Driver Wellness, Safety & the Development of an AwareCar

Joseph F. Coughlin, Bryan Reimer & Bruce Mehler

Massachusetts Institute of Technology
Center for Transportation & Logistics
AgeLab
New England University Transportation Center
77 Massachusetts Avenue, E40-278
Cambridge, MA 02139
(617) 253-0753
coughlin@mit.edu, reimer@mit.edu, bmehler@mit.edu

December 30, 2009

ABSTRACT

Traffic safety has been traditionally addressed through individual improvements to the car by manufacturers; improvements to the driver through education and enforcement; and, improvements to the infrastructure by government. While none of these approaches is incorrect, they are incomplete. We believe that further opportunities for enhancing safety are to be found in creatively exploiting the overlapping and interactive nature of the role of the vehicle, driver, and driving environment in accident prevention and mitigation. We apply wellness, as developed in the fields of health behavior and sports psychology, as an integrating framework to envision driver performance as dynamic and improvable. From this perspective, and building on advances in ambient intelligence, we propose the development of an AwareCar. The AwareCar concept would detect driver state (fatigue or stress); display that information to the driver to improve the driver's situational awareness in relation to road conditions and their own 'normal' driving behaviors; and offer in-vehicle systems to refresh the driver thereby improving performance and safety. Progress in the development of this concept is discussed in the context of the ongoing research, testing, and validation of the MIT AwareCar platform.

WELLNESS AS A DESIGN & ENGINEERING FRAMEWORK

The baby boomers, individuals born between 1946 and 1964, are the nation's largest generation and are now well into middle age and confronting the challenges of aging. Health and active management of their wellbeing occupy a large part of their personal agenda. As the nation's largest generation, their personal attention has made wellbeing a public issue. Wellness, the pursuit of optimal personal performance, is therefore receiving an explosive level of attention from consumers and businesses alike. As one sports apparel manufacturer noted, the aging baby boomers are now experiencing the aches and pains of middle age, but also have the desire and resources to manage them. Typically associated with health, wellness includes the pursuit of total wellbeing and has many dimensions. In addition to basic needs such as access to food, shelter, healthcare, etc., these dimensions include mental wellness, the management of stress; spiritual wellness or a sense of balance in one's life; emotional balance, including mood; reactions to the actions of others; and workplace satisfaction . The ability to achieve these multiple performance goals – optimal health, low stress, balance and emotional wellbeing, is to achieve wellness.

Borrowing from sports psychology, a wellness perspective provides a strategy to achieve optimal performance. This includes personal awareness, a process and continuing motivation to improve, and an on-going assessment of progress. Coughlin (2003, 2007) argues that wellness can be translated into a design feature that can be engineered into products to actively engage the user in the monitoring, management and optimization of their performance in the home, workplace, clinic, retail environment, etc. Wellness, therefore, can been viewed as a system having three functional components: (1) a process and desire for continuous improvement; (2) a means to determine individual wellbeing and progress; and, (3) tools or strategies to improve and achieve optimal performance. The ultimate goal is to refresh and renew the user, improving their overall wellbeing.

Today there are many products that include one, two or all of these elements. A bed manufacturer enables the user to adjust their bed for optimal comfort to 'feel' recharged the next morning. Several sports manufacturers now offer shoes that assure more than comfort; they promise improvement in muscle tone and rejuvenated leg appearance with repeated use. A national electronics retailer sells health monitoring devices along with access to a website to learn more about fitness and to share progress with others, as well as a discount at local gyms, to provide the tools to improve and to be reinvigorated.

While health and wellbeing is important in every part of life's activities, driving may be considered an 'extreme' activity that depends on the awareness and performance of the driver. Today's driving population is older, managing more chronic disease, and balancing competing demands on their attention. How might wellness be applied to the driving experience and engineered into the vehicle? If integrated into the driving experience, could wellness-inspired systems provide improved situational awareness to the driver, reduce impairment from fatigue, stress and distraction, and thereby improve driver performance and overall highway safety?

Advances over the past decade in information technology and embedded intelligent systems are offering new ways to monitor, manage and motivate people in a variety of settings from the home to the workplace (Coughlin, Pope, & Leedle, 2006). Collectively referred to as ambient intelligence, "the application of lighting, sound, vision, domestic appliances, personal healthcare devices and distributed services all cooperate seamlessly with one another to improve the total user experience through the support of natural and intuitive interfaces" these technologies are the foundation to create environments that sense, support and optimize user performance. (Aarts & de Ruyter, 2009). Researchers at the Georgia Institute of Technology, for example, have integrated a wide variety of systems into an 'Aware Home' (Gregory et al., 2000). The Aware Home vision enhances the health, promotes the independence, and improves social engagement of the residents through novel user interfaces, intelligent systems and services that remind them to take medication, monitor their wellbeing and connect them to friends, family and physicians (Coughlin & Pope, 2008). Integrating ambient intelligent concepts with advances in in-vehicle systems presents an opportunity to realize a vehicle that is more than 'simply' a transportation mode, but to transform the car into 'wellness' platform that supports optimal driver performance and improves overall traffic safety.

FRAMEWORK FOR AN INTEGRATED VEHICLE SAFETY / WELLNESS SYSTEM

Figure 1 depicts the overall conceptual framework of the proposed integrated vehicle safety / wellness platform. The framework consists of three wellness-inspired components: 1) detection and ongoing monitoring of driver state, 2) displaying / providing this information to the driver, vehicle systems, and the evolving intelligent transportation system (ITS) infrastructure, and 3) engaging features to alert or calm the driver (refresh) as needed to meet the requirements of the current driving situation.

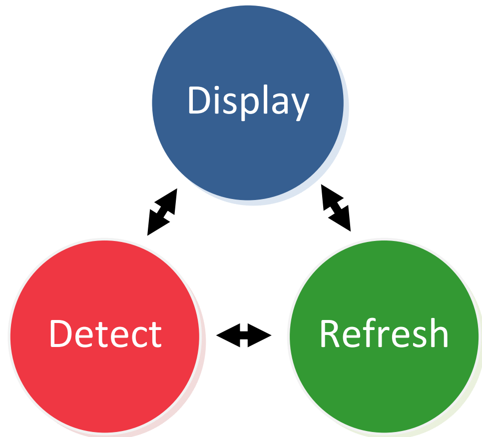

Figure 1: Framework of the MIT integrated vehicle safety / wellness system

This model assumes that the driver is an active participant in the operation and control of the vehicle. While semi-autonomous systems are starting to make their way into production vehicles, it will likely be many years before fully autonomous operation for the entire course of travel will become the norm and that vehicles will only contain passengers. As long as a human being plays a role in the operation of the vehicle, even if this eventually consists of mostly monitoring largely automated systems, the state of the driver (i.e. their attentiveness, trust and comfort in systems decisions, and ability to respond appropriately to changing conditions) will continue to be an important component of safe operation (Brookhuis, de Waard, & Janssen, 2001; Merat & Jamson, 2009; Parasuraman & Riley, 1997).

The quality of an operator's performance is significantly impacted by their level of arousal and ability to attend appropriately to relevant events. The relationship between arousal level and performance has been depicted as an inverted-U shaped curve generally referred to as the Yerkes-Dodson Law (Yerkes & Dodson, 1908; see also Broadhurst, 1959; Duffy, 1962). Underlying this principle of behavior is the observation that both under arousal (fatigue) and over arousal (stress) are associated with decrements in performance. Optimal performance occurs in a range between these extremes where the level of arousal and attention is appropriately balanced for the demands of the task.

Arousal is a broad concept and this same inverted-U relationship can be applied to similar constructs. Figure 2 is a recasting of the Yerkes-Dodson Law relating performance to the level of workload / stress (arousal) and an updated adaptation to driving and similar operational tasks (Reimer, Coughlin, & Mehler, 2009). In this model, both sides of the arousal curve, underload and fatigue as well as overload and high distraction, represent regions of concern. The driver who is fatigued due to lack of sleep or lulled into an inattentive state due to monotonous conditions is at high risk for losing control of the vehicle or to failing to respond to an emerging demand for action. At the other end of the spectrum, overload arising from environmental conditions, distractions, along with any internal stressors that the driver brings with them to the driving environment, can combine to saturate their available resources for dealing safely with the primary driving task. From this perspective, the ability to sense and, as needed, encourage / support the driver in moving to a more optimal state of arousal is one of the next frontiers in automotive safety.

It is important to note that, as with any safety system, there are limits to the extent to which the vehicle systems can protect the driver and those in proximity. The driver who is seriously sleep deprived or otherwise impaired (Horne & Reyner, 1999) or who is so overly aroused or distracted that they cannot effectively attend to the driving task, even with prompts or other support from an advanced safety system, bears ultimate responsibility for recognizing this and either not attempting to drive to begin with or finding a safe way to end the driving task. A vehicle safety system that includes state detection capability can play a vital role in bringing this decrement in capability to the driver's attention.

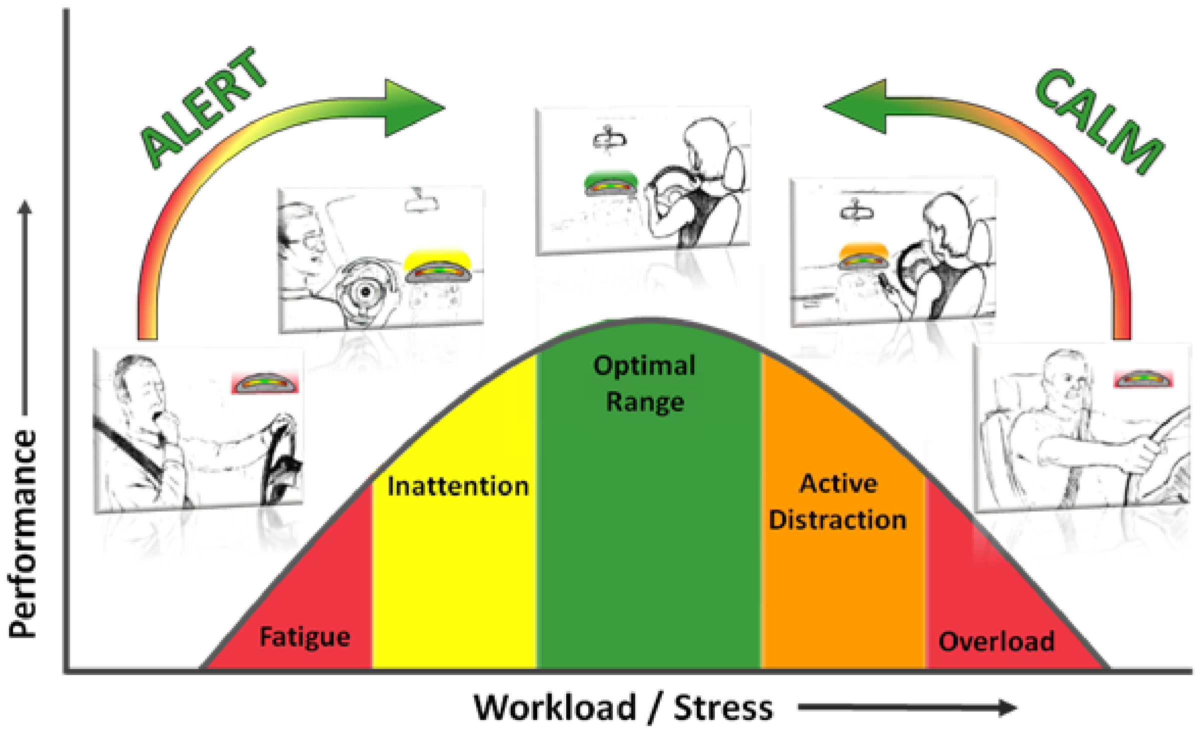

Figure 2: Yerkes Dodson Law adapted to the MIT Wellness Concept

The concept of tuning a component of the vehicle's safety systems in response to current conditions has been an important feature of advanced automotive engineering for some time now. The introduction of electronic stability control is one example in which a vehicle's computer system continuously monitors driving characteristics such as steering, and automatically engages brakes to individual wheels to help the driver maintain control of the vehicle. Driver error is the largest contributing factor to automotive accidents (Brookhuis et al., 2001). A driver's state is a major variable in the capability of an individual to respond to an impending threat. Therefore, exploring methods for assisting in tuning or optimizing driver state based on current conditions seems worthy of serious study and development. The importance of considering the vehicle, the environment, and the driver as interacting components will be taken up in more depth in a moment.

In addition to the primary concern for safety in this model, there is an important derivative benefit from the wellness perspective. Characteristics and actions in the vehicle systems and environment that encourage or support moving the driver from an overload condition to a more optimal operational state involve, by definition, a reduction in the driver's stress level. Similarly, features that encourage movement from a fatigued or inattentive state to a more optimal state of attention involve some form of refreshing or refocusing of attention. In both cases, moving from either extreme on the arousal curve involves moving the driver to a state of more relaxed engagement with the task at hand, which is a key part of any wellness model.

AN INTEGRATED APPROACH TO DRIVER SAFETY

William Haddon, the first administrator of National Highway Traffic Safety Administration (NHTSA), laid out a useful schema that divides accident and injury prevention / mitigation into a nine cell matrix that considers the temporal phases (pre-crash, crash, post-crash) and the primary contributing factors (driver, vehicle, environment) (Haddon, 1972). While Haddon's 'matrix' is a useful framework to understand where interventions might be focused and policy resources allocated, it does not adequately capture the dynamics of contemporary driver safety. We have proposed (Coughlin, 2005; Coughlin & Reimer, 2006; Reimer, Coughlin et al., 2009) a derivation of Haddon's Matrix that emphasizes the overlapping and interacting nature of the role of driver, environment and vehicle in safety and accident prevention, as illustrated in Figure 3. Andreone, Amditis, Deregibus, Damiani and Morreale (2005) are similarly to be recognized for raising the significance of the driver, vehicle and environment interaction in determining safety margins at any given moment.

Current and emerging safety systems have begun to consider and target some aspects of these intersecting regions. For example, adaptive cruise control (ACC), blind spot detection, parking assistance, rumble strips, lane markings, lane departure prevention, and smart airbags all impact two of the three regions. In the case of lane departure prevention systems, the vehicle monitors characteristics of the roadway and autonomously corrects vehicle positioning to prevent off road excursions.

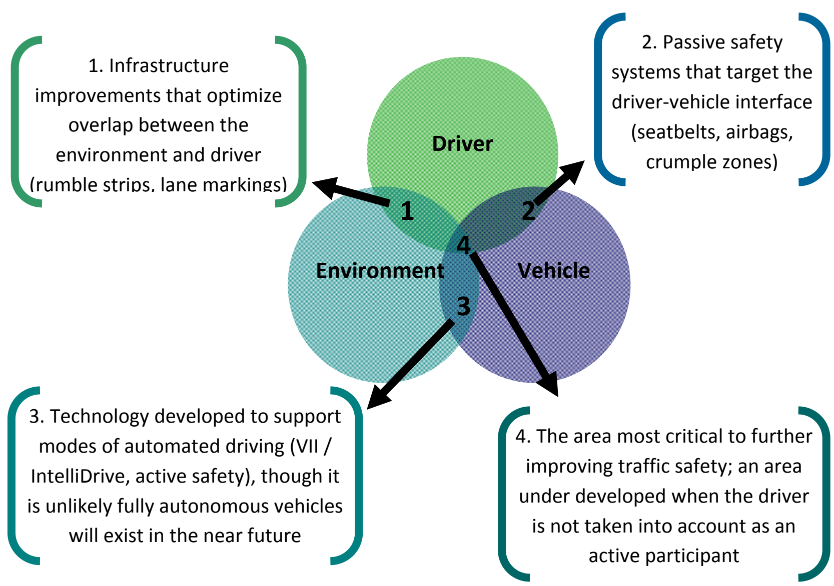

Figure 3: Components of the driving context

In the automated lane departure prevention system example, the driver is essentially a passive component. While such as system offers important safety protections, a potential limitation of such systems is that the driver can be left with a feeling of loss of control, uncertainty about what their role is in appropriately reacting to the automated response and possibly stressed by an unexpected intervention.

Older drivers in particular are more susceptible to confusion and uncertainty in how to react to automated systems as their learned behaviors are often difficult to overcome (Cottè, Meyer, & Coughlin, 2001) without appropriate orientation and education. Consider the case of individuals who learned to drive before the advent of automated braking systems (ABS). A common response for many such individuals upon first experiencing the engagement of ABS in a critical situation is to respond to the unexpected sensations by removing their foot from the brake pedal.

Although taking the driver out of the loop may be the ultimate goal for resolving such situations, it is unlikely that in the near future drivers will be willing to completely relinquish control or that the infrastructure will be developed sufficiently to permit fully autonomous vehicles to interact with legacy vehicles. Designs and supporting information that increase in the driver a sense that the vehicle's systems are assisting them in the process of operating the vehicle safely, as opposed to taking away control of the vehicle, are likely to gain better acceptance and ultimately promote safer operation.

A more complete view of the safety management model shown in Figure 3 would include the driver as an integrated part of this process as indicated in region 4. A full realization would involve efforts on two fronts. The first involves efforts to effectively educate the driver to make them aware of how to most appropriately utilize new safety and driving demand reducing technologies such as adaptive cruise control (ACC) and of vehicle systems expected actions when autonomous or semi-autonomous safety systems are engaged. The second involves making vehicle systems more aware of the state of the driver and making use of this information to encourage the driver to make adjustments in their own behavior so as to reduce or eliminate the need for compensatory or emergency systems to be employed at all.

DRIVER STATE DETECTION

Driver state refers to overall physical and functional characteristics indicative of features such as distraction, fatigue, attentional capacity, and mental workload. State detection can be based upon both overt and covert measures, as indicated in Figure 4. In this model, data on a driver's physiological arousal, apparent emotion, allocation of visual attention, driving style, and driving behavior may be combined with data on vehicle performance and environment conditions to provide individualized and context aware measures of driver state.

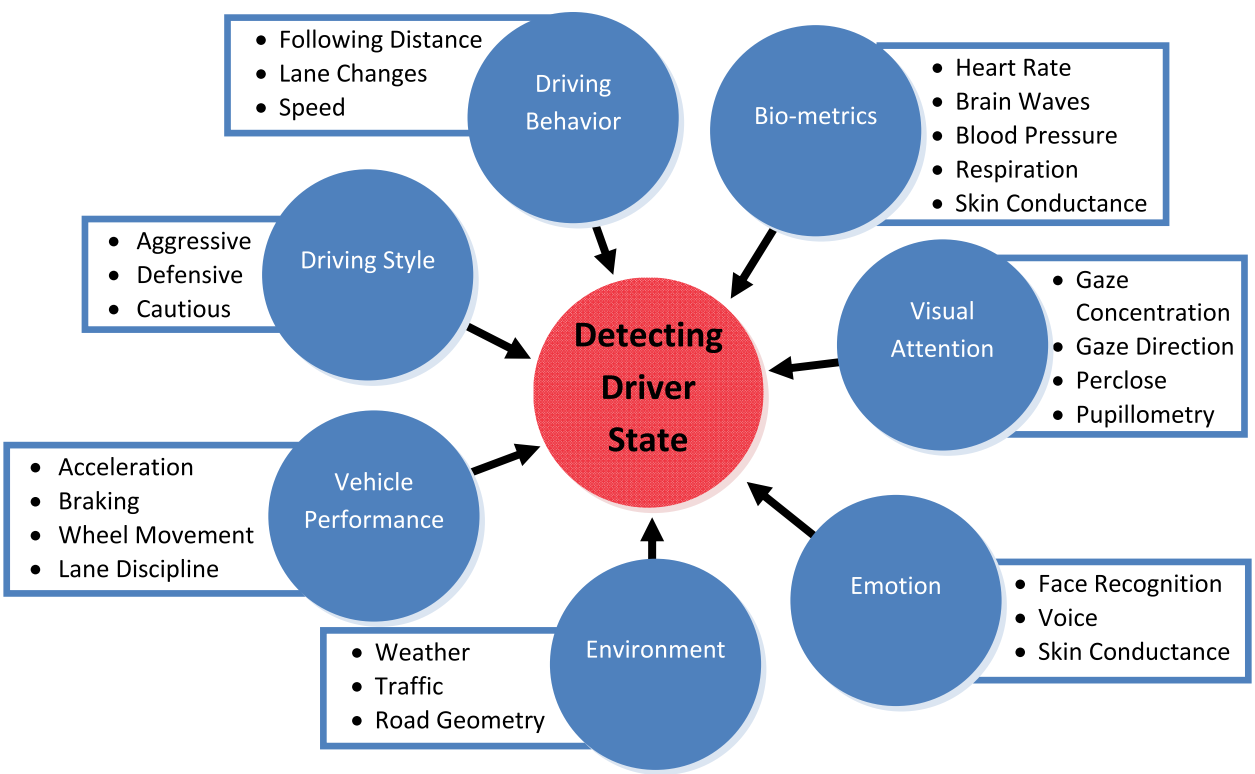

Figure 4: Domains from which inputs for an integrated driver state detection system might be drawn

Research on the selection of appropriate attributes and modeling architectures for state detection is in its infancy (Tan, expected 2010; Vidales & Stajano, 2002). Studies focused on particular domains of state detection largely dominate the literature (i.e. Boyraz, Yang, Sathyanarayana, & Hansen, 2009; Chun-Che, Shih-Shinh, & Li-Chen, 2005; Healey & Picard, 2005; McCall, Achler, & Trivedi, 2004; McCall, Wipf, Trivedi, & Rao, 2007; Pilutti & Ulsoy, 1999; Qiang, Zhiwei, & Lan, 2004). Since 2003, research in our group at MIT has emphasized looking at a broad set of measures including physiology, visual attention, vehicle performance, driving behavior, physical function, health status and environment as inputs to state detection (Mehler, Reimer, Pohlmeyer, & Coughlin, 2008; Reimer, D'Ambrosio, Coughlin, Fried, & Biederman, 2007; Reimer, D'Ambrosio et al., 2008; Reimer, Mehler et al., 2008; Reimer, Mehler, Pohlmeyer, Coughlin, & Dusek, 2006; Reimer & Sodhi, 2006) with a view toward the eventual integration of inputs from across domains.

In collaboration with Ford Motor Company, a formal feasibility assessment of bio-metric based state detection considering a wide range of possible physiological measures was conducted in 2006-2007 in the MIT AgeLab driving simulator "Miss Daisy" (Mehler, Reimer, Coughlin, & Dusek, 2009; Mehler, Reimer, D'Ambrosio, Piña, & Coughlin, 2010). A field assessment platform integrating a broad set of inputs for state detection was proposed (Reimer & Coughlin, 2006) to validate and extend the work carried out under simulation. An instrumented vehicle platform termed the "AwareCar" was developed for the synchronized collection and assessment of inputs to models for driver state detection and was first implemented and field tested in 2007 in a Volvo XC90 provided on loan by Ford Motor Company. Information from each of the domains represented in Figure 4 was included in the data collection stream. Ramon et al. (2008) have also reported work on an integrated platform that includes some of the features of the AwareCar, although visual attention measures based on eye tracking technology and more advanced driving control variables such as those derived from lane tracking were not a part of their system architecture. The MIT development platform also included functionality for the evaluation of display and refresh mechanisms (Reimer, Coughlin et al., 2009).

Initial studies with the vehicle (Reimer, 2009; Reimer, Mehler, Coughlin, Godfrey, & Tan, 2009) successfully confirmed that bio-metric signals such as heart rate, skin conductance and eye movement, selected on the basis of their utility in the simulator (see Mehler et al., 2009 for background on measure selection), can also play an important role in the detection of workload under actual on-road driving conditions. Figure 5 illustrates changes in heart rate and skin conductance with a low, moderate and more difficult cognitive demand added to the driving task (Reimer, Mehler et al., 2009). These differences in psychophysiological indices are consistent with the patterns observed in the simulator (Mehler et al., 2009). In both cases, heart rate and skin conductance are more sensitive at representing incremental changes in workload than are changes in driving performance.

Figure 6 indicates changes in visual attention across the same low, medium and high levels of demand (Reimer, 2009). These data indicate that a more complex, non-linear relationship exists between visual behavior and incremental changes in cognitive load. None the less, under increased cognitive load, drivers restrict the range of their visual scan path and direct visual attention to the center of the roadway. This behavior have been observed in a number of studies and is often referred to as visual tunneling (Harbluk, Noy, Trbovich, & Eizenman, 2007; Sodhi, Reimer, & Llamazares, 2002; Victor, Harbluk, & Engström, 2005). This appears to be a compensatory mechanism associated with an attempt to manage overall workload demands. While there may well be certain load managing advantages to this behavior, it comes at the cost of a loss in peripheral visual information.

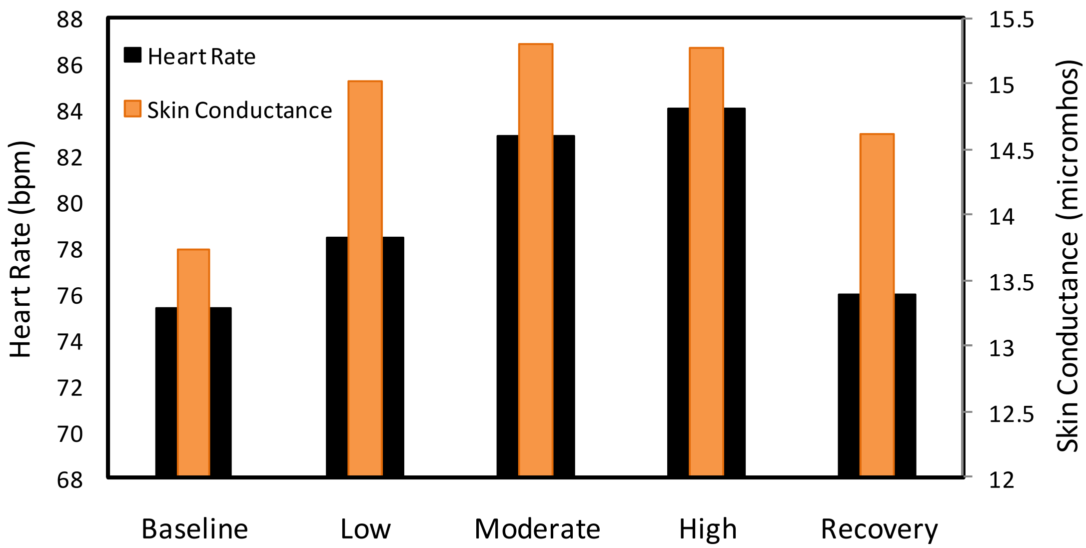

Figure 5: Heart rate and skin conductance reactions to low, moderate and more difficult cognitive demands

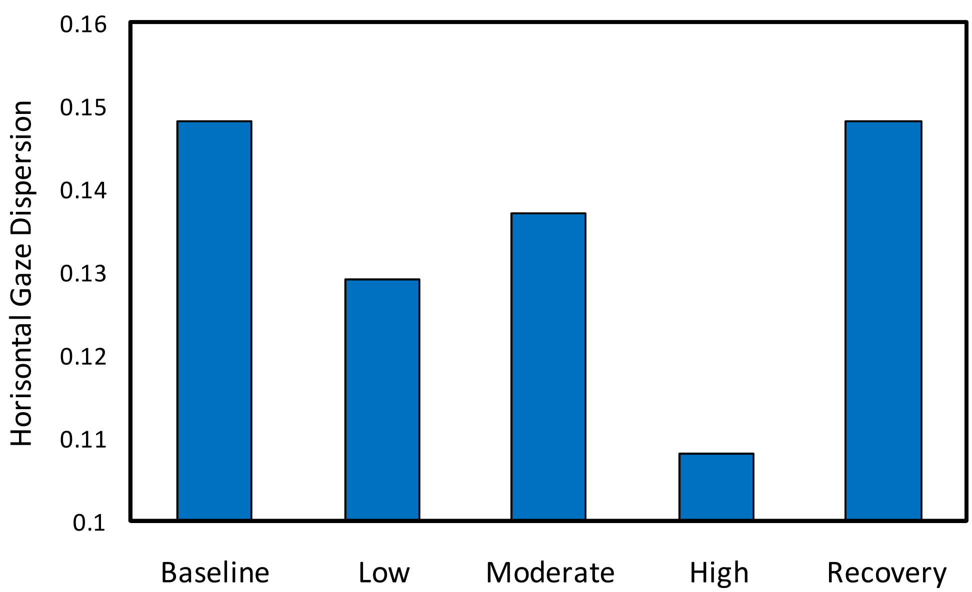

Figure 6: Reductions in horizontal gaze dispersion with a low, moderate and more difficult cognitive demand

More recent data collection has been undertaken to extend these assessments with larger groups of drivers drawn from samples across the lifespan (Coughlin, Reimer, & Mehler, 2009). The data generated as part of this work is providing the depth of observational information that is essential in developing the foundation for creating useful detection algorithms (Tan, expected 2010).

In summary, safety systems that target individual regions of the Haddon matrix are partially incomplete and do not adequately consider the driver's overall arousal level and capacity for handling additional workload. State detection provides a potentially valuable mechanism for integrating information on the driver into the safety system. In addition, measures of the driver's state can provide an individualized indication of the driver's location on the arousal curve (Reimer, Coughlin et al., 2009). Information about the location on the arousal curve can support the display of important feedback to the driver and trigger appropriate alerting or calming features that can help reduce stress, i.e. refresh, and improve safety.

THE DEVELOPMENT OF DISPLAY AND REFRESH

Various methods are being explored to provide drivers with subtle but informative indications of their current operating state. Figure 7 illustrates one implementation currently under evaluation. This prototype concept employs a visual display device (Ambient Orb from Ambient Devices, Cambridge, MA) programmed to change color based upon the output of a state detection system. Other more integrated approaches could involve designing the display component into a form feature of the vehicle's interior, as a component of the main automotive display system, or through a mid-console driver information system.

Figure 7: Illustration of experimental display methodology

Attractiveness and engagement may be increased through creative design language and customization to individual preferences. Design language refers to style characteristics of a brand such as logo's, shape, or other aspects of a vehicle's 'look and feel'. Providing drivers with display options that appeal to their individual preferences are likely to enhance the effectiveness of the interface. An important aspect of the development of this technology will be the creation of displays that communicate without startling or distracting the driver.

In some instances, the display of information alone will likely provide a sufficient cue to prompt drivers to adjust behaviors towards a more optimal state. For example, in Ford's SmartGauge, the number of leaves on a graphic display decreases with higher fuel consumption. This information is intended to prompt the operator to modify their driving style in a more fuel efficient manner. This same principle can be applied to providing information on driver state for purposes of encouraging behavioral change.

In instances where visual information alone is not sufficient to encourage behavior changes, more active alerting or calming technologies may prove useful. These technologies can target other senses through techniques such as haptic stimulation through the steering wheel or seat. Depending upon the side of the arousal curve (see figure 2), the characteristics of the stimulation could vary to appropriately promote alerting or calming (i.e. refresh).

On the extreme low end of the arousal curve (fatigue), sleep is the only fully effective countermeasure (Horne & Reyner, 1999). However, alerting methods such haptics, auditory cues or changes in aroma may help increase the driver's attention for short periods of time. This may provide the additional margin that supports reaching a safe stopping location. At other points along the arousal curve, where the driver has the capacity to attend but is distracted (inattention), alerting stimulation may help re-center the driver's attention. Examples of such inattention range from day dreaming due to monotony to active distraction from cellular phone conversations or other cognitively distracting interactions. In situations of heightened arousal or workload, calming and attention re-centering feedback mechanisms such as changes in vehicle performance characteristics and massage might be tuned to reduce stress.

In all cases, providing the driver with multiple feedback options that can be tailored to individual preferences is critical to both acceptance and effectiveness. Included among these should be the option of opting out of the feedback system. Even subtitle feedback can be distracting to certain individuals. In addition, the sense of having a choice to engage such features is often important to overcoming resistance to experimenting with and accepting new technologies. As with any new technology, education about the function, characteristics, and potential benefits is key to increasing effective utilization.

As mentioned previously, abrupt warnings can be startling; therefore appropriate implementation of the display feature is a critical connection between effective detection and refresh. The integration of detection, display and refresh provides an important step in the evolution of the next generation of driver centric safety systems. Many of the display and refresh methodologies discussed here have been proposed or experimented with as independent in-vehicles systems. As such they may offer useful features. However, in isolation, they do not take full advantage of what may be gained through a system such as proposed here in which state detection helps balance the appropriate level of alerting and calming to encourage optimal performance in the driver.

CONCLUSION, IMMEDIATE BENIFITS AND FUTURE WORK

In summary, this paper outlines a wellness-inspired vehicle concept that proposes to detect driver state, display that information to the driver to modify their behavior, and introduce systems to improve the driver's performance. A key feature of this framework is the detection of driver state as it relates to the inverted-U arousal curve and optimal operator performance. In our vision of this system, information on driver state should ideally be communicated to the driver, vehicle systems, and the transportation infrastructure. Depending on the state of the driver, the vehicle, and the environment, features to alert or calm the driver are engaged as needed. A full realization of this model would involve both the driver being made more aware of the current demands of the driving situation and the vehicle systems being more aware of the state of the driver.

Wellness is found to be a useful design framework to integrate otherwise disparate work in driver performance and vehicle active safety systems. Engineering research efforts to date have emphasized consideration of a broad set of inputs for integration into state detection algorithms. Efforts to identify methods of classifying driver state and evaluations of different display technologies are ongoing. A crucial aspect of the display component of the model will be the development and validation of methods of communicating information to the driver that aid in moving them in the desired direction on the arousal curve without startling or otherwise distracting them from the driving task. Another important concept in the model is the notion of choice that allows the driver to customize feedback options to match their desired style of interaction with the system. Future work aims to focus on the integration of display and refresh systems that, improve driver performance and ultimately highway safety for all.

While it will take some time before the AwareCar concept can be fully realized, there are immediate benefits to the automobile and insurance industries, the government, and the driving public. The work to date on the detection side of the triangle can be put to immediate use. We have demonstrated, both in the simulator and in on-road assessment, that physiological and eye tracking measures can productively utilized as sensitive measures of changes in cognitive workload on the driver. These techniques can be put to use in assessing the relative demand placed on the driver by various features and in-vehicle interface designs. Integrating these assessment methodologies into the development process should aid manufacturers in selecting optimized designs with the least demand on the driver, resulting in greater user satisfaction, increased safety, and less stress.

ACKNOWLEDGEMENTS

Support for this research has been provided by Ford Motor Company, AARP, the Santos Family Foundation and the United States Department of Transportation's Region One New England University Transportation Center. The MIT AgeLab and New England University Transportation Center are actively engaged in a number of related research projects investigating driver distraction, in-vehicle interface development and assessment, and the impact of age and health status on driver capacity and performance. For more information please contact agelab@mit.edu.

SUGGESTED READING

The concepts and data presented here are drawn in part from a number of published sources. For additional background and detail, we suggest reference to the following:

Coughlin, J. F., & Reimer, B. (2006). New Demands from an Older Population: An Integrated Approach to Defining the Future of Older Driver Safety. *Proceedings of the Society of Automotive Engineers Convergence Conference*, Detroit, MI.

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

Mehler, B., Reimer, B., Coughlin, J. F., & Dusek, J. A. (2009). The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record, 2138*, 6-12.

Reimer, B. (2009). Cognitive Task Complexity and the Impact on Drivers' Visual Tunneling. *Transportation Research Record, 2138*, 13-19.

Reimer, B., Coughlin, J. F., & Mehler, B. (2009). Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior. *Proceedings of the ITS-America*, Washington, DC.

REFERENCES

Aarts, E., & de Ruyter, B. (2009). New Research Perspectives on Ambient Intelligence. *Journal of Ambient Intelligence and Smart Environments, 1*(1), 5-14.

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

Boyraz, P., Yang, X., Sathyanarayana, A., & Hansen, J. H. L. (2009). Computer Vision Systems for 'Context-Aware' Active Vehicle Safety and Driver Assistance. *Proceedings of the Enhanced Safety for Vehicles (ESV)*, Stuttgart, Germany, 13-15.

Broadhurst, P. L. (1959). The interaction of task difficulty and motivation: The Yerkes-Dodson law revived. *Acta Psychologica, 16*(321-338).

Brookhuis, K., de Waard, D., & Janssen, W. H. (2001). Behavioural impacts of Advanced Driver Assistance Systems–an overview. *European Journal of Transport and Infrastructure Research, 1*(3), 245-253.

Chun-Che, W., Shih-Shinh, H., & Li-Chen, F. (2005). Driver assistance system for lane detection and vehicle recognition with night vision. *Proceedings of the Intelligent Robots and Systems, 2005. (IROS 2005). 2005 IEEE/RSJ International Conference on*, 3530-3535.

Cottè, N., Meyer, J., & Coughlin, J. F. (2001). Older and younger drivers' response to collision warning systems. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, Santa Monica, CA., 277-280.

Coughlin, J. F. (2003). *Wellness as a Business Strategy: AgeLab White Paper & Workshop*. Cambridge, MA.

Coughlin, J. F. (2005). Not your father's auto industry? Aging, the automobile, and the driver for product innovation. *Generations*(Winter 2004-2005), 38-44.

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

Coughlin, J. F., & Pope, J. (2008). Innovations in Health, Wellness & Aging-in-Place: Development of a Consumer-Centered Approach to Intelligent Home Services. *IEEE Engineering in Medicine & Biology*(July-August), 47-52.

Coughlin, J. F., Pope, J. E., & Leedle, B. R. (2006). Old age, new technology, and future innovations in disease management and home health care. *Home Health Care Management and Practice, 18*(3), 196-207.

Coughlin, J. F., & Reimer, B. (2006). New Demands from an Older Population: An Integrated Approach to Defining the Future of Older Driver Safety. *Proceedings of the Society of Automotive Engineers Convergence Conference*, Detroit, MI.

Coughlin, J. F., Reimer, B., & Mehler, B. (2009). *Stress State Detection While Driving Using Physiological Measures: On-Road Validation and Evaluation of Age and Gender Relationships (Driver Wellness, Impairment & the Development of a Driver AwareCar: Technical Report to Ford Motor Company)*. Cambridge, MA: Massachusetts Institute of Technology.

Duffy, E. (1962). *Activation and behavior*. Oxford, England: Wiley.

Gregory, D. A., Christopher, G. A., Aaron, F. B., Irfan, A. E., Blair, M., Elizabeth, D. M., et al. (2000). *Living laboratories: the future computing environments group at the Georgia Institute of Technology*. Paper presented at the CHI '00 extended abstracts on Human factors in computing systems.

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

Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: impacts on drivers' visual behavior and braking performance. *Accident Analysis and Prevention, 39*(2), 372-379.

Healey, J. A., & Picard, R. W. (2005). Detecting stress during real-world driving tasks using physiological sensors. *Intelligent Transportation Systems, IEEE Transactions on, 6*(2), 156-166.

Horne, J., & Reyner, L. (1999). Vehicle accidents related to sleep: A review. *Occupational and Environmental Medicine, 56*(5), 289-294.

Kahneman, D. (1999). Objective measures of happiness. In D. Kahneman, E. Diener & N. Schwarz (Eds.), *Well-Being: The Foundations of Hedonic Psychology*. New York: Russell Sage Foundation.

McCall, J. C., Achler, O., & Trivedi, M. M. (2004). Design of an instrumented vehicle test bed for developing a human centered driver support system. *Proceedings of the Intelligent Vehicles Symposium, 2004 IEEE*, 483-488.

McCall, J. C., Wipf, D. P., Trivedi, M. M., & Rao, B. D. (2007). Lane Change Intent Analysis Using Robust Operators and Sparse Bayesian Learning. *Intelligent Transportation Systems, IEEE Transactions on, 8*(3), 431-440.

Mehler, B., Reimer, B., Coughlin, J. F., & Dusek, J. A. (2009). The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record, 2138*, 6-12.

Mehler, B., Reimer, B., D'Ambrosio, L. A., Piña, A., & Coughlin, J. F. (2010). An Evaluation of Time of Day Influences on Simulated Driving Performance and Physiological Arousal. *Proceedings of the Transportation Research Board of The National Academies*, Washington, DC.

Mehler, B., Reimer, B., Pohlmeyer, A. E., & Coughlin, J. F. (2008). The association between heart rate reactivity and driving performance under dual task demands in late middle age drivers. *Advances in Transportation Studies, An International Journal, Special Issue*, 53-70.

Merat, N., & Jamson, A. H. (2009). How Do Drivers Behave in a Highly Automated Car? *Proceedings of the 5th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Big Sky, MT., 514-521.

Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors, 39*(2), 230-253.

Pilutti, T., & Ulsoy, A. G. (1999). Identification of driver state for lane-keeping tasks. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 29*(50), 486-502.

Qiang, J., Zhiwei, Z., & Lan, P. (2004). Real-time nonintrusive monitoring and prediction of driver fatigue. *Vehicular Technology, IEEE Transactions on, 53*(4), 1052-1068.

Ramon, C., Clarion, A., Gehin, C., Petit, C., Collet, C., & Dittmar, A. (2008). An integrated platform to assess drivers's physilogical and functional states. *Proceedings of the 30th Annual International IEEE EMBS Conference*, Vancouver, British Columbia, Canada.

Reimer, B. (2009). Cognitive Task Complexity and the Impact on Drivers' Visual Tunneling. *Transportation Research Record, 2138*, 13-19.

Reimer, B., & Coughlin, J. F. (November 8, 2006). Instrumentation requirements for a test platform. personal e-mail communication with J. Rupp & S. Rouhana (Ford Motor Company).

Reimer, B., Coughlin, J. F., & Mehler, B. (2009). Development of a Driver Aware Vehicle for Monitoring, Managing & Motivating Older Operator Behavior. *Proceedings of the ITS-America*, Washington, DC.

Reimer, B., D'Ambrosio, L. D., Coughlin, J. F., Fried, R., & Biederman, J. (2007). Task-induced fatigue and collisions in adult drivers with attention deficit hyperactivity disorder. *Traffic Injury Prevention, 8*(3), 290-299.

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

Reimer, B., Mehler, B., Coughlin, J. F., Godfrey, K. M., & Tan, C. (2009). An On-Road Assessment of the Impact of Cognitive Workload on Physiological Arousal in Young Adult Drivers. *Proceedings of the AutomotiveUI*, Essen, Germany.

Reimer, B., Mehler, B., Coughlin, J. F., Wang, Y., D'Ambrosio, L. A., Roy, N., et al. (2008, September 22-24). A Comparison of the effect of a low to moderately demanding cognitive task on simulated driving performance and heart rate in middle aged and young adult drivers. *Proceedings of the International Conference on Cyberworlds*, C Hanzhou, Zhejiang, P. R. China.

Reimer, B., Mehler, B. L., Pohlmeyer, A. E., Coughlin, J. F., & Dusek, J. A. (2006). The use of heart rate in a driving simulator as an indicator of age-related differences in driver workload. *Advances in Transportation Studies an International Journal, Special Issue*, 9-20.

Reimer, B., & Sodhi, M. (2006). Detecting eye movements in dynamic environments. *Behavior Research Methods, 38*(4), 667-682.

Sodhi, M., Reimer, B., & Llamazares, I. (2002). Glance analysis of driver eye movements to evaluate distraction. *Behavior Research Methods, Instruments, and Computers, 34*(4), 529-538.

Tan, C. (expected 2010). *Development a framework for the multi-parametric classification of levels of cognitive workload in drivers.* Technische Universität München TUM, München, Germany.

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensitivity of eye-movement measures to in-task difficulty. *Transportation Research Part F, 8*, 167-190.

Vidales, P., & Stajano, F. (2002). The Sentient Car: Context-Aware Automotive Telematics. *Proceedings of the Fourth International Conference on Ubiquitous Computing*, Goteborg, Sweden, 47-48.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurology & Psychology, 18*, 459-482.

ABOUT THE AUTHORS

Joseph F. Coughlin, Ph.D.

Joseph F. Coughlin, PhD is founder and Director of the Massachusetts Institute of Technology AgeLab. He leads the US Department of Transportation-sponsored New England University Transportation Center which includes MIT, Harvard University and each of the six New England state universities. Working with industry and governments worldwide, he is recognized as a leader in understanding the future transportation demands, new technologies and design opportunities for an aging and mobile society. A member of the Transportation Research Board's Advisory Committee on the Safe Mobility of Older Persons, he is co-editor with AgeLab's Lisa D'Ambrosio, of Aging America and Transportation: Personal Choices and Public Policy, forthcoming Springer Publishing, 2010. He teaches transportation policy in MIT's Engineering Systems Division and is a member of the Gallup-Healthways Well-Being Index Scientific Advisory Board. Prior to joining MIT, Dr. Coughlin led EG&G's Transportation Technical Services practice consulting to the US Department of Transportation.

Bryan Reimer, Ph.D.

Bryan Reimer is a Research Engineer in the MIT AgeLab and the Associate Director of the New England Region University Transportation Center. His research seeks to develop new models and methodologies to measure and understand human behavior in dynamic environments utilizing physiological signals, visual perception, biomechanics and overall performance measures. Dr. Reimer is a graduate of the University of Rhode Island with a BS in Industrial engineering, an MS in Manufacturing engineering and a Ph.D. in Industrial and Manufacturing Engineering. He directs work focused on how drivers across the lifespan are affected by and adapt to new in-vehicle technologies, different types and levels of cognitive load, medical impairment and intervention.

Bruce Mehler, M.A.

Bruce Mehler is a Research Scientist in the Massachusetts Institute of Technology AgeLab and is the Director of Applications & Development at NeuroDyne Medical Corporation. He has an extensive background in the development and application of non-invasive physiological monitoring technologies and in the interpretation of psychophysiological data. In addition to academic publications and presentations on stress assessment and physiological monitoring, he has clinical experience in field of stress management training and serves on the board of the Biofeedback Society of New England. He received his MA in Psychology from Boston University and his BS from the University of Washington.

About the New England University Transportation Center

The New England University Transportation Center is a research, education and technology transfer program sponsored by the US Department of Transportation. Led by MIT, and based in MIT's Center for Transportation & Logistics, the New England Center includes Harvard University and each of the New England state universities. Together the faculty, researchers and students at these institutions conduct work in partnership with industry, state & local governments, foundations and other stakeholders to address the future transportation challenges of aging, new technologies and environmental change on the nation's transportation system. For more information about the New England University Transportation Center, visit web.utc.mit.edu. For more information about the US Department of Transportation's University Transportation Centers Program, please visit utc.dot.gov.

About the AgeLab

The Massachusetts Institute of Technology AgeLab conducts research in human behavior and technology to develop new ideas to improve the quality of life of older people. Based within MIT's Engineering Systems Division and Center for Transportation & Logistics, the AgeLab has assembled a multidisciplinary team of researchers, as well as government and industry partners, to develop innovations that will invent how we will live, work and play tomorrow. For more information about AgeLab, visit web.mit.edu/agelab.