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Safeguards for On-Board Wireless Communications

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Abstract

Telematics, especially wireless-based technologies such as email and web access, are likely to have a huge impact in the future on the driving experience. These applications have the potential of providing a tremendous amount of information to the driver, increasing the functionality of motor vehicles to a significant degree.

In contrast to the optimistic market projections, the safety picture is less positive for telematics as these systems could distract drivers to a significant degree, making driving less safe rather than safer. This paper identifies (1) the problems associated with telematics use (especially for navigation systems and phones), (2) the factors contributing to driver overload (visual demand, cognitive demand, immediacy), (3) why safety initiatives are needed, (4) ongoing safety rulemaking (by organizations such as SAE and ISO) and (5) why a workload manager may be the best solution to safety concerns.

Introduction

Telematics -- navigation, entertainment, communications, safety, security, and other computer and communication based services -- will significantly alter the driving experience. Automobile manufacturers and suppliers look upon telematics systems, applications, and services as a significant source of future revenue (Richardson and Green, 2000). At this point in the U.S., the initiative for these systems is primarily technology pull rather than customer push, though as prices fall and customer exposure grows, the situation should change. One way to reduce hardware costs is to move computation and some data storage off board. For that to occur, low cost wireless communications are needed, communications likely to occur over a high-speed cellular network. Projections for the future all agree that both the market penetration and bandwidth available to the individual customer ("the size of the pipe") of cellular communications will grow in the future. A side benefit of increased bandwidth is opportunities to provide new services, especially those related to web access.

The Problems

Telematics hardware can occupy a significant portion of the instrument panel, requiring openings for large displays, competing for space with other systems (especially heating, ventilation, and air conditioning), requiring space for supporting electronics, and wireways to connect modules. Because of the placement of telematics components, classical issues of impact tolerance and aggressiveness must be considered when telematics hardware is designed. Impact considerations are certainly important to plastics engineers designing instrument panels, the audience for this paper. Impact considerations will not be discussed in this paper as they can be readily addressed using existing means.

A potentially more insidious concern is that these systems have the potential to distract drivers. Operation of these systems requires much more of drivers than conventional interfaces such as for the headlights or the windshield wipers, not only in terms of the demands at any moment, but more importantly, for a much longer duration. Evidence of their distraction potential comes from Japan, where the current telematics products, namely navigation systems and cellular phones, are a huge market success. The success of navigation systems is in part due to the lack of navigation cues in the natural driving environment in Japan – streets are often not named, buildings are numbered chronologically, and the road network is often not gridlike. Furthermore, the high cost of landline calls and the high cost of real estate (causing funds to be diverted to other purchases) all are important in the Japanese situation.

Although there are no legal requirements for the design of telematics systems in Japan, there is a voluntary guideline from JAMA (Japan Automobile Manufacturers Association, 2000), which because of group pressure, is treated as a requirement by the original equipment manufacturers (OEMs) in Japan. Compliance by aftermarket suppliers is inconsistent.

In Japan, unlike other parts of the world, the National Police Agency (NPA) records if a navigation system or a cellular phone was a contributing cause when investigating crashes. Table 1 shows some of the crash statistics.

Table 1. Driver Tasks and Crashes (January – November, 1999)

Cell Phone		Navigation System	
Task	Crashes	Task	Crashes
Receiving Call	1077		
Dialing	504	Looking	151
Talking	350	Operating	46
Other	487	Other	8
Total	2418		205

Since these data have been collected, the use of handheld phones is no longer allowed, and there are reports in significant decreases in the number of cellular phone related crashes (on the order of 75%, Nissan, 1999). This may represent a combination of the elimination of some of the riskier tasks as well as a reduction in the number of calls made and received while driving

(Tsuda, 2000). A clearer understanding will emerge when the next set of crash statistics is released. Readers interested in such data and fluent in Japanese should examine the Japanese version of the NPA web site (http://www.npa.go.jp/) or a prior paper by the author (Green, 2000a) containing translations of selected narratives from the police reports. The narratives are quite convincing in making the point that use of these systems was the primary cause of crashes enumerated in Table 1.

Also with regard to Table 1, notice that the number of navigation system-induced crashes is not zero, even though the JAMA regulation concerning navigation system design is quite limiting, in part because of noncompliant aftermarket products. Second, notice the leading reason for cell phone-related crashes, receiving a call. In part, this is because the cell phone is sometimes in an inaccessible location, a purse or sometimes in a brief case, possibly on the back seat. Normal human behavior is to answer the phone when it rings, often regardless of the risks of doing such. While requiring the use of hands free phones will reduce the risk associated with retrieving the phone, the primary problem is that the act of answering the phone can occur at an inopportune moment, for example in heavy traffic. Likewise, hands free phones have the potential of reducing the dialing-related crashes. However, even if these sources of crashes were to drop to zero, there would still be crashes associated with talking on the phone, and making it easier to place and receive calls while driving could elevate the number of phone conversation related-crashes. Epidemiological data on cell-phone related crashes show that the use of a phone while driving elevates the risk ratio by about 4 (Green, 2000a).

For those who find statistics unconvincing, consider common experience. If a motorist is observed wandering in the lane at night, they are probably drunk, and drinking and driving is illegal because the crash risk is not acceptable. If a motorist is wandering in the lane during the day, they are probably on the phone. If the behavior and consequences of drinking and driving and, driving and phoning are the same, then the constraints should be the same.

Some counter this view by suggesting the driver conversations with passengers and conversations with others on the phone are the same. Those conversations are quite different. A passenger is well aware of the traffic situation and alters what they say and when, especially if they are in the front seat. In fact, in many situations, that passenger functions as a co-driver, for example, checking the mirrors during lane change maneuvers. For those who need further convincing, see what happens when driving a colleague along a known route and a turn is made at an intersection. If not guiding the driver, the passenger will automatically stop talking and scan to see if it is safe to turn.

A person on the phone talking to a driver has no knowledge of the driving situation and converses as if conversation was the sole task. Accordingly, they may flood the driver with considerable detail, detail the driver would normally write down as the conversation unfolds. Making written notes while driving is generally unwise.

Wireless communications not only can send voice, but also can send data. However, there is very little information on the usability of likely applications, email and web access, while driving. In research the author will be describing in detail later this year (Lai, Cheng, Green, and Tsimhoni, 2001), we found that listening to email and CNN news stories minimally interfered with steering when the driving workload was low.

As workload increases, the situation changes. Lee, Caven, Haake, and Brown (2000) reported an experiment in which drivers utilized a voice-based email system while driving a moderate fidelity simulator. They found that response times while following a lead vehicle braking increased significantly, from 800 to 1200 ms for a simple driving situation and from 1200 to 1450 ms for a more complex situation. This smaller increase in the complex situation is the opposite of what might be expected. A subsequent analysis showed that at 55 mi/hr collisions increased by 3.5% for typical headways and a variety of vehicle decelerations while at 35 mi/hr the increase was 38.5%. These were accompanied by increases in collision velocity of 27.3% and 80.7% respectively. These are meaningful changes.

What Are the Sources of Overload?

Three factors need to be considered.

Visual demand is the most commonly cited source of overload for telematics applications. Those unfamiliar with the literature speak of potential problems of looking at detailed complex maps. However, as we have shown for driving in the U.S., simple turn-by-turn displays are the primary and preferred source of visual guidance (Brooks, Nowakowski, and Green, 1998), and glance durations to them tend to be fairly short. Furthermore, for well-designed navigation systems, drivers tend to rely upon the voice guidance, not the visual display.

Our experience is that the primary source of visual demand occurs when searching to scroll through menus (of system options or street addresses) and when searching for letters and numbers (during data entry) on a touch screen. The aggregate visual demand is quite substantial because the time to complete these tasks can be quite lengthy, sometime in excess of 1 minute (Green, 1999c).

Some believe that converting all visual-manual interfaces to voice interfaces can solve the excess demand problem. In some cases, there are technological limitations. For example, continuous, speaker-independent recognition of letters and numbers is beginning to reach desired accuracy levels for use in automotive products. Observations suggest that discrete, character-by-character entry is quite demanding, especially where characters must be said slowly and feedback (usually a beep) is provided after each character is recognized.

Even if continuous recognition is employed, there is still the problem of informing the driver of the options available at any moment. If this is done by a visual display, then a visual demand is created. If the options are spoken to the driver, the driver must listen to them, creating a cognitive demand. Human short-term memory is limited in its capacity and some tasks are ill suited for conversion to voice. To link this with common experience, think of using a complex phone-based interface, say for airlines, and hearing a menu with 8 options. Can people remember option 2 when they hear option 8? Do they ask for the list of options to be repeated? Imagine trying to perform this task while driving.

Finally, even when memory overload does not occur, voice interfaces can create visual demand. For example, Tijerina, Parmer, and Goodman (1998) observed that when destinations were entered while driving using a voice-recognition interface, drivers often looked at the microphone/speaker, not at the road. Although this behavior is contrary to safe driving, it is a natural and expected behavior. In most societies people are taught that it is rude not to make eye contact with their audience. In motor vehicles, only the embodiment of the audience is visible (the voice interface), not the audience, but drivers nonetheless make eye contact with it. Engineers must design interfaces for expected use, how people are likely to behave, even if that behavior is not sensible.

Cognitive demand, in its simplest terms, is how much thinking a driver needs to do about the driving task and the in-vehicle task. Cognitive demands can result from complex spatial task such as planning a maneuver, recalling a list, performing mental arithmetic, comprehending a complex sentence, or other tasks. Even tasks with very simple components can be quite complex if there are a large number of goals to be tracked. Using computer jargon, human factors specialists talk about the size of the goal stack. (Where was I? What is the next step? What is the step after that?)

Cognitive demands are not as well understood in the automotive context as visual demands. As the complexity and feature content of automotive driver interfaces increases, the negative safety implications of cognitive demand will become increasingly important for automotive design.

Immediacy refers to the time period over which a visual or cognitive demand occurs. Immediacy, as exemplified by the ringing phone, has to do with the innate priority of a task, in particular an in-vehicle task. Tasks that interrupt driving pose considerable risks.

Why Safety Initiatives Are Needed?

Some people believe that telematics safety should be ignored, either because it is a driver responsibility (which conflicts with the accepted legal principle of foreseeable use) or that education is the answer. As any engineer knows, the best way to eliminate hazards is to design them out.

The most cogent arguments for safety initiatives were made by Roslyn Millman, the Deputy Administrator of NHTSA at their hearings in July of 2000 (Millman, 2000). Her comments are summarized in Table 2.

Table 2. Millman's Arguments for Action

#	Assertion	Her Response
1	"The genie is out of the bottle" - that potentially distractive devices have invaded the driver's domain so pervasively, attempts to control them now are … ill-advised	This problem will grow larger and more complex. Waiting only increases the difficulty we will have solving it.
2	Eating fast food, applying cosmetics, and other in-car distractions also present risks, so why are we not worrying about them?	… we should not accept one risk because we have yet to address another or because have accepted a particular risk.
3	Hands-free equipment will lessen or eliminate driver distraction.	Hands-free is not risk free.
4	Existing laws are adequate to deter drivers from the inappropriate use of distracting devices.	… existing laws are not necessarily adequate to limit distractions from wireless phones or other electronics.
5	Wireless phones and other devices contribute to highway safety, because they allow people immediately to notify law enforcement and emergency services, reducing their response time, or provide directions to drivers who may be lost or unfamiliar with an area.	… these benefits … in no way reduce the risks from a driver's use of a wireless phone or other devices in a moving vehicle and that is the threat ... Moreover, we obtain these same benefits, if the caller or user is not driving or if only 911 calls are possible in moving vehicles.

What Is Being Done about These Problems?

The first step after defining a problem is to study it and seek solutions. For user interfaces to wireless telematics applications, that step takes the form of human factors research. The author and his research team (and many others) are carrying out such studies (www.umich.edu/~driving). However, the level of expenditures is an order of magnitude less than desired. The lack of data is creating significant problems (1) for product engineers who are guessing at answers to key interface questions and (2) for developers of standards who lack the comprehensive basis for their activities. Nonetheless, exercising prudence, several standard development efforts are underway (Green, 2000b; Rupp, 2000). Much of the recent activity was stimulated by public concern for telematics safety expressed on the NHTSA driver distraction web site (http://www-nrd.nhtsa.dot.gov/driver-distraction/Welcome.htm) which lead to commitments being made (for example by AAM) at public hearings in the summer of 2000. Current activities are summarized in Table 3.

Table 3. Current Safety Initiatives

Organization	Activity
Alliance of Automobile Manufacturers (AAM)	Developing very general guidelines (soon to be released) based on European Union guidelines; will identify long term research needs
European Union (EU)	Developed general ("motherhood") guidelines for human-machine interfaces
Federal Highway Administration (FHWA)	Funded to sets of guidelines for in-vehicle information systems (Green, Levison, Paelke, and Serafin, 1995; Campbell, Carney, and Kantowitz, 1997).
Intelligent Transportation Society of America (ITS-A)	Board level task force on driver distraction formed, to present at U.S. House of Representative hearings
International Standards Organization ISO TC 22/SC 13/WG 8 (parallel to CEN 278 WG 10)	Working on international standards for dialog management, suitability for use while driving, message priority, and accessibility while driving (draft and working draft standards)
Japan Automobile Manufacturers Association (JAMA)	Developed human—machine interface guideline used by OEMs in Japan
National Highway Traffic Safety Administration (NHTSA), U.S. Department of Transportation	Sponsored Internet forum that identified public sentiment for constraints on cell phones; sponsored workshops on research needs (Westat, 2000); also funding program (Crash Avoidance Metrics Partnership-CAMP), 3 year effort to develop workload metrics to start in 2001
Society of Automotive Engineers (SAE)	Developing standards for accessibility while driving (SAE J2364, "the 15-second rule"), compliance calculations for SAE J2364 (SAE J2365), and message priority (SAE J2395)

In the short term, SAE and ISO activities will have the most impact. SAE Recommended Practice J2364 (Green, 1999b, Society of Automotive Engineers, 2000b) specifies what drivers are allowed to do with a navigation system having visual displays and manual controls, though the rule makes sense, in principle, for any driver interface with visual displays and manual controls. That rule states, "Any navigation function that is accessible by the driver while a vehicle is in motion shall have a static total task time of less than 15 seconds." …"The total task time measured in a stationary vehicle, buck, or mock-up in which a subject is only performing the task of interest. " Timing starts when the driver's hand leaves the steering wheel and ends when feedback from the last step is provided. Thus, for entering a destination, timing begins with the interface displaying the home screen and ends when route guidance is provided. Portions of that sequence, such as entering just the street address, are not considered a task since no useful guidance can be provided from that information alone.

Compliance with the rule is determined by having a small sample of carefully selected drivers (10 or less between the ages of 45 and 65) who use the interface 3 times after 5 practice trials. All but a few of the subjects must complete task in less than 15 seconds.

This rule was established to provide a simple, low cost, reliable, and valid method for assessing safety. There are a significant number of studies in the literature showing that static task time and eyes-off-the-road time are well correlated, which in turn is correlated with crash risk. (The more one looks away from the road, the greater the crash risk.)

The 15-second limit was selected as a compromise. There is significant evidence that use of conventional controls and displays (wipers, headlights, etc.) with total task times of 3 to 5 seconds lead to a minimum of crashes, while navigation tasks (that can take a minute or more) are of concern. The human factors literature suggests that tasks on the order of 9 to 12 seconds, depending on the study and measure, are at the limit of what should be performed in a moving vehicle. There is no guarantee that task times requiring less than 15 seconds are safe or that tasks in excess of 15 seconds are unsafe, but the 15 second criterion represents a reasonable starting point. In many ways, selecting the time limit parallels selecting a maximum acceptable blood alcohol concentration (BAC) to determine when a driver is too intoxicated to drive (currently .08 in the U.S.). Increasing the BAC increases the likelihood of crash, but there is no magic point at which performance dramatically degrades. The same is true for static task time.

The rule does not say drivers can continually look at a display for 15 seconds. In fact, when the 15-second static task is carried out in a driving context, it usually takes longer (20-25 seconds) and is segmented. Analyses of the crash risk of visually demanding interfaces by the author have shown that the major safety benefits come from reducing the total task time from no constraints to 15 seconds. Additional constraints on glance duration result in only very minor reductions in crash risk.

Supporting J2364 is SAE J2365, still under discussion (Green, 1999a, Society of Automotive Engineers, 2000a). J2365 provides estimates for various types of keystrokes, mental activities, and other actions (Table 4). Given a step-by-step description of a driver's task, J2365 provides a method to quickly estimate total task times using a spreadsheet. Depending on the task complexity and spreadsheet preparation, those estimates can be generated in minutes to hours. The enormous advantage of J2365 is that task times can be estimated when the design is still a "back of the envelope" concept, that is, in the early stages of design when interface modifications are trivial to make. Evaluations made late in design, when working hardware and software are available, are unlikely to lead to any significant changes to promote safety. Those changes are just too costly.

Table 4. Operator Times from SAE J2365 (seconds)

Code	Name	Description	Time (s)	Adjusted Time (s) (Note 1)
Rn	Reach near	from steering wheel to other parts of the wheel, stalks, or pods	0.31	0.56
Rf	Reach far	from steering wheel to center console	0.45	0.81
C1	Cursor once	press a cursor key once	0.80	1.44
C2	Cursor 2 times or more	time/keystroke for the second and each successive cursor keystroke	0.40	0.72
L1	Letter or space 1	press a letter or space key once	1.00	1.80
L2	Letter or space 2 times or more	time/keystroke for the second and each successive cursor keystroke	0.50	0.90
N1	Number once	press the letter or space key once	0.90	1.44
N2	Number 2 times or more	time/keystroke for the second and each successive number key	0.45	0.81
E	Enter	press the enter key	1.20	2.16
F	Function keys or shift	press the function keys or shift	1.20	2.16
M	Mental	time/mental operation	1.50	2.70
S	Search	search for something on the display	2.30	4.14
Rs	Response time of system-scroll	time to scroll one line	0.00	0.00
Rm	Response time of system-new menu	time for new menu to be painted	0.50	0.50

Note 1: The final column shows the data adjusted for the test user population (55-60) using the 1.7 multiplier (where appropriate).

In parallel with SAE work are activities of the International Standards Organization, in particular Technical Committee 22, Subcommittee 13, Working Group 8 (Ergonomics of Road Vehicles – Transport Information and Control Systems). As noted in Table 3, they have been developing standards for message priority, dialog management, and other purposes, and have a task force addressing the issue of driver distraction. At this point, Working Group 8 is seeking to integrate the U.S. 15 second rule, the JAMA regulation, and German proposals for an occlusion-based procedure into a single evaluation method suitable for broad use. That effort is hampered by a lack of data comparing the alternative evaluation methods.

Noteworthy from all of this activity is the lack of formal action on voice interfaces. In part, that is because of the lack of research data on specific tasks, but also a lack of speech experts on the SAE and ISO ergonomics committees. At this point, many countries prohibit the use of phones while driving while others require the use of hands-free phones. In the U.S., several communities have banned the use of cell phones while driving and discussions are starting in several cities (Los Angeles, Chicago, New York) about constraints on cell phone use. Similarly, most states have had bill proposed but none have passed. (See Hahn, Tetlock, and Burnett, 2000 for a status report.) Clearly, the action of a single state or city could have significant implications for voice-based telematics systems. The lack of an industry consensus standard that has real safety implications only invites the cities and states to act, and could lead to national regulatory disarray that would negatively impact the marketing of voice-based telematics systems, applications, and services.

The Ultimate Solution – A Workload Manager

While the rules being developed that will protect motorists, they can be very restrictive as some are based upon assumptions of reasonable worst case conditions. There is significant manufacturer and supplier interest in a more flexible approach, one that permits drivers to do a wide range of tasks when the driving workload is low, but provides constraints when the workload is high. This flexibility can be achieved by a workload manager (Michon, 1993), software and hardware that will assess the driving demands and driver capabilities on a moment-to-moment basis, and regulate the flow of information to the driver accordingly. So, for example, incoming cell phone calls might be automatically routed to an answering machine in heavy traffic, but permitted when no traffic is present on a straight road.

The sensing capabilities needed by a workload manager are or soon will be available in luxury vehicles, vehicles for which a manager is most needed. Those vehicles will have navigation systems, systems that know where the vehicle is located and have the information needed to compute the demand of driving due to road geometry. The adaptive cruise control will sense nearby vehicles and provide information about traffic. The clock will provide information about the time of day and, combined with the state of the headlight and wiper switches serve as a basis for visibility estimates. The traction control system will be able to provide data on the condition of the road surface. The speedometer knows how fast the vehicle is moving. Finally, steering wheel and throttle sensors, along with the driver personality module in the key, will provide information about the age and driving capabilities of the driver. Thus, all of the inputs needed by a workload manager will be available. Missing are the rules used to combine the data, rules that need to be developed based on research. Unfortunately, the research needed for that purpose is not being conducted, and many years of research will need to be completed before such software could be developed. The research needs are well understood (Sloss and Green, 2000).

Closing Thoughts

The automotive industry recognizes that future revenue largely depends on the success of telematics, especially systems that rely upon wireless communications. Such systems have the potential of vastly improving vehicle safety and adding significantly to the comfort and convenience of motoring. However, these systems also have the potential of overloading drivers, and a consequence, significantly adding to the risk of driving. The critical element is the driver interface.

Recognizing the crash risk due to visual demands, cognitive demands, and the immediacy of in-vehicle tasks, numerous bodies are developing guidelines, recommended practices, and safety standards affecting interface design. Current activities of SAE and ISO are most important.

Some believe that rather than focussing on regulations, simply making all driver interfaces voice based will solve the overload problem and provide the desired levels of safety. Voice interfaces can be beneficial, but only in some circumstances.

In the long run, the ultimate solution is to develop workload managers that regulate information flow to the driver in response to the driving situation. However, both short-term activities to develop standards and long-term activities, such as the development of workload managers, are hampered by a lack of a research basis for decisions. There are no signs that the funding necessary, an order of magnitude increase over the current situation, will occur, and this should be a significant concern to organizations that see a future in telematics.

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