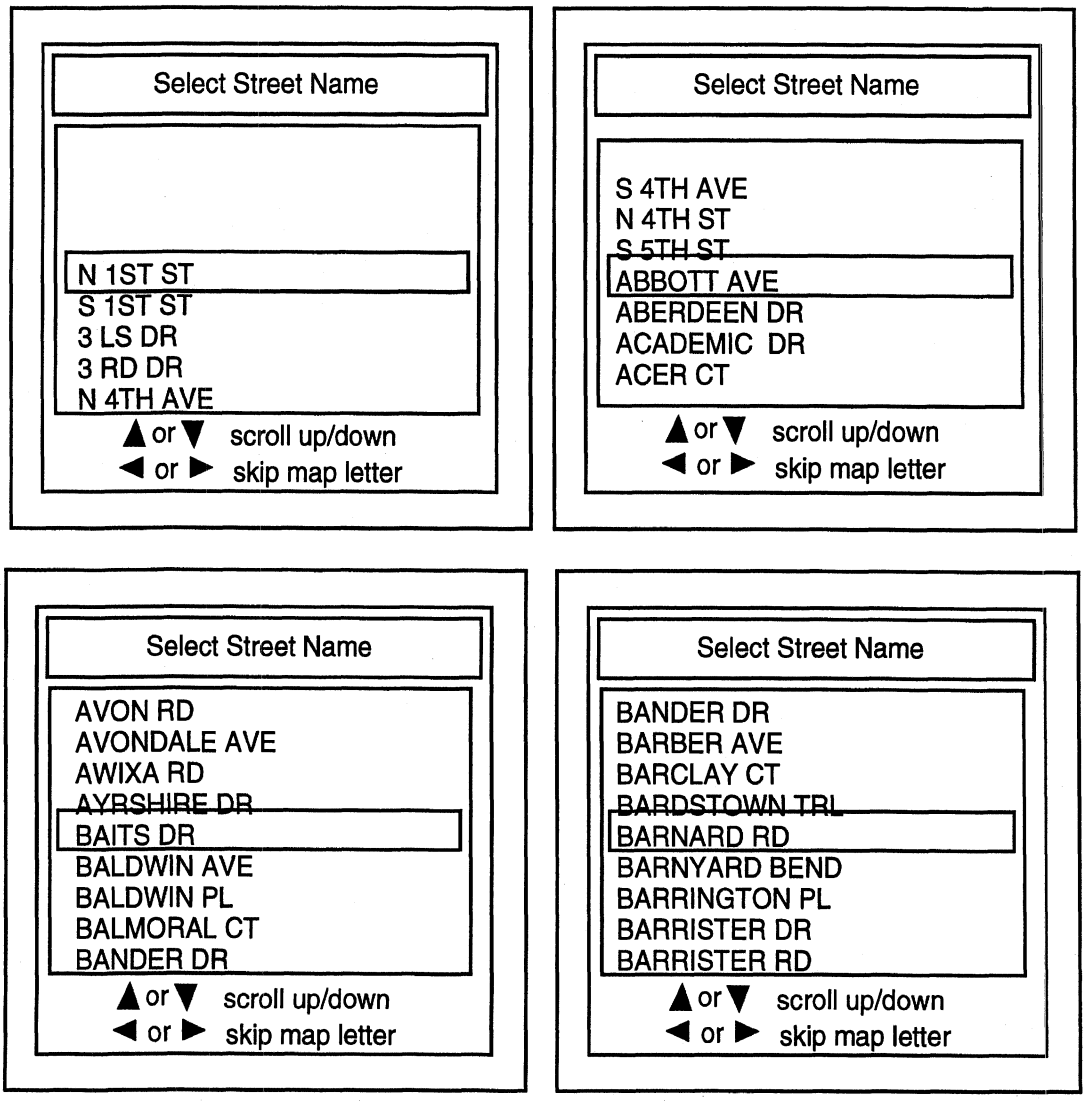
Note 2: By observation, only expert users make use of alphabetic entry combined with backwards scrolling to retrieve city and street names, so the reverse alphabetic scrolling method was not considered.

Goal 3: Select a street.

This procedure is similar to that for selecting a city, except that a street name is being matched, not a city name. For convenience, it is repeated here.

After the list of streets has appeared, scroll through the list of streets until the desired street is found. If the first letter of the street name does not match the first letter for the desired name, use the up and down arrow keys until a match of the first letter is found. Then use the right and left arrows to scroll through the list of streets one street at a time. When a match is found, select it. (See Figure 4.)

Note: There is no shortcut list of recently visited streets.



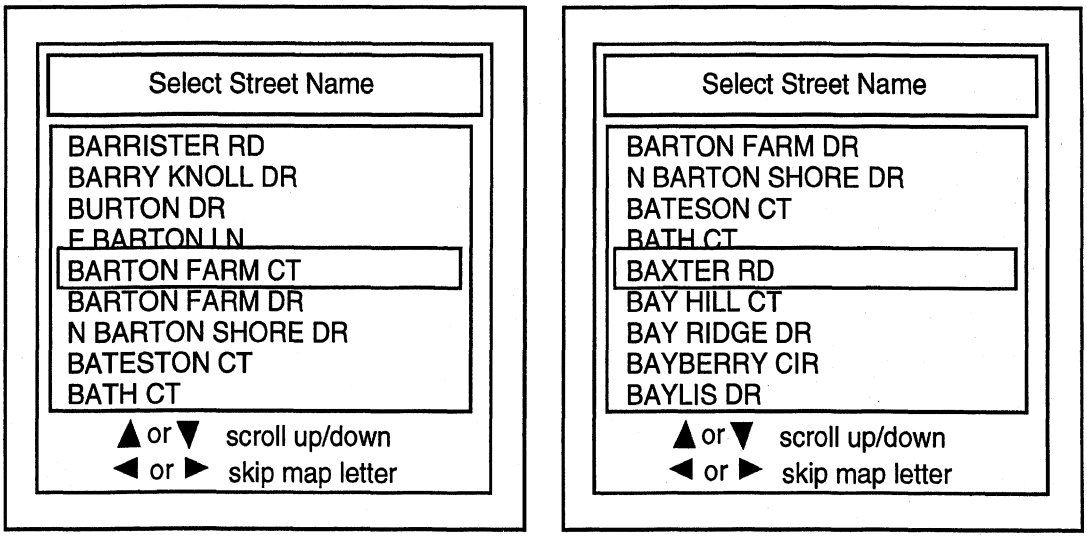


Figure 4. List of Street Names

Method for goal: find matching entry in alphabetized list using scrolling method

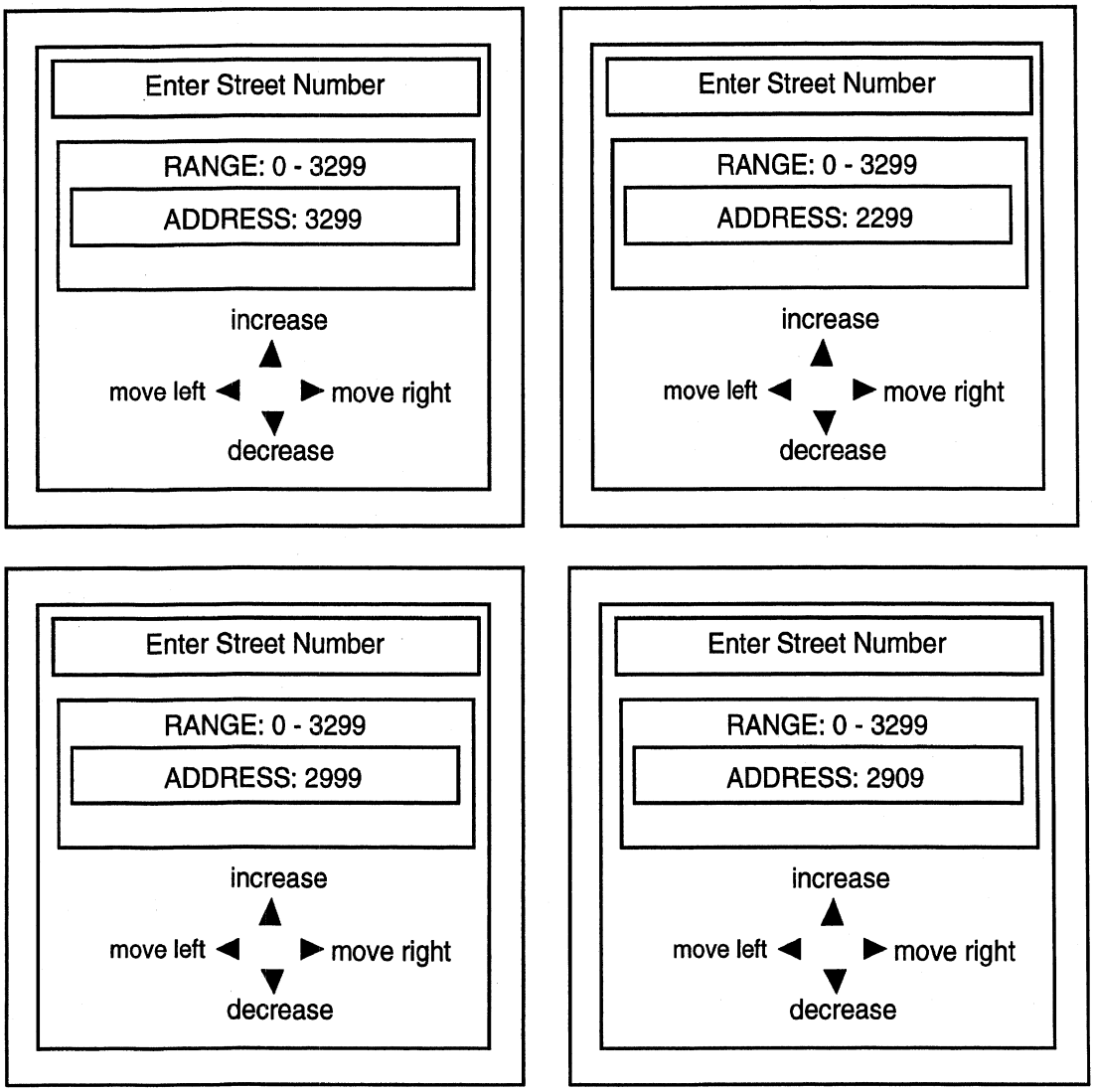
wait for list of streets to appear
1: read highlighted item, decide 1st character if name of current entry matches desired street (see note 1)
2: if first pass, selected method (pure or alpha scroll)
    if not matching 1st character
        press bottom of round switch (4-way cursor) to go to next character
        go to step 1 (to read the next item)
    if matching 1st character
        current character = second character
        compare current character of highlighted item with spelling of desired street
        2.1 if current character matches and last character is current character
            confirm correct entry
            hit enter
            go to next goal
        if current character matches and not last character
            increment current character
            go to 2.1 (compare current character)
        if current character does not match displayed character
            press key to scroll down 1 entry (see note 2)
            go to 2.1
exit: next goal

Note 1: In the initial name comparison, N, S, E, and W (e.g., N 1ST ST) are ignored.

Note 2: This sequence only approximates that which subjects use as some chunking of the street designators (St., Ave., Dr., etc.) is likely. However, that chunking has only a minor impact on the total task time, so for ease of calculation, chunking can be ignored.

Goal 4: Select a street address.

After the screen showing the range of streets appears, compare the first column of the desired street address with the display address. If the columns values match, move to the next column (using the right and left arrow keys). If they do not match, then use the up and down arrow keys to increase or decrease the displayed value to match the desired address. When all the values match, select the address (by hitting enter). (See Figure 5.)



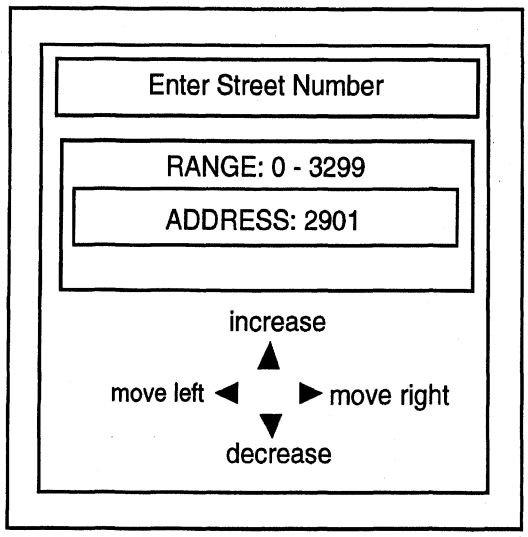


Figure 5. Street Number Screens

Method for incrementing/decrementing numbers using 4-way cursor switch (round key)

Recall the desired street address, read the maximum allowable street address, and if necessary, pad the desired name with leading zeros to match the number of characters in the maximum value.

current digit=left most digit

determine next field to change: Decide if the value in the current display field is the same as that in the recalled field

1. decide if value of currently displayed field <, =, > value of recalled field
    case 1: currently displayed field = value of recalled field
        decide if last field
        if last field
            confirm displayed = recalled street number
            hit enter key
            go to exit
        if not last field
            go to next field: press right side of round key (four-way cursor)
            current digit = next digit
            go to 1
    case 2: displayed > recalled
        compute difference in current field = displayed - recalled
        decrease display value by pressing bottom of key "difference" times
        confirm displayed = recalled
        go to case 1
    case 3: displayed < recalled (note 1)

Note 1: Experts realize that addresses form a circularly linked list. So, if the displayed address is 9 Main Street and the desired address is 2 Main Street, the optimum

strategy is to press the up arrow (increase) key three times (9->0, 0->1, 1->2) rather than the down arrow (decrease) seven times (9->8, 8->7, 7->6, 6->5, 5->4, 4->3, 3->2). The efficiency with which this shortcut is used will depend on experience. For example, early in becoming an expert, the user may use the up arrow key to go from 9 -> 0, but not 9->2, even though use of the up arrow requires fewer keystrokes.

Goal 5: Select route criteria.

After the route-criteria screen appears, select the desired criteria from the list of three shown. (See Figure 6.)

Note: At this point, the task timing ends and the person returns to driving. However, several seconds are required for the system to calculate a route and display the route. That added time is not included in the total task time.

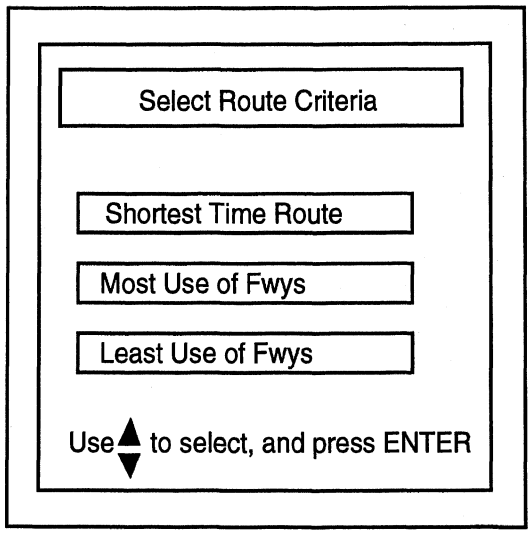


Figure 6. Route Selection Criteria

Read the "route criteria" screen and search for "shortest time route"
Press the enter key to select the first entry.

Note: Assumptions are the same as for the address-entry method selection described previously.

7. Determine the appropriate mental, keystroke, and other operators that are appropriate for each step.

8. Enter the times for each operator.

9. Adjust the times based on the age distribution of the expected user population. For young subjects (18-30), use the keystroke times as is. For middle-aged subjects (40-55), multiply the keystroke times by 1.4. For older subjects (>65), multiple the keystroke times by 2.2.

10. Add up the execution times for each operator. This is easiest to do using a spreadsheet.

For these steps, see the spreadsheet the follows.

11. Verify that the times make sense and revise as needed.

Execution Trace of Entering 2901 Baxter Road, Ann Arbor via Street Address Method into a PathMaster
working draft analysis subject to revision
version of July 23, 1999
note: Multiplier for age 55-60 is 1.7, this needs to be checked

Goal: Action	Operator	Time (s) young	Time (s) old
0: Reach for the navigation interface			
Move hand to the device	Rf	0.31	0.53
		0.31	0.53
1: Get to the desired destination entry mode			
Read the "destination mode" (where) screen and search for "street address" (first item)	M	1.5	2.55
Press the enter key to select the first entry (street address)	E	1.2	2.04
		2.7	4.59
2: Select a city			
Wait for the city menu to appear	Rm	0.5	0.5
Read highlighted item (Aida)	M	1.5	2.55
First letter matches (A), so compare with second letter (of Ann Arbor)	M		2.55
Second letter does not match so scroll down (to Addison)-press right side of switch	C1	0.75	1.28
Second letter does not match so scroll down (to Algonquin)-press right side of switch	C2	0.25	0.43
Second letter does not match so scroll down (to Allen Park)-press right side of switch	C2	0.25	0.43
Second letter does not match so scroll down (to Alsip)-press right side of switch	C2	0.25	0.43
Second letter does not match so scroll down (to Alto)-press right side of switch	C2	0.25	0.43
Second letter does not match so scroll down (to Ann Arbor)-press right side of switch	C2	0.25	0.43
Second letter and all other letters match (Ann Arbor), confirm match	M	1.5	2.55
Press enter key	E	1.2	2.04
		6.7	13.62
3: Select a street			
Wait for street menu to appear	Rm	0.5	0.5
Read highlighted item (N 1ST ST)	M	1.5	2.55
Decide alpha scroll	M		2.55
1st char. of street (1 from 1ST) not desired (B), so scroll to next letter-press right side of switch	C1	0.75	1.28

Wait for street names starting with "A" to appear (measured)	R	0.13	0.13
1st char. of street (A from Abbott) not desired (B), so scroll to next letter-press right side of switch	C2	0.25	0.68
Wait for street names starting with "B" to appear (measured)	R	0.13	0.13
Confirm first character of street name B (from BAITS DR) matches target (BAXTER)	M	1.5	2.55
2nd character does not match, so scroll down (to BALDWIN AVE)	C1	0.75	1.28
2nd character does not match, so scroll down (to BALDWIN PL)	C2	0.25	0.43
2nd character does not match, so scroll down (to BALMORAL CT)	C2	0.25	0.43
2nd character does not match, so scroll down (to BANDER DR)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARBER AVE)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARCLAY CT)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARDSTOWN TRL)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARNARD RD)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARNYARD BEND)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARRINGTON PL)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARRISTER DR)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARRY KNOLL DR)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARTON DR)	C2	0.25	0.43
2nd charatcer does not match, so scroll down (to E BARTON LN)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARTON FARM CT)	C2	0.25	0.43
2nd character does not match, so scroll down (to BARTON FARM DR)	C2	0.25	0.43
2nd character does not match, so scroll down (to N BARTON SHORE DR)	C2	0.25	0.43
2nd character does not match, so scroll down (to BATESTON CT)	C2	0.25	0.43
2nd character does not match, so scroll down (to BATH CT)	C2	0.25	0.43
2nd character does not match, so scroll down (to BAXTER RD)	C2	0.25	0.43
Confirm BAXTER RD matches desired street name	M	1.5	2.55
Press enter key	E	1.2	2.04
		12.96	24.41

4: Select a street address			
Wait for searching address range message to appear	Rm	0.5	0.5
Wait for street address range to appear	Rm	0.5	0.5
Decide if displayed (3299) and recalled (2901) street addresses match	M	1.5	2.55
compute difference in current field = displayed - recalled (3-2=1)	M		2.55
decrease display value by pressing bottom of key 1 time	C1	0.75	1.36

decide if last field	M		2.55
compute difference in current field = displayed - recalled (9-2=7)	M	1.5	2.55
press up arrow key 7 times	C1 + 6C2	2.25	3.83
decide if last field	M		2.55
compute difference in current field = displayed - recalled (9-0=9)	M	1.5	2.55
press up arrow key 9 times	C1 + 8C2	2.75	4.67
decide if last field	M		2.55
compute difference in current field = displayed - recalled (9-1=8)	M	1.5	2.55
press up arrow key 8 times	C1 +7C2	2.5	4.25
decide if last field (confirm match)	M	1.5	2.55
press enter key	E	1.2	2.04
		17.95	40.1
5: Select route criteria			
Wait for route criteria message to appear	Rm	0.5	0.5
Read the route criteria screen and search for "shortest time route"	M	1.5	2.55
Press the enter key to select the first entry	E	1.2	2.04
Wait for route is being calcuated message????			
		3.2	5.09
Task is complete, system then calculates route			
Total time is:		43.82	88.34