Common Automotive Navigation System Usability Problems and a Standard Test Protocol to Identify Them

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Abstract

Although there has been considerable research on in-vehicle navigation systems, many safety and usability problems re-occur in system after system, even in systems that have been subjected to some sort of safety or human factors evaluation. This paper describes those problems and a test protocol to identify them.

Common problems were identified from detailed evaluations of four contemporary navigation systems. Those problems, described in layman's terms, were found both with destination entry and route guidance. Destination entry problems were associated with (1) the layout and labeling of the control and menus, (2) audio and visual feedback, and (3) order of entry of the destination information. Route guidance problems were most commonly associated with (1) starting guidance and ending, (2) display design and readability, (3) voice guidance and timing, and (4) rerouting.

The test protocol, developed as part of the process of evaluating the four systems, consists of two parts. The first part concentrates on the control layout, destination entry, and other tasks performed while the vehicle is parked. The second part concentrates on the route guidance while the vehicle is in motion. Both parts of the protocol rely on verifying compliance with human factors principles as determined by experts (heuristic evaluation) as well as data from carefully chosen test subjects using the system.

Introduction

Current automotive navigation systems are capable of providing reasonably accurate and reliable door-to-door guidance. Market predictions suggest by 2009, 25 percent of the vehicles produced will have navigation systems (Richardson and Green, 2000). A well-designed navigation system can prevent wrong turns, reduce travel times, and hopefully, alleviate some of the driver's workload. However, poor usability can misdirect drivers, increase driving workload, and lead drivers to make unsafe maneuvers.

There has been considerable human factors research on navigation systems over the past 10 to 15 years. (See Dingus, et al., 1996 and 1997 for reviews, and see Llaneras and Singer, 2002 for an inventory of current technology.) Additionally, several sets of safety and usability guidelines for in-vehicle navigation systems have been developed, and they are listed in Table 1. (See http://www.umich.edu/~driving/guidelines.html for the full text of all of them.) It is uncertain how widely these guidelines have been used or even distributed. This is in spite of considerable attention they have received, in particular, the guidelines from the Alliance of Automobile Manufactures and from the Society of Automotive Engineers (SAE).

Table 1. Relevant human factors in-vehicle navigation system guidelines.

Guideline, Practice or Standard	Title	Pages
Alliance of Automobile Manufactures, 2002.	*Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communications systems.*	65
SAE Recommended Practices J2364 and J2365, 2000.	*Recommended Practice Navigation and Route Guidance Function Accessibility While Driving,* and *Recommended Practice Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks.*	30
Japanese Automobile Manufactures Association (JAMA), 2000.	*Guidelines for In-Vehicle Display Systems.*	5
Stevens, de Lancey, Davison, Allen, and Quimby, 1999.	*A Safety checklist for the Assessment of in-Vehicle Information Systems: Scoring Performance.*	18
Campbell, Carney, and Kantowitz, 1997.	*Human Factors Design Guidelines for Advanced Traveler Information systems (ATIS) and Commercial Vehicle Operations (CVO).*	261
Ross, et al. 1996.	*HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by ATT systems.*	480
Green, Levison, Paelke, and Serafin, 1993.	*Preliminary Human Factors Guidelines for Driver Information Systems.*	111

Developers should also realize that compliance with guidelines does not assure a system will be safe or easy to use, and because of limited research resources and the time required to achieve consensus for a guideline, everything that one needs to know about interface design does not

appear in guidelines. As an example, much of the research on navigation and related systems conducted at the University of Michigan Transportation Research Institute (UMTRI) has yet to be included in many of the guidelines (e.g., Brooks, Nowakowski, and Green, 1999; Brooks, Lenneman, et al., 1999; George, Green, and Fleming, 1996; Green, 1996; Green and George, 1995; and Green, Williams, et al., 1993). Unfortunately, even with all of the research, guidelines, and feedback from several generations of products on the market, many basic safety and usability problems still seem to re-occur, and the need for an awareness of these problems and product usability testing is greater now than ever before.

After evaluating many navigation systems over the years, including four formal evaluations, the authors have identified a core set of tasks that drivers perform with navigation systems, and in doing so, identified common usability problems as well. Further, similar problems for other systems could be identified using a standard evaluation protocol. This paper identifies those common problems and a protocol to spot them. To put the problems in context, the protocol is described first.

Methods

A Standard Usability Testing Protocol for Navigation Systems

Overview

The protocol set forth in this paper, in an abbreviated fashion, was designed to be comprehensive in the sense that it covers the basic tasks performed by those using a navigation system as well as tasks that commonly lead to usability problems. Recognizing the features offered vary from product to product, the protocol was designed to be easily adaptable, allowing construction of a more detailed, product-specific, usability test plan using this protocol as a template. The protocol set forth here was not intended to replace human factors design expertise or usability testing, but rather to provide a common reference for practitioners to assist in the development of safer and easier to use navigation systems.

The evaluation protocol has 2 parts, each requiring about 1 to 1.5 hours per evaluator or test participant. This was done for two reasons. First, during testing, test participants usually require a break after about 2 hours (especially when driving), and second, many video recording devices only hold about 120 minutes on a typical media. It should also be noted that all of the systems used to develop this procedure used manual controls and visual displays for data entry, and therefore, the evaluation of speech input has not been included.

Evaluation Protocol Part 1: Destination Entry While Parked

1. *Before using the system, write down each control label or icon and describe everything that control could possibly do or how the control should be expected to function.* Since accurately assessing the effectiveness of labels and icons is difficult to do in a small usability study, writing down all the options for a control given its label before the system is used may lead to insights into how a control label might be misinterpreted.

2. *Determine how each control functions by using it.* Comparing the actual control function with how it was expected to function can provide a list of possible errors.

3. *Evaluate each controls size, shape, location, and sensitivity.* Additionally, consider wearing a pair of winter gloves or mittens while operating the controls.

4. *Enter at least three typical street addresses.* (According to Nowakowski, Green, and Utsui, 2000, this requires, on average, the entry of approximately 15 letters and numbers.)

5. *Enter several addresses with numeric streets (such as 7th Street) and streets addresses containing quadrant identifiers (such as 1320 West Huron or 401 North State Street).* Setting these types of addresses have been known to cause drivers some confusion.

6. *Enter several points of interest as the destination (such as airports, conference centers, or the nearest gas station).* Airports and conference centers are common destinations for business travelers, but often become the cause of entry problems.

7. *Set destinations using any other means available to the system.* This might include setting a destination by intersection, address book, or a previous destinations list.

8. *Adjust some of the system settings.* This might include changing the map from heading-up to north-up, adjusting the volume, editing the route preferences, adjusting the map scale, changing the colors, brightness, or contrast, or editing the address book.

9. *Assess which features or functions are accessible while the vehicle is in motion, and reevaluate the controls used with these features while the vehicle is in motion.* Specifically, a control's size, location, or feel may seem adequate while the vehicle is parked, but less than optimal when used while the vehicle is in motion.

10. *Any feature or function should be in compliance with local government regulations and industry recommended practices regarding navigation system operation.* In the U.S. there are no current regulations covering navigation system interfaces. However, both the Alliance of Automobile Manufactures and SAE have published guidelines with testing procedures.

Evaluation Protocol Part 2: Route Guidance

Part 2 covers the route guidance and dynamic features of the system (such as rerouting). Any destination entry required during this phase should be performed while the vehicle is parked. Since the route following task is the primary focus of this phase, the evaluation is most insightful if the test participants are unfamiliar with the destinations or route, forcing the participants to rely on the guidance provided by the system and making usability problems more apparent.

The test route that was developed was composed of 5 destinations, 31 turns, and covering about 21 miles of driving. (See Appendix A.) This length was ideal in that it provided for a route within the time requirements without too much repetition of road segments. The test route was also developed to provide a wide variety of road types (Table 2) and route features (Table 3), while still providing a relatively safe route. For example, routes segments that involved left turns onto busy four-lane roads at intersections without a traffic light were excluded.

Table 2. Descriptions of residential, suburban, city, and expressway driving.

Scenario	Lanes	Speed Range (MPH)	Traffic Density	Scenery
Residential	1	15-25	Low	Primarily housing with a high density of driveways
Suburban	1-2	35-45	Moderate to High	A mix of housing and businesses with frequent parking lot entrances
City	1-2	25-35	High	Primarily businesses with frequent blind driveways and alleys
Expressway	2+	55-75	Moderate to High	High-speed, limited-access

Table 3. Features of a good route.

Route Features	Rationale
1. A balance of left and right turns at controlled (signals and stop signs) and uncontrolled intersections	The turn direction and intersection control type were sufficiently randomized and balanced so that subjects would use the navigation system to maneuver rather than acting without it based on some bias.
2. A mixture of driving scenarios (Table 3), speeds, and traffic densities	Route guidance optimization can vary as a function of the traffic density, road spacing, and the overall visual clutter of the driving environment.
3. Forks, merges, entrance and exit ramps, nonstandard, and 5-way intersections	Many nonstandard intersection types and geometries have traditionally been handled poorly by navigation systems.
4. Successive, closely-spaced, or back-to-back turns	These maneuvers often caused drivers frustrations when the information was poorly timed.
5. Hard to see streets (e.g., turns where the target street is obscured by a hill or curve)	Difficult maneuvers were included to find the most potential problems in a limited period of time.
6. Detours or induced wrong turns	An important part of the evaluation was to see what happened when the driver misses a turn or otherwise deviates from the route.
7. Consider poor GPS coverage	Driving near high-rise buildings, tunnels, or multi-level intersections can cause "urban canyon" effects, leading to large localization errors and periods of no reception.

Heuristic Evaluation

Generally, when the system is early in development, several human factors experts are on-hand, and time is short, an "expert evaluation" using the heuristic evaluation method (Nielsen and Molich, 1990; Nielsen, 1994b) can provide a good first-cut analysis in a day or two. Using this method, the expert evaluators systematically examine the system looking for violations of known usability principles and guidelines. As discussed by Nielsen and Landauer (1993), Virzi (1992), and Nielsen (1994a), heuristic evaluations typically provide the best results when performed by 3 to 5 human factors experts. While a single evaluator typically finds only 35 percent of the usability problems in an interface, the aggregated results of 3 to 5 evaluators yields between 65

and 75 percent of the usability problems. We would caution against replacing this step with a checklist for common usability problems to be used by a person who is not a certified human factors specialist. They often lack the requisite technical knowledge of the material and the awareness necessary to be effective in spotting and resolving problems.

Formal User Testing

Ideally, a next step in the usability testing of a navigation system would involve a series of iterative formal user testing sessions. User testing is most productive when there are few "show stoppers." Otherwise, the users tend to get stuck on those problems, and other problems are never identified.

User testing also requires time, up to a week or two, to prepare materials, prepare consent forms, and then recruit and test the drivers. Additionally, user testing may require approval from a human subjects review board or other oversight committee in some organizations, a process than can take a month or more to complete. Blanket approval for a series of tests obtained in advance can eliminate this potential delay. However, the most of the schedule for user testing is allocated to set up and data analysis, not the actual testing. In spite of these challenges, user testing identifies usability problems experts might miss, and it provides visible evidence of major problems (sometimes in the form of obscenities on tapes from actual users). Overall, user testing is worth the time and effort.

Safety and usability are achieved by multiple passes through a user test-redesign loop, especially early in design. User testing should not be done in the form of a massive test after the design is completed. User testing follows a similar approach to heuristic evaluation employing 3 to 5 carefully chosen test participants for each iteration of the design. Because the purpose is to identify problems and not exact mean levels of performance for a population, small user samples are sufficient. The test participants should be (1) licensed drivers, (2) unfamiliar with the navigation system, and (3) representative of the range of drivers who may use an in-vehicle navigation system, with special attention being paid to including older drivers. Test participants should not be the system developers or fellow engineers. Experience has shown that testing novice users provides the most salient results. In this type of test, the task completion times, errors, and comments are used to determine where usability problems exist. Although the test participants provide information on where usability problems existed, often the exact causes of the problem will need to come from a post-test analysis by human factors experts. Readers seeking additional information on usability testing should see Rubin (1994) or Dumas and Redish (1999).

Test Equipment: Video Recording Systems

Although no specific test equipment is required to conduct a usability evaluation, a camcorder or other video recording device should be employed to document user-system interactions and usability problems. While notes and still photography have also been used, these are difficult to take while driving, and the video and audio recordings allow for post-evaluation analysis. Often the tapes reveal additional usability problems that were not noticed by the evaluators. Additionally, many usability problems (such as a wrong turn) can not always be traced to a single design element. The video documentation of event sequences and message timing provides insights into the real causes of the usability and safety problems.

Generally, a single camera focused on the navigation system display is sufficient, but more complex arrangements using multiple cameras provide useful information. Since often the vehicle cannot be modified for recording equipment, photographic vacuum-suction mounts, a tripod, or a series of spring-loaded curtain rods provide a stable platform for mounting cameras. Multiple synchronized cameras using a video quad splitter can be used to capture the navigation system, the driver's face, and the road and traffic in a single recording. Including the driver's face often provides cues relating to confusion (or anguish) which are useful in convincing the engineers and designers that the problems noted are worthy of concern. Including the road scene provides context when analyzing the videotapes, such as when turns occurred and how fast the vehicle was going (allowing judgments to be made as to whether the driver was slowing down too early or too late for a turn).

Common Safety and Usability Problems Found in Product Tests

Overview

Several separate usability studies were conducted on four different navigation systems using the protocol described in this paper. Some of the systems were tested using the protocol as a heuristic evaluation, some were tested using the protocol as a formal user testing plan, and some were tested using both methods during different stages of development. Two of the systems were production units designed specifically for in-vehicle use (the Magellan Pathmaster and the Nissan OEM navigation system found in the Infiniti line of vehicles). One system was a preproduction prototype running on a laptop with an 8.4-inch screen mounted in the vehicle and operated by a hand-held remote control. The final system was a commercially available software package (Destinator 1.0), which ran on a handheld device (a Compaq iPaq 3635). An attempt was made to express the usability problems in the following sections in the words, actions, and examples of real drivers participating in UMTRI tests.

Common Usability Problems with Navigation System Destination Entry

1. Controls and Menus

1. *What does this button do?*

   Button labels using abbreviations or vague terms (such as POI for Point of Interest, or view, route, and map) were frequently misinterpreted during usability testing.

2. *Why isn't that button (or control) over here?*

   Three types of problems were continually noted with control location. First, drivers noted that controls frequently used together were located far apart (violations of the proximity compatibility principle). Second, drivers noted that often buttons for frequent tasks or critical tasks while driving (map zoom, scrolling, or destination entry) were often located with the furthest reaches. Finally, inconsistencies were noted in the placement of virtual controls between screens.

3. *When I pressed a button, the system did not respond (or jumped ahead two steps).*

   Judgments regarding button sensitivity seem to vary with age. Often, button presses were not registering for younger drivers (sensitivity too low), whereas for older drivers, each button depression registered as two or three key presses (sensitivity too high).

4. *Does "back" save my changes?*

Progress, such as completing a step or saving changes, was generally associated with forward movement using an "enter" or an "Ok" button, while leaving a screen using a "back" or "previous" key was associated with canceling any changes that were made. Thus, users did not believe that changes were saved when they were required to exit a screen using a back or cancel button.

5. *I do not understand how these menus are organized.*

Users had problems finding features (as indicated by comments about seemingly out of place menu items) for all of the navigation systems.

2.   Audio and Visual Feedback

1. *Was that beep from the navigation system or the radio?*

As more systems are added to vehicles without coordination, opportunities for confusion among signals will increase. Additionally, aftermarket units suffer the unique challenge of providing clear sounds while competing with vehicle noise and the radio.

2. *Why was there only one beep for everything?*

Most systems used a single tone leaving the driver unsure whether the beep meant attention, accepted keystroke, erroneous keystroke, or acknowledgment of completion.

3.   Destination Entry

1. *Oops, I guess it was asking for city and I tried to enter the street name.*

Destination entry generally required the following four steps to be completed in a specific order (depending on the system): (1) category (for a point of interest), (2) city, (3) street, and (4) house number. The most serious destination entry problem was an out of sequence entry error, which usually occurred in the following ways:

1. Drivers tried to start address entry with the street name (even though the system was requesting the city or the category first) because postal addresses are normally given this way. Even experienced users made these types of errors.
2. The system attempted to speed the entry process by using defaults (the last city or category). Not realizing this, the drivers began entering their desired destination using the wrong city or category.
3. Drivers lost track of where they were in the entry process, and the previously entered information had either disappeared from the screen or was not obvious.

2. *I do not know exactly what city my destination is in.*

Often, when entering a destination, the exact city is not known. For example, when forced to choose a city for a point of interest such as Detroit Metro Airport, drivers unfamiliar with the area choose Detroit, but drivers familiar with the area choose a variety of cities near the airport. Additionally, most systems made a distinction between a city and its surrounding townships, but this is a distinction not often made even by local residents or businesses when giving an address.

3. *There were too many extra steps, ok boxes, etc.*

   Each extra dialog box that must be clicked through can add up to two seconds to the destination entry time, since the driver must read the dialog box, decide, and press the ok button. Drivers also suggested moving common settings from the entry dialog to a system preferences dialog.

4. *Did I set the right address? How do I get there?*

   After entering a destination, at least half of the drivers wanted some confirmation of the destination and an overview of the route. Usually, this was achieved by zooming out or by panning the map to trace the route while noting the major roads used. Typical route summary features were too complicated since they were simply a compilation of all the voice commands.

Common Usability Problems with Navigation System Route Guidance

1.   Starting and Ending Guidance

1. *Please proceed to what highlighted route?*

   After a destination was set, systems provided the map view and in the worst case, no instructions, or in the best case, a vague auditory instruction such as "Please proceed to the highlighted route." Often the provided map view contained no labeled streets or the highlighted route was not visible (because of the zoom settings). If the driver was in a parking lot or facing the wrong direction, it might take several minutes to figure out how to reach the beginning of the route.

2. *Recalculating the route? I have not even left the parking lot yet!*

   Often, the driver was required to maneuver the vehicle through a parking lot or out of a driveway to get to the highlighted route. However, the systems would try to recalculate the route each time the vehicle changed direction.

3. *"You have reached your destination." But I'm not even on the right street?*

   Some of the systems appeared to use a circular radius around the destination as the cue to provide the final guidance message. However, in some cases, such as a destination on the corner or on a parallel road, the driver may have been given the message "You have reached your destination," before guidance had completed.

4. *Is my destination on the left or on the right?*

   Upon reaching the destination, drivers often asked this question.

5. *I have reached my destination, but what was the address again?*

   When approaching a new destination, all of the drivers had forgotten the target address, prompting them to ask why the destination address was not displayed or if it was displayed briefly, why it disappeared.

2.   Display Design and Readability

1. *I cannot read text or symbols that small.*

    Text size legibility is governed by both the character height on the display and the viewing distance, which combine to form the visual angle of character height. Although there is much research on this topic (Brooks and Green, 1998, and Nowakowski and Green, 1998), all of the systems suffered from text that was initially too small to read.

2. *There is too much clutter on the map. The information I want is being overlapped.*

    Clutter on the map generally became an issue under the following conditions:

    1. The driver had turned on extra labels (such as ATM's or restaurants) while in a less populated area but then entered a city center.
    2. Using the reversed (night) color schemes gave the impression of more clutter.
    3. The use of 3D or perspective views increased the map clutter as these views compress the advanced information (street names and graphics) towards the top of the screen.
    4. Too many streets were labeled. Based on driver comments, the following table of priorities was constructed:

Priority	Directive
1.	Label all streets used along the calculated route.
2.	Label all major cross streets that are shown on the map.
3.	Label one or two cross streets before a turn.
4.	Label one or two cross streets after a turn.
5.	Labeling cross streets is preferred to labeling parallel streets.
6.	Any landmarks labeled should be highly visible in the real world, i.e., label the McDonalds instead of the small café in the strip mall.
7.	Allow other labels, icons, or graphics only when the clutter is minimal.

3. *A picture is worth 1000 words when it comes to describing spatial information.*

    Drivers preferred that spatial information be represented graphically, and thus graphical countdown bars were preferred to numeric countdown displays and turn arrows were preferred to reading text such as "Turn Right" on the screen. Another example of this principle is shown in Figure 1.
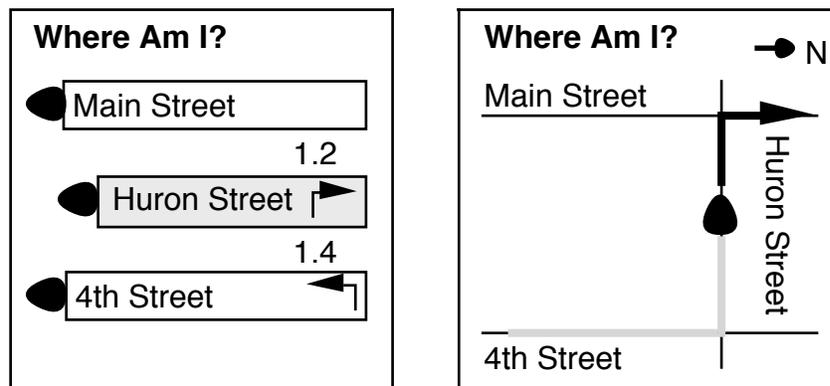
Figure 1. Most drivers spent up to a minute (often unsuccessfully) trying to interpret images like the one on the left while the simplified image on the right conveys the same information more quickly.

4. *The voice said…but the display shows…*

Brooks, Nowakowski, and Green (1999) found that drivers always glance to the display after an auditory alert, and usability comments were often made regarding inconsistencies between the voice commands and the display. As an example, the auditory instructions described a turn in three tenths of a mile, but the turn display only showed the last 500 feet before the turn. Since the entire distance to the turn was not visible when driver first glanced to the turn display, the drivers tended to underestimate the distance to the turn and executed the turn several streets too early.

5. *The roads were not labeled in the turn display.*

Some of the systems used a map view to depict a turn. However, without labeling the critical streets, the map added complexity (over a simple turn arrow) without information.

5. *The roads were not labeled in the turn display.*

Some of the systems used a map view to depict a turn. However, without labeling the critical streets, the map added complexity (over a simple turn arrow) but no critical information needed to make the turn decision.

6. *Oops, I was waiting for the countdown to reach 0 as I drove by the street.*

When the target road was difficult to locate, the frequency of glances to the display increased. A majority of drivers were even observed to fixate on the display, in several cases, driving right past the street waiting for the countdown reach 0 before returning their full attention to the road.

3.   *Voice Commands and Audio Guidance*

1. *How far is a short distance?*

The use of vague terminology (such as "in a short distance" or "ahead") lead to several wrong turns or panic invoked actions (unsafe lane changes, etc) occurring 5 to 10 seconds after the voice instruction was given. Drivers usually interpreted ambiguous turn instructions to mean turn immediately. Drivers preferred when the system used concrete wording such as "next right turn" or "In 3 tenths of a mile, right turn onto I-94 East."

2. *What fork in the road?*

Drivers became agitated, confused, or adversarial towards the navigation systems when the system used the incorrect terms to describe the road geometry. The phrases fork, merge, and at the end of the road were often overused and incorrectly used.

3. *Advanced warnings of non-standard geometry make no sense out of context.*

Telling the driver, "In 2 1/2 miles, keep to the left or second left turn," generally leaves the driver confused for 2 1/2 miles trying to figure out what the system meant by that instruction.

4. *I can't remember that much information.*

A study by Fleming, Green, and Katz (1998) on listening to traffic messages found that regardless of the message length, drivers only reliably remembered an average of four key terms from the message. The longest messages provided by a system contained up to six key pieces of information, suggesting the need to balance the amount of information given across messages.

5. *I want to know what is next after I finish my turn.*

Within a few seconds after completing a turn, drivers requested to know what the next turn would be. Although most systems provided this type of message, there were numerous cases where the systems suppressed this message, prompting comments such as "I'm waiting" from the drivers.

6. *The location of the final turn message depends on how fast I'm driving.*

Most of the systems appeared optimized for in-town driving (30-35 mph) when giving the final turn message. However, when traveling on roads at 45 mph, instances occurred where the final turn message came too late (such as several seconds after the start of the left or right turn lane). Similarly, when traveling slower, 25 mph, there were instances where the turn message came too early, causing the drivers to turn too soon or to think that they have missed the turn. Both George, Green, and Fleming (1996) and Campbell, Carney, and Kantowitz (1997) published guidelines on this issue.

7. *The timing for freeway messages should be different than for street messages.*

The timing of the final freeway exit message varied widely, in part, because of the different reference points possible (beginning of ramp, end of ramp, etc). Unfortunately, this message often came long after the drivers had exited the freeway.

8. *Sometimes the system repeats itself too much.*

The use of long messages combined with short successive turns often lead to the system repeating the same information three or four times in the span of a minute or two as demonstrated below where "at the end of the road" was repeated four times:

1: In about 2 miles, exit on your right.
2: In about 1 mile, exit on your right, then left turn at the end of the road.
3: Exit on your right, then left turn at the end of the road.
4: In about 1/4 mile, left turn at the end of the road.
5: Left turn at the end of the road.

The following suggestions were made by drivers:

1. Successive turn information should be provided with the final turn message, but excluded from the after-turn and advance warnings.
2. If the name of the target street (or expressway) is given, it should be given in the advanced warning message only.
3. Modifiers, like "at the end of the road" do not need to be in every single message.

4. Routing and Rerouting

1. *I think I made a wrong turn, but I do not know what to do about it.*

If a driver makes a wrong turn and was unsure about the turn, they usually realized the mistake within 4-7 seconds. If the driver did not know what to do next, he or she would give the system about 30 seconds before assuming it was broken.

2. *I think I missed the turn. I will just turn around over there.*

If a driver missed a turn, one common strategy was to find a place to turn around (a driveway, a parking lot, a side street, etc.). However, by the time the driver completed their maneuver, the system had already recalculated the route several times.

3. *Why do I have to make a U-turn when I can just…*

   Most drivers became annoyed with the system asked them to make a U-turn when an easier option, such as going around the block, was perceived to exist. This was especially true during the initial guidance.

4. *Stop complaining; I cannot go that way.*

   The amount of feedback provided when rerouting varied from a brief text message that flashed on the screen to tones and dialog boxes requiring driver confirmation. When the systems provided very little feedback, incidents were recorded where the driver made a wrong turn, and the system compensated without the driver ever realizing the error. However, this also lead to cases where the driver became confused after noticing a change in the route without realizing that a wrong turn had been made.

   When the system provided too much output, such as a combination of tones, notices that the vehicle has left the route, intrusive dialog boxes, etc., drivers became adversarial towards the system. "Well, you told me to turn there," or "Stop complaining; I cannot go that way." In the worst case, a system instructed the driver to make a U-turn, but there was nowhere for the driver to turn around for at least a mile with the system recalculating the route every 15 to 20 seconds.

Conclusions

Thus, this paper describes a two pronged approach to identify safety and usability problems with navigation systems. Heuristics analysis is used to quickly identify a large number of problems. The reliance on multiple human factors experts and established principles provides a basis for identifying problems and recommending changes. Follow-up testing with small samples provides reinforcing information on the primary problems, expands the variety of problems noted, and provides audio and video records of real users befuddled by an interface, a strong motivation for change.

These methods have been used to identify problems with four navigation systems. Common problems include (1) drivers not understanding what various controls do, (2) confusion about how to navigate an interface (when to hit ok and when to hit back), (3) using the same auditory feedback (beep) for everything so what is being communicated is uncertain, (4) not knowing how to enter an incomplete address, (5) not being unable to find the beginning of a route, (6) text and maps that are too small to read and do not contain critical information, (7) voice commands that are incorrect, vague, or poorly timed, and (8) mistimed rerouting.

Having reached this point, some readers may believe that navigation systems are examples of overwhelmingly bad design because that has been the focus of this paper. However, in the authors' experience, and to give the manufacturers of these systems due credit, this is not the case. It is interesting to note that similar usability problems were encountered in all systems regardless of their price and prestige, but during the usability testing, each tested system still performed satisfactorily under most circumstances. The particular systems tested in this paper were by no means any worse than the industry average at the time of testing. Furthermore, the research described here emphasizes safety and usability during early exposure. Long term use could potentially lead to different results.

Nonetheless, there are still many opportunities to improve the safety and usability of contemporary navigation systems. The proliferation of minor usability problems as described in this paper only highlight the need for a standardized usability testing protocol for in-vehicle navigation systems. It is the authors' hope, that by presenting problems users experience in their own words, designers will gain a better understanding of those problems, and design future systems that minimize such problems.

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Appendix A – A typical Test Route in Ann Arbor, Michigan

Destination 1: Virginia Park, Ann Arbor (Starting from 2901 Baxter Road, Ann Arbor, MI)

Distance to Turn	Turn Direction	Street Name	Number of Lanes	Type* (R,S,C,E)	Comment
250 ft	right	Huron Parkway	2	S	Starts in a parking lot
0.25 mi	left	Plymouth Road	2	S	Road changes name
2.60 mi	right	Main Street	1	C	Non-90-degree turn
0.25 mi	right	Huron Street	2	S	
1.00 mi	left	Jackson Road	2	S	Left fork
0.25 mi	left	Virginia Street	1	R	Successive turn
0.25 mi	right			R	Destination reached

Destination 2: 1208 Prospect Street, Ann Arbor

Distance	Direction	Street Name	Lanes	Type	Comment
0.10 mi	left	Liberty Street	1	R	Starts on Virginia St
1.00 mi	right	Main Street	1	C	Force a detour a block or
0.20 mi	left	Packard Road	1	C	two before Main St.
0.80 mi	left	E. University Ave	1	R	Hard to see street
0.10 mi	right	Prospect Avenue	1	R	Intersects in a curve
0.10 mi	right			R	Destination reached

Destination 3: 2050 Seneca Avenue, Ann Arbor

Distance	Direction	Street Name	Lanes	Type	Comment
0.10 mi	left	Forrest Street	1	R	5-way intersection
0.30 mi	right	Hill Street	1	R	
0.25 mi	left	Oswego Street	1	R	Hard to see street
250 ft	right	Seneca Ave	1	R	Successive turn
250 ft	right			R	Destination reached

Destination 4: 4201 Varsity Drive

Distance	Direction	Street Name	Lanes	Type	Comment
0.10 mi	right	Hill Street	1	R	Starts on Hill Street
1.00 mi	left	State Street	2	S	Passes I-94 Entrance
3.00 mi	left	Ellsworth Road	1	S	
0.60 mi	right	Varsity Drive	1	S	Industrial Complex
0.30 mi	left			S	Destination reached

Destination 5: 2901 Baxter Road

Distance	Direction	Street Name	Lanes	Type	Comment
0.30 mi	left	Ellsworth Road	1	S	Starts on Varsity Dr
0.60 mi	right	State Street	2	S	
0.40 mi	right	I-94	2	E	Entrance ramp
3.50 mi	right	U.S. 23	2	E	Complex interchange
5.00 mi	right	Plymouth Road	2	S	Exit Ramp
0.25 mi	left	Plymouth Road	2	S	
1.00 mi	left	Huron Parkway	2	S	Becomes divided
0.30 mi	left	Baxter Road	1	S	Destination reached

Note: Type refers to the type of road: Residential, Suburban, City, or Expressway