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## **Potential Safety Impacts of Automotive Navigation Systems**

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### **Abstract**

This paper does not purport that navigation systems are safe or unsafe, but attempts to identify potential topics of concern relating to the driver interface. The first section of the paper describes some of the classes of measures by which the safety of navigation systems can be assessed. Of them, eye fixation frequencies and duration, TTC, and TLC have the most promise for pinpointing safety concerns. However, additional work is needed to develop the tools to collect and analyze such measures. Of the navigation tasks that drivers can perform, the primary concern is with destination entry, though information retrieval, route following (with maps), and destination retrieval also deserve attention. A better understanding of the crash-inducing potential of navigation systems may be obtained by consideration of likely crash scenarios, some of which are described. Systematic analyses of crash scenarios involving navigation systems have yet to appear in the literature.

### **Introduction**

The purpose of this paper is to discuss (1) how the safety of a navigation system might be assessed experimentally, (2) the tasks drivers perform with navigation systems, and (3) the circumstances that could lead to crashes while using a navigation system. Readers should view this paper as an early version of "thought-piece" to encourage discussion, not as a scholarly review supported by empirical results or as a position paper for product liability actions.

This information is presented from the perspective of a scientist who has done research on human factors issues associated with navigation systems. He also has a Rockwell Pathmaster navigation system installed in his own car and uses it periodically. The Pathmaster provides voice-assisted turn-by-turn guidance, has an arrow-based turn display, and can show route maps. The Pathmaster does not utilize traffic information to provide dynamic route guidance. The data base is reasonably complete and accurate except for the area to the west of where he lives. He does not drive in that area very often.

### **How Can Safety Be Measured?**

Identifying the potential risks of a navigation system, if there are any, is extremely difficult. A first step in evaluating any traffic safety problem generally involves examining crash statistics. This can be a challenge for navigation systems as crashes in general are rare events. This, coupled with the low market penetration of navigation systems in the U.S. and Europe, results in too few cases (crashes) for a meaningful

statistical analysis. Even if there were enough cases, there is currently no record of whether a vehicle was fitted with a navigation system by the crash investigator, let alone whether the navigation system might have been in use. In the future, data on navigation system installation may be available (at least for OEM systems) by backtracking using the VIN. While the installation rate in Japan is quite high (soon to be in the millions of units), the Japanese National Police Agency, the primary source of accident data, tends to be quite restrictive in the information they release (in contrast to the western nations). The Japanese policy is changing. Nonetheless, crash-based insights into navigation system safety are unlikely in the near term.

An alternative approach is to use secondary indicators as measures of crash risk (Burger, Smith, Queen, and Slack, 1977; Green, 1995a, b). For example, in a recent UMTRI study participants used either an Ali-Scout or a Pathmaster navigation system to drive a four-segment route around Troy, Michigan (Katz, Fleming, Hunter, Green, and Damouth, 1996). While there were no critical incidents while driving using a PathMaster navigation system, there were four associated with the Ali-Scout (when subjects changed lanes without looking). (In each of these four crash opportunities, other drivers reacted by honking, braking, etc.) The problem in comparing the two interfaces is that there were over 50 Ali-Scout users but only 5 Pathmaster users (due to equipment problems). The study design did not permit collecting baseline data for using written instructions or paper maps. Thus, it is difficult to make safety inferences even from large and expensive studies. Future opportunities to conduct such research are rare.

A third approach is to rely on more behavioral measures such as time-to-collision (TTC). Time-to-collision is defined as how long it would take for a collision to occur if all vehicles on the road retained their current velocity and acceleration tensors indefinitely. TTC is a measure of the safety cocoon around a vehicle, and consequently has considerable appeal for safety evaluations. However, devices for measuring TTC for safety evaluations are just being developed. Additionally, driver norms for TTC (needed to assess what is safe and unsafe) are lacking and there are no plans to develop norms.

Even more indirect measures of crash potential are eye fixation, speed variance, and lane maintenance measures such as lane variance and time-to-line-crossing (TLC) (Godthelp, 1988; Godthelp, Milgram, and Blaauw, 1984). There is beginning to be a considerable body of data on glance durations. Glance data is usually collected by aiming a video camera at the driver's face, and playing back the tape at slow speed to determine the duration of each off-road glance and count their frequency. Data reduction time is typically 30-40 times subject testing times, so data reduction is often relegated to bored, low paid, undergraduate students. Although more automated methods are being developed, it will be several years before they are reliable and affordable enough for wide-spread use. As an aside, the technical challenges of automated systems include getting a magnetically-sensing head tracker to work in a magnetically-unfriendly environment (car body), counteracting the solar overload of the IR-based eye tracker, and resolving the optical interference of glasses, worn by virtually all older drivers. Further, norms on acceptable and unacceptable glance durations and frequencies from the road are limited (Hada, 1994).

Another approach would be to examine the influence of an installed navigation system on drivers' speed variance and lane variance. However, use of the navigation system is intermittent, so obtaining differences in normal driving on straight roads is difficult (Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993). A solution to the intermittency problems is to partition each trip link into sections and only examine those sections where navigation system use is likely, namely near turns. (Walker, Alicandri, Sedney, and Roberts, 1990, 1991, 1992). The difficulty is that driving at the critical points is highly variable, so measuring differences is a challenge. This idea is discussed in greater detail in later portions of this paper.

Not only are there problems in detecting differences, but it is uncertain what levels of performance are unacceptable as normative data on "plain old driving" are lacking. One interesting approach is to collect experimental data from drivers who are legally intoxicated and use that data to establish levels of unacceptable driving performance. The advantage of this approach is that is a large body of data relating BAC level to crash risk. This idea assumes that the mechanism of impairment due to alcohol is the same as that due to other factors, which may not be the case.

Thus, it will be some time before there is a clear picture of the safety consequences of using navigation systems while driving. The most useful insights may come from driver performance measures as measurement technologies evolve.

### **What Tasks Do Drivers Perform with Navigation Systems?**

However, that does not mean that those interested in navigation system safety should do nothing while time passes. One option is to consider the conditions under which navigation system-induced crashes could occur and to target those conditions for examination. To avoid a biased perspective, the alternative--what would the driver do if a navigation system was not present--should also be considered. Would drivers be looking at a paper map while driving, a presentation scheme clearly less well suited to navigation than most contemporary navigation systems (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995)? Would drivers be looking at scraps of paper for directions? Would they slow to a crawl, trying to read nonilluminated street signs with 6-inch high letters at night? How likely are they to be rear-ended in this situation? Would they accumulate excess miles while searching for destinations, exposing themselves and others to increased crash risk by increasing the total vehicle miles traveled?

Furthermore, stopping to use a navigation system (instead of continuing to drive) may be a risky option in some circumstances. For example, for most expressways, the safest option is to drive to the nearest exit and find a place to park. Uncertainties about the safety of the location is of major concern to drivers, and in some areas, just finding a place to park is not easy. If exits are widely spaced, a considerable distance may be traveled before the navigation information can be entered, eliminating the travel advantage of electronic navigation systems. The implications of stopping need to be explored more fully.

There are four basic tasks drivers can perform with a navigation system: (1) enter a destination, (2) retrieve a destination, (3) obtain information about a potential

destination, (4) plan a route, and (5) follow guidance. The major concern is what a driver should be allowed to do while driving.

### **Destination Entry**

Destination entry can be a challenging task, depending on the method used (Paelke and Green, 1993). Times on the order of a minute (in situations simulating a parked vehicle) are reported in the literature (Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; Steinfeld, Manes, Green, and Hunter, 1996). If the destination is entered using manual controls and visual display (presumably inside the vehicle), then the driver is distracted from attending to the road. Two possible solutions are offered. One, place the display on a HUD. While this solves the direction of gaze problem, it is unknown if this solves the locus of attention problem. This solution is worth investigating experimentally. Another alternative is to make entry by voice, as is the case for some systems in Japan. Published experimental evidence on voice entry is lacking, but desired.

What a driver might enter varies quite widely with the interface style and features provided. Entry may require keying of every item, combinations of keying and scrolling, or scrolling entirely. Scrolling may involve scrolling through a list of items or scrolling a map to a particular location. Scrolling is a visually demanding task, a task not readily done while driving. On the other hand, scanning a keyboard to find one key among many may also have a high visual demand. Of particular concern is the "cognitive capture" issue, tasks that have a high start up cost (such as finding a reference point on an unstructured map), so that it is highly desired to complete them without interruption, even at the expense of other tasks. In driving, the result can be long periods of time without reference to the road.

Entry tasks may require a driver to enter a street address, an intersection, an expressway exit, the destination or point of interest name, the destination phone number, or even its longitude and latitude. The author's experience is that phone number entry is much faster than other methods, but that method requires having current phone numbers in the data base. Destination entry times can be extremely large if the user does not know the name of the jurisdiction for the destination used by the navigation system. ("I know the street address and know where I want to go is just north of Ann Arbor, and I even know it is Washtenaw County, but I do not know the name of the city or township.") In these cases, several tries may be required. There is a reasonable probability the driver never obtains guidance to the exact street address desired.

It is generally assumed that destination entry is done once per trip, usually before it starts. Often this is not the case. Some examples are:

- The driver was in a hurry and knew the general direction in which to start. The destination was added immediately thereafter.
- The driver decided to change destination enroute. ("Even though it is late, we should stop and get some milk on the way home." "Daddy, I need to go to the bathroom.")
- The system does not use congestion information to calculate a route. Hearing a congestion report on the radio and having general knowledge of the area, the driver

planned the route around the congestion. When the congestion was passed, the destination was entered to obtain guidance for the final leg of the route to an unfamiliar destination.

- The driver entered the wrong destination (North Main Street instead of South Main).
- The driver does not know the exact destination at the beginning of the trip (e.g., the desired intersection) and therefore enters a location near the destination. Driving in the area near the interim destination provides information on the actual destination, which is then entered.

### **Destination Retrieval**

Destination retrieval times in static situations are typically on the order of 10 seconds (Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; Steinfeld, Manes, Green, and Hunter, 1996). Retrieval typically requires two keystrokes to get to a stored list, and then keying in the first few characters of a destination name or scrolling to get to it. Evidence as to whether lists should be alphabetical or by order of use (last first) is lacking.

### **Route Following**

In route following, the driver is guided turn by turn, often by an arrow-like display (supplemented by voice) to the destination. The critical design feature is the timing of voice messages (George, Green, and Fleming, 1995; Green and George, 1995). Experience has shown that if the timing is off or the voice is too commanding (so drivers act without checking traffic), then problems will occur. Although visual displays help plan the route, execution of a turn seems to rely more on voice commands. A good voice system paired with a mediocre display may be acceptable, but the opposite is not true.

The human factors data suggests that eye fixation times for navigation systems are of moderate duration except when maps are used (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995). In contrast to the U.S., maps are critical for driving in Japan because of differences in the nature of the Japanese road network. The consequence is more time spent looking away from the road. The major problems occur when drivers need to search a map for a street or place whose location on the map is completely unknown (as opposed to finding the street being driven or the next cross street). Times for scanning a map are close to those for destination retrieval.

### **Information Retrieval**

At this time, navigation systems in the U.S. do not support information retrieval. In Japan, systems tend to be more information rich, and hence the use of the term "infomobile" instead of "automobile." Data on the potential tasks a driver might perform is lacking, but use of yellow page functions to obtain information on potential destinations in great detail (even the menu for a restaurant) is a possibility.

## **Administrative Functions**

This includes calibration and related activities. These activities are rarely performed and almost never at highway speeds, so safety implications of them are not a concern.

### **When Might Navigation System-Related Crashes Occur?**

Thus, from the perspective of task duration, the primary tasks of concern are destination entry and information retrieval (tasks of potentially equal complexity). Map reading and destination retrieval are at a second level of concern. However, task frequency needs to be considered as well as duration. A destination is usually entered once per trip, but as was noted earlier, there are a few exceptions. Route guidance information is consulted numerous times on each trip.

Following are a few navigation-related crash situations for both near and far from turn points. The first two involve destination entry. The second two involve route following. Additional thoughts as to the likelihood of these types of encounters would be useful in identifying potential navigation-related safety problems. The collision typology of Massie, Campbell, and Blower (1993) could be useful in this analysis.

Situation 1: The driver is on an expressway and looking at the navigation system while entering a destination and

- something occurs without warning requiring an immediate response (lead vehicle brakes or another vehicle cuts in).
- the driver drifts out of the lane into another vehicle.
- the road curves but the driver continues to steer straight.
- the driver does not see a lane drop and drives off the road.
- the driver does not see an obstruction (parked vehicle) and collides.
- there is a general change in the speed of traffic (due to a sag in the road) and the driver collides with a lead vehicle.
- an animal darts out on to the road and the driver never sees it.

Situation 2: The driver is in an urban area and looking at the navigation system while entering a destination and

- the driver misses a stop sign or traffic light and collides with a vehicle on a crossing path. This might include never seeing the signal at all or not noticing a state change.
- traffic ahead slows (for a variety of reasons) and the driver rear-ends a lead vehicle.
- a parked car from the roadside or a driveway partially obstructs the driver's path but the driver never swerves to avoid it.

Situation 3: The driver is on an limited-access road and receives guidance too late, either because the guidance was poorly timed or the driver missed the prepare-to-exit message. The driver hastily attempts to change lanes to get to the exit.

#### Situation 4: The driver is in an urban area and

- receives the turn message too late and brakes abruptly, inviting a potential rear end collision.
- receives a prepare-to-turn or turn message. Thinking it to be a command (and believing the computer knows all) the driver turns or changes lanes without checking for traffic.
- receives a prepare-to-turn or turn message. Thinking it to be a command, the driver turns down a one-way street in the wrong direction. This is a data base-induced error.
- receives a prepare-to-turn or turn message. Thinking it to be a command, the driver ignores a traffic sign or signal.
- receives a prepare-to-turn or turn message, but is unsure of the exact turn location. The driver proceeds at an excessively slow speed and is rear ended.
- receives a prepare-to-turn or turn message, but is unsure of the exact turn location. The driver is so intent on finding the turn point that they miss a traffic sign or signal and strike a crossing vehicle.

#### **Closing Remarks**

Thus, there are technological means to determine if there are safety problems associated with navigation systems. However, it will be sometime before they are developed to the level that safety questions are easy to examine. In the interim, in addition to pursuing the development of those technologies aggressively, some thought needs to be given to the circumstances under which navigation-induced crashes could occur. Using this approach, areas of concern could be identified and navigation interfaces could be designed so that even hints of a crash-induced potential could be removed. The success of the navigation market in the U.S. and Europe will depend on reducing the system cost to a more reasonable level, and as indicated by this paper, enhancing the safety (and, consequently the usability) of driver interfaces.

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