DEVELOPMENT OF A DRIVER AWARE VEHICLE FOR MONITORING, MANAGING & MOTIVATING OLDER OPERATOR BEHAVIOR

Bryan Reimer
MIT AgeLab & New England University Transportation Center
77 Massachusetts Avenue - Rm E40-291
Cambridge, MA 02139
617-252-2177, reimer@mit.edu

Joseph F. Coughlin
MIT AgeLab & New England University Transportation Center
77 Massachusetts Avenue - Rm E40-279
Cambridge, MA 02139
617-253-4978, coughlin@mit.edu

Bruce Mehler
MIT AgeLab & New England University Transportation Center
77 Massachusetts Avenue - Rm E40-291
Cambridge, MA 02139
617-253-3534, bmehler@mit.edu

Abstract

We present research in progress to develop an "Aware" vehicle concept to improve operator performance, mobility and safety. The Aware Vehicle project, in part, seeks to develop systems that communicate with the infrastructure, monitor the operating environment and detect operator state. A further component of this system is informational feedback to the driver that will inform the driver of their relative wellbeing, enhancing their awareness of the operating environment, thus enhancing their capacity to self-regulate and improve their driving. Our approach emphasizes context aware technologies and their possible capacity to monitor driver performance, manage workload, and motivate safe driving behaviors of passenger car and commercial drivers across the lifespan are discussed. We conclude with questions and implications for future research and practice.

Keywords

Intelligent Vehicles, Sensor Fusion, Driver State, Feedback, Older Driver, Safety

CONTEXT AWARE TECHNOLOGIES & AN AGING POPULATION: SEAMLESS SUPPORT FROM THE HOME TO THE CAR

Context aware technologies employ sensors and other informational sources to inform users and/or systems about the operating environment and activities within a given domain. Advanced implementations of these systems will increasingly seek to integrate information concerning the physical, physiological and psychological dimensions of the user. The integration of these three dimensions enables the output of context aware, and other ambient intelligence systems, to provide enhanced monitoring and reporting to a third party on the well-being or behavior of a target population in the home, hospital or workplace. This context rich information can better inform the management of activities or resources and ultimately the support and motivation of certain behaviors that improve overall wellbeing (7). Less work, however, has been done in mobile environments – such as passenger vehicles, motor carriers, rail and other transportation modes – that would benefit from an integrated approach to monitoring, managing, and motivating enhanced operator behavior (6), although there is an emerging body of work in this area (2, 13, 18, 19).

Intelligent transportation systems (ITS) have demonstrated considerable promise in improving the management of highway systems and enhancing safety. We seek to build upon current ITS applications and United States Department of Transportation Initiative's (IVI) concepts to integrate and present data about the physical world to drivers and system operators to further integrate context aware systems.

In addition to discussing the role for the development of operator aware technologies in transportation settings, we also suggest the value of active feedback to the operator. Such aware technologies and feedback systems should ideally be based upon the integration of information from the operational environment (vehicle, infrastructure, whether, traffic conditions, etc.) and the state of the driver. The latter may be drawn from observable behavior such as head movements and eye blinks, physiological indices, inferential patterns associated with various vehicle control interactions, and possibly even self-expressed ratings of physical state and emotional state (4). Older operators, in particular, may benefit from such an application due to their desire to maintain their mobility and a demonstrated tendency to self-regulate driving behavior.

OLDER OPERATORS: FUTURE CHALLENGES, NEW OPPORTUNITIES

While significant improvements have been made in traffic safety, there remains an intolerably high fatality rate on the world's roadways. Over 40,000 deaths occur annually in the United States and similar rates are experienced in European countries, Japan and other industrialized countries. The World Health Organization has identified traffic safety as one of the top 10 causes of death over the next few decades. Human performance, and most notably human error, contributes to most of these fatalities and related injuries. The dominant analytical approach to understanding traffic safety factors and points of influence is the Haddon Matrix. The Haddon Matrix divides safety analysis into a nine cell matrix that considers temporal phases (pre-crash, crash, post-crash) and primary contributing factors (driver, vehicle, environment) (12). The role of the driver in the Hadden matrix is particularly relevant to our interest in older operator performance. Choices, either conscious or unconscious, that the driver makes in the pre-crash phase about whether to drive, under what conditions, and how they attend and manage the demands of driving, have major impact on the likelihood and possible severity of an accident.

The literature suggests that older drivers frequently assess and self-regulate their driving behavior, taking into account the environment (e.g. road conditions, weather conditions, other drivers) and their perceived physical and cognitive capacity (6). Sometimes these evaluations are based on extremely limited data, such as "looking out the window" to assess the likelihood of poor weather conditions or reflecting on how they feel today to estimate their ability to drive. This mode of self-regulation is far from optimal. Some older adults, particularly men, tend to over-estimate their capacity; whereas many older women have been found to lack the confidence to adequately rate their capabilities. A loss of confidence that results in an under-rating of one's capabilities often translates into diminished mobility and declines in both quality of life and health (9). A mistake in either direction may risk safety or limit mobility, independence and life satisfaction (9).

In all highly motorized nations, people over 50 are the fastest growing cohort of drivers. Similarly, the average age of professional vehicle operators (transit drivers, truckers, train operators) is increasingly in the late 40's or early 50's. This aging trend will only increase as there is currently a shortage of experienced operators and drivers are expected to remain on the job longer as a result (1). The average driver is now much older and more likely to be managing multiple health conditions (obesity, diabetes, high blood pressure, high cholesterol) as well as multiple medications. More than 100 million Americans of all ages suffer from at least one chronic disease, 60 million manage two, and an estimated 20 million live with three or more (5). Drivers will expect to be able to drive longer – while the needs and desires to operate communication, navigation, entertainment and other devices in the vehicle (multi-tasking) are increasing. Advances in safety technology often result in the impression that driving is safer than it once was; however, the impact of some innovations may not be as great as is commonly assumed. Safety innovations such as automated braking systems (ABS) have been shown to provide less experienced drivers with a feeling that they have a greater margin for error, leaving room for attending to non-driving-centric activities. Older adults often do not fully understand the principles of such "new" systems, are distracted by key features of the implementation, and, as a result, the potential safety benefits are not fully realized.

In this paper, we present an "aware" vehicle architecture that focuses on optimizing the information gained from integrating the three contributing components of the Haddon Matrix with a more comprehensive estimation of the driver's state. We hope this system will (1) provide information that empowers the operator to make optimal decisions about whether or not to drive, as well as to be more aware of their real-time performance; (2) potentially provide additional dynamic information to the ITS infrastructure and the real-time management of the system; and (3) personalize operator behavioral information that can be utilized to enhance driving skills and possibly providing additional motivation for improved performance through mechanisms as qualifying for an insurance discount.

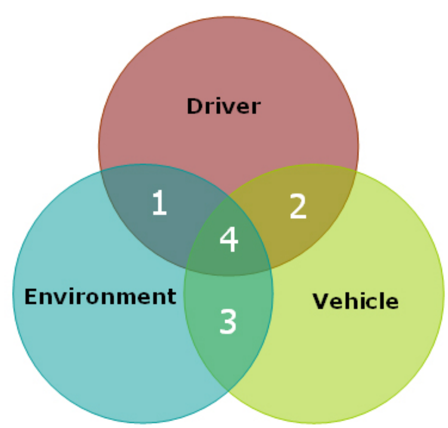

Figure 1. Components of the driving context as detailed by the Haddon Matrix with the overlap between the regions numbered.

Figure 1 details the components of the driving context, as defined by Haddon, with the fusion of the three components highlighted. Integrating components of the Haddon Matrix to develop new automotive safety systems is not a novel concept (8). Transportation human factors research has been traditionally defined around infrastructure improvements that optimize the overlap between the environment and driver (region 1). Passive safety systems that largely target the driver-vehicle interface are highlighted in region 2. Technology development to support modes of automated driving that were first explored in the 1980's and continued through the three stages of DARPA Grand Challenge fall in region 3. Although taking the driver out of the loop may be the ultimate goal, it is unlikely that in the near future drivers will be willing to completely relinquish control or that the infrastructure will be developed to permit fully autonomous vehicles to interact with each other. Thus, the overlap of all three components of the driving context (region 4) is the area most critical to further improving traffic safety. Many active safety systems have been developed to target this white space. However, the implementation of these technologies are non-standardized and frequently do not take into account the older operators' mental model of the driving task.

The increasing complexity of new driver interfaces and the aging of the driver population combine to present a unique challenge to the design of future vehicle systems that accommodate the diverse skill sets and experiences of operatories across the lifespan. While others have begun to conceptualize methods of managing these issues (3), the increased number and proportion of drivers over age 50 present a new but manageable challenge on roadways worldwide that is yet to be considered in these models.

Increased vehicle system sophistication, complexity of the overall driving environment, and the growing range of devices carried into the vehicle, are converging with an increase in the diversity of operators. This diversity is characterized by multiple chronic diseases, multiple and interacting medications, as well as varying degrees of understanding of how to properly interact with evolving semi-automatic or automatic safety systems. Taken together, changes in the environment (density, speed, complexity of visual space), vehicle (number & complexity of controls, multi-tasking distractions) and the operator (health status, aging) are increasing the challenge for the operator to accurately judge their own physical and cognitive capacity and situational awareness and to act upon that judgment appropriately.

The creative exploitation of available technologies and context aware applications provide the opportunity to dynamically monitor the operator's state and objective performance. Effective access to this information has the potential to enhance the driver's self-regulatory behaviors by increasing their awareness of their own relative wellbeing behind the wheel. For example, just how fatigued are they; are they too distracted from the task at hand; is stress resulting in diminished function? A variety of sensing systems are available to monitor the overall driving context. These systems can be integrated to provide a more robust sensing system designed to manage and motivate operator behavior. In the Aware Vehicle project at the MIT AgeLab, we are exploring these and other concepts aimed at increasing older driver performance, safety, and independence.

DEVELOPMENT OF AN AWARE VEHICLE TO MONITOR THE OVERALL DRIVING CONTEXT

The MIT AgeLab Aware Vehicle project is currently focused on expanding the sensing systems available to detect overt and covert measures of driver state (see figure 2) and on developing models that combine these measures with information from the vehicle and the environment to provide a more comprehensive awareness of the driver's influence on the overall driving context. A software architecture has been developed and integrated with our driving simulator, "Miss Daisy", and in two field vehicles, providing a robust development environment for monitoring, managing and motivating operator performance.

The most comprehensive of the on-road vehicles was developed in collaboration with the United States Department of Transportation's New England University Transportation Center, Ford Motor Company, and AARP. It uses a Volvo XC90 as a research platform for development. The system provides time synchronized measurements of CAN data, forward and rear radar tracking, global positioning data, lane positioning, eye tracking, physiological monitoring and steering wheel grip force, along with audio and video recordings from the cab and the vehicle surroundings to provide a robust representation of the environment, vehicle status, and operator behavior.

Reports on physiological data collection in automotive environments (14) and on changes in visual attention with increasing auditory workload (15) detail early research in driver monitoring using these platforms. Current research focuses on understanding the full challenges and opportunities of context aware applications in mobile, even extreme, environments as they relate to drivers of all capacities and ages.

Three key questions guided this effort:

- What are the key data points from the vehicle, infrastructure, and the operator that provide a comprehensive and integrated assessment of individual operator's situational awareness and management of driver workload?
- How, when, and where is this data most effectively presented to the operator?
- If these data are presented to the operator, will the driver alter his/her behavior in real time as well as inform their overall pattern of driving?

While the overall objectives of the aware vehicle project are years from deployment in consumer level production vehicles, near term implementations of aware technologies are being realized currently. For example, one effort focuses on optimizing techniques for monitoring overt and covert measures of attention and capacity (figure 2), as well as perceived behavior, to provide designers with new tools to optimize human machine interfaces (11). These techniques will help designers consider individual differences in attentional focus and capacity that are present throughout the driving population and that are accentuated with functional ageing.

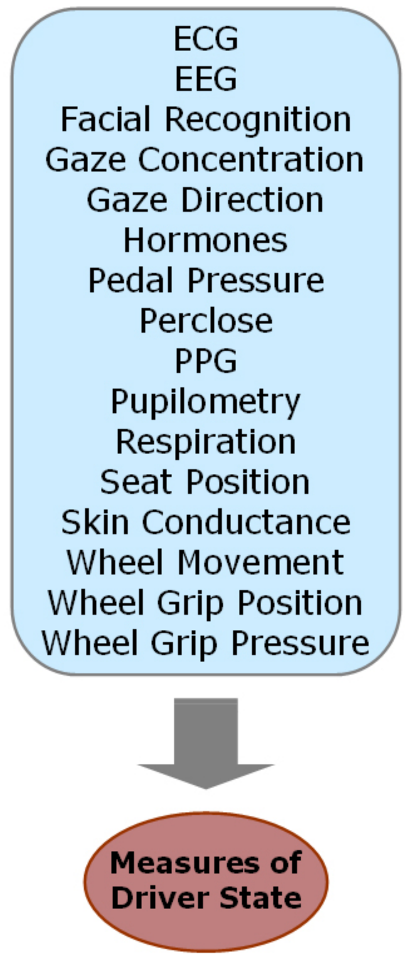

Figure 2. Overt and covert measures of human behavior being considered for an overall assessment of driver state.

ADVANCED DRIVER AND VEHICLE MANAGEMENT SYSTEMS

Concerns over distraction and increased workload arising from the growth of information available to the driver, coupled with the expanding desire for connectivity, has been amply raised in both the academic and popular literature. The ageing of the operator base only adds to the need for new methods of managing the demands and attentional requirements of modern driving. The EU COMMUNICAR, and the follow-on AIDE (2) project, are prime examples of comprehensive projects aimed at exploring methods of managing the demand load by harmonizing and prioritizing the delivery of messages coming from a driving assistance system as well as controlling telematic devices and entertainment functions. The DOT SAVE-IT project (17) in the U.S. is another key example. This work has helped inform the development of first and second generation management systems for production vehicles such as Volvo's Intelligent Driver Information System (3).

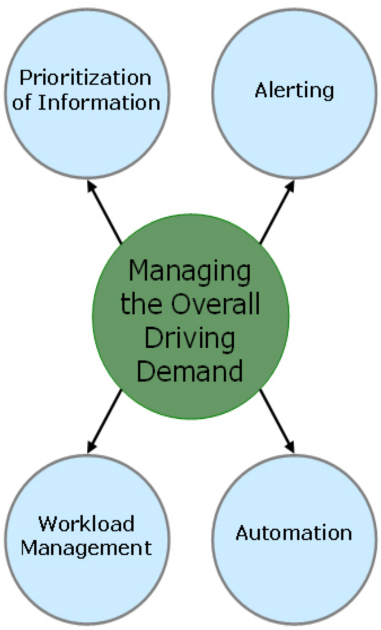

Figure 3. Overview of the potential output of the conceptual driver and vehicle management

Figure 3 provides an overview of deployable management systems ranging from those prioritizing information delivery to reduce workload, to alerting the inattentive or fatigued driver of the need to attend to an immerging situation, to taking over automatic control of braking or steering as appropriate for the context such as an imminent collision. An import factor in the development of advanced management systems is the ability to take the operator's current state / capacity into account. Systems in production now, or expected to come on line shortly, utilize primarily classical performance measures such as headway separation and lane position variables. As noted previously, one focus in the Aware Vehicle project is an exploration of additional overt as well as covert measures to evaluate their sensitivity and utility in extending our assessment of driver state. Data collected to date indicates that certain physiological indices can detect increased cognitive workload prior to the appearance of detectable changes in driving performance measures (14). This information could potentially be used to improve and extend the workload management system's "awareness" of driver state and make adjustments accordingly. Information on other aspects of physical condition required to perform vehicle maneuvers, such as active range of motion and functional flexibility, may also prove useful (16).

FEEDBACK AS MOTIVATIONAL TOOL FOR ENHANCING DRIVER PERFORMANCE AND INDEPENDENCE

Our vision of an Aware Vehicle aims not only to increase the vehicle's awareness of the driver and the environment, but also to provide tools that increase the driver's awareness as well. We see the driver as a potentially active as opposed to passive component in the evolving world of workload management and active safety systems. If the driver is provided with the option for obtaining useful feedback about the status of the driving environment as well as their own state, they can potentially modify their behavior in ways that moderate or eliminate the need for more dramatic intervention by advanced automated control systems.

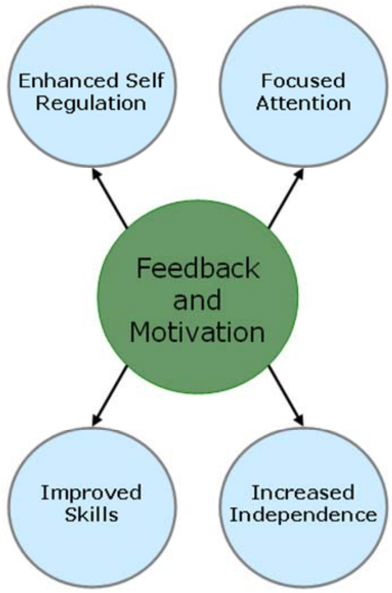

Figure 4. Conceptual output of a feedback and motivation system.

Since critical self-assessment and regulation is a recognized hallmark of the older driver (6), we believe that feedback is critical for motivating optimal driver behaviors.

The potential output a combined active and passive feedback system based on the Aware Vehicle infrastructure is conceptualized in figure 4. Availability of feedback, both real-time and retrospective, is viewed as a means to support learning and motivating driver behavior. How to present this information in the most effective manner is a question currently being explored as part of the Aware Vehicle Program. There are clearly roles for concurrent, delayed, retrospective, and cumulative feedback – all have been discussed in the context of informing drivers of distraction (10). Future research will examine both the interface and impact of dynamic feedback options in and outside of the vehicle. In addition, the extent to which the operator may wish to share information remains an outstanding question. For example, should the data be available to insurers for safety discounts, to on-line personalized driver education programs, etc.?

CONCLUSIONS & FUTURE WORK

The fusion of advanced overt and covert sensing technologies to monitor driver state being explored as part of this research effort will expand the capability of the vehicle as a platform for monitoring performance, managing workload and motivating behavior. Current occupant state sensing systems are largely based upon vehicle dynamics and the operating environment. A few systems have been proposed or are in development that attempt to classify overt behaviors such as eye and head movements (3), however, these efforts focus primarily on fatigue aspects of driver state. We believe that both sides of the arousal curve (figure 5), under-arousal and over-arousal, play a significant role in the optimal attention versus distraction / inattention dimension. Consequently, we are investing significant efforts in understanding the detection and impact of the, inattentive, active distraction and over arousal regions of the model of the relationship.

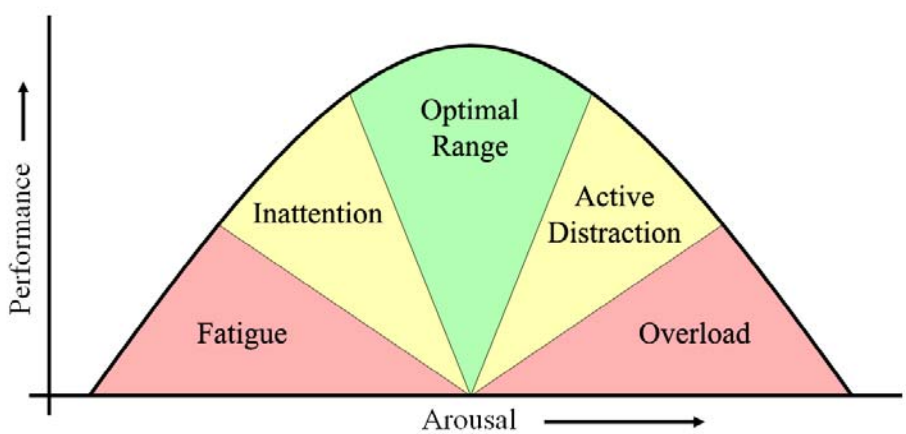

Figure 5. An extension of arousal performance curve to the modern driving context.

We believe that this work will lead to practical tools for technology integration and design by posing and answering some important questions. For example, how might an understanding driver state be used as a as a design tool for future in-vehicle systems as well as a platform to develop vehicle subsystems to improve driver performance? How might real-time feedback and archived driving performance information alter current older driver education curricula, rehabilitation, and appropriate curtailment or extension of independent driving based on a continuous learning and objective assessment model in which the driver is an active participant? Would the availability of such feedback encourage personal health, informed self-regulation and wellness as objectives pursued by the driver and something that government agencies, insurance companies, and families could actively support and reinforce? Would such data provide a potential source of information to provide dynamic insurance pricing that motivates and rewards safe behaviors? Finally, how might national fleets of aware vehicles support enhanced operation and management of intelligent vehicle initiatives underway in the US, Europe, Japan, and around the world, etc.? These and other intriguing questions continue to manage and motivate the Aware Vehicle project.

Acknowledgments

The authors gratefully acknowledge the support of the United States Department of Transportation's Region I New England University Transportation Center at MIT, AARP, Allstate, Ford Motor Company, Healthways, and Volkswagen for their support. We also wish to acknowledge the efforts of Jeff Rupp of the Ford Motor Company, Raj Balsamy of VI Engineering, Alex Narvaez and Vincent Lammers, in developing the MIT AgeLab "AwareCar", a research platform for the continued exploration and refinement of the concepts presented.

REFERENCES

(1) The US truck driver shortage: Analysis and forecasts. In *No.* Global Insight, Inc., prepared for the American Trucking Association, 2005

(2) L. Andreone, A. Amditis, E. Deregibus, S. Damiani, D. Morreale, and F. Bellotti, "Beyond Context-Awareness: Driver-Vehicle-Environment Adaptively. From the COMUNICAR Project to the AIDE Concept." Proc. IFAC 16th World Congress, 2005

(3) R. Broström, J. Engström, A. Agnvall, and G. Markkula, "Towards the next generation intelligent driver information system (IDIS): The Volvo car interaction manager concept", Proc. 2006 ITS World Congress, 2006

(4) S. Chartrand, *Patents; A car that can wink, laugh, cry and get angry. But noting about its passing capabilities*, in *The New York Times*, New York, 2004

(5) J. Coughlin, "Longevity, Lifestyle & Anticipating the New Demands of Aging on the Trasportation Enterprise", *Public Works Management & Policy*, Vol. forthcoming 2009

(6) J. Coughlin, J. Pope, and B. Leedle Jr, "Old age, new technology, and future innovations in disease management and home health care", *Home Health Care Management and Practice*, Vol. 18, 3, 2006, p. 196-207

(7) J.F. Coughlin, "Disruptive Demographics, Design & the Future of Everyday Environments", *Design Management Review*, Vol. 18, 2, 2007, p. 53-59

(8) J.F. Coughlin and B. Reimer, "New Demands from an Older Population: An Integrated Approach to Defining the Future of Older Driver Safety", Proc. The Society of Automotive Engineers Convergence Conference, 2006

(9) L.A. D'Ambrosio, L.K.M. Donorfio, J.F. Coughlin, M. Mohyde, and J. Meyer, "Gender differences in self-regulation patterns and attitudes toward driving among older adults", *Journal of Women and Aging*, Vol. 20, 3-4, 2008, p. 265-283

(10) B. Donmez, L. Boyle, and J.D. Lee, *Designing Feedback to Mitigate Distraction.*, in *In Driver Distraction. Theory, Effects, and Mitigation*, M.A. Regan, J.D. Lee, and K.L. Young, Editors. CRC Press, New York, pp. 519-531, 2009

(11) A. Gruenstein, J. Orszulak, S. Liu, S. Roberts, B. Reimer, B. Mehler, S. Seneff, J. Glass, and J. Coughlin, "City Browser: Developing a conversational automotive HMI", Proc. Work in progress CHI Annual Meeting, 2009

(12) W.J. Haddon, "A Logical Framework for Categorizing Highway Safety Phenomena and Activity", *Journal of Trauma*, Vol. 12, 3, 1972, p. 193-207

(13) J.C. McCall, O. Achler, and M.M. Trivedi, "Design of an instrumented vehicle test bed for developing a human centered driver support system", Proc. Intelligent Vehicles Symposium, 2004 IEEE, 2004, p. 483-488

(14) B. Mehler, B. Reimer, J.F. Coughlin, and J.A. Dusek, "The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers", Proc. Transportation Research Board of The National Academies, 2009

(15) B. Reimer, "Cognitive Task Complexity and the Impact on Drivers' Visual Tunneling", Proc. Transportation Research Board of The National Academies, 2009

(16) B. Reimer, L.A. D'Ambrosio, J.F. coughlin, R.M. Puleo, J.E. Cichon, and J.D. Griffith, "The Effects of Age on Spinal Rotation during a driving Task", *Transportation Research Record* Vol. 2079, 2008, p. 57-61

(17) Save-IT, *SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT) Program.* RSPS/Volpe National Transportation Systems Center (Public Release of Project Proposal), Cambridge, MA, 2002

(18) C. Sorensen, M. Wu, T. Sivaharan, G.S. Blair, P. Okanada, A. Friday, and H. Duran-Limon, "A context-aware middleware for applications in mobile ad hoc environments", Proc. 2nd Workshop on Middleware for Pervasive and Ad-Hoc Computing, 2004, p. 107-110

(19) P. Vidales and F. Stajano, "The Sentient Car: Context-Aware Automotive Telematics", Proc. Fourth International Conference on Ubiquitous Computing, 2002, p. 47-48