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# Visual and Task Demands of Driver Information Systems

Paul Green

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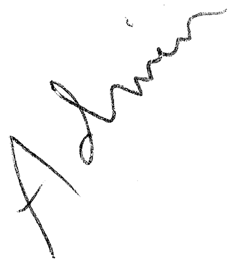

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16. Abstract

This report answers 12 questions (e.g., What is the relationship between visual demand and crashes?) that provided a basis for the development of SAE Recommended Practice J2364 (Navigation and Route Guidance Function Accessibility While Driving). Key findings follow.

Navigation-system-induced crashes have been identified in Japan, the only place where they are recorded. In the U.S., approximately 21 deaths and 2100 injuries are expected in 2007 if there are no restrictions on navigation system data entry in moving vehicles. This estimate was based on calculations of visual demand that consider mean glance time, the number of glances per task, frequency of use, and market penetration.

Destination-entry tasks take 1 to 2.5 minutes to complete, an order of magnitude greater than most in-vehicle tasks drivers now routinely perform. About 80 percent of the time entering destinations is spent looking away from the road, and consequently there is almost one lane departure per entry attempt. Lane departures, eyes-off-the-road time, on-the-road task time, and static (single) task time are highly correlated with each other, with single-factor linear regressions having $r^2$ values in excess of 0.5. Given its ease of collection, especially early in design, static task time is recommended as the primary measure to establish the safety and usability of navigation systems. Existing guidelines suggest a task limit of 10 seconds and driver preferences suggest limits of 5 to 10 seconds. Considerations of existing design practice suggest a maximum time of 15 seconds for navigation-data-entry tasks.

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HUMAN FACTORS

# Visual and Task Demands of Driver Information Systems

UMTRI Technical Report 98-16
Paul Green

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Ann Arbor, Michigan, USA
June, 1999

## PURPOSE

- provide background material for the development of SAE Recommended Practice J2364 (Navigation Function Accessibility While Driving)
- provide information to enhance the safety and usability of driver interfaces for navigation systems

## FINDINGS

| Issue | Rationale | Evidence |
|---|---|---|
| Have navigation systems been a causal factor in crashes? | Entry and retrieval of destinations while driving should not cause crashes. This is consistent with the "when in doubt, err on the side of safety" principle and "When in doubt, lock it out." for nav systems. | • very little evidence, only coded in Japanese National Police Agency data<br>• 1 navigation-related fatality and 58 injuries in 1st 6 months of 1998 in Japan (only data available)<br>• estimated 8.3 fatalities and 481 injuries in U.S. in 1998 if market penetration and frequency of use matched Japan<br>• Aside: Japanese regulations prohibit destination entry on the move |
| What is the relationship between visual demand and crashes? | Time spent looking inside the vehicle is not spent looking at the road for potential crash-inducing hazards. | • extrapolating from Wierwille's work:<br># U.S. deaths per year = growth.rate.in.VMT<br>* (target.year-1989) * market.penetration.rate<br>*[-.133 + .0447 * (mean glance t)$^{1.5}$<br>* (# of glances) * (glance frequency)]<br>= 21.1 fatalities/year in 2007<br>-> 2110 injuries/year |
| How long does destination input and retrieval take?<br><br>Do those tasks degrade driving performance? | Operating a navigation system should not be time consuming and interfere with maintaining speed and lane position, searching for hazards, or other crash-avoidance tasks. | • with manual controls and visual displays, destination entry takes 1 to 2.5 minutes<br>• Point of Interest (POI) entry takes take 10% longer than street address or intersection methods<br>• destination retrieval takes about 10 s (depending on the address and data base)<br>• the worst interface for a task takes twice as long to use as the best<br>• the number of lane departures when entering an address is almost 1 per trial |

| Issue | Rationale | Evidence |
|---|---|---|
| How long do drivers prefer to look in a vehicle at an object? | From their experience, drivers have a sense of how long is too long (and how frequent is too often). | • experimental approach is for drivers to look at nonattention demanding targets for as long as they feel safe/comfortable to do so<br>• also addressed by having drivers rate how safe/comfortable/secure they felt completing various tasks<br>• concerns regarding terms to use (e.g., safe, comfortable) and English-Japanese differences<br>• U.S. data suggests typical times of 0.8 to 0.9 s; Japanese data suggest 2.0 s; may be cultural or driving condition difference<br>• Rockwell - "Drivers loath to go for more than 2 seconds without information from the road."<br>• suggests total glance times should not exceed 5 to 10 s for drivers to feel safe |
| How much time do drivers spend looking at in-vehicle controls and displays? | For existing controls and displays, there are few interface-induced crashes, so those glance durations should be conducive to safe driving. | • mean glance durations typically do not exceed 1.2 to 1.5 s<br>• glance durations are log-normal with dispersions of 0.2 to 0.6 s (information useful in calculating the probability of long glances) |
| How often do lane departures occur for in-vehicle tasks?<br>What is the relationship between task completion time, glance statistics, and lane departures for existing interfaces? | Lane departures can lead to crashes and therefore should be minimized. Since lane departures require a working interface and a vehicle or simulator to collect, surrogate (correlated) measures should be considered. | • The number of lane departures is 0 when the number of glances is less than 2 to 2.5. Otherwise, using time in s, the # of lane departures / trial<br>= 1.3 (total glance time)<br>= 3.6 (mean glance time) + 0.25<br>= 2.2 (number of glances) - 1.<br>= 0.8 (task time) - 0.15<br>• very slight correlation between # glances and glance duration; treat glance duration as constant in rough estimates<br>• S.D. of many measures is about half of their means (mean glance time, mean task time, total glance time)<br>• mean task time = 1.9 * # glances + 0.5<br>= 1.6 * total glance time + 0.8.<br>(Total glance time = total eyes-off-the-road time.) |

| Issue | Rationale | Evidence |
|---|---|---|
| What do existing guidelines require concerning the use of navigation systems in a moving motor vehicle? | Designs should be consistent with accepted practice. | • British Standards Institute (BSI) guidelines use limits of modified Zwahlen diagram (max of 4 glances, no more than 2 s each)<br>• Battelle guidelines suggest (1) the navigation function provides added value while driving, (2) the mean glance time <1.6 s, (3) the task requires 4 or fewer glances, (4) the function cannot be implemented using voice option, and (5) 2 or fewer control actions are required.<br>• JAMA guidelines prohibit (1) displaying very narrow roads, (2) watching TV, (3) reading displays with scrolling characters, (4) displaying messages with more than 31 characters, (5) scrolling maps, (6) searching for addresses, (7) selecting destinations using a cursor. |

## KEY REFERENCES


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## PREFACE

This report was produced for the Navigation Subcommittee (Jim Foley, chair) of the SAE ITS Safety and Human Factors Committee (Gene Farber, chair). The report and other related activities were funded by the Society of Automotive Engineers using funding to support the development of ITS standards. The content and wording of this report were determined by the author and represent his interpretations of the literature.

This report provides the background for the development of Society of Automotive Engineers (SAE) Recommended Practice J2364 (Navigation and Route Guidance Function Accessibility While Driving). This recommended practice will specify which navigation functions should not be accessible to drivers while a vehicle is in motion. In parallel, a standard is being developed by the International Standards Organization (ISO) for the same purpose. In the interests of international harmonization, the two standards should be identical.

Supplementing this document will be another recommended practice, SAE J2365 (Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks), and a related ISO standard. Application of that standard will assist designers in creating safe and easy to use driver interfaces for navigation and related systems. The focus of that standard is on data entry tasks, the tasks of greatest concern in a moving vehicle.

When this project was planned, the sponsors of this research believed that studies of driver use of navigation functions, such as destination entry and retrieval, had been thoroughly examined in on-the-road experiments, and hence developing a standard for that purpose would prove straightforward. In fact, to the best of the author's knowledge, there were no such studies in the open literature when the project began, though two studies have been completed since then (Tijerina, Parmer, and Goodman, 1998; Tijerina, 1999), and there have been proprietary corporate studies. Further, except for in Japan (where many of the features being considered are outlawed for use while driving), use of a navigation system is not recorded in crash data bases.

Many believe that navigation systems can contribute to driving safety. They offer superior guidance to paper maps or written directions (so drivers are less likely to be lost), resulting in less wasted travel (and a lower crash exposure). They also require less attention than paper maps while driving (Dingus, Hulse, McGehee, and Manakkal, 1994). This report, however, is not a review of the overall safety impact of navigation systems. This report only addresses function access while a vehicle is in motion.

Even though only a few deaths are attributable to navigation-system use, and the number of studies of navigation-system safety and usability is limited, safety and usability still warrant attention. Consistent with the principle of "when in doubt, err on the side of safety," protection should be provided when risk is uncertain. Further, consistent with practice in other fields (the use of animal surrogates in medical tests, the use of physical models in engineering), data and models of human performance are the primary evidence provided here.

Since driving is primarily a visual task and navigation systems can present considerable visual demand, identifying how excessive visual demand can be determined is appropriate. Accordingly, the literature on visual occlusion, volitional glance behavior, eye fixations to navigation systems, and other topics related to visual demand has been examined in detail. The content of the SAE Recommended Practice J2364 and this report evolved in parallel. As the emphasis of the recommended practice shifted from measuring glance durations to task times, some effort was made to adjust the focus of this report. However, limits in the resources available constrained the extent of those adjustments, and several topics (the relationship between visual occlusion time, Zwahlen's research) were considered in drafts of this report but were eliminated from the final version. In particular, an initial review of Zwahlen's work suggested inconsistencies between studies whose resolution was beyond the scope of this project.

For many of the studies examined, reanalysis of research results was required. This included plotting data in tables that had never been plotted, picking points off of figures to generate tabular summaries, generating new statistical summaries, and completing regression analysis of published data sets to determine predictive equations. In several cases, the published literature was inadequate and the authors were contacted for details (on test vehicles, subject samples, traffic, or test roads), a process complicated by language barriers. This report covers the essence of what has been learned to date.

This thorough review of the basic literature was a time-consuming effort, certainly more extensive than was originally envisioned, but it has led to a convergence of the research results. Based on this literature review a scientifically based recommended practice has emerged, one that relies on fact, not opinion.

Furthermore, this effort effectively achieves the secondary goal of providing a basis for identifying where excessive visual demand occurs for functions other than navigation and route guidance.

The author would like to thank Dr. Jim Foley of Visteon for serving as the technical monitor for SAE of this project and for reviewing this report. In addition, the author would like to thank Aaron Steinfeld for generating some of the report graphics and Dave Benedict for his particularly careful review of the draft manuscript. Chris Monk, Christopher Nowakowski, Susan Scott, Louis Tijerina, and Hiroshi Tsuda also provided numerous comments on the draft manuscript. 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

## What Are the Issues?

As part of the Intelligent Transportation System (ITS) initiative, major activities are underway to increase the use of computers and communications technology in motor vehicles. The intent is to make travel more efficient, safer, and more enjoyable to users. These activities should lead to less wasted travel, reduced travel costs, reduced fuel imports, less traffic-related air pollution, and fewer deaths in traffic crashes. These activities also lead to many new products, desired by consumers, which suppliers and manufacturers want to produce, which in turn should result in associated economic benefits and employment.

For these benefits to be achieved, ITS products must be safe, usable, and useful to consumers. For in-vehicle-navigation and route-guidance systems used to guide drivers to destinations, the tasks of interest are (1) identifying the destination to the navigation system, (2) following the system's guidance, and (3) calibration and set up. The safety and usability in route-following tasks has been the topic of several studies (e.g., Green, 1992; Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993; Schraagen, 1993; Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995; Srinivasan and Jovanis, 1997; Burnett and Joyner, 1997; Katz, Fleming, Green, Hunter, and Damouth, 1997; Kimura, Marunaka and Sugiura, 1997). Little research has been done on calibration and other miscellaneous navigation-system tasks, probably because they are performed infrequently.

This particular report concerns what drivers should <u>not</u> do while a vehicle is in motion, specifically in regards to retrieving and entering information. A determination of what should not be acceptable needs to be based on scientific criteria, not merely informed opinions. Although there are many ways information can be entered and retrieved by drivers, this report only concerns using manual controls for input and visual displays for information presentation to drivers. At present, these are the primary means used, though voice input to motor vehicles is of significant interest. Unfortunately, there is little information on the attentional demands of voice control while driving, though the general belief is that voice input interferes with driving much less than does input using manual controls.

Poorly designed navigation systems can distract drivers from the primary task of driving, making the entry and retrieval of destinations unnecessarily difficult and frustrating drivers. These consequences could lead drivers to not purchase navigation systems, not find them useful, not use them, or to potentially be a causal factor in crashes.

## How to Determine What Is Not Allowed

In developing this report, considerable thought was given to how research evidence should be evaluated. (See Appendix A.) One of the key principles was "converging evidence," to provide arguments from a variety of perspectives (Table 1) to reach a conclusion concerning what should not be allowed. As was noted in the preface, the topic of visual occlusion (12) was not considered in this final draft due to the lack of resources.

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 in a vehicle when it feels safe or comfortable to 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? |
| Visual Occlusion | 12 | When vision is occluded, how much time does the literature suggest is available to glance inside the vehicle? |

Readers should note that this report places considerable evidence on the human-performance literature. In part, that is because of the lack of crash data, but also in consideration of the nature of driving. Since driving is basically a visual task, understanding the relationship between the visual demands of driving and driving performance is essential. In addition to comparisons using analogous tasks, measurements of the visual demands of driving and the time available for other tasks provide useful insights.

Generating this report required evaluating the evidence available, developing criteria for determining how to decide what should be allowed, and in applying those decision criteria. Several key principles outlined in Appendix A were followed. These principles were extremely helpful in resolving impasses in Navigation Subcommittee discussions. With regard to the literature, there were four major principles:

1. When in doubt, err on the side of safety.
2. Emphasize the literature over personal experience.
3. All studies are not equal.
4. When the quality or relevance of a study is in doubt, include the study along with caveats.

## NAVIGATION-SYSTEM-RELATED CRASHES

**Question 1: Is there statistical evidence that crashes are more likely when a navigation system is used, in particular during destination input?**

**Question 2: Are there cases in which navigation-system use was the cause of a crash?**

**Rationale:** Entry and retrieval of destinations while driving should not cause crashes. Crash risk can be identified by examination of crash statistics. Minimizing the likelihood of crashes is consistent with the "when in doubt, err on the side of safety" principle and variations of it ("Do no harm," "Minimize harm to the driver," etc.) or for navigation systems, "When in doubt, lock it out."

Where automotive safety issues are to be considered, the key evidence is the crash literature. There is no U.S. or European statistical data associating crashes with navigation-system use. The presence of navigation systems, let alone their use, is not coded in any state or federal crash data base, or is it tracked by rental fleets such as Hertz. Even if that data were available, the relatively small number of systems on the road in the United States at this time would make statistical inferences difficult.

In contrast, there are now several million navigation systems installed in vehicles in Japan, and the Japanese National Police Agency has been collecting some crash data relating to their use. At the time of the first draft of this report (and well into the development of J2364), there were no publicly available Japanese crash data on navigation-system use. During this project, a presentation was made at a meeting of the ITS Safety and Human Factors Committee concerning mobile-phone- and navigation-system-related crashes. What follows is a summary of that presentation and the associated handout (Tsuda and Fukumura, 1999). Their presentation was based on a translation (from Japanese) of materials provided by the Japanese National Police Agency. The data presented was obtained from post-crash interviews of drivers by the police. The presenters believe the drivers were truthful in reporting. The data set includes all injury-producing and fatal motor-vehicle crashes in Japan, but not crashes involving property damage only. The period examined was August 1997 to May 1998. The original report or the data set on which it was based were not available to the author. As a footnote, all 11 Japanese vehicle manufacturers comply with the Japan Automobile Manufacturers Association (JAMA) guidelines which prohibit many of the tasks being considered here, including destination entry while moving. Aftermarket suppliers and old OEM products may not be in compliance. In Japan, drivers rely on electronics map displays for guidance, while U.S. systems emphasize turn-by-turn displays. To provide further perspective, there are approximately 5,000,000 navigation-system-equipped vehicles in Japan, and in 1997, 12.2 percent of the vehicles sold had navigation systems installed.

Table 2 shows the total number of crashes associated with navigation systems in Japan for the first six months of 1998. (For baseline data from the National Police Agency, see http://www.npa.go.jp/koutuu1/homee.htm.) The annual total should be double the values shown. Thus, there were an estimated 2 deaths and 116 injuries from navigation system operation in Japan in 1998 (versus 22 fatalities and 1,793 injuries associated with mobile-phone use for the first six months of 1998). To put these consequences in perspective, a fatality was defined as a crash-induced death that occurs within 30 days of the crash (versus 24 hours in the United States). An injury was defined as any instance where medical treatment was needed. Given the categories listed, an operation should be synonymous with data entry. Since operation-induced crashes can occur only for older and non-OEM systems (since destination entry is locked out), their nonzero value is worthy of note. The data of Tsuda and Fukunaga (1998) suggest that approximately 63 percent of the units shipped to date were aftermarket units.

Table 2. Navigation-System-Induced Crashes in Japan, January-June 1998: Driver Tasks

| | Looking (at display, mostly maps or route) | Operating | Other | Total |
|---|---|---|---|---|
| Injury | 43 | 14 | 1 | 58 |
| Fatality | 0 | 1 | 0 | 1 |
| Total Crashes | 43 | 15 | 1 | 59 |
| % | 72.9 | 25.4 | 1.7 | 100 |

Table 3 shows the types of crashes associated with navigation systems. Rear-end crashes and crashes associated with inattention predominate and were overrepresented in this sample.

Table 3. Types of Crashes Associated with Navigation-System Use

| | Rear-end Vehicle | Struck Other Vehicle (not rear) | Pedestrian | Single Vehicle | Total |
|---|---|---|---|---|---|
| Injury | 34 | 19 | 4 | 1 | 58 |
| Fatality | 1 | 0 | 0 | 0 | 1 |
| Total Crashes | 35 | 19 | 4 | 1 | 59 |
| % | 59.3 | 32.3 | 6.8 | 1.7 | 100. |

Table 4 shows the crash frequency by time of day. The numbers are somewhat more uniform (in contrast to overall crash frequency). Typically, crash rates (in terms of crashes per hour) peak at about 4 p.m., being about triple the minimum (of 4 a.m.) (National Highway Traffic Safety Administration, 1998).

Table 4. Navigation System Induced Crashes as a Function of Time of Day

| | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-16 | 16-18 | 18-20 | 20-22 | 22-24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injury | 5 | 3 | 4 | 5 | 3 | 6 | 6 | 6 | 5 | 5 | 6 | 4 |
| Fatality | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Crashes | 6 | 3 | 4 | 5 | 3 | 6 | 6 | 6 | 5 | 5 | 6 | 4 |

In Table 5, notice that these crashes occurred primarily in regular-sized passenger cars. Data on the installation rates by vehicle type were not available to the author.

Table 5. Navigation-System-Induced-Crash Frequency by Vehicle Type

| | Cars | | | Trucks | | | Motorcycle, specialty, other | Total |
|---|---|---|---|---|---|---|---|---|
| | large | regular | small | large | regular | small | | |
| Injury | 0 | 55 | 1 | 1 | 1 | 0 | 0 | 58 |
| Fatality | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total Crashes | 0 | 56 | 1 | 1 | 1 | 0 | 0 | 59 |
| % | 0.0 | 94.9 | 1.7 | 1.7 | 1.7 | 0.0 | 0.0 | 100. |

As shown in Table 6, notice that drivers of almost all ages were involved in navigation system-induced crashes. Data on the fraction of systems owned by drivers in each age group are not available to the author.

Table 6. Navigation System Induced Crashes as a Function of Driver Age

| | | 16-24 | 25-29 | 30-39 | 40-49 | 50-59 | 60-64 | >65 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Injury crashes | men | 8 | 12 | 13 | 9 | 5 | 0 | 5 | 52 |
| | women | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 6 |
| | subtotal | 9 | 14 | 16 | 9 | 5 | 0 | 5 | 58 |
| fatal crashes | men | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | women | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | subtotal | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total | men | 9 | 12 | 13 | 9 | 5 | 0 | 5 | 53 |
| | women | 0 | 1 | 2 | 3 | 0 | 0 | 0 | 6 |
| | subtotal | 10 | 14 | 16 | 9 | 5 | 0 | 5 | 59 |
| % | | 16.9 | 23.7 | 27.1 | 15.3 | 8.5 | 0 | 8.5 | |

Crash data has been collected in operational field tests of navigation systems (e.g., TravTek, ADVANCE, FAST-TRAC) conducted in the United States but there have been no crashes. However, those studies have emphasized use of complex entry functions prior to driving, and the number of miles accumulated to the point where much less than one crash would be expected for any reason. Further, the TravTek interface locked out destination designation when the vehicle was moving, so crashes related to destination entry and retrieval could not occur.

As an aside, these field tests have made interesting use of critical incident methods to identify potential concerns and such methods may be useful in future research. For example, in the TravTek camera car study (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995) the number of safety-related errors and incidents for a turn-by-turn interface with voice was comparable to using a paper map and written directions on paper. There were far more incidents and errors for an electronic map without voice guidance.

Thus, there is very little crash data on navigation-system-induced crashes, primarily because navigation-system use is coded in only one crash data base, and except for Japan, the installation rate is extremely low. The limited Japanese data available suggest there have been navigation-system-induced crashes, though further investigation of their cause is warranted. Given this uncertainty and following the principle "minimizing harm to the driver," some protection is desired. Consistent with other fields, such as medicine, new products that could jeopardize human life should not be produced until they are proven safe. In this case, the lack of crash data (because they are not recorded) does not establish that these systems are safe or usable in general, or specifically which tasks should not be performed in a moving vehicle. Further, waiting many years for data base modifications and crashes to accumulate is not desired. Therefore, the evidence for a recommended practice must also consider other evidence such as existing design guidelines, driving performance and visual demand studies, and driver preferences.

## VISUAL DEMAND AND CRASHES

### Question 3: What is the relationship between visual demand and crashes?

**Rationale:** If there is a relationship between visual demand and crashes, and the demand of in-vehicle systems is computable, then crash frequencies should be predictable. These data can be used to assess the risk of destination entry and retrieval in a moving vehicle overall, and the risk of specific interface configurations.

### Wierwille (1995)

Given the paucity of on-road studies of driver operation of navigation-system features, other secondary indicators need to be considered. Although it is uncertain what fraction of the total information used by drivers is visual (Sivak, 1996), there is no debate that one cannot drive without vision, even though one can drive quite well when acoustic, haptic, and all other modalities of information perception are removed.

Adding in-vehicle tasks with a significant visual component can overload drivers. Drivers could respond by shedding tasks, reducing task priorities, modifying tasks, reducing task quality, postponing execution, or reassigning the task to others. (See Appendix B.) Each of these strategies has advantages and disadvantages, but none of them is completely satisfactory.

One consequence of visual overload is an elevated risk of crashes. To determine how often use of various vehicle features led to crashes, Wierwille and Tijerina (1996) examined 190,000 narratives in the North Carolina police-reported crash data base for 1989. Using an iterative process, a variety of key words associated with visual allocation and workload were identified. Some 1562 cases were selected for investigation based on evidence that (1) the driver's vision was diverted from the road, (2) this diversion was the primary cause of the crash, and (3) the crash involved more than $500 in property damage or injury of death. For example, "The driver was adjusting the radio and not paying attention to the car in front" (Wierwille and Tijerina, 1996, p. 81). Cases pertaining to 19 items (speedometer, mirrors, vents, etc.) were then examined in greater detail. Each case probably represented the involvement of a vehicle in a crash, not the number of crashes as stated in the paper (though the two values are close). Here the term *crashes* is used for consistency.

In a related study, Wierwille (1995) describes how several estimates of the relative frequency of use (per week) obtained from the literature were combined and linked with actual estimates to determine the absolute frequency of various tasks. Finally, a variety of sources described later in this report were used to estimate the number of glances required and mean task duration for the tasks of interest. Using regression, two equations were developed to estimate the number of involvements (Figure 1). In brief, these equations assert that the probability of a crash depends upon the aggregate eyes-off-the-road time, the product of the three terms shown in equations 1 and 2. The reason for raising glance time to the 1.5 power is that risk increases considerably with long glances.

(1) # of crashes = (mean glance time) x (mean # of glances) x (frequency of use)

(2) # of crashes = $(\text{mean glance time})^{1.5}$ x (mean # of glances) x (frequency of use)

For both equations, the correlations between the predicted and actual values were well over 0.9, quite high, with the 1.5 power expression (equation 2) offering a slightly better fit. Figure 1 shows the relationship between the number of cases and the regression prediction (recomputed by the author) for the 1.5 power expression. Removing the speedometer reading data, a highly overlearned task, improves the correlation further (Figure 2).

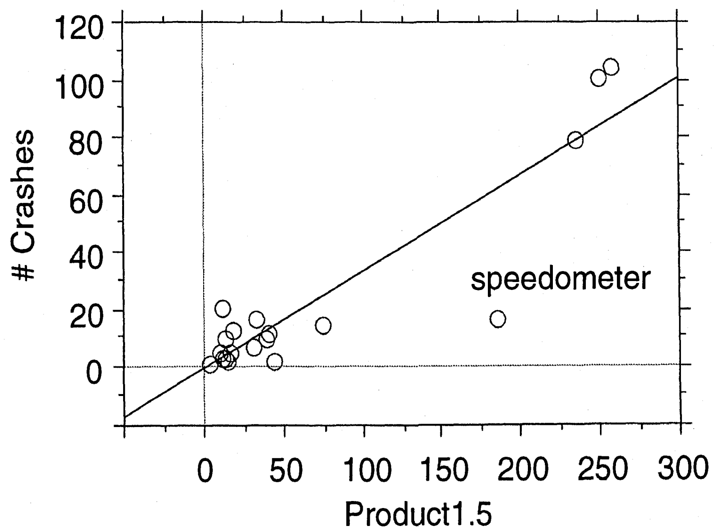



Figure 1. Predicted Number of Crashes from Wierwille's Analysis

# Crashes = -0.554 + 0.335 * product1.5, R2=0.829
Note: Product1.5 is the right side of equation 2.

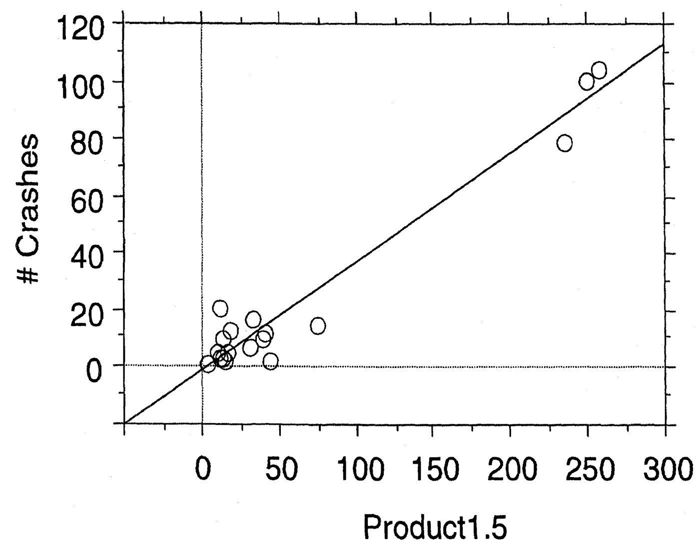



Figure 2. Predicted Number of Crashes without the Speedometer Data

#.crashes = -0.70 + 0.378* product1.5, R2=0.948

The Wierwille analysis is quite remarkable because it represents the first effort to establish a quantitative link between visual demand and crashes, a concern human factors specialists have expressed for decades. The analysis was carefully done and based on reputable sources. The results seem reasonable. However, one must apply the analysis with some care as the slope of the regression equation was determined primarily by four data points: the speedometer, mirrors (mostly distraction in the mirrors), standard radio functions, and smoking/lighting.

Given Wierwille's model, how many navigation-system-induced crashes associated with destination entry in the United States would one expect per year? To predict such one needs to (1) modify Wierwille's model to predict U.S. crashes, not just involvements in North Carolina, (2) estimate navigation system usage, (3) calculate the predicted values.

To predict the number of U.S. crashes (step 1), only passenger cars were considered, the primary target for navigation systems (though trucks should be included in future estimates). Table 7 show deaths, injuries, and property-damage-only (PDO) crashes nationally for passenger cars based upon U.S. Department of Transportation data (U.S. Department of Transportation, 1997) from 1992-1994 (the closest time period to 1989 for which crash data is available). During that period North Carolina represented about 3.7 percent of all fatal crashes in the United States, 4.3 percent of the injuries, and 3.3 percent of the PDO crashes. The percentage has been increasing slightly over time. According to Blower (1998), North Carolina crashes are representative of those in the U.S. in a variety of ways (day vs. night, age of the drivers involved, etc.), so using crashes from that state to represent the United States is reasonable, and furthermore, the fraction of the United States total is fairly stable.

Table 7. North Carolina and U.S. Crash Frequency data

| | | 1992 | 1993 | 1994 |
|---|---|---|---|---|
| North Carolina (from U.S. DOT, 1998, p. 65) | fatal | 1093 | 1116 | 1164 |
| | injury | 107918 | 113079 | 121817 |
| | PDO | 150330 | 161683 | 176134 |
| | total | 259341 | 275878 | 299115 |
| U.S. (from U.S. DOT, 1996, p. 17 & 18.) | fatal | 29817 | 30233 | 30273 |
| | injury | 2640000 | 2610000 | 2742000 |
| | PDO | 4852000 | 4812000 | 5155000 |
| | total | 7521817 | 7453233 | 7927273 |

Source: Traffic Safety Facts 1996, p 18. (U.S. Department of Transportation, 1997)

Traffic Safety Facts 1996, p 18. (U.S. Department of Transportation, 1997a) indicates there were 45,582 motor-vehicle-related deaths in the United States, including motorists and nonmotorists. Linking those with the 189,464 narratives in the North Carolina data base, each narrative can be thought of as translating into 0.24 deaths in the United States for that year. Thus, the 1562 occurrences Wierwille identified for that year can be thought of as offering explanations for 375 deaths for that year.

Taking the expression one step further, the expression from Wierwille's data is:

# cases = -.554 + .336 (mean glance t)$^{1.5}$ (# of glances) (frequency)

Using the .fatalities/case in 1989 calculated above, then

# 1989 U.S. fatalities = -.133 + .0447 (mean glance t)$^{1.5}$ (# of glances) (frequency).

However, every vehicle will not have a navigation system, so the expected number of fatalities must be decreased in proportion to the installation rate (Table 8).

Table 8. Parameters Affecting Estimates of Fatalities

| Variable | Value | Source/comment |
|---|---|---|
| mean glance time (s) | 2.7 | mean of data for Alpine, Delco, and Zexel navigation systems for POI task from Tijerina, Parmer, and Goodman (1998). |
| glances/entry | 27.5 | mean eyes-off-the-road time divided by mean glance time above |
| frequency/week | 2 | personal estimate and conversations with colleagues |
| market penetration (%) | 10 | Cole and Londal (1998) indicate median market penetration of 10% by 2007 (5/20 interquartile). Include aftermarket products, a 10% mean seems reasonable. |
| VMT adjustment (% per year) | 1.9 | annual growth rate estimated from data on annual VMT (U.S. Department of Transportation, 1997b, p VM-19) |

Finally, any projections of fatalities must consider that destination entry induced crashes are a function of exposure, and the more miles and trips driven, the more crashes that will occur. Although advances in vehicle design (e.g., air bags, improved structures) have reduced the fatality rate per mile since 1989, vehicle-miles traveled continues to increase since then (2,096,487 million miles driven) (U.S. Department of Transportation, 1997b). Based on published data (U.S. Department of Transportation, 1997b), VMT is growing at approximately 1.9 percent per year, and so the expected number of fatalities should be incremented by that amount for every year since 1989. Therefore, fatalities in the future can be estimated as follows:

$$\#\ \text{U.S. deaths in year x} = \text{growth.rate.in.VMT}^* \ (\text{year.x-1989})\ ^* \ \text{market.penetration.rate}^* \ [-.133 + .0447\ (\text{mean glance t})^{1.5}\ (\#\ \text{of glances})\ (\text{frequency})]$$

for 2007

$$(1.019)^*(2007-1989)^*(.1)^* \ (-.133 + .0447\ (2.7)^{1.5}\ (27.5)\ (2)$$

$$= 21.1\ \text{fatalities/year}$$

If the effect of VMT is assumed to be canceled by advances in vehicle design, the estimate is 11.5 fatalities per year. In Japan, there is a comparable but still low level of market penetration (5,000,000 vehicles, probably about 10 percent), so the Japanese situation now and the U.S situation in 2007 are comparable on that basis. The one fatality per six months in Japan leads to an expected two fatalities per year. As a check, there are typically 100 injury crashes for each fatality producing crash. In the six-month period of interest, there were 58 navigation-system-related injuries, so the 2 fatalities per year estimate may be high. Given the fatality data, an estimate of 1.2 ((58 x 2) / 100) might be better. However, 63 percent of the units shipped were not OEM. Presumably OEM units, because they meet the JAMA standard, should not result in operation-induced crashes. Accordingly, the expected number of fatalities at equivalent market penetration is 1.9 =1.2 * (1/0.63) fatalities per year. Finally, the number of deaths per year is much greater than in Japan because there are more people, vehicles, and vehicle miles traveled. In 1997 there were 41,967 motor vehicle fatalities in the United States (U.S. Department of Transportation, 1998, p. 15) versus 9,640 in Japan for the same year (Japanese National Police Agency, 1999). Thus, the U.S. total is 4.35 times that of Japan. Accordingly, one would expect approximately 8.3 (=1.9*4.35) deaths in the United States per year (and 58 * 8.3 = 481 injuries) extrapolating from the Japanese data. The two estimates are therefore reasonably consistent and probably bracket the expected number of fatalities.

Thus, although the data are limited, the literature suggests that destination designation tasks (1) lead to significantly greater visual demands (e.g., eyes-off-the-road times) than existing systems, and (2) since more demand leads to more crashes, they are likely to result in a measurable number of crashes. This estimated number (21/year in the United States) is consistent with projections from Japanese crash experience.

## DESTINATION DESIGNATION AND DRIVING PERFORMANCE

### Question 4: Does the input and retrieval of destinations significantly degrade driving performance?

### Question 5: How long do input-related navigation system tasks take to complete and how do they compare with existing tasks?

**Rationale:** Operating a navigation system should not interfere with drivers staying in their lanes, maintaining speed, searching for potential hazards, or performing other tasks they need to do to avoid crashes.

### Tijerina, Parmer, and Goodman (1998)

In the absence of crash data, safety and usability need to be established by other means. To the best of the author's knowledge, there are no studies in the open literature that report driver performance with navigation/route guidance controls for a moving vehicle, either in a simulator or on the road. However, there are two pertinent test-track experiments that were completed as this report was being written (Tijerina, Parmer, and Goodman, 1998; Tijerina, 1999). In the first experiment there were 16 entry-level test drivers (8 age 35 or less, 8 over 55) with an equal number of men and women in each age group. They drove an instrumented 1993 Toyota Camry around the Transportation Research Center (TRC) 7.5 mile oval track at 45 mi/hr in light traffic while operating four commercially available route-guidance systems. The four systems were (1) Delco Telepath 100 (which required cycling through a list of destinations), (2) Alpine NVA-N751A (with a hand-held remote), (3), Zexel Navmate (similar to the Rockwell PathMaster and Siemens TetraStar), and (4) Clarion Eclipse voice-actuated audio navigation system. Subjects also operated a car radio (Clarion Eclipse) and dialed a cellular phone (Audiovox Model MVX-500) to provide baseline data. Navigation tasks included retrieving points of interest (POI) and entering an address using a street address, an intersection (except for the Delco system), and points of interest. Radio tasks included selecting frequencies. Telephone tasks included dialing unknown 7- and 10-digit numbers. Tasks were verbally requested by an experimenter to begin only on straight sections. Destinations were hand written by subjects on cards prior to driving. Subjects were given four practice trials for each task with each interface prior to driving.

Table 9 shows the mean eyes-off-the-road time for each device for each navigation task. Times were scaled from histograms of the data. Notice that the mean times for the street address and intersection tasks were approximately the same overall, though there were significant differences in task completion times between and within devices. Those task times were approximately 15 percent greater than the point of interest task times (on average). Note that regardless of the task, that task times averaged over a minute for interfaces with visual displays and manual controls. This is far in excess of the 4 s or less required for ordinary instrument panel tasks (such as operating the wiper/washer controls) and several times greater than dialing a mobile phone (20-30 s), a task considered as marginal in terms of safety (Goodman, Bents, Tijerina, Wierwille, Lerner, and Benel, 1997) and one outlawed in several countries.

Table 9. Mean Eyes-Off-the-Road Time (s) by Navigation Task

| Task | Alpine hand held | Clarion voice | Zexel scrolling list | Mean |
|---|---|---|---|---|
| street address | 92 | 45 | 75 | 71 |
| intersection | 117 | 26 | 68 | 70 |
| point of interest | 90 | 24 | 70 | 61 |
| mean | 100 | 32 | 71 | 67 |

Table 10 shows several dependent measures for each device for the POI task. For manually-based systems (Alpine, Delco, and Zexel) between 77 and 80 percent of the trial time was spent not looking at the road, with one exception. For an unknown reason, for young drivers using the Zexel interface, the value was 50 percent. In contrast, for the voice system, only about one-third of the trial time was spent not looking at the road. Furthermore, except for the voice interface, mean glance durations were 2.6 s or greater. (For the voice system, glances to the note card showing the address to be entered were required.) Thus, all of the manually-based navigation systems had significant visual demands. Tasks required a minute or so to complete, with three-fourths of that time spent not looking at the road, often for substantial periods. Laboratory data collected by UMTRI for destination designation where time sharing was not required led to time estimates of the same magnitude. Those data (Steinfeld, Manes, Green, and Hunter, 1996) are described in another section of this report. Of considerable concern to driving safety was that there was almost one lane departure per entry trial for several navigation systems. This unacceptably high value was 14 times greater than that for dialing a phone. Consistent with the principle of "minimize harm to the driver," these data suggest destinations should not be entered or retrieved while driving using several presently available navigation systems because those actions could compromise driver safety.

Table 10. Results from Tijerina, Parmer, and Goodman (1998)

| | Group | Alpine hand held | Delco | Clarion voice recognition | Zexel scrolling list | cell phone |
|---|---|---|---|---|---|---|
| Trial time (s), POI | young | 78 | 56 | 74 | 70 | 22 |
| | old | 158 | 98 | 76 | 140 | 30 |
| Mean eyes-off-road time (s), POI | young | 60 | 44 | 24 | 35 | 18 |
| | old | 121 | 78 | 26 | 108 | 16 |
| Mean glance to device (s) | all | 2.6 | 2.7 | 1.1 | 2.7 | 3.2 |
| Mean # lane excursions per trial | all | 0.88 | 0.24 | 0 | 0.99 | 0.07 |

As a footnote, additional research has been conducted on these same interfaces to examine the relationship between measures of performance (Tijerina, 1999). Those results appears later in this report.

## Static Studies of Navigation System Input

The lack of studies in the open literature that report times for navigation input tasks while driving on public roads makes establishing a recommended practice for such activities challenging. However, several laboratory studies involving navigation-system input provide insight into the problems experienced and allow for the development of estimates for task times. Dual-task (driving) performance times can be estimated by inflating laboratory data for single-task performance. The most current summary of that literature appears in Steinfeld, Manes, Green, and Hunter (1996). Table 11 summarizes the studies to date.

Table 11. Static Tests of Navigation System Input

| Study | # subjects | Tasks |
|---|---|---|
| Loring and Wiklund (1990a) | 12 (including young and old) | • enter and retrieve destinations using 3 SuperCard prototypes of ADVANCE interfaces |
| Loring and Wiklund (1990b) | 9 of unknown ages | • perform numerous tasks with a single prototype for ADVANCE |
| Dingus, Hulse, Krage, Szczublewski, and Berry (1991) | 72 (18-25 yrs, 30-45 yrs, 55+ yrs) | • perform 7 predrive tasks with a touchscreen & simulated TravTek interface (SuperCard) |
| Paelke (1993) (see also Paelke and Green, 1993) | 16 (8 <30 yrs, 8 >65 yrs) | • practice driving-like tracking tasks, then enter addresses with and without concurrent task<br>• 4 interfaces (TravTek-like, Qwerty, phone pad, PathMaster-like) simulated in SuperCard |
| Steinfeld, Manes, Green, and Hunter (1996) (see also Manes, Green, and Hunter, 1996) | 36 drivers (12 18-30, 12 40-55, 12 >65) | • operate real and simulated (in SuperCard) Ali-Scout<br>• destination entry and retrieval<br>• part of FAST-TRAC program |

## ADVANCE and TravTek Studies

Tables 12, 13 and 14 present the mean task completion times from Loring and Wiklund (1990a), Loring and Wiklund (1990b), and Dingus, Hulse, Krage, Szczublewski, and Berry (1991). Dingus, et al. also provide a step-by-step overview of each task. The units for the task completion times of Loring and Wiklund (1990a) are not given, but presumed to be minutes. To assist the reader, the task times in these tables have been resorted in increasing order by time, except for Table 13 where they are grouped by category. Notice that in all three tables, most tasks take minutes to complete, especially tasks associated with destinations. The lengthy durations of these tasks are clearly unacceptable while driving and exceed the limits of the proposed 15-Second Rule (Green, 1999). That rule states that static task times should not exceed 15 seconds. In recognition of this, Dingus, Hulse, Krage, Szczublewski, and Berry (1991) specifically identified the tasks they examined as "pre-drive." Even though the list in Table 14 seems extensive and sufficient for most interface decisions, readers are reminded that the data was collected using an early prototype interface in a laboratory, not by time sharing in a moving vehicle. Tasks that could be completed within 5 s included correcting a typo and getting help (both 1 s), determining the distance to next maneuver (2 s),and finally, determining heading, getting the next instruction, and adjusting the volume (all about 4 s). Quite different times are likely for other interfaces, and, furthermore, task completion time is implementation specific. For example, for the interface evaluated, there was a dedicated help key, so times to access help were very short. In the Loring and Wiklund (1990a) data, there was almost a two-fold difference between interfaces for one of the tasks examined.

Table 12 ADVANCE Interface Task Times from Loring and Wiklund (1990a)

| Task | A: soft keys & dedicated keys | B: touchscreen & dedicated keys | C: dedicated keys |
|---|---|---|---|
| Determine present location on a map | 0.911 | 2.924 | 1.125 |
| View traffic conditions near present location | 2.725 | 3.461 | 1.571 |
| Plan a route to the Grand Hotel in San Francisco | 3.576 | 2.974 | 3.076 |
| Get info on Symphony Hall from list of public places | 3.550 | 3.032 | 4.352 |

Table 13. ADVANCE Interface Task Times from Loring and Wiklund (1990b)

| When | Task | Mean Time (s) |
|---|---|---|
| Exploration | reset your present location to 0 Motorola Road (specify the full address.) | 117.33 |
| | find out the address of the nearest restaurant | 72.33 |
| | display restaurants on the map | 40.56 |
| | adjust the volume | 32.75 |
| | find out what the system thinks is the current address | 20.14 |
| | zoom out until you can see Interstate 294 labeled | 19.50 |
| | find out your current location on a map | 12.56 |
| | change map view from N-up to heading-up (and back) | 9.89 |
| | scroll the map down until you see Dundee Road | 9.63 |
| | find out where the nearest restaurant is | 7.88 |
| | find out what the system can do | 5.75 |
| | find out your current compass heading | 4.22 |
| Route Planning | set 542 Lindbert Lane as destination. Pick it from a map. | 86.56 |
| | tell the device to plan a route to your destination | 86.00 |
| | access another function of the device | 32.25 |
| | find out how many miles you will drive on your route | 25.44 |
| | select "view from road" as the format for your route guidance | 20.00 |
| | view your current location and your destination on the same map | 8.44 |
| While Driving | replan your route to avoid Doolittle | 194.67 |
| | save the trip plan you just drove | 134.00 |
| | find out how far you have driven since the beginning of your trip | 51.75 |
| | find out how far it is to your next destination | 6.14 |
| | get the next instruction | 4.67 |
| | turn the voice down | 4.56 |
| | find out how far it is to your next maneuver | 2.29 |
| | correct a typographical error | 1.00 |
| Other Tasks | add another leg to the trip plan "Sales Calls" 3450 Bayberry Rd, Northbrook | 96.44 |
| | delete the trip plan named "Steve's House" | 67.78 |
| | add yourself to the list of drivers | 44.78 |
| | modify your preferences by hiding the "What to Do" box | 44.33 |
| | tailor the first leg by setting preference to min. distance | 35.63 |
| | recall the trip plan name "Sales Calls" | 32.89 |
| | change current driver to "Clark" | 30.25 |
| | delete the driver name "Jon" | 26.89 |
| | delete the first left from the trip plan "Sales Calls" | 19.88 |
| | get help on the task you are doing now | 1.00 |

Table 14. Task Completion Times from
Dingus, Hulse, Krage, Szczublewski, and Berry (1991)

| Task | Time (s) |
|---|---|
| set voice messaging option | 40 |
| summon emergency service (multiple steps) | 40 |
| retrieve stored destination from a list | 50 |
| use yellow pages feature to select a business | 100 |
| enter an unfamiliar destination | 130 |
| add destination and route to list of those stored | 160 |
| determine areas where congestion is present | 240 |

**Paelke (1993)**

A sense of how implementation of a specific task affects task-completion time emerges from the research of Paelke (1993). Shown in Figure 3 are the mean entry times for drivers entering street numbers, street names, and cities using simulations of four types of destination entry systems, two of which simulated real systems. Some of the entry data were collected while drivers performed a concurrent tracking task meant to resemble driving. Generally, no system required less than 40 s on average to enter an address.

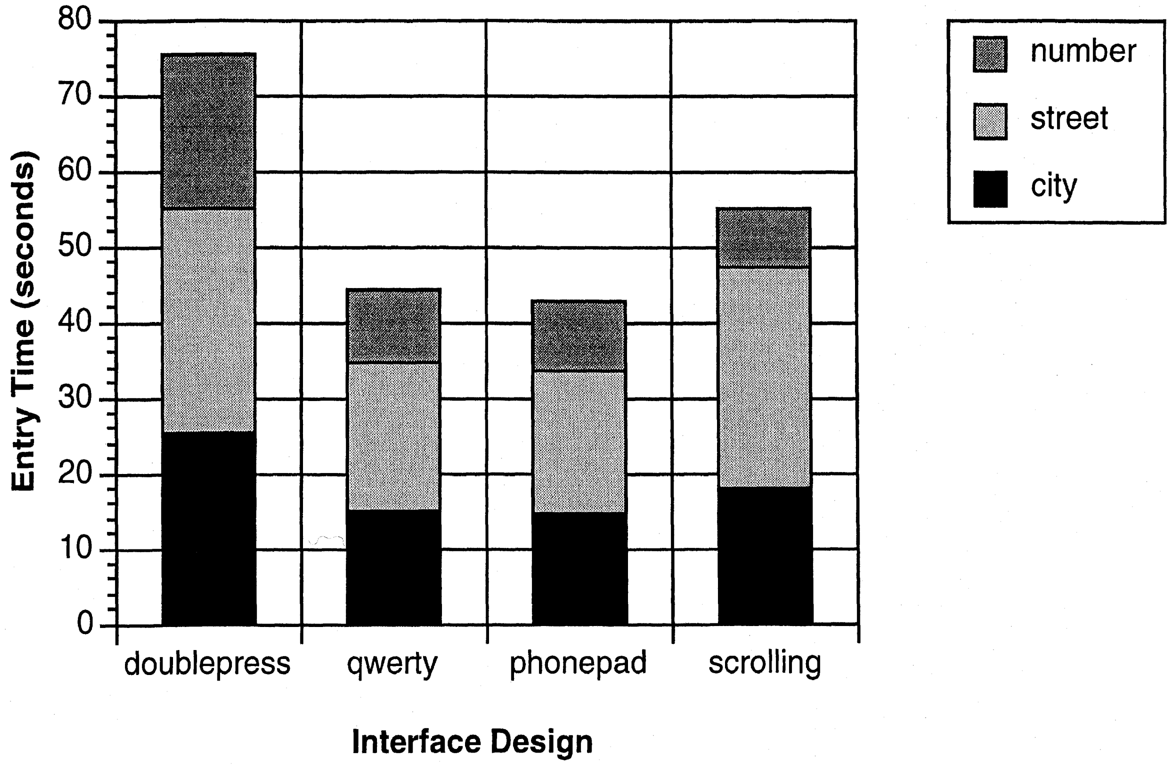



Figure 3. Mean Destination Entry Times from Paelke (1993)

Figure 4 compares the entry times for the stationary and timesharing conditions. Based on this figure, timesharing increased the mean task completion times by 30 percent. These values are reasonably close but slightly below the best estimates from the comparison of the static and dynamic values in Tijerina's research. However, the driving simulation was very simple, and often drivers did not treat driving/tracking as a high-priority task. There was no penalty for leaving the lane. Drivers did not crash. There was no shaking from driving off the road or worrisome sounds. Sometimes drivers wandered well outside the lane, something they would not do in a higher fidelity simulation or on the road. For conditions where the address entry task was performed, the standard deviation of lane position almost doubled with the addition of the address entry task, a level greater than is likely to occur in real driving. In real driving, drivers would probably sacrifice entry performance so that they can monitor lane keeping more closely. Lane-departure data are not reported by Paelke (1983). Further, in real driving, in-vehicle task completion times will depend on traffic, lane width, vehicle dynamics, etc., and a higher value would be expected. Nonetheless, the 30 percent increment represents a reasonable first approximation for curved two-lane roads with no traffic or intersections. As a comparison, analysis of Tijerina (1999) shows an overhead of 12 percent for all tasks and 25 percent for navigation tasks, though Tijerina's work involved driving on straight roads and using only older drivers. Other studies in the literature (e.g., Noy, research at TNO or Groningen) may provide other sources of estimates for overhead values.

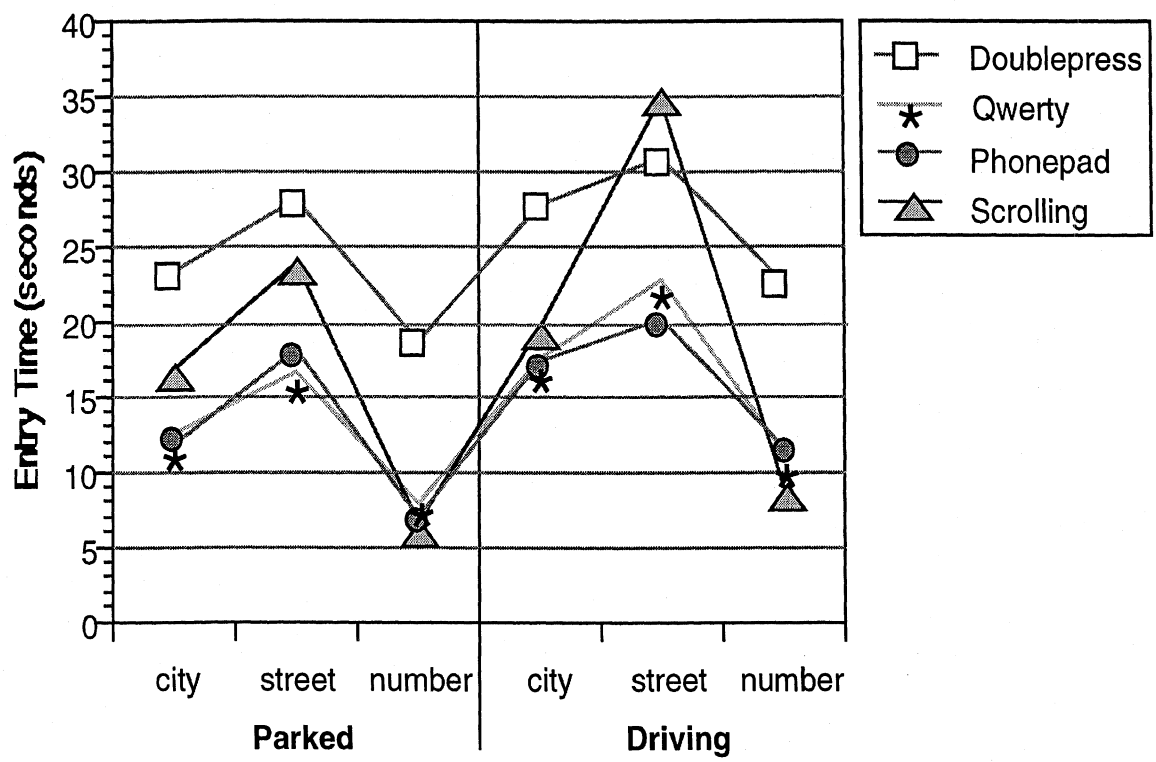



Figure 4. Destination Entry Times When Parked and Driving

### FAST TRAC Evaluation of Ali-Scout

Steinfeld, Manes, Green, and Hunter (1996) had subjects retrieve and enter destinations using an Ali-Scout navigation system after watching an instructional videotape and then practicing those tasks. The mean retrieval time was 10.48 s (median of 6.23 s) while the mean entry time was 64.68 s (median 51.48 s). The log-transformed times were normally distributed. For the 15 addresses examined in each task, mean retrieval times ranged from 1.8 to 19.0 s while mean entry times ranged from 47.3 to 84 s. Times decreased with practice by about 30 percent from the beginning to the end of the experiment, and the learning-curve data suggest further improvements with practice would be minimal. These times, however, should not be viewed as typical for a well designed interface. The Ali-Scout keys were extremely small and difficult to select. Further, each key face displayed two characters, so entering a single character sometimes required two keystrokes. Finally, the address was specified by entering the longitude and latitude, and not by a more readily remembered number and street name.

The data also showed wide differences in age with older subjects taking about 2.4 times longer to enter destinations and 2.8 times longer to retrieve them. (See Figure 5.) This suggests that standards that concern input tasks need to take age into account.


Figure 5. Age-Sex Interaction Plots for Destination Retrieval and Destination Entry

## Summary

1. Except for the Tijerina test-track experiments, there are no studies in which destinations were entered while people drove real vehicles.
2. For POI and address entry tasks (both by street address and intersection) using interfaces with manual controls and visual displays took 1 to 2.5 minutes, depending on the interface, driver age, and the experiment.
3. Address entry took about 15 percent longer than POI tasks.
4. Destination retrieval tasks from stored lists require from 10-50 s to complete, depending on the interface, when completed staticly.
5. Entering destinations using either the street address, intersection, or POI methods takes several times longer than dialing a phone number, a task considered marginal in terms of safety and outlawed in several countries.

6. Just under 80 percent of the time entering destinations was spent looking inside the vehicle, not at the road.
7. For several systems with manual entry of addresses, there was almost one lane departure for every trial.
8. In laboratory evaluations, the mean time for navigation tasks for the best and worst interface often differ by a factor of two.
9. The difference in task completion times between young and old subjects varies between a factor of two and three.
10. As a first approximation, the completion times for navigation entry tasks while driving without traffic on winding roads can be estimated by increasing the nontime-shared task times by 30 percent. Obviously, this value will vary with primary task workload (due to road geometry, traffic, etc.).

## PREFERENCES AND FREE-GLANCE BEHAVIOR

### Question 6. How often and for how long do drivers prefer to look in a vehicle when it feels safe or comfortable to do so?

**Rationale:** One way to determine how long it is safe or comfortable for drivers to look away from the road is to have them do just that on a real road and measure in-vehicle glance durations. The advantage of this approach over measuring glance durations to real displays is that there is no cognitive capture. That is, there is nothing about the display that will distract drivers to look longer than they feel is safe.

There are two studies in the open literature concerning free-viewing behavior independent of a particular display (Table 15). In Hada (1994) the task was to look where a display might appear (three locations) "as long as you feel safe to do so" (Hada, 1994, p. 5). In Kimura, Osumi, and Nagai (1990) the instruction was to look at each of the targets "for as long as possible, until they felt uncomfortable." (Kimura, Osumi, and Nagai (1990), p. 709). In both cases, the prompt was not to make a single glance, but to continue glancing as permitted by the road and traffic over several minutes.

Table 16. Studies of Free Viewing

| Study | Subjects | Vehicle | Locations | Roads and Speeds |
|---|---|---|---|---|
| Hada (1994) Experiment 1 | 22 drivers (10 < 35 12 > 60) | 1991 Honda Accord station wagon with NAC V corneal reflection device | HUD position, speedometer/tachometer cluster, top of the center console (all indicated by large dots) | expressway (M-14, 70 mi/hr), a rural road (Ford Road, 55 mi/hr), and suburban street (Sheldon Road, 35 mi/hr) near Ann Arbor, Michigan during daytime off-peak hours |
| Hada (1994) Experiment 2 | 8 young drivers | | speedometer/tachometer cluster, top of the center console (all indicated by large dots) | 4 streets in downtown Ann Arbor (William, State, Liberty, Main) during daytime off-peak hours, stop and go traffic |
| Kimura, Osumi, and Nagai (1990) | 8 young drivers | unknown -EOG record | speedometer/tachometer console area and the very center of the center console | rural expressways (90-100 km/hr) and 1- and 2-lane, one way urban streets (40-60 km/hr) in moderate traffic, 4 hour drive |

### Hada (1994)

Figure 6 shows the distribution of all 10,660 glances to the targets for experiment 1 of Hada (1994). Another 1,638 were collected in experiment 2. Notice the data appear to be log-normally distributed. The cumulative distribution shown was created by the author from the frequency histogram in Hada's report. According to the approximate cumulative data, the median is about 0.68 s. On the upper end, the 95 percentile is 2.2 s, the 97.5 percentile is 2.5 s and the 99 percentile is 3.6 s. On the low end, 10 percent of the responses are less than 0.3 s and 3 percent are less than 0.2 s. Additional statistics (dispersion values, etc.), a more accurate cumulative distribution, and data on the sequential dependencies of successive glances will be provided at a later date.

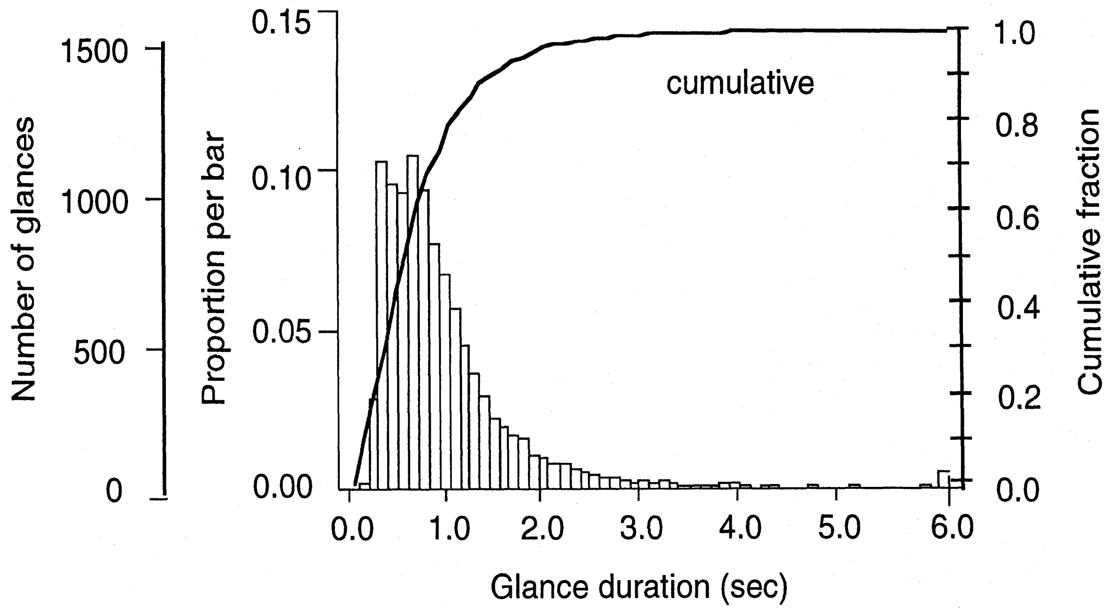



Figure 6. Histogram of All glances from Hada (1994) - Experiment 1

Figure 7 shows the median glance duration by location and road type. The means were approximately 0.15 to 0.20 s longer than the medians. Only glances to 2 locations could be examined in urban driving. Differences between display locations were quite small, approximately 50 ms. Differences due to the road being driven were much greater, on the order of 150 ms. Older drivers tended to have shorter glance durations than younger drivers, with the difference being about 80 ms.

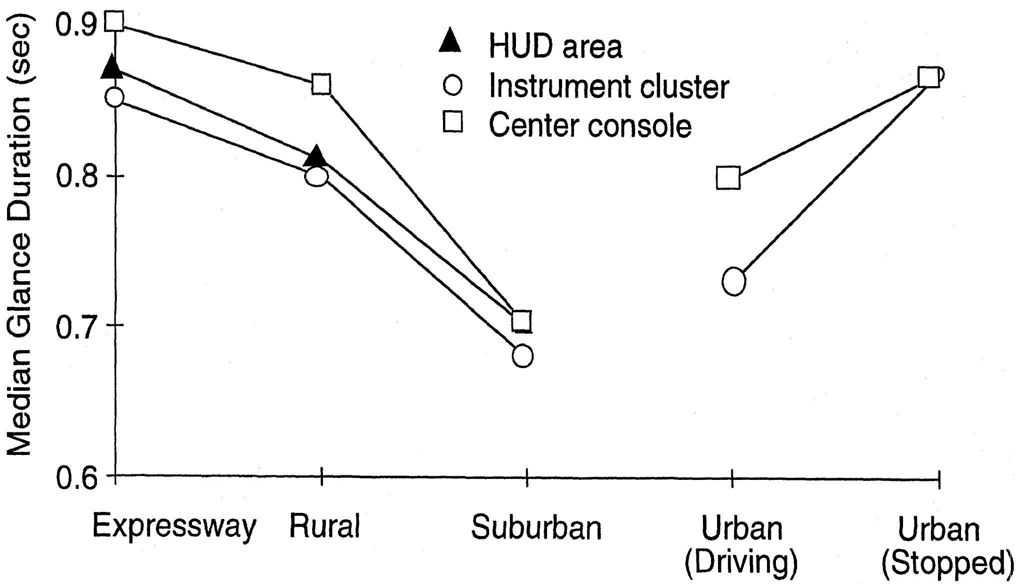



Figure 7. Median Glance Durations Reported by Hada (1994)

On average, subjects looked at the display once every 3 s. Table 17 shows the glance frequency data for both experiments. The interval between glance initiation is the inverse of the frequency. Data on the distribution of the intervals is not presented in the report but should be determined (by reanalyzing the data) at a later date. Of interest is the distribution of the interglance intervals, the time between glances.

Table 17. Glance Frequencies for Each Road Type from Hada (1994)

| Statistic | Road type - Experiment 1 | | | Urban - Driving | | Urban - Stopped | |
|---|---|---|---|---|---|---|---|
| | xway | Rural road | Suburb. street | Instr. cluster | Center console | Instr. cluster | Center console |
| Mean freq. (Hz) | 0.34 | 0.35 | 0.30 | 0.38 | 0.40 | 0.31 | 0.31 |
| Interval between glance initiation (s) | 2.94 | 2.86 | 3.33 | 2.63 | 2.50 | 3.23 | 3.23 |
| Standard dev. (Hz) | 0.11 | 0.10 | 0.10 | 0.16 | 0.22 | 0.07 | 0.10 |

Interestingly, there was a slight but significant tendency for drivers to look at the HUD area less often than the center console (by less than 3 percent) and older drivers to look inside the vehicle slightly less often than younger drivers (by about 2 percent)

Table 18 gives the percentile distributions for all glances in both experiments. Transition times to and from the road were believed to be included in the interglance interval (time spent looking at the road and elsewhere), not the target glance durations. From this evidence, Hada concludes "drivers were able to look at visual targets for at least 0.3 s in most cases." Therefore, when information needs to be obtained in one glance, it should be designed to be understood within this duration" (Hada, 1994, p i). However, readers should keep in mind that interior glances of 0.3 s, both from the evidence presented here and in other sections, are quite rare, and are too short to obtain much meaningful information. For a comparable worst case (95 percentile interglance interval), a 0.33 s glance on an expressway to a display would be followed 5.68 s glance to the road, resulting in a 6.01 s combined glance interval. Since percentiles do not add, this estimate does not represent a true 95 percentile combined glance interval but is provided as a computationally simple example.

Table 18. Percentile Distributions for Both Experiments

| Road type | Target glance duration (s) | Interglance Interval (s) | | Percentage |
|---|---|---|---|---|
| | 5 th percentile | Mean | 95 th percentile | Mean |
| Expressway | 0.33 | 2.94 | 5.68 | 38 |
| Rural road | 0.32 | 2.86 | 5.95 | 35 |
| Suburban street | 0.30 | 3.33 | 7.09 | 25 |
| Urban street (driving) | 0.27 | 2.56 | 12.20 | 19 |
| Urban street (stopped) | 0.27 | 3.23 | 5.43 | 16 |

**Kimura, Osumi, and Nagai (1990)**

Kimura, Osumi, and Nagai (1990) describe a series of experiments concerned with the design of CRT displays in motor vehicles. The research was originally reported in Kimura, Sugiura, Shinkai, and Nagai, 1988. (See also Kishi, Sugiura, and Kimura, 1992 for a Japanese summary.) Figure 8 shows the results as presented in Kishi and Suguira (1993). A minimum of supporting statistics were provided. In contrast with other presentations of the results, this figure shows both the cumulative and the probability density function, and, therefore, a clearer sense of the distribution. According to text in Kimura, Osumi, and Nagai (1990), the 95 percentile time that subjects were able to gaze steadily without feeling uncomfortable (5 percentile on the figure) was 1.0 s, though the figure suggests the time may be under 1.0 s. The 50 percent time was 2.0 s. The mode was 1.2 s. The x axis appears logarithmic and the relationship between log fixation time and cumulative percent appears linear over the range of fixation durations of 0.9 to 3.5 s. The data in the figure has been digitized and additional statistical analysis may be provided at a later date. A similar figure appears in Kimura, Marunaka, and Sugiura, 1997, p 156 with the Y axis scale reversed. According to that paper, one needs to allow for about 0.1 s to transition from the road to the display and another 0.1 s or so to transition back. The actual time spent looking at the display is therefore 0.2 to 0.25 s less than the values in the figure, and consequently, the x axis in Figure 8 should more properly be labeled as "eyes-off-the-road time."

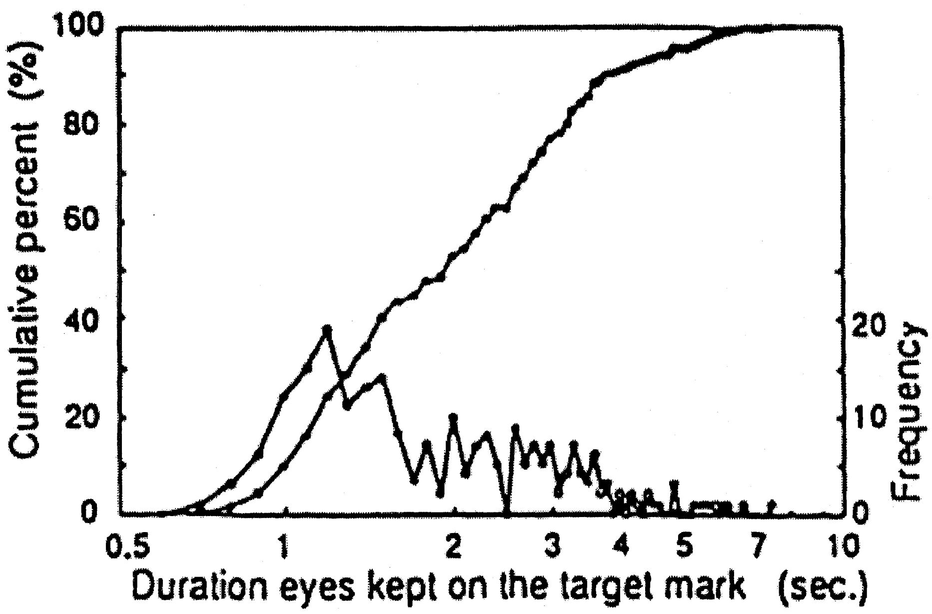



Figure 8. Distribution of Fixation Time from Kishi and Sugiura, 1993, p 99

**Summary**

Glance durations reported by Hada (1994) for U.S. drivers were log-normally distributed. Median glance durations were 0.86 s on the expressway, 0.81 s on the rural road, 0.68 s on the suburban street, 0.79 s on the urban street, and 0.87 s while stopped at urban intersections. Mean glance durations being about 0.15 s longer the medians. Display location had a minor impact (50 ms) as did driver age (80 ms).

In comparison, Kishi and Sugiura report median glance times of 2.0 s for Japanese drivers, considerably longer. Adjusting for transition between the road and the interior, the on-target time was actually 1.8 s or less, a value almost 1 s greater than reported by Hada. According to Hada, differences between roads and due to age are on the order of a tenth of a second or so, far less than the differences between the two studies. Kimura (1998) explains these differences of almost a factor of 2 as due to the response criterion using the data of Ito and Miki (1997) described later. In Hada (1994) subjects were instructed to look "for as long as you feel safe to do so " whereas instructions in Kimura, et al. (1990) were to look "for as long as possible until you feel uncomfortable." These difference are not believed to be due to differences in the traffic in two countries (e.g., being stopped in traffic in Japan, where there is ample time to glance at a display). Further examination of these differences is desired.

While differences between these studies continue to be explored, the author would suggest giving greater weight to Hada's data for the development of an SAE recommended practice, since that data concerns U.S. traffic and drivers, but to also consider Kimura's research. Hada's data suggests that drivers will feel safe looking at an in-vehicle display for about 0.8 s on average provided they have about 3 s between glances in the vehicle to study the road.

## RATINGS OF GLANCE COMFORT AND SAFETY

**Question 7: What is the relationship between actual glance durations and frequencies and, ratings of safety and comfort?**

**Rationale:** When asked to perform various in-vehicle tasks, drivers should be comfortable. How comfortable/uncomfortable or safe/unsafe drivers feel they are should be considered in determining what drivers should not do in a moving vehicle. Admittedly, this evidence is "softer" than other evidence presented in the report. However, it is important to sell vehicles that drivers want, so their comfort should be considered. Furthermore, this evidence is particularly appealing to the Japanese and should be of value as SAE documentation evolves into ISO standards.

An extension of the free viewing context is to have drivers perform real tasks, and after the fact ask them how safe or comfortable each condition was. Three studies have taken that approach (Table 19). The author, not familiar with Japanese, has only a partial translation of the VICS report. Some of the details related to the Ito and Miki paper were obtained from conversations with Hiroshi Tsuda (Nissan) who was in communication with Mr. Ito.

Table 19. Studies of Viewing Comfort and Safety

| Study | Subjects | Vehicles | Display and Task | Roads |
|---|---|---|---|---|
| VICS Promotion Council (1993) | 64 subjects | 7 different vehicles | 9 tasks (e.g., ask if turn right or left at next intersection, is there parking near the destination), ratings on 5 point scale + eye fixations | simulated urban and expressway at proving ground |
| Ito and Miki (1997)- experiment 2 | 35 subjects, ages 25-40 | Toyota Crown, Nissan Cedric, Mitsubishi Diamante, & Acura Legend | read 9-42 kanji and kana characters, 7-8 mm, on a 6-inch LCD | simulated urban setting (proving ground with traffic lights) and a simulated expressway (100 km/hr test course) |
| Nowakowski and Green (1998) | 16 drivers (8 18-30, 8 >65) | 1992 Taurus station wagon | show map on 5-inch LCD, 3 tasks: (1) identify driven road, (2) identify cross street, (3) find street on map | expressway (M-14, I-94), drive at 60 mi/hr light traffic |

## VICS Promotion Council (1993)

The VICS report describes experiments concerning icons, display location, and other issues. In the study of interest, subjects drove on a test course and looked at stylized maps, complex maps, or text displays from time to time (Table 20). Ratings of driver stress were also obtained. The anchors are believed to be identical to that of Ito and Miki (1997), as initially translated by Tsuda, 1997 (personal communication). Apparently some of the terms have multiple meanings in Japanese (Table 21). While the differences in Japanese may be subtle, the differences in English could have enormous legal impact for U.S. applications (for example, "insecure" versus "dangerous").

Table 20. Tasks Identified in VICS Promotion Council (1993)

| # | Map | Question / Task |
|---|---|---|
| 1 | simple map (with near and distant congestion) | Should you turn right or left ahead? |
| 2 | full map (with near and distant congestion) | Should you turn right or left ahead? |
| 3 | full map (with 6 points of congestion) | Where should you turn (points A, B, or C) to avoid congestion? |
| 4 | full map (with 10 parking areas) | Is there parking near the destination? |
| 5 | full map (with 9 parking areas & 6 points of congestion) | Is there parking near the destination? |
| 6 | full map (with 9 parking areas & 6 points congestion, some information is deleted) | Is there parking near the destination? |
| 7 | brief information (10 digits) | indicate when finished reading all letters |
| 8 | brief information (20 digits) | indicate when finished reading all letters |
| 9 | brief information (30 digits) | indicate when finished reading all letters |

Table 21. Terms Used in Rating Driver Stress

| Rating | Japanese Term | English Term |
|---|---|---|
| 5 | maxtutakukininaranai | not uncomfortable at all |
| 4 | kininaranai | I did not feel insecure |
| 3 | dotiratomoienai | drive without feeling any stress |
| 2 | yayfuannkanngaaru | feeling slightly insecure |
| 1 | fuannkannwokannjiru | feeling insecure |

Based on the partial translation of the report, the following may be true. Some of these statements were taken literally from the translation and the author is not completely sure what they mean, but they represent the best information available.

- For younger subjects, there was a high correlation between the number of eye glances and ratings of stress (called an "unsafety rating" in one translation, "insecure" in another). Older subjects did not.

- There was no correlation between glance duration and the ratings of stress. Drivers reported stress after 1-2 s have passed.
- Drivers felt unsafe/stressed if more than 30 characters (believed to be a mixture of alphabetic, kanji, hiragana, katakana) were shown.

Table 22 shows the regression equations and variance accounted for three speed ranges for the number of glances, the mean glance duration, and their product, the total glance time. It appears that poor ratings (feeling unsafe/stressed) were most closely associated with the number of glances, and secondarily, total glance time. Over the ranges of glance times explored, there was no correlation between mean glance duration and a rated lack of safety/stress, and in one case (40s), increasing the glance duration actually increased safety. Readers should note, however, that there were few instances of extremely long glance durations (over 2.0 s) and these results may be due to the particular tasks selected (simple map reading). Figures 9-11 graphically represent these relationships.

Table 22. Regression Equations for the "Unsafety" Rating (y) from the VICS Report

| Speed (km/hr) | # Glances | Total Glance Time | Mean Glance Duration |
|---|---|---|---|
| 20s, 30s | y=-0.472x + 5.264<br>r2=0.956 | y=-0.297x+5.218,<br>r2=0.780 | y=-0.181x + 4.321,<br>r2=0.008 |
| 40s | y=-0.345x + 5.280<br>r2=0.555 | y=-0.207x+5.199<br>r2=0.524 | y=-0.442x +4.920<br>r2=0.380 |
| 50s | y=-0.219x + 5.103<br>r2=0.707 | y=-.113x +4.958<br>r2=0.462 | y=.487x +3.436<br>r2=0.089 |

Table 23 shows the impact of selecting different criteria for each speed. For example, if the goal is for drivers to feel secure (rating =4.0), then for the 20-30 km/hr a maximum of 2.7 glances is desired. Readers should note that the criterion of ratings of 2.5, 3.5, and 4.5 did not appear on the original scale but were added here for clarity. For 50 km/hr, 5.0 glances are allowed, almost double. However, if drivers are to feel comfortable, then only 1 glance on every 2 trials is allowed. If the criterion is starting to feel slightly secure, then 7.3 glances are allowed, a huge difference. The rationale for selecting a criterion needs further thought.

Table 23. Estimated Total Glance Time
and Mean Number of Glances Based on the VICS Report

| Criterion | Rating | 20s, 30s | 40s | 50s |
|---|---|---|---|---|
| not insecure | 2.5 | 9.15 5.9 | 13.04 8.1 | 21.75 11.9 |
| indifferent (neither secure or insecure) | 3.0 | 7.47 4.8 | 10.62 6.6 | 17.33 9.6 |
| start to feel slightly secure | 3.5 | 5.78 3.7 | 8.21 5.2 | 12.90 7.3 |
| secure (not feel insecure) | 4.0 | 4.10 2.7 | 5.79 3.7 | 8.48 5.0 |
| comfortable (not uncomfortable at all) | 5.0 | 0.73 0.6 | 0.96 0.8 | -0.37 0.5 |

Note: Since the values were estimated from regression lines, some values are negative.

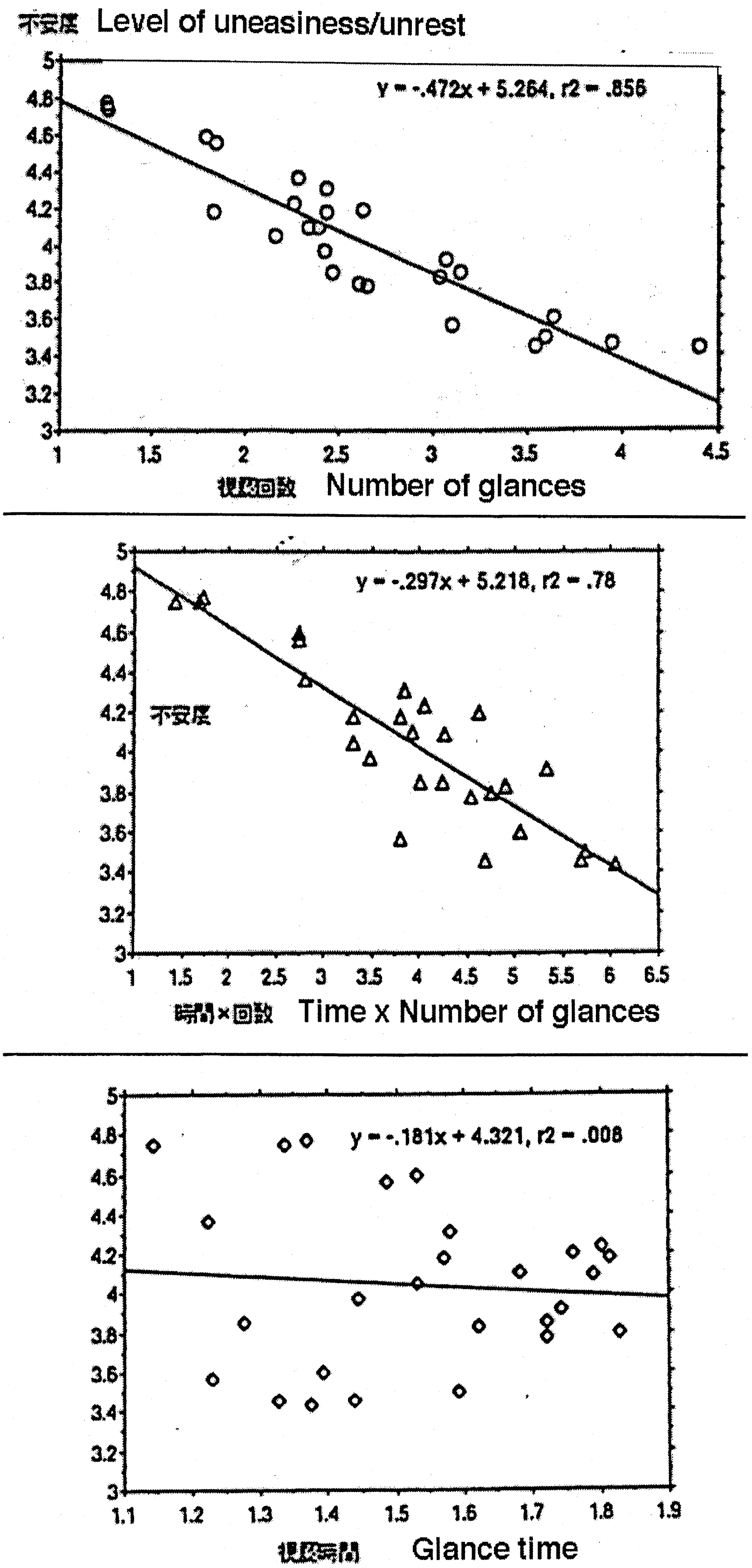



Figure 9. Number of Glances, Total Glance Duration, and Glance Duration vs. Rating, Ages 20, 30 Source: VICS Promotion Council, 1993, p. 17.

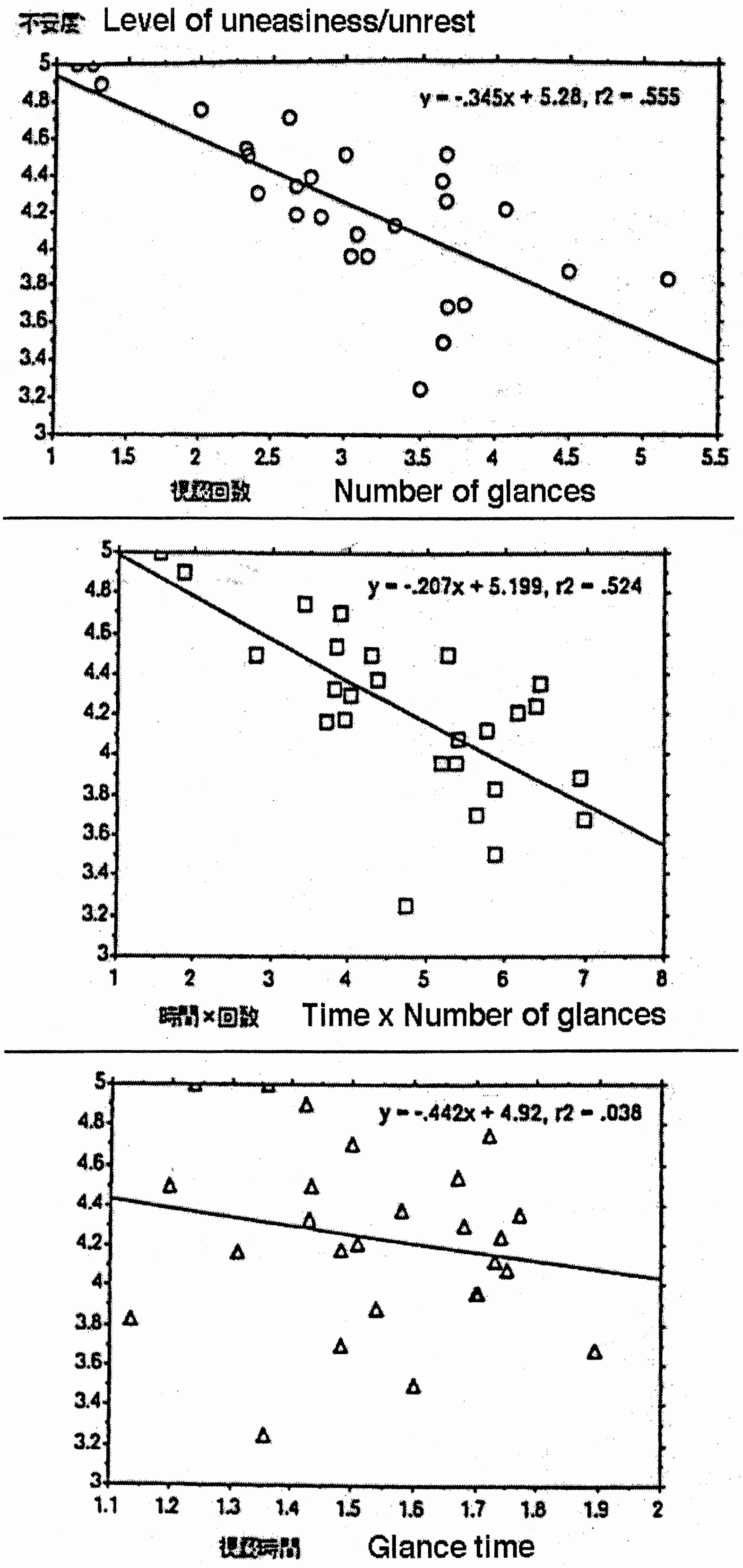



Figure 10. Number of Glances, Total Glance Duration, and Glance Duration vs. Rating, Age 40 Source: VICS Promotion Council, 1993, p. 18.

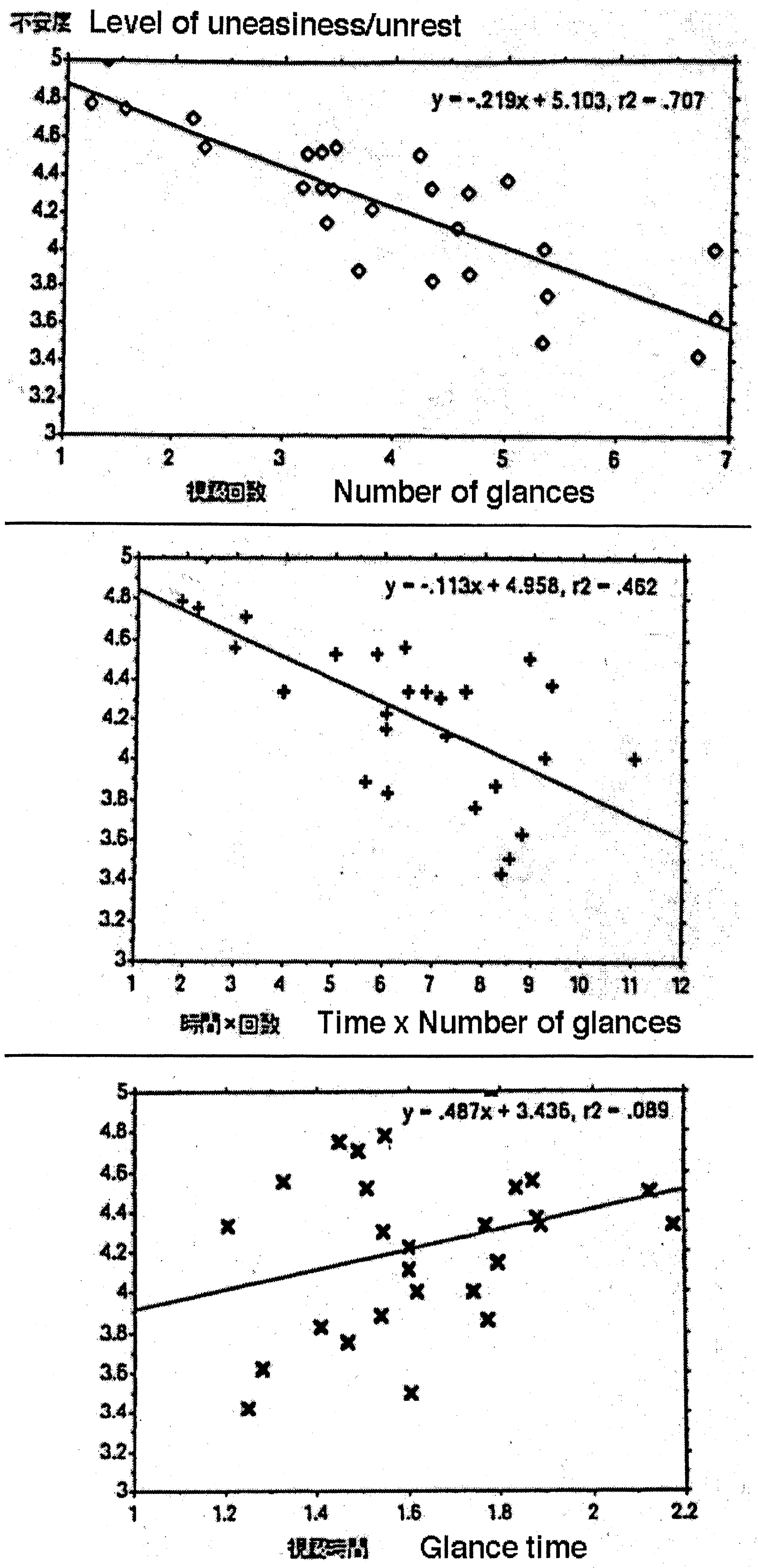



Figure 11. Number of Glances, Total Glance Duration, and Glance Duration vs. Rating, Age 50 Source: VICS Promotion Council, 1993, p. 19.

### Ito and Miki (1997), Experiment 2

Figure 12 shows the results from Ito and Miki (1997) indicating an inverse linear relationship between total viewing time (total-eyes-off-the-road time, including transition time) and the subjective evaluation. Japanese text was provided for subjective anchors 1-5, where 3 was "without feeling any stress" and 4 was "secure" (Kimura, 1998).

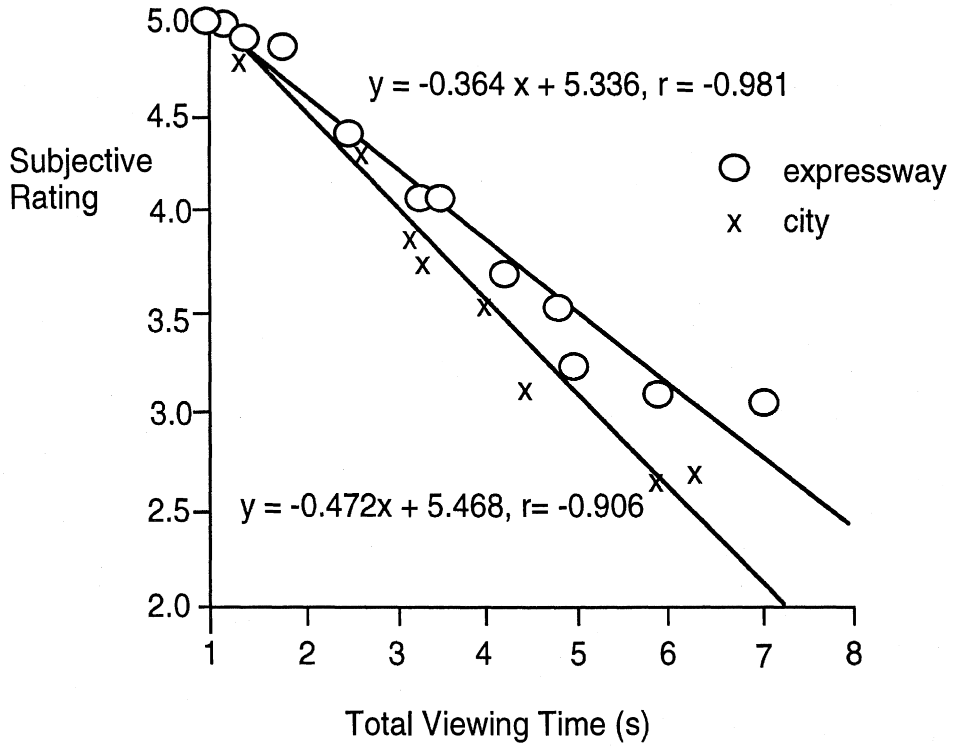



Figure 12. Relationship Between Stress and Total Viewing Time from Ito and Miki, 1997, p. 5

Based on the anchor terms provided for 3 and 4 and the associated Ito and Miki data, time limits for various criteria were calculated (Table 24). The criteria are complicated somewhat by the double negatives arising from the translation. The equations for time shown are based on rearranging those shown in Figure 12.

Table 24. Acceptable Eyes-Off-Road Time Based on Ito and Miki (1997)

| Criterion | Rating | Expressway (s) | City Driving (s) |
|---|---|---|---|
| not secure | 2.5 | 7.8 | 6.3 |
| indifferent (neither secure or insecure) | 3.0 | 6.4 | 5.2 |
| start to feel slightly secure | 3.5 | 5.0 | 4.2 |
| secure (not feeling insecure) | 4.0 | 3.7 | 3.1 |
| comfortable (not uncomfortable at all) | 5.0 | 0.9 | 1.0 |

Note: Time = 14.66 - 2.75 (rating) for expressway
Time = 11.58 - 2.12 (rating) for city

It is important to emphasize that these criteria are for young and middle-aged Japanese drivers on Japanese roads, roads whose level of congestion is greater than that typically found in the United States or Europe. Using a narrow definition of safety, one might argue an acceptable system would offer drivers a minimal sense of security (rating =3.5), leading to acceptable total eyes off the road times of 5.0 s for expressways and 4.2 s for city driving (approximately). While the distribution of responses for each duration is unknown, at 3.5 s, half of the subjects should feel more secure and half should have some degree of insecurity. If the goal is for drivers to feel secure, then times just over 3 s are appropriate. However, the ultimate goal is to make products that are comfortable for drivers, a criteria that suggests total off the road times of only 1 s, a time limit that is not realistic.

**Nowakowski and Green (1998)**
Nowakowski and Green (1998) had 16 drivers (8 under 30, 8 over 65) perform a variety of real map-reading tasks while driving on an expressway. These tasks included finding the name of the driven road, finding a particular cross street, and finding a street. In contrast to many of the conventional instrument panel tasks explored in the literature, these tasks tended to have much longer glance durations. In this experiment, drivers were asked to rate how safe they felt each task to be (1=very safe, 5=very unsafe). Lane departures and noteworthy speed decreases within trials were also recorded.

Figure 13 shows the relationship between response time and ratings of safety. Labels for 2, 3, and 4 on the y-axis were not in the original data but are provided here for convenience. These data suggest that the upper margin between safe and unsafe tasks is when the on-the-road response time exceeds 5 s. Extrapolating from Figure 13, a task with an on-the-road response time of about 12.7 s would be deemed very unsafe on average. Interestingly, a task rated unsafe would have an on-the-road task completion time of approximately 10.3 s. Readers should keep in mind that for an equivalent response time, the eyes-off-the-road time for map reading is likely to be greater than for data entry because of the relatively greater visual demands. Therefore acceptable task completion times are likely to be lower for map reading than those involving data entry.

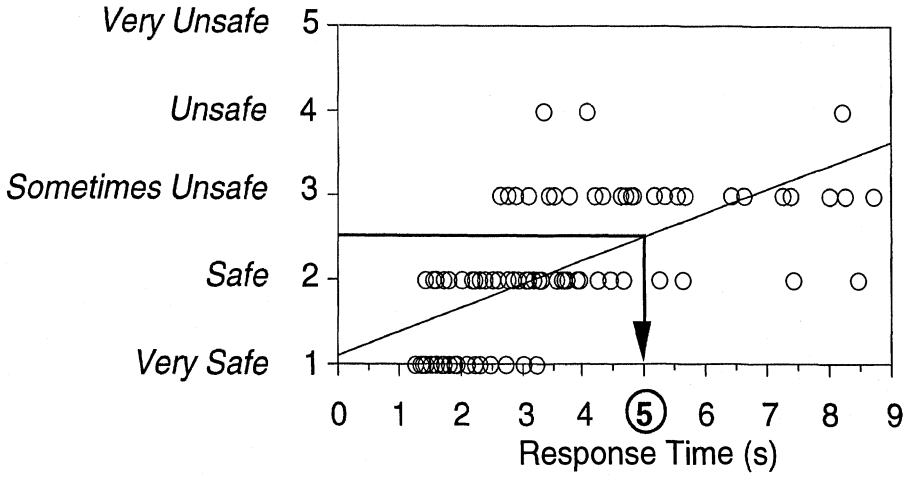



Figure 13. Response Time as a Predictor of Rating

## Summary

Depending on the criteria selected, the data from Ito and Miki (1997) could be used to argue for maximum eyes-off-the-road times of between 4 and 5 s, just over 3 s, or only 1 s. The VICS data could also be used to argue for a wide range of options. The Nowakowski and Green (1998) results could be used to argue for a task time limit of 5 s (measured on-the-road) as being near the margin for almost exclusively visual tasks, with times of just over 10 s being clearly identified as unsafe. Because they are not as visually demanding, higher limits could be suggested for data entry tasks.

Thus, the rating data provide support for keeping activities at 5 to 10 s or less, the actual value depending upon the measure. These values are considerably less than those suggested by other measures, though cultural differences and differences in traffic may also be important. Further efforts to understand why these times are relatively brief and the basis for driver decisions is desired.

## TYPICAL DRIVER EYE GLANCES

**Question 8: How much time do drivers actually spend glancing at existing vehicle controls and displays and, during entry tasks, navigation displays?**

**Rationale:** Some have made the argument that since there has not been a massive carnage from using the controls (climate control, lights, wiper, etc.) and displays (mirrors, speedometer, etc.) in current vehicles, then use of them does not present an unreasonable risk to drivers. Although this may be true on average, this may not be true for every existing control and display (complex radios, phones), especially with the current upward creep in complexity. That does not say they could not be better designed, and there is grudging acknowledgment that a few tasks take excessively long. Nonetheless, glance durations for existing controls and displays do provide a benchmark of what may be reasonable glance durations, at least on average. Accordingly, baseline data along with data for new systems is provided here. New systems that have glance durations and operation times of approximately the same duration as routine in-vehicle tasks should pose no undue risk to drivers.

It has been suggested that the concern is not with the mean glance time, but with outliers (Tijerina, Parmer, and Goodman, 1998). Accordingly, considering the mean times still makes sense because the means and standard deviations of glance times are correlated, so glance distributions with large means will have more outliers.

### Overview

A glance can be a single fixation or a series of fixations. Since the focus of this report is on where visual attention is allocated, a detailed examination of individual fixations is beyond what is necessary for this initial review as is an exhaustive review of the rich literature on driver eye glances. For a current review of the data on glances to the road, see Serafin, 1993; 1994. Table 25 lists some of the on-road studies examined as part of this project that provide data relevant to glances to in-vehicle components.

Table 25. Eye Glance Studies Relevant to In-Vehicle Components

| Study | Method | Results and comments |
|---|---|---|
| Bhise, Forbes, and Farber (1986) | synopsis of literature | • glance durations range from 0.4 to 1.3-s for conventional instrument panel (IP) displays and mirrors |
| Rockwell (1988) | recorded 106 drivers (200 sessions total), given verbal command to operate radio, also obtained mirror glance data, driving in light to moderate traffic, 45-55 mi/hr, full-size late model cars, daylight only | • mean # glances more sensitive than average glance duration<br>• older drivers require 20% more glances<br>• radios with small legends, etc. can increase mean glance duration by 20%<br>• mean glance durations are 20% shorter in heavy traffic |

| | | |
|---|---|---|
| Wierwille, Antin, Dingus, and Hulse (1988) | 32 subjects drove on expressways, 2-lane state road and residential streets verbally cued to operate 8 navigation and 18 conventional functions | • obtained task completion times, mean glance times, and lane departures<br>• navigation function mean times were generally greater than those for conventional controls and displays |
| Hayes, Kurokawa, and Wierwille (1988) | 24 drivers (18 to 25, 26 to 48, 49 to 72) drove 1985 Cadillac Sedan de Ville over expressways, 2-lane roads, city streets, and residential roads, while operating an auxiliary IP | • provides extensive data on number of glances, mean glance times, total glance times, total task times, and number of lane departures for a variety of existing in-vehicle controls and displays (figures are later in this section) |
| Taoka (1990) | analysis of Nagata and Kuriyama (1985) mirror data, and Rockwell and Wierwille studies | • mean glance durations of 0.75 to 1.63 s for driving tasks |
| Kurokawa (1990) | 24 subjects (8 ages 18 to 25, 8 26 to 48, 8 49 to 72) drove 1985 Cadillac Sedan de Ville over expressways, 2-lane roads, city streets, and residential roads, while operating an auxiliary IP | • provides extensive glance duration and mean number of glance data for a variety of existing in-vehicle controls and displays in a driving simulator |
| Kishi, Sugiura, and Kimura (1992) | video camera recorded 5 drivers of unknown age as they drove on a rural expressway and on urban streets, traffic levels were unspecified | • most mean fixation durations were about 1 s (Note: Although the term fixation is used, durations of this length are more commonly associated with glances.)<br>• all means were < 1.5 s<br>• means for expressway were greater |
| VICS Promotion Council (1993) | 46 drivers on test course simulating city and highway driving,<br>11 different displays (maps, etc.), 1 task/display | • increasing information increased # of glances needed<br>• older drivers needed twice as long to recognize information on city roads than on the highway |
| Tijerina, Kantowitz, Kiger and Rockwell (1994) | 7 truck drivers under unspecified driving conditions, 4 to 22 trials/task | • extensive tabular data on glance duration and frequency |
| Kiger, Rockwell, and Tijerina (1995) | 10 line-haul truck drivers, ages 32-60; 1992 Volvo/White GMC conventional tractor with 16.2 m (52 ft) weighted trailer; route including freeways and rural roads, day and night | • longer glances off road scenes when not following a lead vehicle (5.6 vs. 4.0 s)<br>• longer glances to scene for 2-lane roads than freeways (9.2 vs. 3.9 s)<br>• shorter in-vehicle and mirror glances on rural road vs. freeways (1.09 vs. 1.38 s) |

| | | |
|---|---|---|
| Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995- camera car | 18 visitors (6 in 3 age groups) and 12 high-mileage drivers (2 age groups) drove to 6 destinations in a TravTek-equipped car using the system to reach destinations, 130,000 total glances | • for route map, half the number of long glances with voice versus without<br>• for route map, drove 1 mi/hr slower without voice<br>• about 10% more abrupt braking with route map than turn-by-turn display<br>• about 1/3 fewer lane deviations with turn-by-turn display than route map<br>• shorter glances for turn-by-turn displays than route maps (by 5%)<br>• 1/3 to 1/2 as many glances required when a voice is provided in addition to a visual display<br>• 1/2 to 1/3 the number of high rated workload situations for turn-by-turn vs. route map with the lowest # when voice was provided<br>• about 1/2 as many driving errors when voice is present<br>• about 1/3 fewer driving errors for turn-by-turn vs. route map |
| Ito and Miki (1997) experiment 1 | video camera recorded glances of 35 subjects while they performed tasks such as checking instruments and operating the radio and climate control unit, as well as entering phone numbers and other tasks ("set" destinations). Subjects drove through a simulated urban setting and at 100 km/hr on a test track. Simulated traffic was present. | • all tasks had mean glance durations of 2 s or less<br>• all conventional tasks required 2 glances or less<br>• most navigation tasks required 5 or more glances<br>• some required 18 glances |
| Ito and Miki (1997) experiment 2 | 35 subjects silently read text messages (kanji and kana) while driving. The test situation was the same as the previous experiment | • time required to read Japanese characters (about 6.2 characters/s), mix of kana and kanji is unknown |

Bhise, Forbes, and Farber (1986) is an often cited reference in the literature. Unfortunately, only overheads from that presentation exist, not the actual manuscript. A key part of that paper is a description of video observations of a driver's hand and eye movements in a car (Table 26). The vehicle type, test road, speed, and number of subjects are unknown. The data-collection protocol is similar to that used by Rockwell and the data reported could be the same as reported in Rockwell (1988). From the information they present, Bhise, Forbes, and Farber (1986) conclude that glances to in-vehicle devices are from 1.0 to 1.2 s duration.

Table 26. Typical Glance Durations Reported by Bhise, Forbes, and Farber (1986)

| # of Glances Required | Task | Mean Glance Duration (s) |
|---|---|---|
| 1 | analog speedometer-normal driving | 0.4 to 0.7 |
| | analog speedometer-check reading | 0.8 |
| | analog speedometer-exact value | 1.2 |
| | analog fuel gauge | 1.3 |
| | digital clock | 1.0 to 1.2 |
| | mirror-left outside | 0.5 to 1.0 |
| | mirror-inside | 0.5 to 0.7 |
| | turn on radio | 1.1 |
| | change fan speed | 1.0 |
| 2 to 7 | turn on radio, find station & adjust sound | 1.1 |
| 7 to 15 | read all labels on 12-button panel | 1.0 |

## Rockwell (1988)

Rockwell (1988), a commonly cited data reference, presents data for radio and mirror glances from extensive on-road studies (Table 27). Speed and lane drifts were recorded but not reported. Glance durations depended upon the task. For example, mirror glance durations involving discrimination ("specify the adjacent car's color") were longer than those involving detection or traffic checks (means of 1.27 and 1.10 s, respectively). Further, mirror glances tended to be normally distributed, while radio glances were log normal.

Table 27. Overall Glance Data from Rockwell (1988)

| | Study | # Sessions | Mean | Median | s | 5% | 95% |
|---|---|---|---|---|---|---|---|
| Radio | A | 35 | 1.27 | 1.20 | 0.48 | 0.82 | 2.16 |
| | B | 100 | 1.28 | 1.29 | 0.50 | 0.89 | 1.83 |
| | C | 72 | 1.42 | 1.30 | 0.42 | 0.80 | 2.50 |
| Left Mirror | A | 35 | 1.06 | 0.96 | 0.40 | 0.80 | 1.20* |
| | B | 100 | 1.22 | 1.15 | 0.28 | 0.94 | 1.80 |
| | C | 72 | 1.10 | 1.10 | 0.33 | 0.70 | 1.70 |

* This value was shown as 0.20 in the original report, a value that does not make sense (95 percent must be greater than 5 percent), so 0.2 is probably a typo.

Rockwell also reports that glance durations for women were consistently less than those for men (by about 10 percent, primarily for the radio). There were also minor age differences, with older drivers having slightly longer glance durations for the radio, but shorter durations for mirrors. However, the two age groups were under 35 versus over 45, a split that may not reveal the full variation in the population. Rockwell also notes that glance durations to the mirror and radio were reduced by 20 percent in heavy traffic.

Averaging across subjects for all three studies, a mean glance duration to the radio was 1.37 s (0.91 s for the 5 percentile, 1.59 s for the 95 percentile). In discussing the data, Rockwell notes the following: "For years researchers studying car following and eye movements have a found a 2 second rule, i.e., drivers are loath to go without roadway information for more than 2 seconds (and rightly so)" (Rockwell, 1988, p 322).

In exploring the differences between interfaces, Rockwell reports that there were small differences between least usable and most usable designs in glance duration (by up to 20 percent), but the primary influence of a poor design was to increase the number of glances needed. Table 28 shows typical mean glance durations for various radio tasks. These are probably data from the mid-80s. Increases in radio interface complexity since then should lead to greater estimates for glance durations for current radios.

Table 28. Mean Glance Durations for Radio Tasks

| Command (N=250) | Mean Glance Duration (s) |
|---|---|
| select station | 1.50 |
| tune station | 1.50 |
| volume | 0.97 |
| sound quality | 1.51 |
| basic cassette | 1.59 |
| memory set | 1.37 |

**Wierwille and Dingus (1988)**

One of the most comprehensive studies of in-vehicle tasks is Tom Dingus's dissertation. (See Wierwille, Antin, Dingus, and Hulse, 1988; Dingus, 1988; Dingus, Antin, Hulse, and Wierwille, 1986; Dingus, Antin, Hulse, and Wierwille, 1989). This section reviews that work in detail, providing the means, standard deviations, and correlations for various tasks. In addition, regression models linking the measures (created by the author based on Dingus's data) are provided. Equations relating some of these measures to each other appear in a later section as well.

While driving, subjects were verbally cued to read the speedometer, read the time, adjust the fan, and perform traditional in-vehicle tasks, as well as complete tasks associated with an Etak map display, such as reading the name of the next cross street. Although technology has advanced considerably since 1988, the basic characteristics that influence response time to map content (the contrast ratio, the amount of map detail, and in many cases even the character height) have changed little since 1988, so the times from this study are likely to reflect current products.

Table 29 shows the total glance times and the sum of the individual (single) glance times. Total glance times for navigation tasks (shown in italics in the tables that follow) were often greater than for traditional in-vehicle tasks. The navigation tasks explored in this experiment were quite simple relative to destination entry.

Table 29. Total Glance Times from Wierwille, Antin, Dingus, and Hulse (1988)

| Range (s) | Task | Mean total time (s) | Standard deviation (s) |
|---|---|---|---|
| < 1.0 | Speed | 0.78 | 0.65 |
| | Following Traffic | 0.98 | 0.60 |
| 1.0 - 2.5 | Time | 1.04 | 0.56 |
| | Vent | 1.13 | 0.99 |
| | *Destination Direction* | *1.57* | *0.94* |
| | Remaining Fuel | 1.58 | 0.95 |
| | Tone Controls | 1.59 | 1.03 |
| | Info. Lights | 1.75 | 0.93 |
| | *Destination Distance* | *1.83* | *1.09* |
| | 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 |
| | *Correct Direction* | *2.96* | *1.86* |
| 2.5 - 4.0 | Fuel Range | 3.00 | 1.43 |
| | Temperature | 3.50 | 1.73 |
| | Cassette Tape* | 3.23 | 1.55 |
| | *Heading* | *3.58* | *2.23* |
| *4.0 - 8.0* | *Zoom Level* | *4.00* | *2.17* |
| | Cruise Control | 4.82 | 3.80 |
| | Power Mirror | 5.71 | 2.78 |
| | Tune Radio | 7.60 | 3.41 |
| *> 8.0* | *Cross Street* | *8.63* | *4.86* |
| | *Roadway Distance* | *8.84* | *5.20* |
| | *Roadway Name* | *10.63* | *5.80* |

Table 30 shows the mean glance time and the number of glances. Several of the total glance times for the conventional tasks are quite large, such as 7.60 s to tune the radio. (The 1985 Cadillac Sedan de Ville utilized by Wierwille had a knob for tuning.) The limited frequency of use data available suggests that manual tuning of the radio is quite rare, as opposed to using the presets (Green, 1979; Wierwille, 1995). For contemporary radios with frequency up/down buttons and a digital display of the frequency, finding a particular station can be a very demanding and distracting task.

Table 30. Mean and Standard Deviation of Glance Times and Number of Glances

| Task | Single glance mean | Single glance sd | # glances mean | # glances sd |
|---|---|---|---|---|
| speed | 0.62 | 0.48 | 1.26 | 0.40 |
| following traffic | 0.75 | 0.36 | 1.31 | 0.57 |
| time | 0.83 | 0.38 | 1.26 | 0.46 |
| vent | 0.62 | 0.40 | 1.83 | 1.03 |
| *destination direction* | *1.20* | *0.73* | *1.31* | *0.62* |
| remaining fuel | 1.04 | 0.50 | 1.52 | 0.71 |
| tone controls | 0.92 | 0.41 | 1.73 | 0.82 |
| info. lights | 0.83 | 0.35 | 2.12 | 1.16 |
| *destination distance* | *1.06* | *0.56* | *1.73* | *0.93* |
| fan | 1.10 | 0.48 | 1.78 | 1.00 |
| balance | 0.86 | 0.35 | 2.59 | 1.18 |
| sentinel | 1.01 | 0.47 | 2.51 | 1.81 |
| defrost | 1.14 | 0.61 | 2.51 | 1.49 |
| fuel economy | 1.14 | 0.58 | 2.48 | 0.94 |
| *correct direction* | *1.45* | *0.67* | *2.04* | *1.25* |
| fuel range | 1.19 | 1.02 | 2.54 | 0.60 |
| temperature | 1.10 | 0.52 | 3.18 | 1.66 |
| cassette tape | 0.80 | 0.29 | 2.06 | 1.29 |
| *heading* | *1.30* | *0.56* | *2.76* | *1.81* |
| *zoom* | *1.04* | *0.65* | *2.91* | *1.65* |
| cruise control | 0.82 | 0.36 | 5.88 | 2.81 |
| power mirror | 0.86 | 0.34 | 6.64 | 2.56 |
| tune radio | 1.10 | 0.47 | 6.91 | 2.39 |
| *cross street* | *1.66* | *0.82* | *5.21* | *3.20* |
| *roadway distance* | *1.53* | *0.65* | *5.78* | *2.85* |
| *roadway name* | *1.63* | *0.80* | *6.52* | *3.15* |

## Taoka (1990)

An excellent source of statistical summary of normative glances to mirrors and conventional in-vehicle displays is Taoka (1990). He reanalyzes the data from the mirror data of Nagata and Kuriyama (1985), the Wierwille (1988) data for in-vehicle tasks, and the Rockwell (1988) data for mirrors and radios described previously. (See Table 31.)

Table 31. Taoka's Summary Table of Glance Statistics

| Viewing task | mean (s) | standard deviation (s) | median (s) | dispersion d (s) |
|---|---|---|---|---|
| radio | 1.44 | 0.50 | 1.27 | 0.376 |
| left mirror | 1.10 | 0.30 | 1.06 | 0.268 |
| right mirror | 0.75 | 0.36 | 0.68 | 0.455 |
| speedometer | 0.62 | 0.48 | 0.49 | 0.685 |
| temperature gauge | 1.10 | 0.52 | 0.99 | 0.449 |
| defroster | 1.14 | 0.61 | 1.01 | 0.502 |
| road name sign | 1.63 | 0.80 | 1.46 | 0.465 |

By definition, a logarithmically distributed normal variable can be described as follows:

$z = (\ln(t) - \ln(\text{median time}))/d$ where d is the dispersion parameter and

$d^2 = \ln(1 + (s/\text{mean time})^2)$ where s is the standard deviation of t.

Rearranging the first equation,

$t = \text{median} * e^{zd}$

For in-vehicle features, the range of dispersions was 0.376 to 0.685.

As a computational aid to the reader to promote understanding, the 95 percentile radio time (z=1.645) is 2.35 s. For the range of 0.5 to 3.0 s, the predictions developed from the data (using the parameters in Table 31) and the actual data generally disagree by about 0.01 s and almost never disagree by more than 0.03 s. Further, the best fit occurs for large values of t, the region of greatest interest. Since most of the data were collected using video equipment at 30 frames per second (0.033 s per frame), the fit is extraordinarily good.

**Kishi, Sugiura, and Kimura (1992)**

Kishi, Sugiura, and Kimura, 1992 also report fixation times for conventional controls and displays. (See Kimura, Marunaka, and Sugiura (1997) for an English summary.) Figure 14 shows the means and standard deviations, and Table 32 presents a tabular summary developed from the figure. Notice that the means range from 0.7 to 1.4 s, with most being near or below 1.0 s.

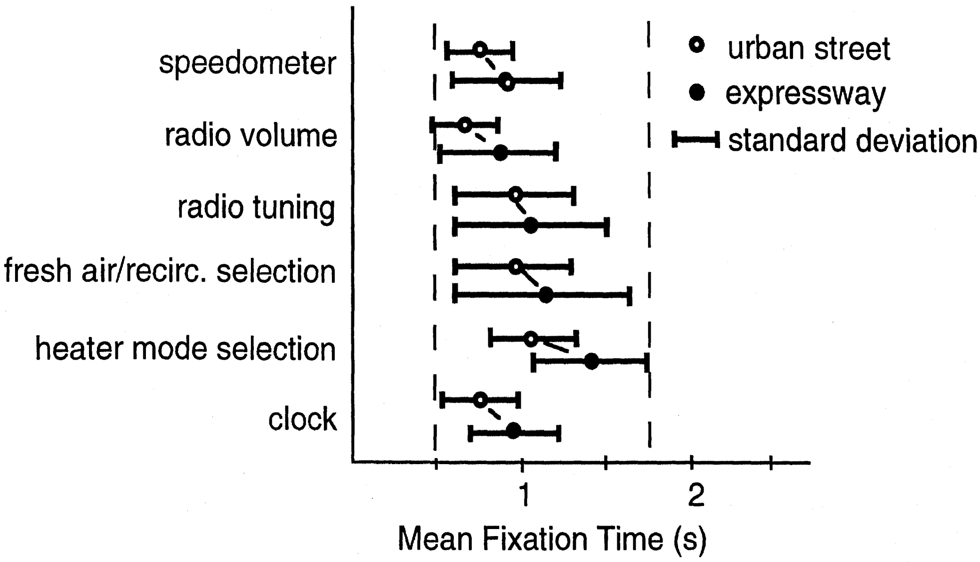



Figure 14. Fixation Times for Conventional Controls and Displays.
Source: Kimura, Marunaka, and Sugiura, 1997, p. 155

Table 32. Times Estimated from Figure 14

| Feature | Urban street | | Expressway | |
|---|---|---|---|---|
| | mean | standard deviation | mean | standard deviation |
| speedometer | 0.80 | 0.20 | 0.90 | 0.32 |
| radio volume | 0.70 | 0.20 | 0.85 | 0.37 |
| radio tuning | 0.95 | 0.33 | 1.10 | 0.43 |
| fresh/recirc air mode | 0.95 | 0.33 | 1.20 | 0.50 |
| heater mode | 1.10 | 0.30 | 1.40 | 0.30 |
| clock | 0.75 | 0.22 | 0.95 | 0.25 |

By way of comparison, Wierwille, Antin, Dingus, and Hulse (1988) reported glance times to the speedometer of 0.78 s, which is fairly close to the time reported here, though their standard deviation was much greater (0.65 s). This may be a result of the limited age range of subjects in the Kimura study. In contrast, Taoka's estimated the glance times for speedometers to be slightly less (0.62 s), with a standard deviation of 0.48 s, a value in between the two previous results.

**VICS Promotion Council (1993)**

The VICS report describes experiments on icons and display location, as well as one experiment on display reading times, the experiment pertinent to this section. The author's understanding of the research is incomplete because only a Japanese language version of the report is available with partial English summaries of a few sections. In the pertinent experiment, subjects drove on a test course and were asked to look at stylized maps, complex maps, or text displays from time to time. Tasks included determining if the there was parking near a destination, which route to take to a destination, or when they were finished reading text.

Based on the partial translation of the report, the following may be true. [Some of these statements were taken literally from the translation and the author is not completely sure what they mean, but they represent the best information available.]

- Increasing the amount of information provided leads to an increase in the number of glances required.
- Congestion information does not appear to affect the number of glances required.
- Older drivers needed twice as long to recognize information on city roads than on highway.

Glance durations ranged from 1.1 to 2.2 s. Most mean glance durations were under 1.9 s. The number of glances required varied from 1.2 to 7 depending on the task.

**Tijerina, Kantowitz, Kiger, and Rockwell (1994)**

This study provides useful data relating external demands to in-vehicle task completion times for truck drivers. Table 33 displays some of the results. Virtually all of the mean glance times were under 2.0 s, and except for tuning the radio, no task involved more than 5 s of eyes-off-road time.

Table 33. Glance Data from Tijerina, Kantowitz, Kiger, and Rockwell (1994)

| Task | Mean Glance Time (s) | Mean # Glances | Mean Eyes-Off-Road Time (s) |
|---|---|---|---|
| left mirror-detect | 1.38 | 1.41 | 1.95 |
| right mirror-detect | 1.22 | 1.59 | 1.94 |
| left mirror-discriminate | 1.52 | 1.50 | 2.28 |
| right mirror-discriminate | 1.45 | 1.86 | 2.69 |
| read exact speed | 1.60 | 1.29 | 2.06 |
| compare posted speed with speedometer | 1.42 | 1.25 | 1.77 |
| read air pressure | 2.11 | 2.00 | 4.21 |
| read engine RPM | 1.66 | 1.61 | 2.67 |
| read fuel gauge | 1.88 | 1.78 | 3.34 |
| read clock | 1.20 | 1.88 | 2.25 |
| read elapsed time | 1.65 | 2.67 | 4.40 |
| radio volume up/down | 1.10 | 1.62 | 1.78 |
| select preset station | 1.46 | 3.19 | 4.65 |
| turn radio to 90.5 | 1.77 | 7.81 | 13.81 |
| change CB frequency | 1.34 | 3.76 | 5.04 |
| turn CB volume up/down | 1.06 | 1.29 | 1.37 |
| AC temp up/down | 1.65 | 2.40 | 3.97 |
| fan speed higher/lower | 1.35 | 1.71 | 2.31 |

## Kiger, Rockwell, and Tijerina (1995)

This study is one of the very few in the literature specifically concerned with driving large trucks. Table 34 shows some of the results. As an aside, two types of glances are reported, natural and those requested by the experimenter. The mean times reported are comparable to others in the literature. Interestingly, when the means and standard deviations for this data set are correlated, there is a reasonable correlation between the mean glance time and the standard deviation (r=0.78), with the standard deviation being about 66 percent of the mean. This estimate is fairly close to the one based on data from Hayes, et al. (1988), where the standard deviation was 55 percent of the mean glance duration. Some caution should be exercised in interpreting this relationship, because the correlation is predominantly due to two data points, the time to look at the road scene and the time to turn the radio. When those two data points are removed, the correlation decreases substantially (to r=.15), and the standard deviation (about 14 percent of the mean) only increases slightly.

Table 34. Truck Driver Glance Data from Kiger, Rockwell, and Tijerina (1995)

| Location | # Glances (see note) | Duration | | # per Request | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| road scene | 14995 | 2.18 | 3.67 | | |
| off road | 8716 | 1.01 | 0.47 | | |
| left mirror-natural | 2324 | 1.01 | 0.43 | | |
| left mirror-requested | 212 | 1.25 | 0.51 | 1.10 | 0.35 |
| right mirror-natural | 1096 | 1.02 | 0.41 | | |
| right mirror-requested | 235 | 1.37 | 0.57 | 1.15 | 0.39 |
| instrument panel | 3086 | 0.88 | 0.36 | | |
| digital clock-requested | 220 | 1,27 | 0.41 | 1.07 | 0.28 |
| air pressure gauge-requested | 243 | 1.53 | 0.61 | 1.17 | 0.50 |
| adjust radio volume | 248 | 0.93 | 0.93 | 1.19 | 0.62 |
| tune radio | 1192 | 1.22 | 1.22 | 5.99 | 3.36 |

Note: The number of glances shown is for duration estimates. The values for the number of glances were based on slightly fewer samples.

Readers interested in additional information on this effort, in particular with regard to lane keeping should see Tijerina, Kiger, Rockwell, and Tornow (1995) and Kantowitz, Hanowski, and Tijerina (1996).

## Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman (1995)

The TravTek camera car experiment involved real drivers (visitors and high mileage drivers familiar with the test locale) operating a real navigation system on public roads. (See also Dingus, Hulse, McGehee, Manakkal, 1994.) Among the types of data collected were driver eye fixations. Table 35 shows the mean glance durations for each interface type (as estimated from figures in the report). The report also provides data on the total number of glances for each interface type for the entire experiment. Data on the number of fixations or the number of glances required per event were not provided. The turn-by-turn display utilized arrows to show the turn direction and a countdown bar as the intersection was approached. Street names were also shown.

Table 35. Glance Data for the TravTek Camera Car Experiment
(Source: Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995, p. 183.)

| Interface | Mean Glance Duration (s) | |
|---|---|---|
| | Local users 1st drive | visitors |
| turn-by-turn with voice | 0.95 | 0.94 |
| turn-by-turn without voice | 1.01 | 0.99 |
| route map with voice | 1.10 | 1.08 |
| route map without voice | 1.20 | 1.32 |
| paper direction | 1.01 | 1.12 |
| paper map | 1.10 | 1.08 |

Table 36 shows the range of glances (averaged across interface type) to other locations to provide a reference. Navigation glance durations were comparable to the "left hand check" location shown in the table.

Table 36. Range of Glance Durations to Various Locations
(Source: McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995, p.-57.)

| Location | Range of Means (s) |
|---|---|
| forward | 1.75-2.80 |
| left of forward | 0.95-1.00 |
| right of forward | 0.80-0.90 |
| rear view mirror | 0.58-0.60 |
| left side mirror | 0.75-0.80 |
| right side mirror | 0.55-0.90 |
| left hand check | 1.00-1.20 |
| right hand check | 0.80-1.00 |
| dashboard | 0.80-0.90 |
| navigation | 0.95-1.10 |
| signs | 0.75-0.95 |
| outside car, other | 0.55-1.00 |
| inside car, other | 0.85-0.95 |
| steering wheel | 0.75-0.90 |

**Ito and Miki (1997), Experiment 1**

In this experiment subjects were cued to respond to various tasks while driving in a simulated urban setting and expressway as described earlier. Figure 15 shows the results, relating the average "look" duration to the number of glances. It is unknown if the look durations included transition to and from the road and if a look and glance were the same or different. Look duration variability was not provided. Notice that navigation related tasks generally required significantly more glances than conventional tasks, usually more than 5 and as many as 18. To assist in comparison with other studies, this glance data shown in the figure has been converted into a tabular format (Table 37).

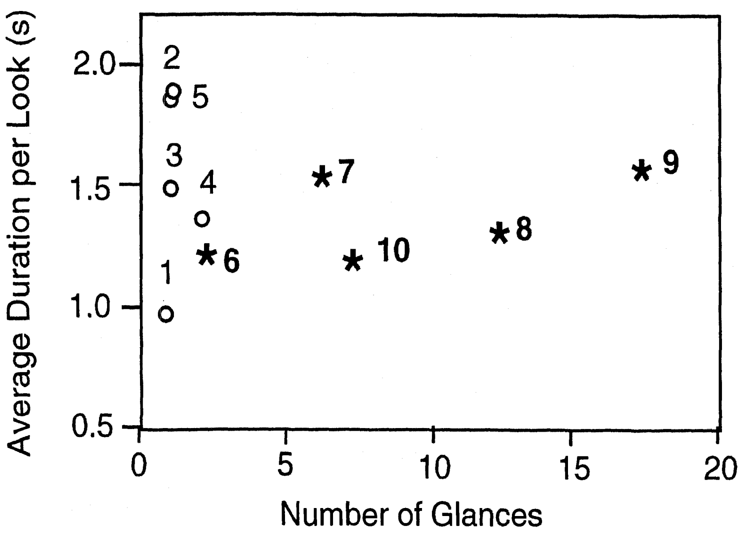



Figure 15. Average Duration per Look vs. Number of Glances
Source: Ito and Miki, 1997, p. 4
Note: All items in bold are uncomfortable to operate

Table 37. Glance Data Reported by Ito and Miki, 1997

| Category | Task | Average look duration (s) | Number of glances |
|---|---|---|---|
| conventional | read speedometer | 1.00 | 1 |
| | manipulate climate control | 1.85 | 1 |
| | read clock | 1.50 | 1 |
| | select radio channel | 1.40 | 2 |
| navigation & phone | read map | 1.85 | 1 |
| | change map scale | 1.25 | 2 |
| | set present location on map | 1.55 | 6 |
| | set destination on map | 1.30 | 12.5 |
| | manipulate cell phone | 1.60 | 17.5 |
| | search for address | 1.20 | 7.5 |

**Ito and Miki (1997), Experiment 2**

In addition, Ito and Miki also report data on the relationship between recognition time (reading time) and the number of Japanese characters presented while driving. The data summarized in Figure 16 suggests that Japanese characters were read at a rate of 6.2 characters/s. The rate at which people read is between 50 and 100 percent of their channel capacity, about 50 bits/s (Namba, 1980). According to Namba, there are approximately 1850 common Chinese (Kanji) characters and 46 Kana characters (106 with variants). By definition, the amount of information (H) in a symbol set (here characters) is $\log_2$ of the number of alternatives, assuming they are equally likely. Thus, there are 10.85 bits of information per Chinese character and 5.6 (or 6.7) bits per Kana. By comparison, each Roman character (ignoring numbers) contains 4.7 bits of information ($\log_2$-(26)). Though unspecified, it is estimated there was a 50/50 mix of Kanji and Kana characters. An average character read in this experiment would therefore contain approximately 8.2 bits of information ((10.85 + 5.6) / 2), the equivalent of 1.75 Roman characters. Thus, the reading rates for languages using Roman characters can be estimated by dividing the slope parameter in Figure 26 by 1.75. By calculation 0.159 s (approximately) is required to read one Japanese character or 0.091 s per Roman character (about 11 characters/s).

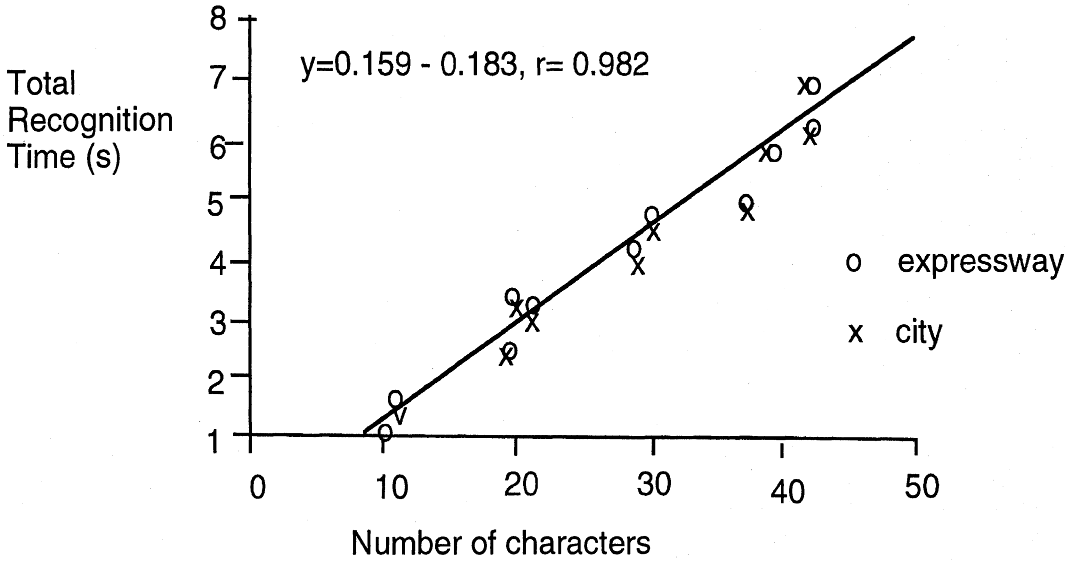



Figure 16. Relationship Between Total Recognition Time and the Number of Japanese Characters while Driving
Source: Ito and Miki, 1997

This estimate makes three unproved assumptions: (1) All characters are equally likely. (2) Sequential dependencies can be ignored. (3) Traffic demands are equal for all situations. Nonetheless, the expression provided is a reasonable engineering approximation sufficient for design.

## Summary

1. There is a significant body of literature on glance durations for conventional instrument panel functions such as the speedometer, radio, clock, etc. The longest mean times for a single glance in a set of functions ranged from 1.2 to 1.85 s, depending on the study and function. Glance durations are predominantly under 1.2 s. Outlier data points occurred for adjusting a mirror (a task that occurs less than once per trip on average) and inserting a cassette tape. Mean glance durations for turn signals tend to be unusually short because drivers do not glance at them each time the turn signal is used.

2. Drivers loath to go for more than 2 seconds without information from the road (Rockwell's 2 second rule).

3. The probability of a long glance of a particular duration can be estimated from the literature. Glance durations are log normal with dispersion values of 0.2 to 0.6 s. Dispersions appear unrelated to mean times. The standard deviation of glance times are about 40 to 50 percent of mean times, being about 5 percent less for activities under 2 to 3 s and 5 percent greater for tasks over that time.

4. Preliminary data shows that except for map reading, the glance durations for most navigation-system-related tasks are not much longer than those for conventional tasks. For conventional functions, the largest number of glances are directed toward the mirrors, climate control, and radio, where as many as 6 to 8 glances occur per event. However, for the navigation tasks described in the literature, tasks much less complex than destination entry, 5 to 18 glances are required, a value generally greater than even the most difficult of existing tasks.

5. In-vehicle glance durations are sensitive to workload. As the demand of driving increases, the duration of in-vehicle glance durations decreases. In heavy traffic, in-vehicle glance durations are reduced by 20 percent from less demanding situations.

6. For conventional controls and displays, there is a very slight correlation between the number of glances required for a task and the mean time per glance, with each additional glance typically adding about 50 ms to the mean, though there are exceptions. For rough engineering estimates, glance durations can be assumed to be constant.

7. While driving, people are estimated to read short strings of English text at about 11 characters per second.

## PREDICTION OF LANE DEPARTURES

**Question 9: How often do lane departures occur for in-vehicle tasks?**

**Question 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?**

**Rationale:** To avoid collisions, drivers must stay in their lane. Clearly, there are many instances in which drivers depart from their lane and no crash occurs. However, the more likely drivers are to leave their lane, the greater the risk of a crash. Tijerina, Kiger, Rockwell, and Wierwille (1996) argue there is particular concern for opposite-direction crashes, single-vehicle road departures, and lane-change crashes.

There are two sources of literature that relate to the prediction of task completion times in vehicles: (1) general studies and models of in-vehicle performance, and (2) task-specific efforts, namely those specifically concerned with data entry for navigation and route guidance. The models of driver performance are covered in a subsequent report.

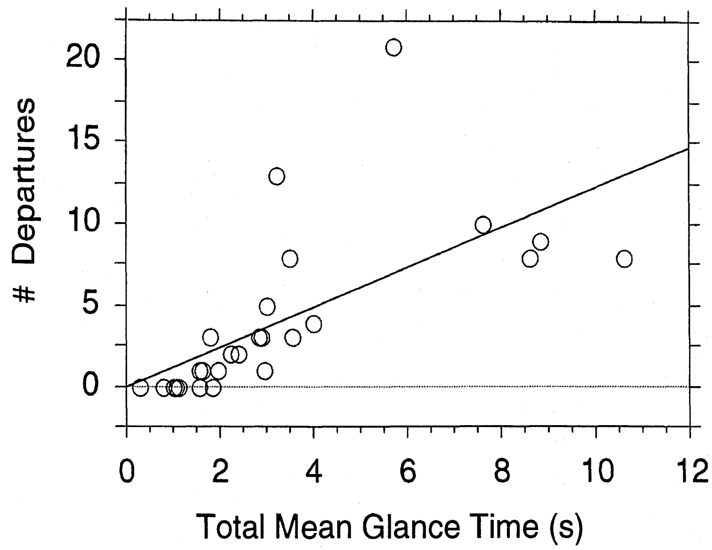
How well drivers stay in their lane is often characterized using lane departures, also know as lane exceedences. Depending on the study a departure may be defined as when (1) at least one of the tires of the subject's vehicle touches the edge line of a lane marking, (2) a tire reaches the center of the centerline, or (3) one tire has gone beyond the farthest edge of the edge line. The definition should have some impact on number of occurrences counted, but the differences are likely to be small.

As a reminder, the research of Zwahlen, although examined in the initial review, has not been included here due to a lack of resources to complete the analysis. Future reviews should pay close attention to that research.

### Wierwille and Dingus (1988)

As a reminder, this study concerns the use of the Etak navigator and other functions by drivers (varying in age) while driving over a wide variety of roads in Virginia. The mean glance durations, etc. were discussed elsewhere in this report.

The correlation between total glance time (total eyes-off-the-road time) and lane departures was moderate, 0.66 (Figure 17). The two deviant points were for the power mirror control (6 s/glance, 21 excursions) and cassette tape loading (3.23 s/glance, 13 excursions). On average, the number of lane departures was approximately -0.005 + 1.227 * total glance time in seconds. Since there were 96 trials/task (almost 100) in this experiment, the number of lane-departure errors in the experiment is approximately the percentage of trials on which lane departures would occur. The shortest mean glance time that led to a lane departure was 1.58 s (determine remaining fuel) while the largest mean glance time that led to no errors was 1.83 s (destination distance). This could suggest that tasks with total glance times of less than approximately 1.58 s will not lead to any appreciable lane drift when driving on mostly uncongested roads, though no departures did occur in some circumstances for total glance times of up to 1.83 s. If under no circumstances should the probability of a departure exceed one percent (on a trial), then the total glance time should not exceed 2.23 s. (The volume balance control had a mean total glance time of 2.23 s and there were two lane exceedences.) Ignoring the mirror and tape tasks, the task most likely to lead to a lane departure was tuning the radio, with a frequency of approximately 0.1 per trial (and a total glance time of 7.6 s). Some might consider this to be an acceptable maximum glance time (total eyes-off-the-road time).




# Departures = -.005 + 1.227 * Total Mean Glance Time; R^2 = .438

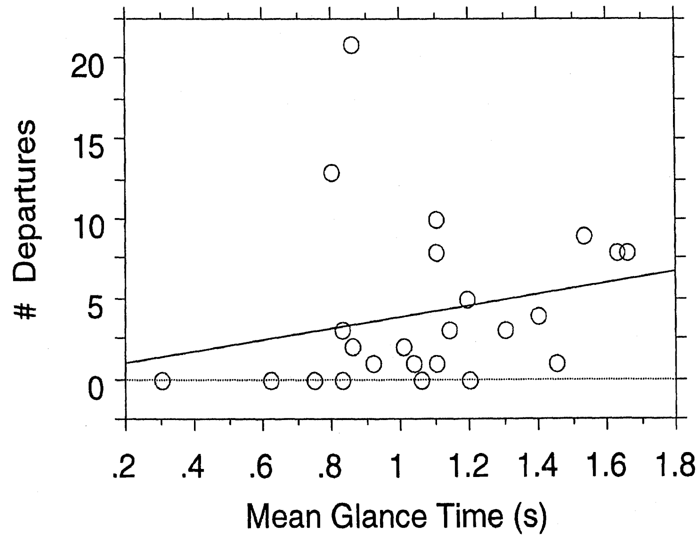
Figure 17. Relationship between Total Glance Time and Lane Departures Based on Wierwille's Data

In some sense, however, pooling all of the data together to predict departures is a bit misleading. Although they actually represent a continuum, in-vehicle tasks involving controls can be grouped into three broad categories for descriptive purposes. The power-mirror and tape-insertion tasks are near continuous control tasks, requiring a high level of visual feedback. Most in-vehicle tasks fit into the moderate control category. The driver looks for the switch, may read a display, and then operates the control with a moderate level of feedback. Destination-entry and retrieval tasks are in this category. The third category of task comprises those requiring little feedback. Dialing a cell phone may be in this category for skilled individuals. The driver finds the device, guides his or her hand to it, and with minimal visual feedback, presses several keys in a sequence before looking again at the device.

One could therefore argue that the number of departures for typical in-vehicle tasks should be estimated with the power-mirror and cassette data treated separately. If that is done, then the number of departures (actually the percentage of trials on which a departure occurs) is approximately 1.03 * (total glance time) -0.343 according to a regression analysis. Using Tijerina's (1999) data described earlier, the mean eyes-off the-road time for the Alpine, Delco, and Zexel systems was 74.3 s and the mean number of lane excursions was 0.70. Using the adjusted equations (cassette and mirror removed), the percentage of trials on which a departure occurs = 1.03 * (74.3)

-0.343 = 76 percent, remarkably close to the 70 value computed. The two measures being compared are somewhat different. However, to the extent that they do agree suggests some level of consistency across studies. More careful examination of the data is desired when the resources are available.

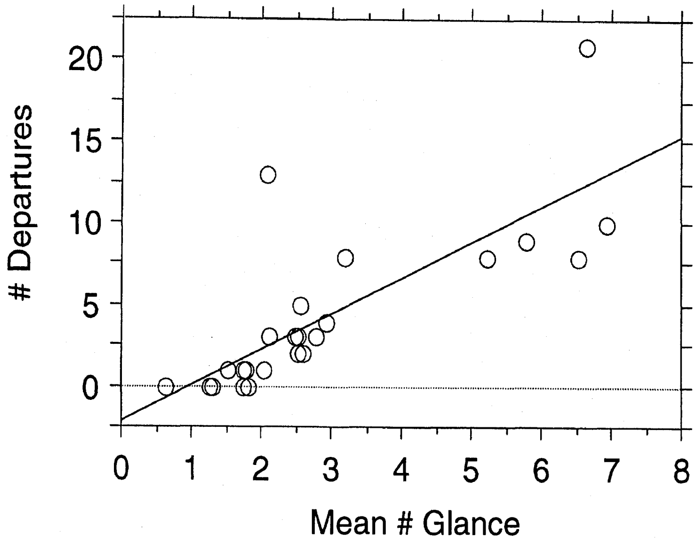
As was noted elsewhere in this report, there is significant concern that long glance times can create problems. Figure 18 shows the relationship between mean glance time and lane departures for this data set. Although the number of lane departures does increase slightly with increasing glance duration, the variance accounted for is only five percent. The two outliers are as before. One reason for the low correlation may be the limited range of glance durations explored, all of which are under 1.7 s. The extremely low value (0.3) represents the turn signal, a control that was not looked at in every trial.




# Departures = .249 + 3.627 * Mean Glance Time; R^2 = .054

Figure 18. Relationship between Mean Glance Time and Lane Departures Based on Wierwille's Data

Figure 19 shows the relationship between the number of glances and the number of lane departures. The correlation was moderately high (r=0.78), even greater than the correlation with total glance time. Interestingly, removing the two outlier points (cassette and mirror) increased the correlation to 0.93. The mean number of glance data suggests that lane excursions are rare for two glances or less, but that for more than two glances, there are opportunities for concern. Ignoring the outliers, the data suggest that for the roads and traffic conditions explored by Wierwille, about five percent of the trials involving operations that required three glances led to a lane excursion.




# Departures = -2.081 + 2.189 * Mean # Glance; R^2 = .615

Figure 19. Relationship between Number of Glance and Lane Departures Based on Wierwille's Data

Note: When the outliers are removed, # Departures = 1.78 * Mean # Glances - 1.78

Taken together, Figures 18 and 19 suggest that both glance duration and the number of glances need to be considered in predicting lane departures, but the number of glances is clearly much more important. As a first approximation, only the number of glances should be considered.

Figure 30 shows the three-way relationship between the mean number of glances, mean glance time, and the number of lane-departure errors. The values on the plot are the number of departures. This plot suggests that keeping the number of glances to two or less will keep the percentage of trial on which a lane departures occurs to one or less (except in one case). However, these data do not suggest what an acceptable maximum glance time should be, since all were 1.5 s long or less. One interpretation of this result is that since drivers did not choose fixations in excess of 1.5 s, this value could be the limit for the mean glance time.

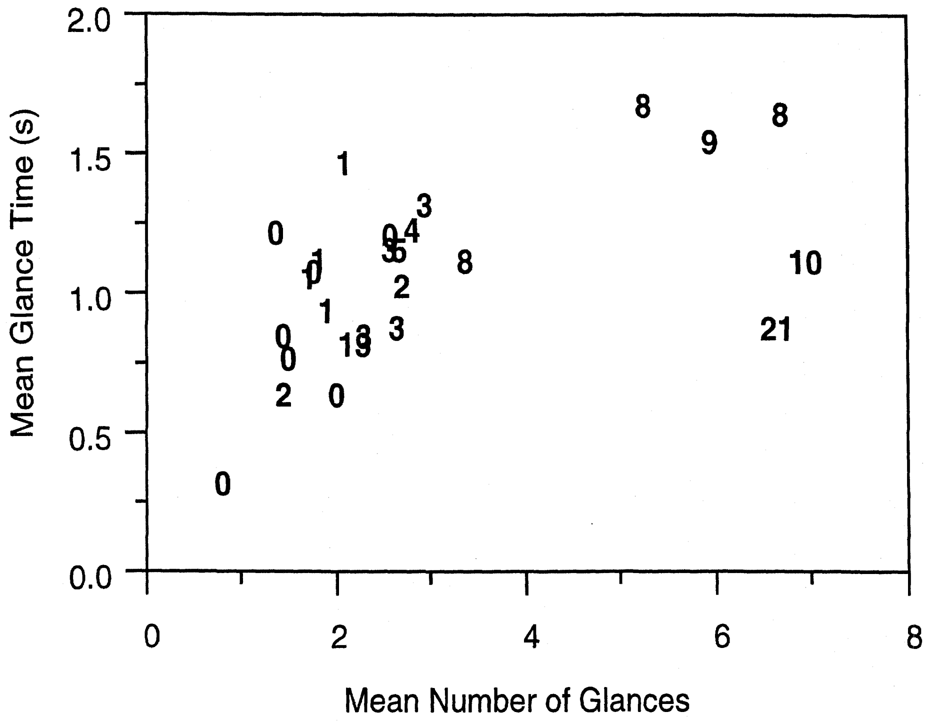
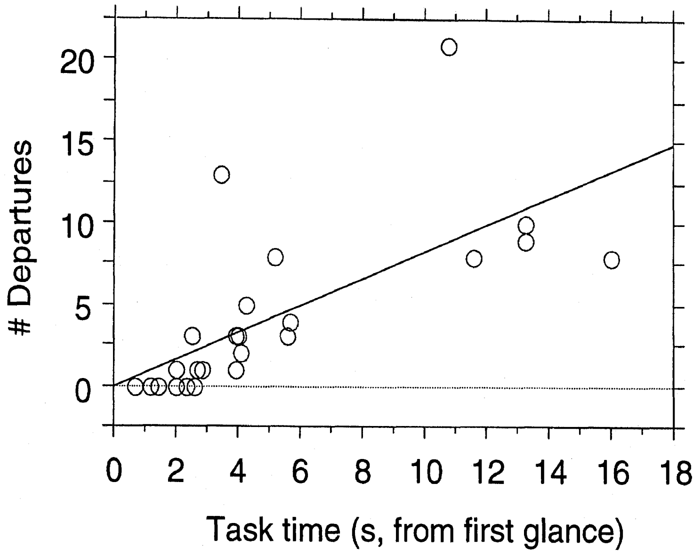



Figure 20. Mean Glance Time, Number of Glance, and Number of Lane Departures

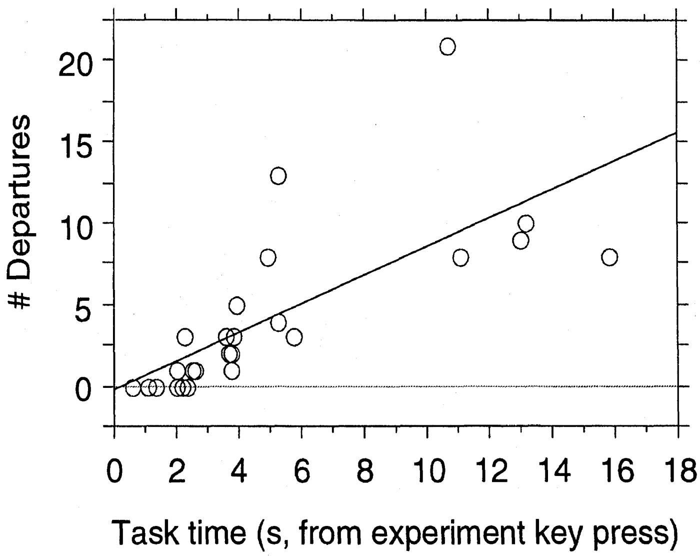
Another variable to consider is the task completion time for auditorally commanded tasks. Both the time from when the first glance occurred and when the subject was judged to begin the task (by an experimenter) were examined. Figures 21 and 22 show the relationship between the glance-based and button-press-based task times and the number of departures. For the glance-based measure, there were virtually no departures for durations of 2 s or less, and few for task times of 3 to 4 s (with the same exception found earlier). For the button-press-based results, departures were rare for task times of up to 3.5 s, with increases occurring at about 5 s. For both measures, each additional second of task time increased the probability of a lane departure (for the test conditions used by Wierwille) by 0.8 to 0.9 percent, except for times under 2 s (where the function is discontinuous). To reiterate, the number of departures in the experiment and the percentage of trials on which a departure occurred are approximately equal in these figures.




# Departures = -.076 + .827 * task time-g; R^2 = .48

Figure 21. Glance-Based Task Times versus Number of Lane Departures

Note: With outliers removed, # Departures = -0.339 +0.688 time-g; R^=0.80

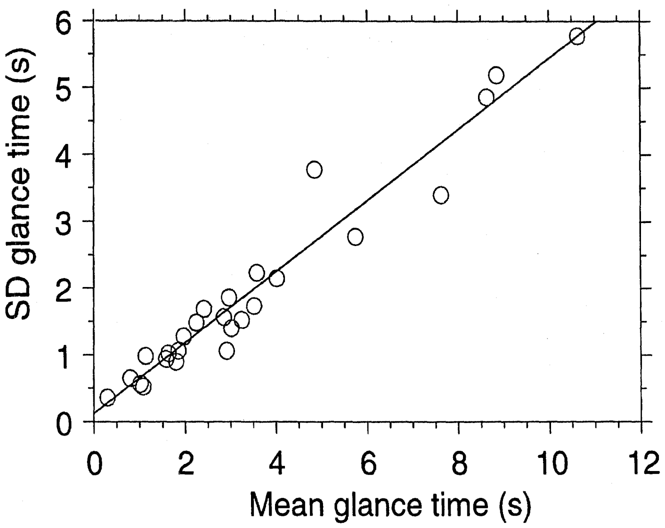



# Departures = -.22 + .876 * task time-key; R^2 = .531

Figure 22. Button-Press-Based Task Times versus Number of Departures

Note: With outliers removed, # Departures = -0.205 + 0.689 task time-key; R^2 = 0.788

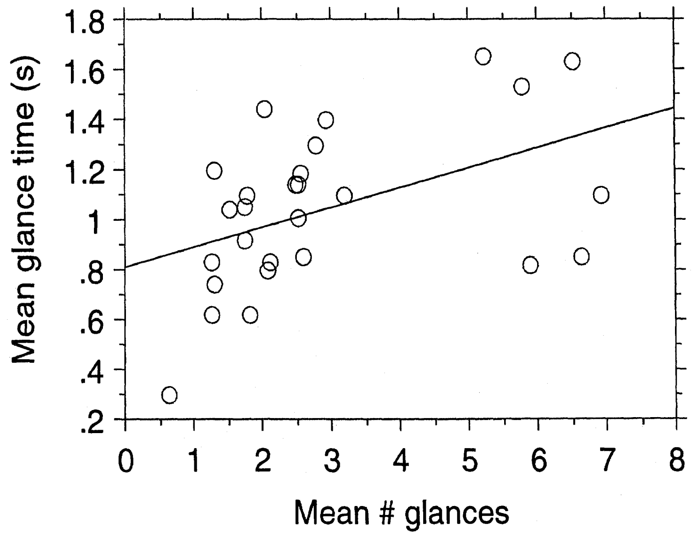
In addition to their relationship with lane departures, there is also interest in relating various performance measures with each other. Figure 23 shows the very high correlation (r=0.98) between the mean glance time and the standard deviation of glance time determined from the data of Wierwille, Antin, Dingus, and Hulse (1988). The standard deviation of the glance time can be estimated as 0.141 + 0.529 (mean glance time in s). Since many studies only report mean glance times and not standard deviations, this equation may be used where estimates of standard deviations are needed (for example, to calculate a percentile glance duration).




SD glance time= .141 + .529 * Mean glance time; R^2 = .946

Figure 23. Mean Versus Standard Deviation of Glance Time from Wierwille

In contrast to other studies, there was a slight correlation of the number of glances with the mean glance time, r=0.46 (Figure 24).




Mean glance time = .814 + .079 * Mean # glances; R^2 = .215

Figure 24. Number of Glances Versus Mean Glance Time from Wierwille

Figure 25 takes the Wierwille and Dingus tabular data and plots the number of glances versus the mean glance length in a format similar to that used by Zwahlen. (See Green, 1995 for a brief discussion.) Notice that all of the conventional tasks had glance durations below 1.2 s and all of the navigation tasks were above that level. The navigation system examined, an Etak Navigator, was a first-generation point-on-a-map system with extremely small text. At the time the study was completed, none of the subjects were likely to have had prior experience with navigation systems, though they had years of experience with conventional controls and displays. Nonetheless, this figure indicates that navigation systems go beyond the bounds of driver experience with controls and displays.

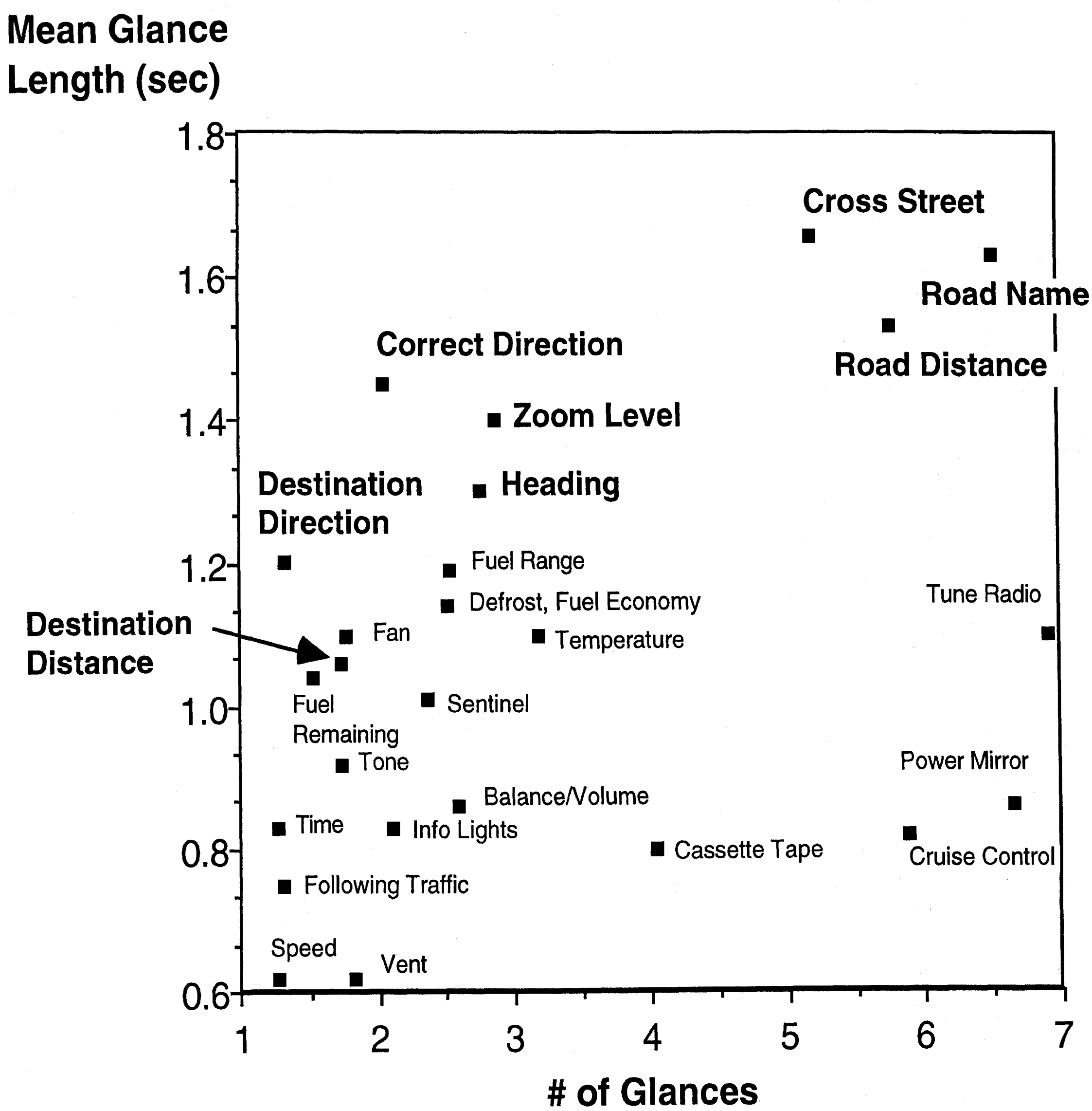
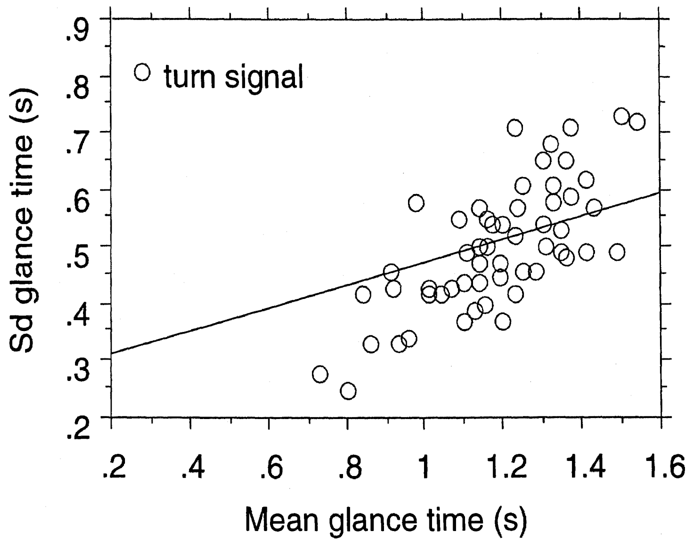



Figure 25. Glance Data from Wierwille, Antin, Dingus, and Hulse (1988)
Note: The labels in bold are navigation system functions.

### Hayes, Kurokawa, and Wierwille (1988)

This on-the-road experiment was one of the few in which task time, eye fixation, and lane-departure data were all collected and reported for 58 tasks within the same experiment. The driver sample varied in age. Following verbal instructions, drivers operated an auxiliary instrument panel that contained a 12-button telephone keypad, two AM/FM radios/cassette players, and several collections of pushbuttons and slide switches.

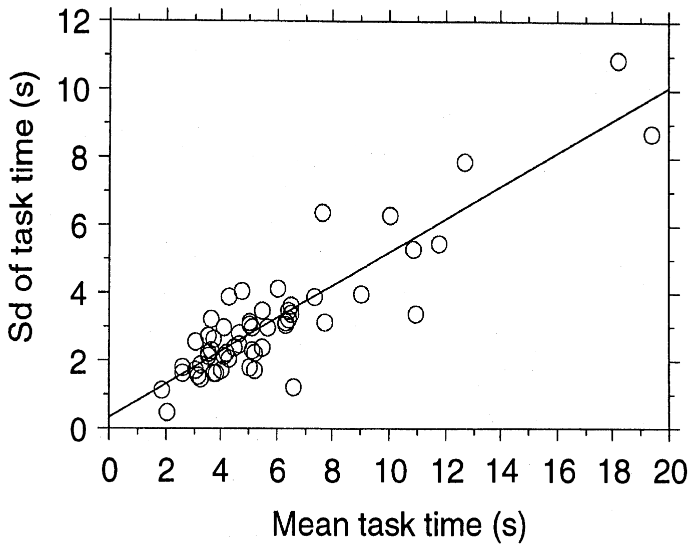
Reanalysis of those data as part of this report revealed several interesting relationships. In general, there was a moderate correlation between the mean and the standard deviation of glance time, with one outlier point, namely the turn signal (Figure 26). There were glances to that control on only some trials, hence its variability was large. (See Figure 26.) With that data point omitted, the correlation increases considerably. Data on the distribution of the individual glance durations (e.g., normal versus log normal) were not provided.




All data: Sd glance time = .273 + .199 * Mean glance time; R^2 = .137
Without turn signal: Sd glance time = .018 + .438 * Mean glance time; R^2 = .518

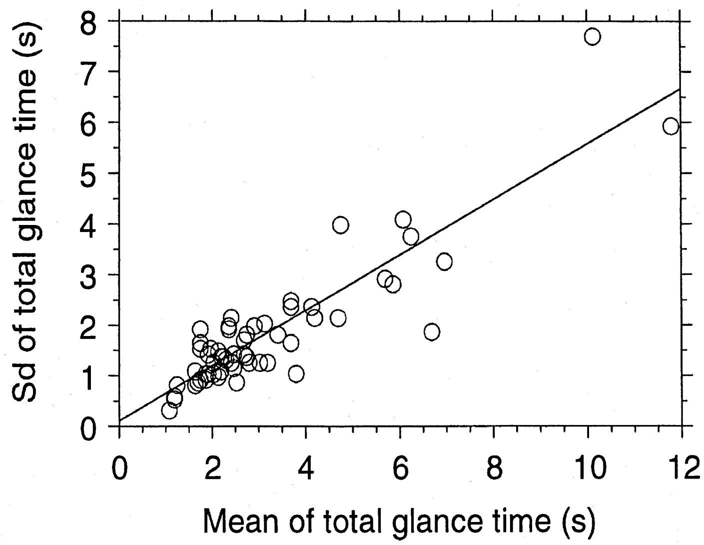
Figure 26. Mean versus Standard Deviation of Glance Time from Hayes, et al. (1988)

Similarly, the task mean time and task standard deviation were correlated as shown in Figure 27. Interestingly, the standard deviation was about 44 percent of the mean for glance time and about 49 percent of the mean for task time. For the total glance time, the standard deviation was 55 percent of the mean (Figure 28). Thus, these data suggest that as a rule of thumb the standard deviation is about half of the mean for a human performance task that take a few seconds to complete, with the fraction being larger for tasks that take more than 2-3 seconds to complete and less for tasks under that range.




Sd of task time = .316 + .49 * Mean task time; R^2 = .8

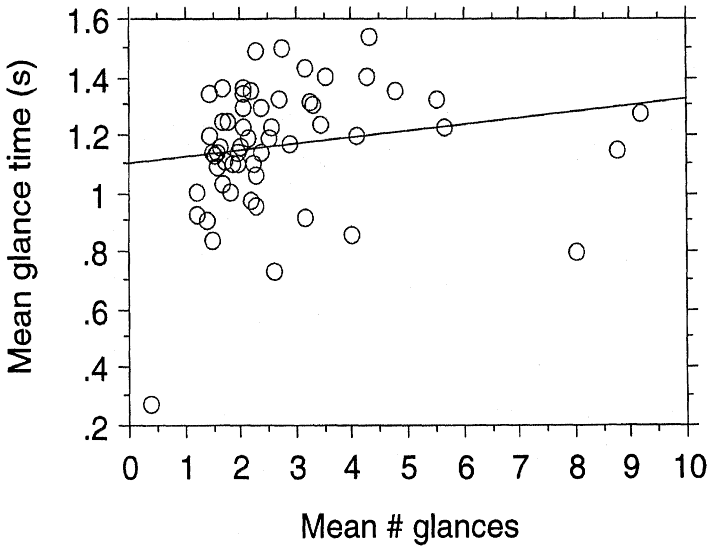
Figure 27. Mean versus Standard Deviation of Task Time from Hayes, et al. (1988)




Sd of total glance time = .119 + .546 * Mean total glance time; R^2 = .801

Figure 28. Mean versus Standard Deviation of Total Glance Time from Hayes, et al. (1988).

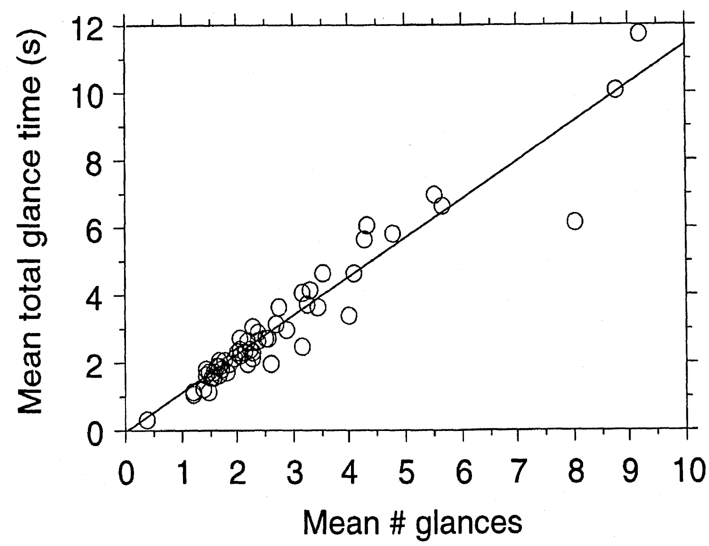
Even more useful are the relationships between the measures obtained. Figure 29 shows that the mean glance time only increases slightly with the number of glances (r=0.095).




Mean glance time = 1.105 + .022 * Mean # glances; R^2 = .032

Figure 29. Mean Number of Glances versus Mean Glance Time (Hayes, et al, 1988)

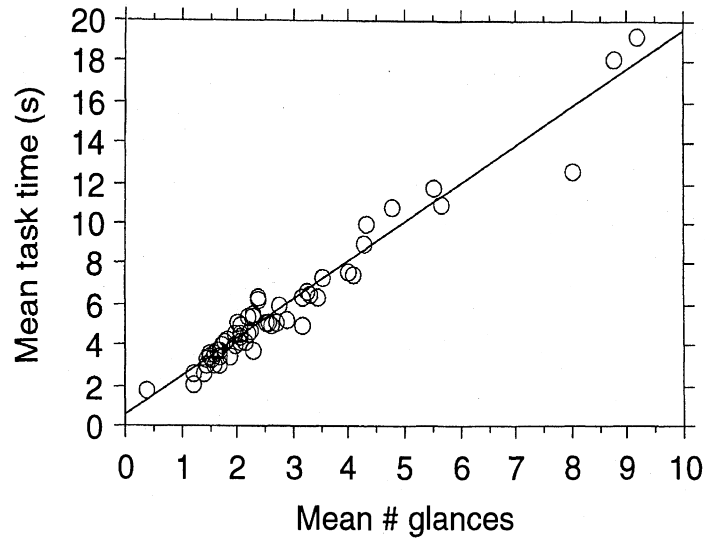
Figure 30 shows that the total glance time (total eyes-off-the-road time) can be estimated by multiplying the number of glances by 1.15.




Mean total glance time = -.063 + 1.151 * Mean # glances; R^2 = .921

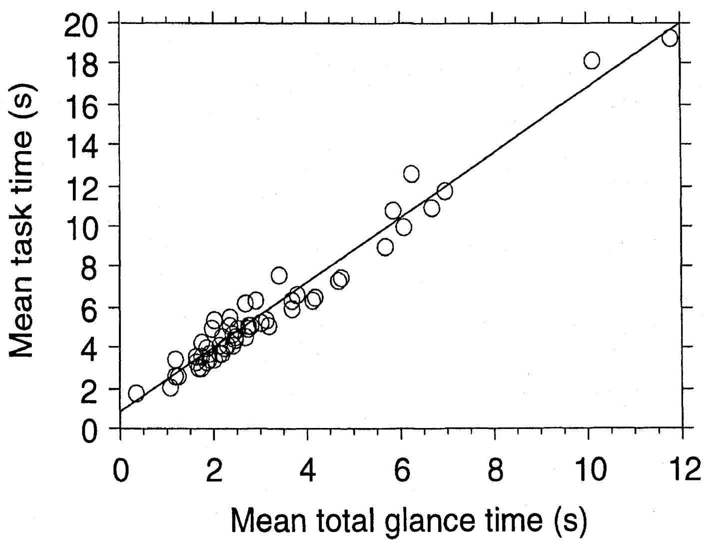
Figure 30. Relationship Between Mean Number of Glances and Total Glance Time

High correlations were also obtained between the mean number of glances and total task time (Figure 31) , and total glance time and the total task time (Figure 32). Accordingly, the total task time is approximately 1.9 times the number of glances plus 0.5. This 0.5 s is somewhat greater that the time required to transition from the road scene to inside of the vehicle and then back outside. The total task time is equal to almost 0.8 plus 1.6 times the total glance time. Hence, this says that the task time has a 60 percent overhead above the glance time. Working backwards, the number of glances is approximately half of the task mean time minus 0.1. The total glance time (eyes-off-the-road time) is approximately 0.6 times the total task time minus 0.36. These relationships are important because in many situations one might have recorded some of the measures of interest, for example task completion time, and yet need other measures, such as the number of glances or the eyes-off-road-time.




Mean task time = .505 + 1.91 * Mean # glances; R^2 = .953

Figure 31. Mean Number of Glances versus Total Task Time




Mean task time = .79 + 1.6 * Total glance time; R^2 = .962

Figure 32. Total Glance Time versus Total Task Time

Readers are reminded that these predictions are for simple instrument panel tasks, not for navigation-related tasks, such as those involving reading maps, tasks that can have much longer glance durations. They do, however, provide a starting point for creating such estimates.

### Kurokawa (1990)

In addition to summarizing Hayes, Kurokawa, and Wierwille (1988), Kurokawa (1990) examined glance and driving behavior in a driving simulator using a subset of the tasks considered by Hayes, et al. Kurokawa examined matters pertaining to the correlation of laboratory and simulator data, instrument panel clutter, and labeling in his experiments. In addition, he also developed computer software to predict eye-fixation times and task completion times for conventional instrument panel controls and displays. That software is not available to the author at the current time though there has been discussion of releasing it in conjunction with FHWA-sponsored research at Virginia Tech. However, Kurokawa (1990) contains considerable information describing the basis for predictions, and it may be possible to reconstruct the software using that document.

### Ito and Miki (1997)

As part of Ito and Miki's first experiment (described earlier), data were collected relating lateral position to total eyes-off-the-road time and maximum lateral deviation. The expression was:

Lateral deviation (mm) = 35 * (total glance time) + 94.

The correlation of the two measures was 0.75. For normal driving (with no in-vehicle task), when drivers were asked to relax, the maximum lateral deviation was 400 mm. This corresponds to a total glance time of 8.7 s. Data on the width of lanes in this experiment were not provided nor were data on the number of lane departures. However, lane width has a major impact on the lane variability that drivers are willing to accept (and on the values in this equation). Furthermore, drivers appear to have a tolerance for allowing some lane variability, adjusting their positions when lane variability becomes large. This behavior is in conflict with the assumptions of a linear model. To put the equation in perspective, for a 3.5-m lane (11.5 feet) and a 1.8-m (6 foot) wide car, the driver needs to travel 0.85 m to reach an edge marking, assuming the driver starts centered. The estimated time is 21.6 s. This number seems extremely large. For Japan a 3.5-m lane and 1.8-m car are quite large. If one assumes a 5-ft-wide (1.5 m) car and a 10-foot (3.2 m) lane, then 17.3 s elapse before a lane edge is encountered. This time seems too large.

### Nowakowski and Green (1998)

In addition to collecting data on driver comfort with tasks of varying durations, Nowakowski and Green also collected data on lane departures and speed drops as drivers performed various map reading tasks while driving on a real road. As was noted earlier, those data are noteworthy because tasks with long glance times do not commonly occur with conventional controls and displays.

Figure 33 shows the driving-error data for the third task (finding a street). A driving error occurred when the test vehicle tire touched an edge line during a trial or the speed dropped 5 mi/hr or more. Notice that the probability of a driving error increased with response time, with times over 13 s having a probability of approximately 0.5

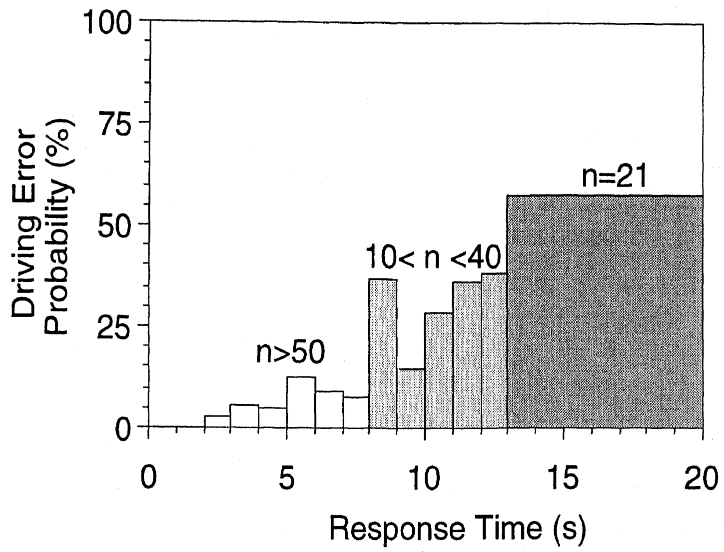



Figure 33. Probability of a Driving Error Given Response Time
(Note: n=# data points in cell.)

## Tijerina (1999)

As a follow up to the test-track study, Tijerina examined the merits of using task time as a surrogate for other measures of driving safety and in particular, the merits of specifying 15 seconds are the maximum task time allowed. The test conditions were selected to represent those being proposed for the experimental validation procedure for SAE J2364. In this experiment, there were 10 drivers, 5 men and 5 women, ages 55 to 65. They performed the same tasks as in the previous experiment using the same interfaces and tasks. Subjects were given five practice trials per task, performing the test tasks both staticly (in a parked vehicle) and dynamically (while driving, as before). There were confederate lead and following vehicles in the dynamic condition, and drivers were instructed to maintain a safe following distance (0.1 mi). Driving was on a test track at 45 mi/hr.

Using files provided by Tijerina, the author recalculated all of the key statistics and regenerated all of the key figures and those data are reported here. The values calculated are close to but not identical to those reported by Tijerina, as he did not include outliers in his analysis. As shown in Figure 34, the correlation between the static and dynamic task times for all tasks was moderate using all of Tijerina's data (r=0.60).

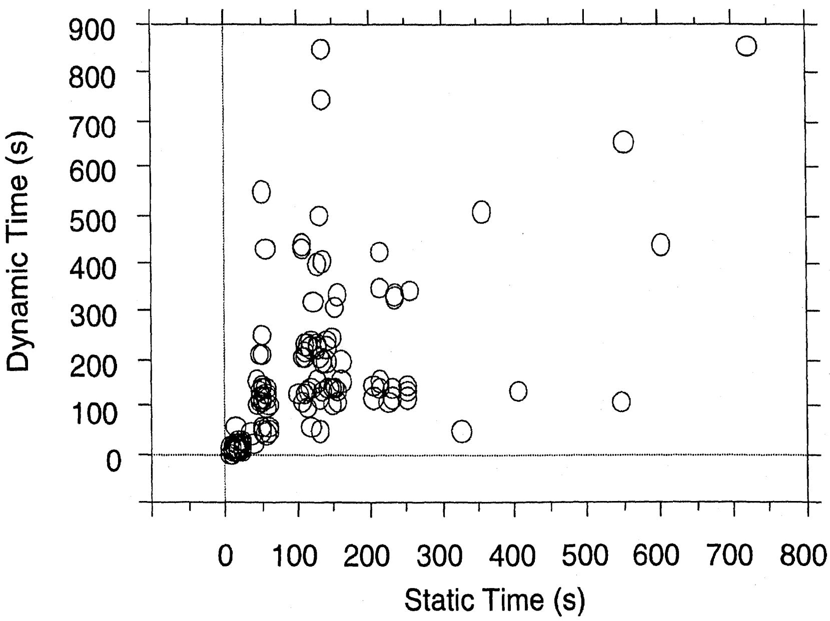



Figure 34. Static versus Dynamic Task Completion Times
dynamic.time = 64.0 + .84* static.time
dynamic.time = 1.12* static.time (forced zero)

Interestingly, in generating a regression expression, Tijerina allowed for a nonzero intercept, which was significantly different from zero in the regression model. One could argue that theoretically a task that takes zero static time should take zero dynamic time and the intercept should be forced through zero. However, one could also theorize that there is an overhead for planning and executing the dynamic task, and hence a nonzero intercept makes sense. The forced zero regression model suggests dynamic times are 12 percent greater than the static times. The issue of a forced zero intercept is most important for predicting performance of tasks of short duration (e.g., those with static completion times of 15 seconds).

One of the concerns with the original data was that it included telephone tasks and voice-navigation-system tasks (with low visual demand) and radio-related tasks (that are extremely brief). Accordingly, the data have been replotted using only the results from the navigation interfaces with visual displays and manual controls (Alpine, Delco, Zexel) and shown in Figure 35. That modification reduces the correlation to 0.50 in the unconstrained case. When a zero intercept is required, the dynamic times are 26 percent greater than the static. With regard to consideration of the 15-second rule, the minimum static task time for any of the 10 subjects on any of the three interfaces was 33 seconds.

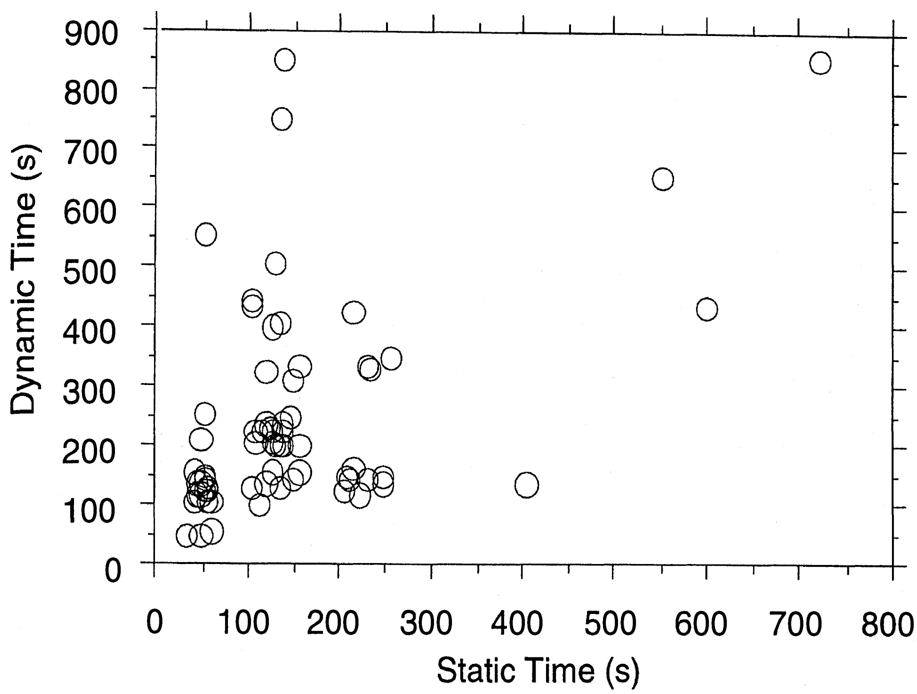



Figure 35. Static versus Dynamic Task Times - Visual/Manual Navigation Interfaces

dynamic.time = 139.3 + 0.70 * static.time
dynamic.time = 1.26* static.time

One of the purposes of Tijerina's work was to determine how well static task times serve as a surrogate for dynamic task times, a measure shown elsewhere in this report to be highly correlated with eyes-off-the road time. Tijerina was also interested in the relationship between static task times and lane departures, a safety-relevant measure (Figure 36). Allowing for a nonzero intercept, the correlations between the two were 0.57 using all the data and 0.61 using only the navigation data. Figure 37 shows the results for the navigation interfaces only. Readers should bear in mind that these correlations involve times from individual trials, not mean times, so the correlations are expected to be low. Furthermore, the lane-departure data are ordinal, adding noise to that variable. As a quick estimate, the number of lane departures is approximately .02 times the static task time overall, 0.03 times the static task time for navigation interfaces.

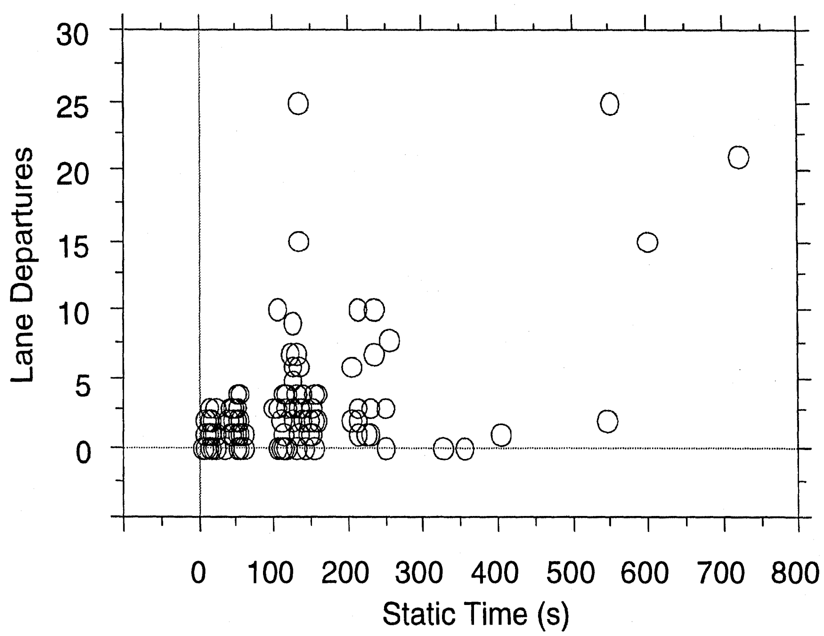



Figure 36. Lane Departures versus Static Task Times

# lane departures = 0.34 + 0.20*static time
#. lane departures = 0.022*static time (forced zero)

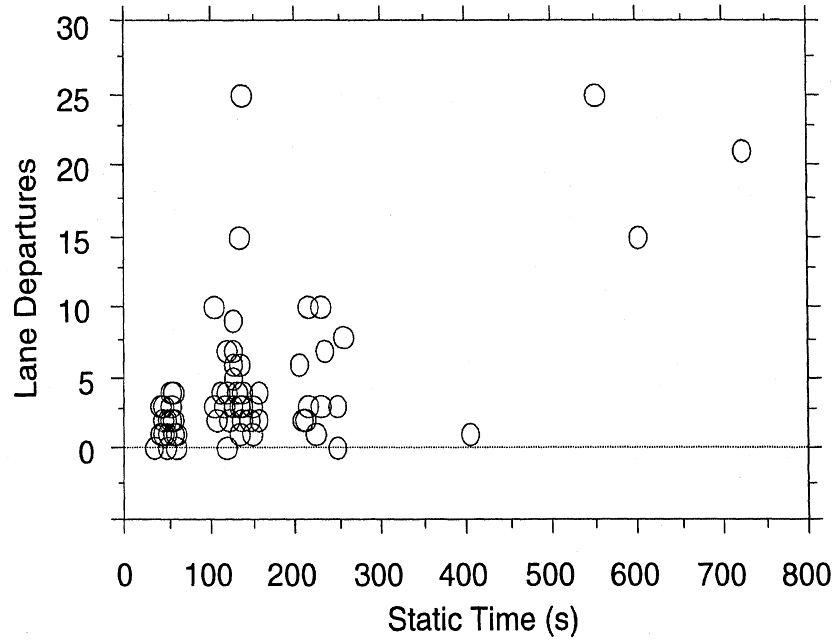



Figure 37. Lane Departures versus Static Task Times - Visual/Manual Navigation Interfaces
# lane departures = 0.72 + 0.025*static time
# lane departures = 0.028*static time (forced zero)

Tijerina was also interested in the relationship between dynamic task times and lane departures, a safety-relevant measure. Figure 38 shows all data. Figure 39 shows the results for navigation visual/manual interfaces only. Without a forced intercept, the correlations were 0.80 for all data and 0.85 for the visual/manual navigation interfaces only. These correlations are greater than those between lane departures and static task times.

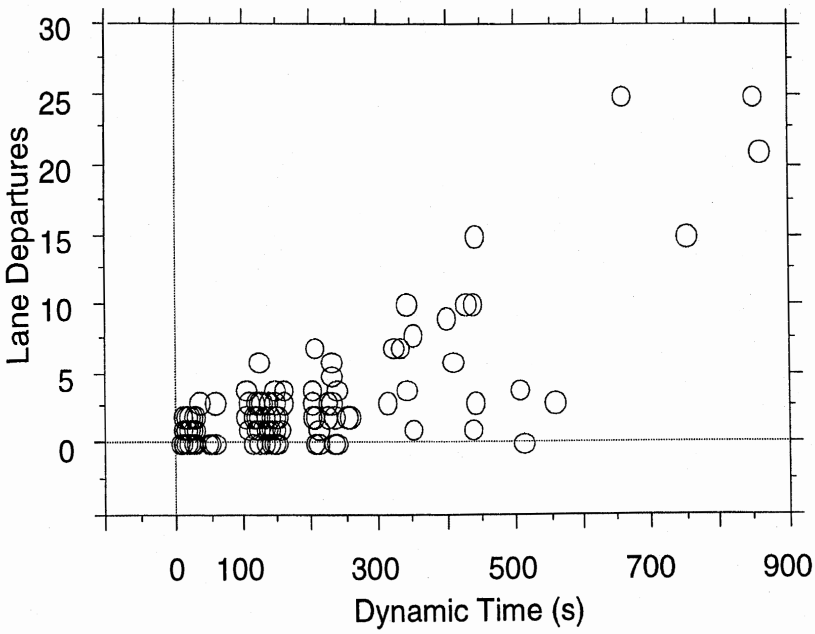



Figure 38. Lane Departures versus Dynamic Task Times
# lane departures = 0.60 + 0.02*dynamic time
# lane departures = 0.018*dynamic time

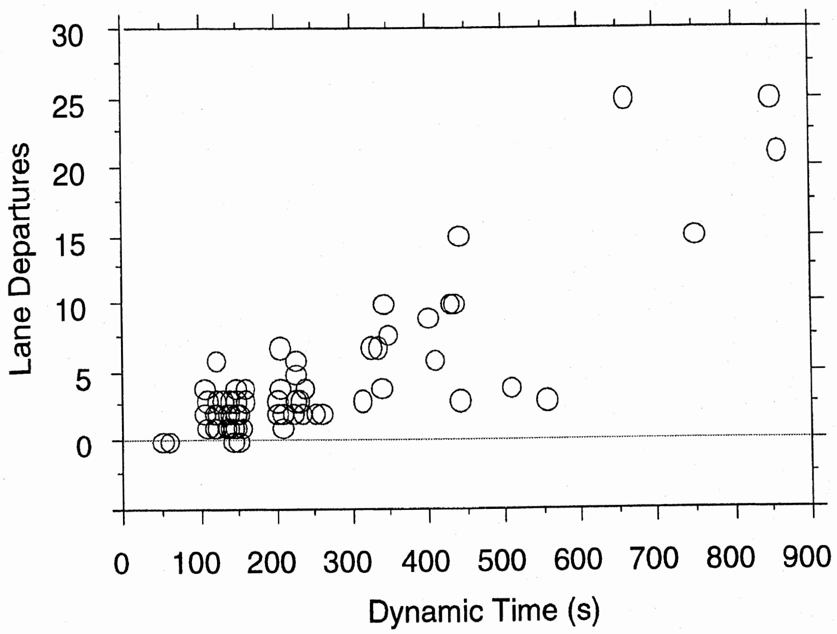


Figure 39. Lane Departures versus Dynamic Task Times - Visual/Manual Navigation Interfaces
# lane departures = -1.59 + 0.025*dynamic time
# lane departures = 0.021*dynamic time

Finally, one might theorize that the number of lane departures was disproportionately larger for long dynamic tasks times when a safety threshold was exceeded. One could read a slight curvilinear trend into Figures 38 and 39, with the number of lane departures increasing with some power of dynamic time. Using the data in those figures as a test case, correlations between powers of dynamic task time and the number of lane departures were examined (Table 38). Treating dynamic time as a power function led to only minor improvements in the correlation. This makes determining a safety-related limit based on lane departures (or static or dynamic task times, both correlated with lane departures) a challenge, as there is not point at which the number of lane departures increases dramatically.

Table 38. Correlations of number of lane departures with (dynamic time)^^power

| power | 1.0 | 1.2 | 1.5 | 2.0 |
|---|---|---|---|---|
| correlation | 0.848 | 0.856 | 0.863 | 0.861 |

## Summary

1. The relationship between glance behavior, lane departures, and speed drops has received some attention in the literature. Further studies examining these relationships are needed. In particular, the influences of road type, speed driven, and traffic, along with driver age should be considered.

2. According to the Wierwille and Dingus data, the number of departures is approximately equal to:

   1.3 * total glance time
   3 .6 * mean glance time + .025
   2.2 * # glances - 2
   0.8 * task time - 0.15.

   How the task time is measured (from when the eyes leave the road or from when the subject is seen to begin) has virtually no impact on the relationship.

3. The standard deviations of most times are about half of their means (glance time, total glance time, task time.)

4. Even more importantly, glance duration seems to vary very little with the number of glances needed to complete a task. Therefore,

   the total glance time = 1.15 * the number of glances
   mean task time + 1.91 * the number of glances +0.5
   mean task time = 1.6 * total glance time + 0.8

5. According to Tijerina's data, the number of lane departures is approximately equal to:
   0.20 * static task time + 0.34 (about 0.22 * static time) for all interfaces and
   0.025 * static task time + 0.72 (about 0.28 * static time) for navigation interfaces

   0.20 * dynamic task time + 0.60 (about 0.18 * dynamic time) for all interfaces and
   0.25 * dynamic task time + 1.59 (about 0.21 * dynamic time) for navigation interfaces

6. According to Tijerina, dynamic and static time are correlated where dynamic time equals:
   0.84 static time + 64 (about 12 percent greater) for all interfaces and
   0.70 * static time + 139 (about 26 percent greater) for navigation interfaces

7. The number of lane departures can be viewed to show a step increase from zero when more than 2 to 2.5 glances are required.

8. Based on the results of Ito and Miki, drivers are likely to begin to reach edge lines of a typical road when total glance times are 15 to 20 s, a value that seems unreasonably large.

9. According to Nowakowski and Green, the probability of a driving error (large speed drop or a lane departure) is about 0.5 for tasks with response times of approximately 13 s or greater.

## DESIGN GUIDELINES

### Question 11. What do existing guidelines require concerning the use of navigation systems in a moving vehicle?

**Rationale:** Human factors guidelines represent accepted advice on how systems should be designed to make them safe and easy to use and, therefore represent a starting point for future guidelines. To varying degrees, human factors experts and the literature were consulted as part of the process of developing those guidelines, so there is some basis for them.

There are five key guidelines that identify specific current legal and quasi-legal requirements for the design of navigation and related information systems: (1) the HARDIE guidelines, (2) the BSI draft guidelines, (3) the UMTRI guidelines, (4) the Battelle guidelines, and (5) the JAMA guidelines. Reflecting the level of knowledge available when they were drafted, several of these documents emphasize principles over specific design requirements, though several contain detailed requirements concerning the format of information on maps. These documents were developed concurrently and for the most part independently. Consequently, there was little cross referencing between these first sets of guidelines. In this section, information concerning what should be displayed is described, even though the recommended practice being produced emphasizes use of controls, to provide a sense of the focus of existing guidelines.

In addition to these specific documents is the evolving European Statement of Principles on Human Machine Interface for In-Vehicle Information and Communication Systems (European Commission, 1998). These 35 principles are extremely general. ("2.3.1 Visually display information should be such that the driver can assimilate it with a few glances which are brief enough not to adversely affect driving. 2.4.3 The system should not require long and uninterruptable sequences of interactions.") To a large degree, the material following in this report attempts to associate values with those two statements.

In addition to these specific requirements, the Japanese Ministry of Transport (http://www.motnet.go.jp/index.htm) has published reminders on its home page regarding navigation system functions (Tsuda and Fukumura, 1998). Those warnings state the navigation system should be operated when the vehicle is stopped and the time staring at the screen should be limited to a minimum (1 second or less).

### HARDIE Guidelines

The HARDIE guidelines (Ross, Vaughn, Engert, Peters, Burnett, and May, 1995) emphasize the presentation of information to drivers and were not intended to consider the input of information, though there is a requirement that a manual zoom should not be available while driving. The guidelines contain a mixture of general (e.g., "systems should include landmarks, paths, and node information," Ross, Vaughn, Engert, Peters, Burnett, and May, 1995, p. 4) and specific requirements. The guidelines also provide information on auditory messages and the visual characteristics of text. Table 39 lists the more important specific prohibitions and requirements. Notice the inconsistency between the first and third items in the table.

Table 39. Specific Requirements and Prohibitions of the HARDIE Guidelines

| Prohibition | Page |
|---|---|
| "Whilst driving, drivers should not be expected to process complex information to obtain the desired route, i.e., the systems should not display a map with a highlighted route." | 1 |
| "Ideally, a map should not be displayed to the driver whilst in motion. If this is deemed to be necessary, then the map information should not be the main source of information at each maneuver, i.e., the map information should be supplemented or replaced by turn-by-turn information specific to that manoeuvre." | 30 |
| "When a map is shown whilst in motion, the information content of the map should be as simple as possible. A suggested maximum amount of information is: current location, destination, highlighted route, name of current road, name of destination road." | 30 |
| "The number of names presented on a display should be limited to 2 or 3." | 34 |
| "Whilst driving, the driver should not be required to manually zoom in and out to different scale levels. Instead, the system should automatically present the optimum amount of usable information." | 36 |
| "On a guidance display, use of text should be limited to street names (or directions relating to relevant road signs) and distance." | 50 |

## BSI Guidelines

The British Standards Institution (1996) Guidelines (DD235: 1996) represents another European attempt to specify what should be allowed when a vehicle is in motion. For the most part, this draft regulation is fairly general in its requirements. Examples appear in Table 40. Many of the standards requirements concern classical human engineering issues--legibility, control placement, etc.--along with the design process.

Table 40. Example General Requirements of the BSI Draft Guidelines

| Statement | Section |
|---|---|
| "The system should be designed so that it does not unduly distract the driver, nor give rise to potentially hazardous driving behaviour by the driver or other road users." | 2.1.2 |
| "Displays should not aim to visually entertain the driver." | 2.2.1 |
| "Route information should be given sufficiently in advance of the manoeuver for it to be accomplished safely." | 2.2.9 |

The BSI guidelines do contain a few very specific requirements pertaining to what a driver should be able to do while a vehicle is in motion. The key statement is in section 2.2.1 shown below. The Figure 6 referred to in that statement is their implementation of the Zwahlen diagram, shown here as Figure 40. The term "look" used in the figure that follows is not defined and is presumed to mean a glance, not a fixation.

> "Visual display information should be such that (sic) a driver can assimilate it at a glance which is brief enough not to affect driving, see figure 6. For example a glance lasting not more than 2 s has been proposed as a reference in less visually demanding conditions (e.g., a straight motorway with little traffic and good visibility)."

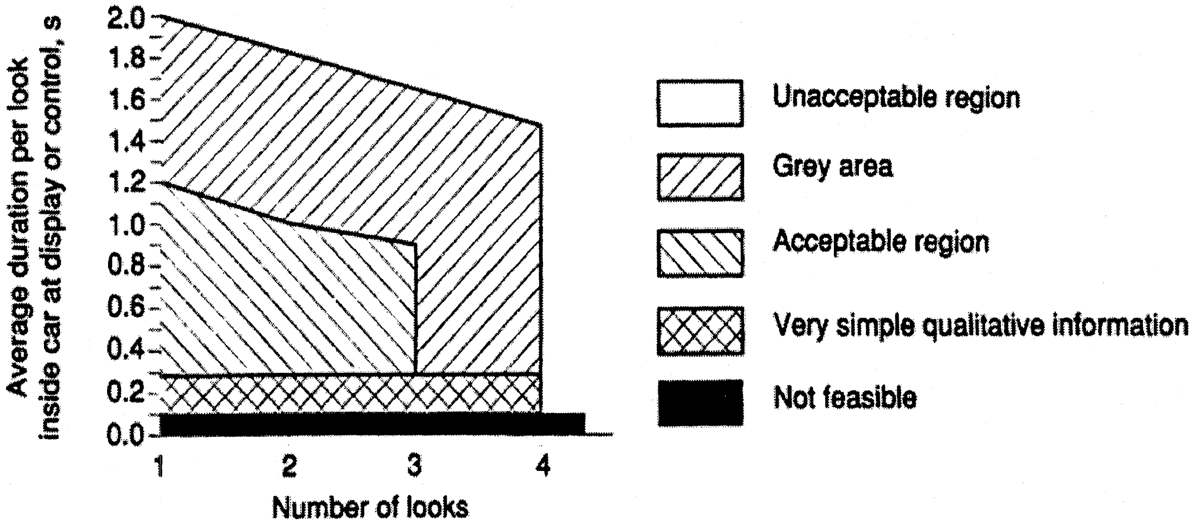



Figure 40. BSI Interpretation of the Zwahlen Diagram
Source: British Standards Institution, 1996, p. 22

These requirements are clarified in section 3.6 (assessment of the system).

> "There is not a single performance level available yet that denotes 'good usability,' nor is there one which describes an accepted safe and valid level of performance. However, 2.2.11 recommends that the driver is able to assimilate visually displayed information with glances of less than 2 s."

It is believed the 2 s limit is from Zwahlen's research though some of Rockwell's described later mentions a 2 s limit.

## UMTRI Guidelines

The UMTRI Guidelines (Green, Levison, Paelke, and Serafin, 1995) were the first set of U.S. guidelines that concerned the design of in-vehicle information systems. Contained in those guidelines are nine general design principles (e.g., "Be consistent," "Arrange controls and displays so they follow the flow of reading: left to right, and top to bottom"), 10 general guidelines for manual controls (e.g., "Eliminate the need for manual user input while driving," "Put controls within easy reach,"), and 30 specific guidelines for navigation visual displays ("Views of intersections should be plan (directly overhead) or aerial (as from a low flying airplane), but not perspective (from the driver's eye view)," "For expressway ramps, give both the route name and direction, and a city locator."). Also included in the UMTRI document were specific guidelines as to which entry tasks a driver undertakes while vehicle is in motion (Table 41). Many of the allowed tasks involve only a single switch action.

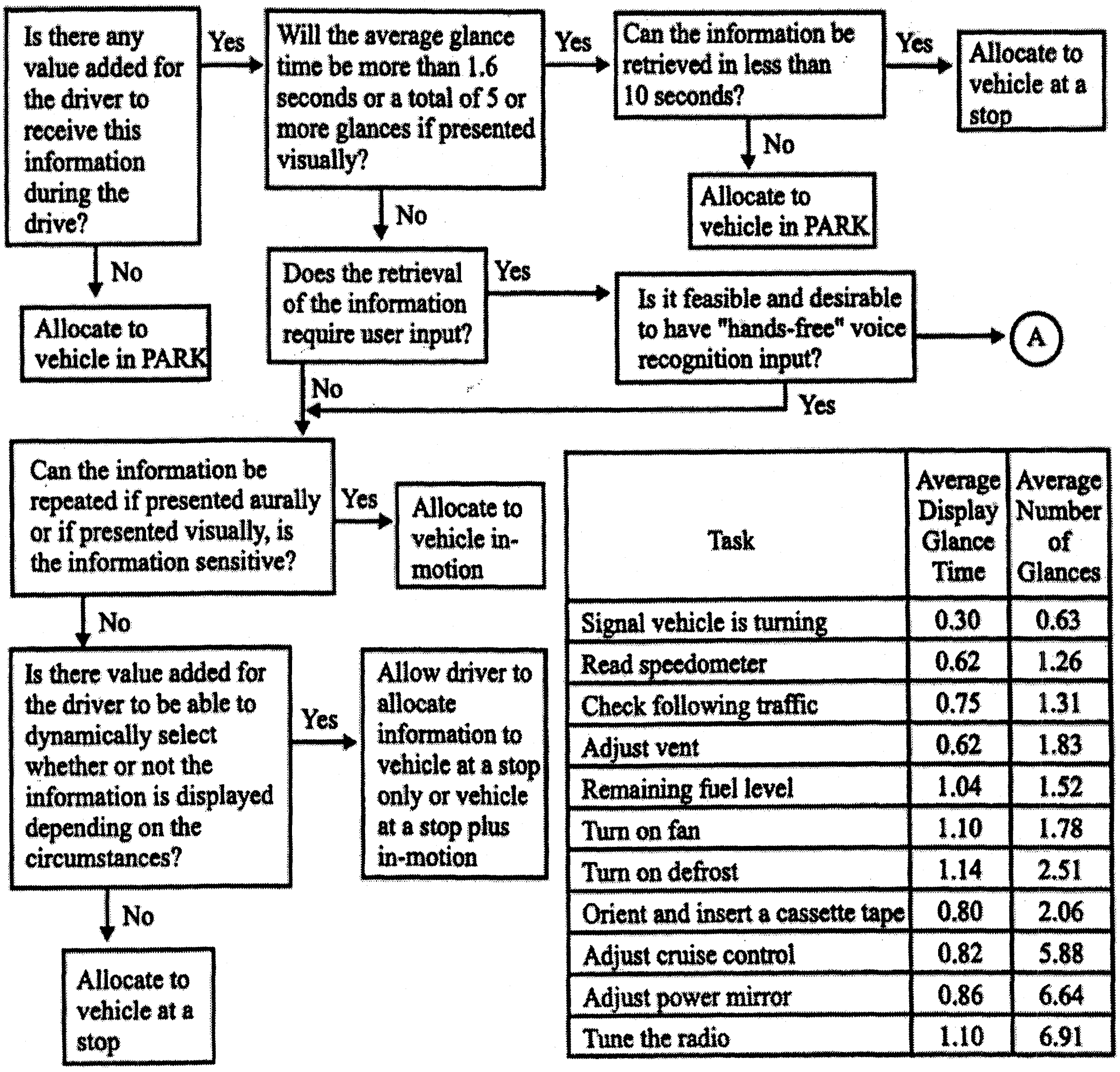
Table 41. Allowed Input Tasks in UMTRI Guidelines

| When Allowed | Task |
|---|---|
| while moving (or at other times) | display brightness and contrast adjustment |
| | voice volume |
| | repeat last voice message |
| | zoom in/zoom out |
| | "route hop" (resetting the navigation system when the known and displayed positions differ |
| | declutter (show fewer map details) |
| | switch between turn display and overview map |
| zero speed (e.g. stopped at traffic light) or predrive | map scrolling (may be possible while moving) |
| | switch between north up and heading up display (may be possible while moving) |
| Predrive (when the vehicle is in park) | destination entry |
| | accessing business listings (yellow pages) |
| | setting voice (male vs. female voice, etc.) and infrequently used system options |
| | system calibration such as setting the compass |

These guidelines were based on accepted practice and the extent to which tasks would interfere with driving, which was primarily a function of task duration. The distinction between the zero speed and predrive tasks is that the predrive tasks take longer to complete and may take longer than the portion of a traffic signal cycle that is normally available, thus interfering with traffic flow as the driver delay moving to complete the task. Tasks may be assigned to higher risk categories if the alternative, either stopping or placing the car in park, depending on the task, presented greater risk to the driver. (For data on performing the predrive tasks using a TravTek interface, see Dingus, Hulse, Krage, Szczublewski, and Berry, 1991. Most of the tasks allowed while moving were accessed directly (a single switch action) when the top level navigation screen was shown.

### Battelle Guidelines

The Battelle Guidelines (Campbell, Carney, and Kantowitz, 1997), originally planned as an enhancement of the UMTRI Guidelines, provide quite detailed coverage of in trucks and buses, warnings, and display legibility. Section 12 of the guidelines provides rules (Trip Status Allocation Design Tool, Figure 41) as to when features should be operable (in motion, stopped, in park). These rules are based on the analysis of Hulse, Dingus, Mollenhauer, Liu, Jahns, Brown and McKinney (1993), who in turn cite work by French (1990) as the supporting source. However, French (1990) refers to typical glance time data from Labiale (1989) as well as a report he co-authored with Zwahlen (Parviainen, French, and Zwahlen, 1988). The 1988 report, page 88, states the following: "One possible design guide to be used when designing a visual display is presented in Exhibit 18" (Figure 42). "The graph is based upon the work of Senders et al (Ref 119), Zwahlen (1979 Tunnel Study), and Zwahlen (1985 RRPM Study). Note however that these value are for very undemanding driving situations only (tangent sections/very light traffic/90 km/h) and would have to be modified to consider more stressful driving situations (such as curve driving or heavy traffic)." A figure label indicates the speed is 55 mi/hr.




| Task | Average Display Glance Time | Average Number of Glances |
|---|---|---|
| Signal vehicle is turning | 0.30 | 0.63 |
| Read speedometer | 0.62 | 1.26 |
| Check following traffic | 0.75 | 1.31 |
| Adjust vent | 0.62 | 1.83 |
| Remaining fuel level | 1.04 | 1.52 |
| Turn on fan | 1.10 | 1.78 |
| Turn on defrost | 1.14 | 2.51 |
| Orient and insert a cassette tape | 0.80 | 2.06 |
| Adjust cruise control | 0.82 | 5.88 |
| Adjust power mirror | 0.86 | 6.64 |
| Tune the radio | 1.10 | 6.91 |

Figure 41. Rules for Deciding What a Driver Can Do While a Vehicle Is in Motion
Source: Campbell, Carney, and Kantowitz, 1997, p. 15-4, 15-5

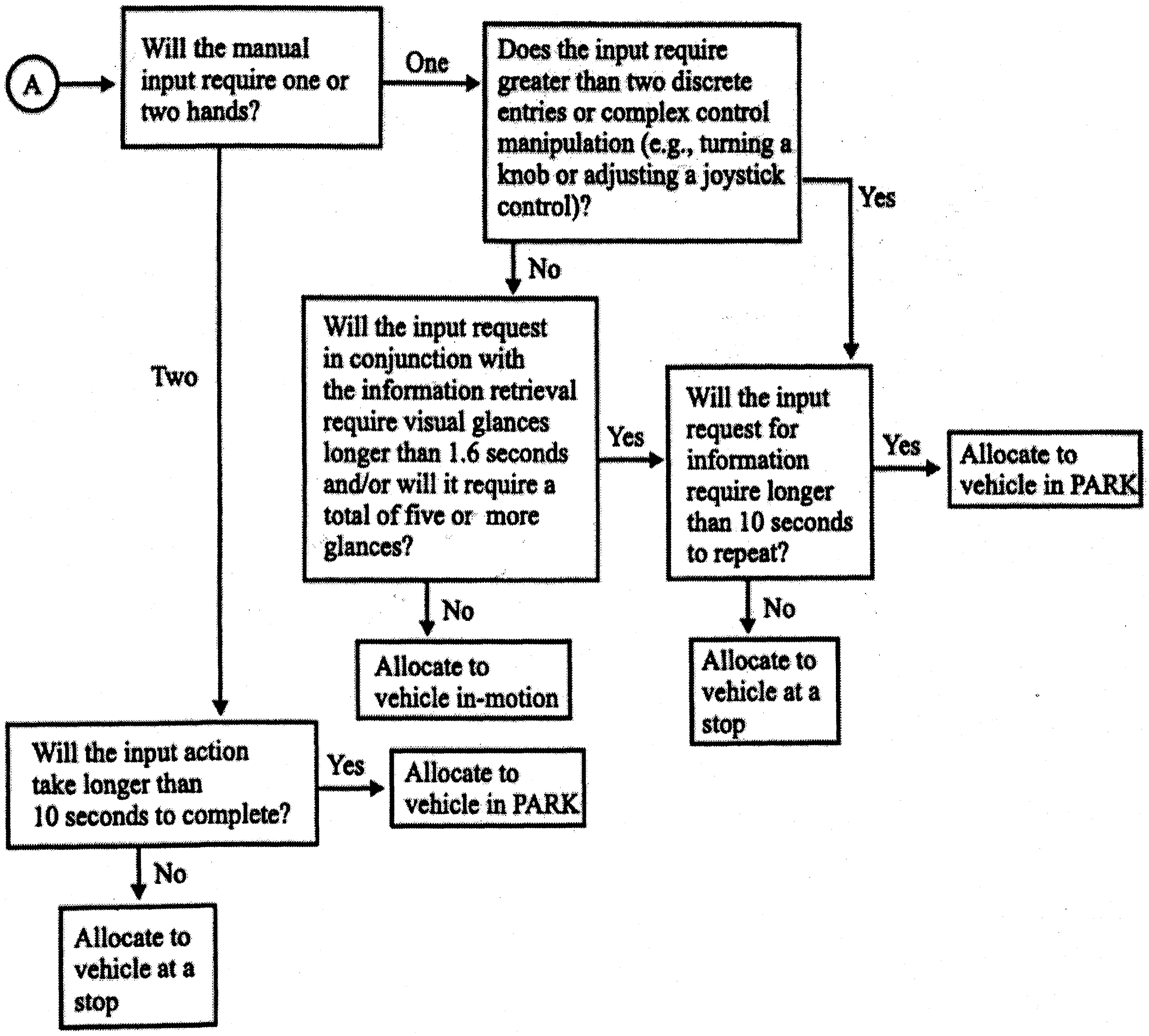



Figure 41. Rules for Deciding What a Driver Can Do While a Vehicle Is in Motion (continued)

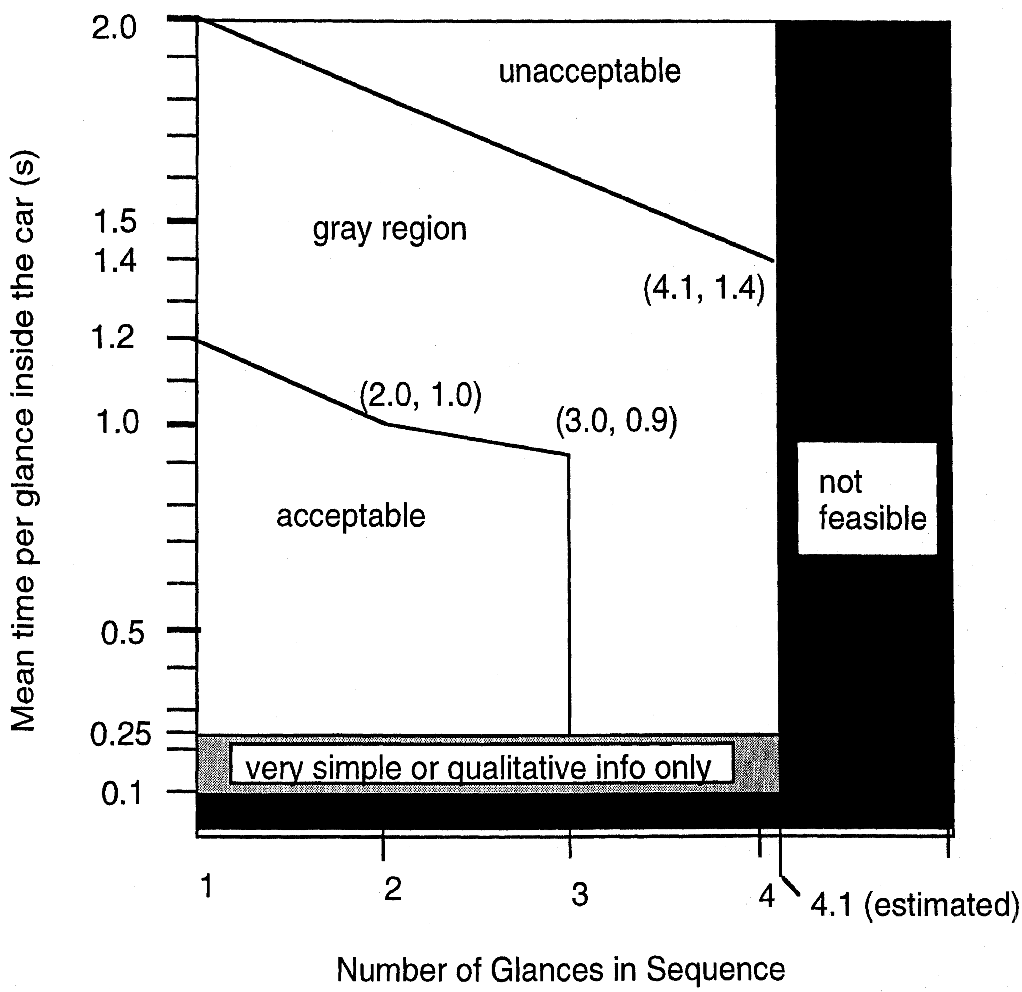



Figure 42. Zwahlen's 1988 Recommendations (Redrawn), p. 89

In brief, Battelle indicates that tasks carried out while the vehicle is in motion should be (1) of added value if received while driving, (2) have average glance times of less than 1.6 s and require five or more glances, (3) not be implemented as a voice input, (4) not require more than two discrete entries or complex control actions (e.g., turning a knob or using a joystick), and (5) require 10 s or less to complete. Further, the displayed information should be repeatable if provided aurally or "sensitive" if presented visually. Sensitive is not defined but probably refers to time sensitive.

In addition, section 7 specifically describes what information could be available while a vehicle is in motion (Table 42) and what could be available while the vehicle is in "park." Interestingly, the Battelle Guidelines indicate that rerouting options and mileage to a destination should be presented when a vehicle is in park.

Table 42. Information That Could Be Available While the Vehicle Is in Motion

| Item | Page |
|---|---|
| notification the driver is off route | 7-24 |
| vehicle's current position | 7-24 |
| suggested procedure for getting back on route | 7-24 |
| distance to next turn | 7-26 |
| name of street to turn on | 7-26 |
| lane suggestion for next turn | 7-26 |
| direction of turn | 7-26 |
| name of current street | 7-26 |
| when vehicle needs to get into lane for turn or exit | 7-28 |
| maximum speed for negotiating exit ramp safely | 7-28 |
| distance to toll booth | 7-30 |
| cost of toll | 7-30 |
| remaining balance in toll account | 7-30 |
| number of tolls to be paid on route | 7-30 |
| notice toll was charged | 7-30 |
| notification of incidents | 7-32 |
| description of incidents | 7-32 |

## JAMA Regulation

The JAMA standard is the only one in existence that provides specific requirements for the design or operation of navigation or related in-vehicle information systems in Japan (Ito and Miki, 1997; Takaishi, 1997), and is far more restrictive than the other guidelines listed previously. While the guidelines seem reasonable, there is no supporting documentation explaining the empirical basis for each guideline, including general references to previous research. That should not be meant to imply, however, such evidence was not considered when the guideline was developed. The research supported under the VICS program (described elsewhere) served as this basis.

The Japanese National Police Agency has been promoting the JAMA regulation as "voluntary guidance." While this regulation does not have the same impact as a statutory law, manufacturers are nonetheless strongly "encouraged" to follow the regulation, and a consequence, compliance is widespread (Takaishi, 1997).

The JAMA guideline applies to "picture display equipment" installed in motor vehicles and which is visible to the driver. The prohibited display features are listed in Table 43 with translations differing as to whether the coverage is "when the car is running" (when the engine is on) or "while driving" (when the vehicle is in motion). The driver must be able to comprehend the information "quickly"/"in a short time" with the specifics being undefined. Note that the constraint on message length assumes a mix of English, traditional Japanese, and Chinese characters, all of differing information content. Namba (1980) and Fukuda (1992a,b) deal with this problem by converting the information conveyed by each character into bits. This literature will be reviewed in a report concerning the implementation of the proposed standard.

Table 43. Display Features Prohibited by JAMA

| Prohibited Display Feature | Article |
|---|---|
| showing roads narrower than 5.5 m wide in urban areas unless they are important to traffic flow or are on the route | 3.1, 6.2, 6.3 |
| scrolling to show location updates that result in confusion | 3.1 |
| images of television broadcasts or video playback | 3.2 |
| phone numbers and addresses as guiding information | 3.3 |
| introductions to restaurants and hotels, though pictures showing their location may be presented | 3.4 |
| traffic jam information that is not optimized | 3.5 |
| warnings that are not discernible from other information | 3.5 |
| travel time displays that require complex calculations by the driver | 3.5 |
| scrolling characters | 3.5 |
| messages longer than 31 characters (Kanji, Katakana, alphanumeric) excluding punctuation and units | 3.5 |

Some of the prohibitions may be the result of navigation problems unique to Japan. For example, the prohibition of phone numbers and addresses as guiding information may reflect problems in using the number field from a street address as guidance since buildings numbered chronologically, not spatially, in Japan. Providing the phone number will encourage drivers to call for terminal guidance, an undesired situation while driving (Scott, 1998).

Complex switch operations (Table 44) are also prohibited.

Table 44. Prohibited Control Operations (Article 4)

| |
|---|
| setting or revising a destination using a cursor |
| scrolling of maps |
| selection of different area maps |
| manipulation of cellular phone keys |
| input of addresses and other information |
| search of addresses, phone numbers, restaurants, hotels, etc. |
| selection of information indicated by dynamic information |
| scrolling of dynamic information |

## Summary

Table 45 summarizes the main requirements from each set of guidelines as to what is not allowed while the vehicle is in motion. The BSI and Battelle guidelines provide a computational solution, though they differ in the specifics (glances less than 2 s versus 1.6, etc.). The other guidelines, especially the JAMA guidelines, provide specific prohibitions. At this point, the overwhelming majority of systems produced to date have been sold in Japan. Due to the nature of Japanese culture, systems sold in Japan should comply with this "suggested" guideline, and depending on market demands, derivative products developed for other markets may be in compliance.

Table 45. Summary of Existing Guidelines

| Guideline | Key Specifications | Comments |
|---|---|---|
| HARDIE (1995) | • drivers are not expected to process complex information<br>• no manual zoom | • research recommendations<br>• focus is on displays |
| BSI (1996) | • no glances should exceed 2 s<br>• presents Zwahlen diagram | • draft for discussion |
| UMTRI (1995) | • allowed controls: brightness, contrast, volume, repeat voice message, zoom, route hop, declutter, turn/map mode switch<br>• destination entry is predrive<br>• list of items displayable while in motion | • preliminary recommendations<br>• guidelines for interfaces rely on accepted practice |
| Battelle (1997) | • task allowed if: (1) added value while driving, (2) mean glance time <1.6 s, (3) less than 5 glances needed, (4) not implementable as voice, (5) 2 or fewer control actions, (6) completed in 10 s or less<br>• list of items displayable while in motion | • recommendations only<br>• research rationale mentioned |
| JAMA (1996) | • very specific list of what can be shown (e.g., no small roads, no TV, no scrolling characters, no message >31 characters) or accomplished (no map scrolling, no address search, no cursor selection of destination) | • quasi-legal requirement<br>• no supporting research documents with rationale listed (but requirements seem reasonable)<br>• based on Japanese driving conditions |

## CONCLUSIONS

Drafting of the SAE Recommended Practice (J2364) for navigation tasks proceeded in parallel with the development of this report, with drafts of this report being available prior to the initial draft of the standard. As the standard evolved, emphasis shifted from measuring glance behavior to measuring task time for practical reasons, a shift that is supported by the literature.

To determine what drivers should not be allowed to do in a moving vehicle with a navigation system, 11 questions were considered. In reviewing the evidence pertaining to those questions, the quality of the data collected, the applicability of the data, and consistencies among studies were considered. Although the body of literature is considerable, the number of studies specifically concerning navigation-system data entry is limited, in part because the product is so new and in part because the issue is so specific. However, the evidence available is sufficient to develop a recommended practice, though certainly a second-generation practice would benefit from additional research on this topic.

The questions addressed concern crashes and the visual demands of driving, destination designation and driving performance, typical glance behavior and preferences for glance duration, ratings of comfort and safety, prediction of lane departures, and existing guidelines and regulations. Abbreviated responses to each question follows.

### Questions 1 & 2: Have navigation systems been a causal factor in crashes?

There is very little crash data on navigation-system-induced crashes. Navigation-system-use is coded in only one crash data base, and except for Japan, the installation rate is extremely low. For the first six months of 1998, the first time period for which data was collected, the Japanese National Police Agency reported there was one fatality and 58 injuries associated with navigation-system use. Although the number is low and less than that for cell phones, the values reported are not zero and will grow as market penetration increases. Given their relative size and the half year reporting period, approximately eight fatalities and 344 injuries would be expected in the United States per year at similar levels of market penetration and use. As a reminder, all Japanese OEMs do not allow destination entry and other complex tasks in a moving vehicle, so the fatalities and injuries reported are most likely from aftermarket products. Had the regulations not been in place, more fatalities and injuries would be expected.

### Question 3: What is the relationship between visual demand and crashes?

Time spent looking inside the vehicle is not spent looking at the road for potential crash-inducing hazards. Using regression analysis, Wierwille developed an equation to predict the number of involvements in crashes in North Carolina based on narratives of police reports of crashes. Since crash statistics for North Carolina are representative of the United States, they can be used to provide estimates of the number of fatalities in the U.S. for future years. The resulting expression is as follows:

# U.S. deaths in year x = growth.rate.in.VMT* (year.x-1989) *
market.penetration.rate*
-.133 + .0447 (mean glance t)$^{1.5}$ (# of glances) (frequency)

Based on published data, assumptions were made concerning market penetration (10 in the year 2007, destinations entered (2 per week), and glances per destination entered (27.5). Accordingly, without constraints on tasks performed in moving vehicles, 21.1 fatalities are expected in 2007 from entering destinations. Using the rule of thumb of 100 injuries per crash fatality, approximately 2110 navigation-system-induced injuries are expected in that year. Readers are reminded that these are only estimates. Nonetheless, there is reason for concern. The number of fatalities and injuries is well above those that might be attributed to conventional controls and displays. However, because the relationship between visual demand and fatalities is linear, there is not a point at which fatalities dramatically increase, suggesting a threshold value.

**Questions 4 and 5: How long does the input and retrieval of destinations take, and do those tasks degrade driving performance?**

Operating a navigation system should not be so time consuming that it interferes with drivers staying in their lanes, maintaining speed, searching for potential hazards, or performing other tasks they need to do to avoid crashes. The only studies examining driving and navigation-system use are two experiments conducted by Tijerina on a test track. These studies were conducted in simulated traffic in real vehicles by drivers with a moderate level of training with the device. In those studies, using interfaces with manual controls and visual displays, destinations took 1 to 2.5 minutes to enter, with POI tasks taking about 10 percent longer than tasks using the street address or intersection method. In contrast, destination-retrieval tasks take about 10 seconds, with the task duration depending on the particular entry and the size of the data base. Most instrument panel tasks (except for complex radio and climate-control operations), take 5 seconds or less. The best and worst interface for a particular task often differ by a factor of two. The number of lane departures for those navigation-data-entry tasks was just below one versus almost zero for conventional tasks. Departures occur when entering destinations because approximately 80 percent of the time is not spent looking at the road. As a first approximation, task times while driving can be estimated by increasing the static task times by 30 percent.

**Questions 6 & 7. How often and for how long do drivers prefer to look in a vehicle when it feels safe or comfortable to do so? Conversely, when looking for particular frequency-durations combinations, how safe/comfortable do drivers feel they are?**

As a result of a lifetime of driving, drivers know when and how long they can safely and comfortably look inside a vehicle. Both safety and comfort must be considered as it is important to avoid harm to the driver and to produce vehicles that drivers will want.

Further, making drivers uncomfortable does add to the stress of driving, and could have safety implications.

Studies to address the preferred look duration require drivers to glance toward locations without interaction. In such cases, there is no cognitive capture due to the in-vehicle task and less loss of awareness of the driving environment. Thus safe driving is maintained.

The typical glance times established by drivers vary with the study, with data from the United States being about 0.8 to 0.9 s, and data from Japan indicating times of 2.0 s. These differences could be due to the nature of the driving environment, cultural differences, or instructions to subjects. However, these typical times should not be the basis of a requirement. As an example, by definition, the time established using a median is too long 50 percent of the time. If a small percentile is used as a criterion, times become impractically short. Future reviews with resources greater than this one should consider the results from Zwahlen's research.

The second question concerns how drivers feel when looking at real displays on real roads. There is considerable disagreement as to what the criterion for acceptance should be. Should the criterion be "safe," "comfortable," "somewhat comfortable," "neither comfortable or uncomfortable," "not unsafe," or numerous other possibilities? Should the percentile be the mean, the 95 percentile, or something else? The selection of the criterion and percentile has a huge impact on the acceptable value. Further complications arise in that the decisions are being made using English terms, but the studies were carried out using Japanese phrases, and there is debate as to how particular words should be translated.

To provide some example values, for a system offering a minimal sense of security, the acceptable total eyes-off-the-road times is 5.0 s for expressways and 4.2 s for city driving. Data from map reading studies suggest limiting task time to 5 to 10 s. If the goal is for the average driver to feel secure, then times just over 3 s are appropriate. To make products that are comfortable for drivers, eyes-off-the-road times should be 1 s or less.

### Question 8. How much time do drivers actually spend glancing at in-vehicle controls and displays?

There is a significant body of literature on the glance times for conventional controls and displays, but limited data on navigation functions. Although the results vary from study to study, mean glance durations are typically less than 1.2 to 1.5 s, depending on the functions examined. In summarizing the literature, Rockwell suggests the Two-Second Rule, "Drivers loath to go for more than 2 s without information from the road." Glance durations decrease by about 20 percent when the demands of the external environment are high.

Glance durations for conventional controls and displays are log normal with dispersion values of 0.2 to 0.6 s.

**Questions 9 & 10. How often do lane departures occur for in-vehicle tasks? What is the relationship between task completion time, mean number of glances, mean and total glance time, and lane departures for existing interfaces?**

This is a topic needing additional attention. Zwahlen has been a key contributor to this research. However there are concerns that his recommendations are based on vehicles with handling characteristics far inferior to contemporary vehicles. In addition, there may be calculation errors and baseline shifts in his work. These concerns are still being reviewed. This is important because his plot of the allowable number of glances and their durations has often been referenced in the literature and in guidelines.

Generally, the number of lane departures is zero when the number of glances is less than 2 to 2.5. Otherwise, the number of lane departures can be estimated as shown below. All times are in seconds.

= 1.3 (total glance time)
= 3.6 (mean glance time) + 0.25
= 2.2 (number of glances) - 1.
= 0.8 (task time) - 0.15

For conventional controls and displays, there is a very slight correlation between the number of glances required for a task and the mean time per glance, with each additional glance typically adding about 50 ms to the mean.

Glance durations for most navigation-system-related tasks are not much longer than those for conventional tasks. However, the number of glances required is much greater, with 5 to 18 glances not being unusual (versus 2 or so for conventional controls and displays). These values for navigation systems are well beyond the bounds of current driver experience.

Glance data can be used to estimate various task-performance measures. For example, the mean task-completion time (in s) is approximately 1.9 times the number of glances plus 0.5 s. It is also approximately 1.6 times the total glance time (total eyes-off-the-road time) plus 0.8 s.

Dispersions appear unrelated to mean times. The standard deviation of glance times is about 40 to 50 percent of mean times; being about 5 percent less for activities under 2 to 3 s and 5 percent greater for tasks over that time.

**Question 11. What do existing guidelines require concerning the use of navigation systems while a motor vehicle is in motion?**

There are five sets of guidelines that pertain to this topic (HARDIE, BSI, UMTRI, Battelle, and JAMA). The BSI guidelines suggest use of the Zwahlen diagram. The UMTRI guidelines list functions that should be allowed such as brightness control, turn/map mode switch, etc., but only examine a limited set of functions. The Battelle guidelines identify five specific requirements as to what should be allowed in a moving vehicle: (1) the navigation function provides added value while driving, (2) the mean glance time <1.6 s, (3) the task requires four or fewer glances, (4) the function cannot be implemented using voice option, and (5) two or fewer control actions are required. The JAMA guidelines take a different approach by identifying quite specifically the tasks drivers are not allowed to perform in a moving vehicle (e.g., view small roads, watch TV, read displays with scrolling characters, view messages with more than 31 characters, scroll maps, search for addresses, or select destinations using a cursor).

## Summary

Expressed more succinctly, several key conclusions emerge from this report

1. Navigation-system-induced crashes due to driver operation have been documented. At estimated levels of market penetration, 21 deaths are expected in the United States in 2007 from operation, along with another 2,100 injuries.

2. Not allowing destination entry in a moving vehicle should reduce the number of operational deaths to close to zero.

3. Crash probability increases linearly with eyes-off-the-road time, the product of mean glance duration, the number of glances per trial, and frequency of use. There are no points at which crash probability dramatically increases, making selecting of a threshold challenging. Using the equations developed from this project, fatalities and injuries for driver interactions with systems other than navigation can be estimated as well.

4. Depending on driver age and the interfaces, destination entry using visual controls and manual displays takes 1 to 2.5 minutes on average, as compared to a maximum of 5.0 s or less for most instrument panel tasks, though some radio and climate-control tasks take 10 s with longer times reported for more contemporary products. In contrast, destination retrieval tasks take about 10 s.

5. Lane departures are common when destinations are entered, generally almost one per trial. With visual displays and manual controls, about 80 percent of the task time is not spent looking at the road.

6. The relationship between task-completion time and the number/probability of a lane departure is linear. There is no inflection point at which the number of lane departures suddenly increases, so no obvious point emerges at which driving becomes noticeably less safe according to that measure.

7. There are reasonable correlations between static task time, dynamic (time shared) task time, total glance time, and lane departures. All relationships are improved. The scatter in these relationships can be reduced by placing tasks into three categories: (1) highly visual and requiring continuous control (adjusting a mirror, inserting a tape or CD, operating a joystick), (2) moderately visual (most instrument panel and destination entry tasks), and (3) minimally visual (operating a turn signal, dialing a cell phone).

8. There is debate as to how long drivers feel comfortable looking away from the road, with evidence supporting times of just under 1.0 s and 2.0 s. Other studies suggest task durations of up to 5 s are acceptable to drivers, but there are differences of several seconds depending upon the acceptance threshold used (safe, secure, comfortable, etc.) and the fraction of drivers to be accommodated.

9. The JAMA and Battelle guidelines suggest tasks should not exceed approximately 10 s.

This report concerns three fundamental issues: (1) Is there evidence for safety and usability problems associated with data input for navigation interfaces? (2) What measure or measures should be used in J2364 to determine when safety or usability problems occur? (3) What should the threshold values be for acceptance/rejection?

The evidence indicating potential safety and usability problems is clear. There have been fatalities and injuries in Japan and much greater numbers are projected for the United States. Task-completion times are in minutes. These are not times commonly associated with usable driver interfaces.

Measures examined in this report include mean glance duration, the number of glances per trial, eyes-off-the-road time, the number of lane departures, dynamic time, and static time. Although mean glance times increase with task duration, glance times are fairly constant for the tasks of interest, so measuring glance time is of little value. Both the number of glances required and total glance time are closely linked to crash probabilities as shown by Wierwille. However, glance measures are costly and time consuming to collect, and furthermore, require a completed interface. Hence, these measures cannot be collected early in design when changes are easy to make.

Similarly, lane departures are also a measure that is very relevant to safety, but collection of departures requires a completed interface installed in a vehicle or simulator. This costly approach can only be exercised late in design.

As shown in this report, both static and dynamic task times are correlated with glance measures predictive of crashes and lane departures. Furthermore, static times are easy to collect and only require a mockup or a conceptual design, items available early in design. Accordingly, use of static task times will promote iterative design, improving interface quality.

The topic of what constitutes an acceptable task time has received considerable debate. Unresolved are (1) the acceptance criterion to use and the appropriate limit for that criterion (how many crashes are excessive, what is the upper bounds of accepted design practice, what will drivers feel comfortable or uncomfortable doing, which design standards to select, etc.) and (2) the driver age sample that should be utilized in an experimental evaluation. Current thinking is that the time limit should be 15 s, a criterion based on many factors but especially current practice (Green, 1999a,b).

The topics addressed in this report are certainly likely to continue to be discussed and researched. This includes efforts to (1) further examine the relationships between measures, (2) examine the discriminability of the 15-second threshold, (3) tailor the subject testing procedure, (4) examine chunking and task interruptability, and (5) resolve other issues. The hope is that this report contributes to the healthy debate to determine how driver interfaces should be evaluated to assess and enhance safety and usability.

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## APPENDIX A - HOW WAS THE LITERATURE EVALUATED?

As part of the process of producing this report and weighing the evidence to establish a standard, a number of principles or ground rules were established to help focus the discussion of the SAE navigation subcommittee. Those principles are listed in the table that follows (46) roughly in their order of importance.

Table 46. Principles for Considering Evidence

| Principle | Implementation |
|---|---|
| no new research | Project funds were only to be used to obtain, synthesize, and analyze existing research, not to conduct new experiments. |
| do no harm | Should there be uncertainty with regard to the risks that tasks pose to drivers, one should err on the side of safety. If there is doubt, the burden of proof is on establishing that problems do not exist and not to establish they exist. This is consistent with the approach used in health care where new medicines are not introduced until clinical trials with human subjects are completed. |
| converging evidence | The strongest argument, be it legal, engineering, or scientific, is one based on multiple pieces of evidence, all of which point to the same conclusion. In a criminal manner, one might look for fingerprints on a gun that fired a matching bullet, gunpowder residue on the hands, eye witnesses, alibis, a motive to commit the crime, etc. Here, the evidence includes time available based on occlusion studies, volitional glance durations when there are no in-vehicle tasks, ratings of the safety of in-vehicle tasks of varying duration, data relating in-vehicle task times to lane departures, and other measures of driving. |
| emphasize the literature over personal experience | The author and the members of the SAE and ISO committees have considerable experience in using navigation systems and much greater knowledge of the systems' internal workings than most users. Since the focus of this project is on the driving public, the primary emphasis should be on empirical evidence and the published literature. |
| critical review of evidence | The report should not merely parrot back the findings of others, but critically assess the strengths and weakness of each study. Consequently, additional analyses of existing research were necessary in some cases. |
| weigh evidence based on its quality and comprehensiveness, technical relevance | Some of the factors to consider include the reputation and quality of the source (scholarly, peer-reviewed journals are preferred, with reviewed proceedings papers and technical reports as a second source), the reputation of the authors, experimental rigor, size of sample, the representativeness of the subjects and vehicles, appropriateness of the analysis, as well as the general personal assessment of the author. In making decisions, the criticisms in Table 47 were often voiced. |

| | |
|---|---|
| make the report comprehensive to minimize standard development time | If an ISO committee requests additional information on some issue because the original supporting materials were incomplete, that request will lead to a six-month delay in standards development since the working groups only meet twice a year. Such information requests are common and can delay standards by years. The standard ISO plan calls for a three-year process from the submission of a work item to the approval of a standard, but the process often takes longer. Accordingly, for this project, comprehensiveness has been given priority of the time for the production of this report. The cost, however, is not subject to change. |
| support the transition from an SAE to an ISO standard | This includes consultation with experts outside the United States, the inclusion of studies down outside the United States and U.S.-foreign differences, and other activities to gain the support of ISO TC 22/SC 13/WG8 (Ergonomics of Road Vehicles-Transport Information and Control Systems). In the long run, an SAE standard will have far less impact on both U.S. and worldwide vehicle design than will an associated ISO standard. |
| give special attention to words that are legal triggers | allowable, acceptable, safe, risky, hazardous, dangerous, etc. |
| consider the full range of potential users, not just the initial market segment | In Japan, navigation systems have been in use for some time and many drivers may have some degree of experience with them. In the United States, navigation systems are just beginning to be marketed, so many users are novices, though expertise will grow with time. |
| NHTSA is watching | The reliance upon commercial standards is a new approach for the U.S. Department of Transportation, which has attempted to overcome the adversarial atmosphere surrounding standards rulemaking in the past by relying on cooperation. If the resulting standards fail to adequately protect the public, NHTSA will intervene. |
| where the quality of the evidence is uncertain, include it but mention the appropriate caveats | There were several instances in which key details of studies were missing or not translated into English. Given the limited information available on some topics, no information could be discarded. |
| Paul Green is the author and has the final say on the report's language | This report represents the views of the author, Paul Green, not SAE. However, drafts were reviewed extensively by the SAE Navigation Subcommittee and their comments were used to improve the quality of the report. The author discharged his responsibilities not as an academician or a contract employee to government organizations or vehicle manufacturers, but as an independent technical expert as specified in the SAE Technical Standards Board Rules (SAE TSB 001, issued June 1993). |

Table 47. Misunderstood Criticisms of Human Factors Literature

| Criticism | Response |
|---|---|
| This study does not perfectly predict driver performance or crash risk. | In making decisions about which system to select or what is acceptable, data on absolute levels are not needed. Data concerning the relative levels of performance or risk are sufficient. Hence the focus on factor selection should be on identifying interactions. |
| The subjects are not representative of real drivers. | From the literature it is clear that the primary factors that affect driver performance are age, sex, and experience with the task. If, for example, the study only were to include young men, one would expect their performance to represent data on the "good" end of the spectrum. To get a sense of the range of performance likely and potential interactions, data from other sources may be needed. If there was evidence those factors (e.g., age) did not interact with the variables of interest, then exploring age may not be necessary. |
| There were not enough subjects. | The number of subjects to be tested depends on the question to be asked. For hypothesis testing studies involving performance, generally 4 to 6 carefully chosen subjects per cell (age-sex category) is sufficient, a total of 16 to 24 subjects. If the issue is personal preference, a much larger sample is needed, say 50 to 100. |
| The study was not done on the road but in a simulator. | For in-vehicle systems, the primary concern is whether the driving task contained a similar attentional demand as a real driving task. If it did, then the simulation results are useful. Unfortunately, sometimes the similarity must be accepted on faith as the cost of the validation effort may exceed that of conducting the evaluation of interest. |
| The study involved trials but in the real situation, the trials are spread out over years. | This comment gets at the issue of massed versus spaced trials, a topic of considerable interest in the educational psychology literature. Although the criticism is true, when conducting an experiment one needs to collect a considerable amount of data over a brief period of time to meet project schedules, so spending years to collect data is not feasible. An alternative would be reduce the amount of data collected per subject and to increase the number of subjects. However, individual differences are large and tend to mask differences of interest, requiring an even larger sample size with major cost increases. |
| The study is old. | Unless the study concerns a temporally bound implementation of a technology, age is irrelevant. For example, in determining legibility requirements, if the contrast, luminance, and other physical characteristics were fixed, it would not matter if the display was a slide, an LCD, or a CRT. However, if the issue is whether CRT or LCD technology provides a more legible image, then the issue would be temporally bound. Similarly, if one were measuring eye fixations, the choice of technologies would not matter if all had sufficient accuracy for the study needs. |

## APPENDIX B - SOME STRATEGIES TO DEAL WITH OVERLOAD

| Strategy | In-Vehicle Navigation (Secondary) Task (e.g., entering or retrieving destinations, obtaining guidance) | Driving (Primary) Task (e.g., steering, maintaining speed, searching for traffic conflicts) |
|---|---|---|
| shed task (not do it) | The navigation system is not used and the driver is unlikely to purchase another in the future. | Either one completely ignores driving (a very unsafe decision) or one pulls over to the side of the road to perform navigation tasks, a strategy in conflict with optimizing travel efficiency. |
| reduce task priority | The driver takes longer to complete navigation tasks. Slow progress may be frustrating to drivers. | Paying less attention to driving might lead to more crashes, in conflict with the goal of enhancing safety. |
| modify or simplify task | Rather than switch back and forth between map and turn display modes to obtain guidance, a driver might only use the turn display. | Reduce the external demand. When overloaded, drivers will often slow down momentarily to reduce the rate of external information and provide more time for making decisions (e.g., at complex junctions where numerous signs and roads complicate path selection). While slowing down is a preventative measure, it can have the unintended impact of slowing local traffic flow. On expressways, this can result in added lane changes of other drivers, with added crash risk to all drivers. |
| Reduce task quality | quality changes are only possible for some tasks (e.g., set volume less precisely) | Drivers may be less attentive to maintaining lane position or speed, or searching for traffic conflicts, all of which increase crash risk. |
| Postpone execution | The driver completes the task later. This may also involve sampling the in-vehicle display less often. For guidance to be useful, destinations usually are designated early in a trip. Also, turn information needs to be updated in time for drivers to plan maneuvers. | Although drivers may be able to postpone attending to aspects of driving (e.g., checking mirrors) for brief periods of time, the steering task postponement can only be on the order of seconds or less. |

| | | |
|---|---|---|
| Reassign task to others | The passenger operates the navigation system. This can occur only if a trained passenger is present, often not the case. | Having the passenger hold the wheel while the driver operates the navigation system is not desirable. Automation to temporarily steer is well in the future. Assigning the steering to other limbs to free the hands (e.g., a knee) is not desired. All solutions in this cell conflict with the goal of enhancing safety. |

Readers are reminded that the driving scenario will not only include driving and operating a navigation system, but may include operation of complex and unfamiliar radios, dialing and responding to phone calls, and usual tasks such as eating, or putting on makeup, all of which people are known to do while driving. Each of these tasks can be dealt with using the strategies in above table.