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A Holistic Approach to Operator Alertness Research

Deborah M. Freund

Ronald R. Knipling

Alexander C. Landsburg

Ronald R. Simmons

Garold R. Thomas

U.S. Department of Transportation

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ABSTRACT

Operator loss-of-alertness (LOA; also termed “fatigue” or “drowsiness”) is an important cross-modal transportation safety concern. All administrations of the U.S. Department of Transportation (DOT) have active research and countermeasure development programs relating to the LOA problem. This paper examines the role of LOA in transportation safety, and the various DOT programs to address it, conceptualized “holistically” within a paradigm that includes the characteristics and interactions of the operator, the vehicle, and the environment. DOT-supported approaches to prevent LOA, or mitigate its effects, include: fitness-for-duty testing, vehicle-based operator monitoring (psychophysiological and/or performance), modification of the vehicle/workstation and/or physical environment, regulatory measures including both conventional (e.g., hours-of-service) and state-of-the-art (e.g., performance-oriented) approaches, and cultural/public education interventions (e.g., encouragement of rest breaks and napping). Recent research findings and technological innovations portend major advancements in the ability to address this pervasive safety problem utilizing multiple and synergistic approaches. The approaches and research settings are consistent with the missions of the agencies, while providing opportunities for coordinating diverse research activities and avoiding duplication of effort.

KEYWORDS:
transportation
operator
vehicle
loss-of-alertness
fatigue
drowsiness
fitness-for-duty
alertness

INTRODUCTION

The Department of Transportation (DOT) report, "Prospectus on Multi-Modal Aspects of Human Factors in Transportation" (Triggs, et. al., 1991), proposed a general framework for coordination of human factors research programs among the Department's operating administrations. It identified and described several issues based on relevance to transportation, significance to operational safety benefits, and likelihood that research would yield substantial benefits. The report discussed potential gains to the Department from sharing resources through a cross-modal approach to human factors research. It proposed several criteria for selection of multimodal issues:

> Relevance and concern to more than one transport mode;
>
> Reasonable agreement among human factors researchers that it represents a significant problem;
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> Relevance to transport system design and functioning, as judged by transport professionals concerned with real-world operations and by human factors researchers;
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> Potential for advancing scientific theory in areas related to human performance; and
>
> Prospects for progress within the available resources and in a reasonable time frame.

One important safety concern affecting **all** transportation modes is operator loss-of-alertness (LOA). This paper defines LOA from a transportation system viewpoint, proposes a cross-modal descriptive framework and holistic model, outlines the state-of-the-art in the understanding of LOA issues, and describes current research efforts underway to address this issue.

THE TRANSPORTATION SYSTEM

Three elements ***interact*** to form a transportation "system" -- the operator, the vehicle, and the environment. Within that system, there are many interrelationships that affect operational safety (illustrated in Figure 1).

Operator

The human operator is the most critical part of the system and requires major effort if we are to significantly reduce accident frequency. Operators in different transportation modes can range from highly trained and regulated professionals operating individually or in teams to the minimally oriented and inexperienced or infrequent personal and recreational operator.

Vehicle

Transportation operators (both moving and "stationary" transportation operators such as air or vessel traffic controllers and train dispatchers) perform their tasks in a vehicle or workstation which exists within a complex environment. Traditionally, transportation research, particularly in the surface modes, has concentrated on relationships between the operator and the vehicle, and the vehicle and the travelway. Much "human factors" research has historically examined relationships between the operator and the vehicle controls. A great deal of this research has focused on airplane cockpits.

The relatively short operating histories of automobiles and airplanes, the high public profile (of airplanes), and the consumer-related environment and relatively short usable operating life (of automobiles) have encouraged incremental improvements in the usability of their operator-vehicle interfaces. The longer histories and traditions, their role shifts from carriers of both passengers and freight to carriers primarily of freight, coupled with the long vehicle life spans in the rail and marine environments have offered less opportunity for change. All modes, however, have recognized that vehicle-operator interfaces need human factor-related improvements to benefit system performance and safety.

Environments

The operator's relationship to the transportation system is significantly influenced by three environments: physical, operational, and cultural.

Ph ysical Environment

The interaction between the operator and the transportation system in the physical environment is that between the vehicle and its travelway. The travelway is the physical path upon which, or through which, the vehicle moves. The travelway must provide a path that is compatible with the control characteristics and the laws of physics that govern the vehicle. It must also provide information in the form of guidance, advice, and warnings to the vehicle operator.

These physical and informational interactions are subject to loss of quality and quantity from environmental factors. For example, precipitation changes the frictional characteristics of roadways and fog obscures signs and lane markings, influencing the operator's ability to scan, process, and respond to information in a timely manner. In modes other than those based on land, the physical environment may be different, but the operator challenges are still very similar. Water- and air- (aviation) based travelways provide paths within the capabilities of the vehicle controls and the operators' abilities. As in the land-based modes, weather conditions change the condition of the travelways, the manner in which vehicles operate and respond, and the mental (and even the physical) workload of the operator.

The physical environment can be manipulated to influence the operator's alertness and performance. As an example, rumble strips provide an intervention in the physical environment of highway driving. Rumble strips placed on highway pavement just outside the lane boundaries alert the errant driver, by means of sound and vibration, to the fact that he or she is off the road. Several state DOTS have reported that the use of rumble strips produces a marked reduction in run-off-the-road crashes (Wood, 1994). Although water-, rail-, and air-based travelways do not offer a physical analogue to the rumble strip, the combination of vehicle traffic control and electronic navigation systems, autopilot operations, and warning alert signals influence ship, rail, and aircraft operators' alertness and workload. The challenge is to provide operators sufficient environmental feedback to make accurate and timely decisions and to reduce the operator's workload to enable effective management of overwhelming environmental cues. However, the physical environmental feedback must still provide sufficient stimulation to minimize loss of alertness from boredom.

Opera tionai Environment

Another environment that influences the operator's relationship to the transportation system is the "operational environment" of regulations, management practices, and training. This environment focuses on relationships between a highly-regulated cadre of professional operators -- commercial pilots, railroad engineers, truck and bus drivers, and mariners -- and their employers. Since labor costs are a significant part of a transportation operation, operators and crews are viewed as a focal point for improving the economics of operations.

Examples of operational-environment influences include: staffing requirements for ships (with implications for work and watch cycles); operating rules for railroads; hours-of-service regulations for commercial vehicle drivers and train, ship, and commercial air crews; and "strategic napping" policies for airline pilots on long flights. In regard to the latter, studies sponsored by the Federal Aviation Administration (FAA) (e.g., Rosekind, et. al., 1993) have shown that preplanned cockpit naps for each of the three crew members on extended flights can significantly improve subsequent alertness and performance on the flightdeck.

While operational factors are most visible for commercial settings, non-commercial vehicle operators are influenced by "operational" factors such as available travel time (e.g., the need for a private pilot who does not have an instrument rating to fly during certain daylight and weather conditions) and by opportunities for rest (e.g., available highway rest areas).

Cultural Environment

The "cultural environment" contains myriad informational and attitudinal messages about rest, fatigue, and vehicle operation. Each individual operator also carries his or her own "personal" cultural environment of family, social, individual activities and situation. The importance and critical relationships of this environment on the safety of operators, either as individuals or as part of a team, cannot be underestimated. Shipboard operators provide an example of one extreme where the individual lives and works for periods of 6 months or more in an environment that is virtually isolated from the rest of humanity. In such a system, every aspect of the individual's life style is directly of interest and related to his or her performance. Many aspects of this environment can be controlled or affected with direct impacts on safety.

On the other extreme, consider the general traveling public who make up the majority of travelway users -- drivers of automobiles and other vehicles, private aircraft pilots, and recreational boaters. They are the most lightly regulated with regard to factors influencing their fitness for operating a vehicle, the most difficult to reach through education, and, generally, the most apathetic. As a result, operation of a vehicle while in a state of diminished alertness (due to fatigue and/or alcohol misuse and/or substance abuse) contributes to a high number of deaths and injuries every year.

The cultural environment has a pervasive influence on operator attitudes toward the need for sleep and rest. As the U.S. culture has shifted to a "twenty-four" hour operational mode, individuals have relied on intuitive impressions of work-rest requirements or cultural pressures. Unfortunately, intuitive impressions are often flawed while cultural pressures ignore signs of fatigue and other impairing effects, focusing rather on productivity (Moore-Ede, 1993).

LOSS OF ALERTNESS

Loss of alertness (LOA) describes an operator's internal state, during which time the processing of input information fails to reach the conscious cognitive threshold necessary for the operator to provide an appropriate response. While much has been published which describes this condition as "fatigue" (a function of loss or disruption of adequate sleep), LOA within the context of this definition does not specify an underlying cause. LOA results from a complex interaction of a number of conditions, such as boredom, physical and mental workloads, environmental stressors (e.g., temperature, vibration, glare), sleep quality and quantity, and circadian effects.

For that reason, rather than focusing solely on sleep issues, a broader program of research coordination is needed to improve our knowledge of the global range of human-operator LOA processes. Is it a sensory input failure -- the "look, but did not see" phenomenon? Or, is it a cognitive processing issue -- the operator saw, identified, but did not respond appropriately? Identifying, defining, and modeling the appropriate human process will improve the knowledge of the LOA process as well as develop better operational countermeasures. Therefore, we ask 4 basic questions about the nature of loss of alertness.

1. What is it?
2. When does it happen?
3. How much results in a deterioration of operator performance?
4. How can it be controlled?

What is LOA? Many different psychophysiological definitions of LOA are possible, including definitions based on eye activity and brain activity (e.g., eye closure, EEG). LOA is also characterized by performance decrements, such as (in the motor vehicle setting) "drift and jerk" steering and increased lateral weaving.

"Loss of alertness," "fatigue," and "drowsiness" are often used interchangeably in the research literature. Formally, "fatigue" connotes physical and physiological fatigue from muscular exertion. However, it has also been commonly used to describe combined physical and mental process changes after a period of concentration on a task.

"Drowsiness" is used in the context of several Federal Highway Administration Office of Motor Carriers (FHWA/OMC) and National Highway Traffic Safety Administration (NHTSA) studies to refer to a state of reduced alertness, usually accompanied by performance and psychophysiological changes that may result in loss of alertness or being asleep at the wheel (Knipling and Wierwille; Treat, et. al., 1994). However, there is a distinct difference between "alertness" and "attention." A driver must be alert (or awake!) to be able to focus upon external events. An awake (or alert) driver may still be inattentive and fail to perceive a crash threat due to "mind wandering." Mind wandering is a distraction internal or external to the vehicle, or "improper lookout" (Knipling and Wierwille; Treat, et. al., 1994).

"Divided attention" situations require the operator to attend to several things to keep the vehicle operating properly (such as a pilot changing radio frequencies for air-traffic control instructions while maintaining a flight path). While an excess of divided-attention tasks may lead to mental fatigue, this is more of an excess-alerting situation than one of loss-of-alertness.

When does LOA happen? LOA usually occurs when a person works for extended periods of time, and/or gets insufficient sleep, and/or works during periods when circadian rhythms are at their low points. LOA can comprise mental, physical, and/or physiological elements. Its occurrence and effects are not confined to vehicle operators -- workers in non-transportation environments (power plants, chemical process plants, radar and sonar screens) can all suffer its effects (National Commission on Sleep Disorders Research, 1993).

What are the effects of LOA? According to 1989-1993 NHTSA General Estimates System (GES) statistics, an estimated 56,000 crashes annually occur in which driver “drowsiness/fatigue/asleep-at-the-wheel” is cited on the Police Accident Report. This is about one percent of the annual average of 6.3 million police-reported crashes for these years. Reasons for regarding this estimate as conservative include the following:

- GES statistics include police-reported crashes only. Overall, fewer than one-half of all crashes are police-reported. Since drowsy driver crashes primarily involve single vehicles, it is likely that a large proportion are never reported to the police.

- Even within the police-reported crash category, driver drowsiness may be under-reported since there is generally no physical evidence upon which to base a police finding of drowsiness. Crash-involved drivers themselves may not be aware of the role that drowsiness played in their crashes. On the other hand, some crash-involved drivers may consider drowsiness to be a more socially-acceptable explanation for their being involved in a crash than other more censurable errors such as alcohol use, speeding, or inattention.

A number of in-depth studies have indicated far greater percentages of crashes due to LOA, although these studies have generally addressed crash subpopulations such as truck crashes (e.g., American Automobile Association Foundation for Traffic Safety, 1985) or turnpike crashes (e.g., Shafer, 1993) rather than the overall population of motor vehicle crashes. Thus, direct comparisons to national statistics are difficult.

Definitive data on the role of LOA in crashes are likely to come not from more in-depth reconstructive accident investigations but rather from studies involving in situ monitoring (e.g., video recording) of operators. More significantly, this in situ monitoring research may show that partial LOA plays a larger role than complete

LOA (i.e., "asleep-at-the-wheel") in the causation of crashes. Roughly one-half of all roadway crashes involve "unforced" and generally "non-volitional" driver mental errors such as misjudgment and perception/recognition failure (Treat, et. al., 1979; Najm, et. al., 1994). It is well-known that LOA is a frequent -- even everyday -- struggle for many individuals. Further, LOA increases the probability of information processing errors in operational settings. What is not yet known is the actual proportion of operator "unforced mental errors" that are related to LOA in the real world.

Commercial drivers and vehicles are, of course, a special concern in relation to LOA. Combination-unit trucks represent only about 5% of police-reported "drowsy driver" crash involvements, and their rate of involvement per mile traveled is no greater than that of passenger vehicles. However, due primarily to their high exposure rates, the likelihood of involvement for these vehicles and drivers during any given time period (e.g., annually, vehicle life, driving career) is much greater than that of non-commercial vehicles/drivers. This high exposure and resulting crash involvement risk, coupled with the often severe injury consequences of truck crashes, make them potentially the most cost-beneficial motor vehicle platform for driver LOA countermeasures.

Lapses in the operator's alertness level are important considerations in the rail and marine environments, particularly as crew sizes are decreased. In rail, a "dead man's switch" has been used for some time to warn other crew members when the engineer on duty has been injured. The ability of a drowsy engineer to unconsciously reset the switch has resulted in a call to redesign portions of the control stand. In the marine environments, movement to solo operation on the bridge of foreign vessels, and increased work hours, has raised similar concerns.

THE HOLISTIC MODEL

To properly address LOA it is critical to develop a holistic model of the phenomena. The structure of the model acknowledges that the operator's potential for loss of alertness is related to his or her total state of mind and body, which is itself a function of the operator's multifaceted vehicular, cultural, and environmental interactions.

Figure 2 presents a conceptualization of a framework which represents these interactions for a mythical "transmodal" (air/land/water) vehicle. The figure is intended to depict the many approaches to understanding and intervening in operator LOA as well as the various DOT programs relating to LOA.

Traditionally, safety and regulatory activity and research have focused on the operator, his or her fitness for duty, and means for monitoring continuing fitness for duty. To minimize the potential for loss of alertness the whole state of the individual must be considered and appropriate monitoring measures applied or changes made in the environments, be it the vehicle travelway, managerial, social, or cultural.

In considering the immediate control interactions between the operator and the vehicle and how levels of alertness may be detected there are four major elements that control the interactions between the operator and the vehicle/workstation: inputs, processes, outputs, and feedback.

Inputs to the operator include the perceived physical environment with all its complexities. Since vision is the primary sensory channel for vehicle operation in all transportation modes, eye activity in many cases directly reflects the quantity and quality of sensory input. For example, one measure of LOA is “PERCLOS,” the percentage of time that the eyelids are closed 80% or more. When the eyelids are 80% closed, the pupils are covered and virtually all visual stimuli from the environment are occluded (Wierwille, et. al., 1994).

Many complex processes relevant to alertness transpire within the human operator. Eye activity, already addressed in the context of inputs to the operator, is also indicative of psychophysiological processes occurring within the human. The PERCLOS measure described above and eye blink characteristics (e.g., rate and duration) are both known to be indicative of many psychophysiological states and cognitive processes. For example, increases in subject blink rate have been reported as a function of time-on-task and cognitive demandingness of task (Stern, et. al., 1994). Other changes related to task performance have been recorded in driving simulators (e.g., Knipling and Wierwille, 1994 and AAA Foundation, 1985).

Other psychophysiological measurements used to gauge LOA include heart rate variability, electroencephalography (EEG), and skin potentials such as the galvanic skin response (GSR). Virtually all of these may be obtained in situ with minor-to-moderate obtrusiveness. Although generally conceived as being indicative of “baseline” alertness level, these measures may also be predictive of minute-to-minute changes in operator alertness (e.g., EEG research reported by Makeig and Inlow, 1993).

The operator’s state of alertness is influenced heavily by rest-recovery and circadian status, including time-of-day, duration of last sleep period, time since awakening, and time-on-task. Level of alertness may be predicted through a simple logging of these data (Akerstedt and Folkard, 1993). Alternatively, one may use monitoring devices such as an actigraph. These are wristwatch-size devices that monitor and record whole-body activity. These devices have been used in the military to monitor soldiers under continuous operations (Krueger, et. al., 1986), as well as in civilian medical applications (Garcia and Adrados, 1990). Research is underway to enhance software algorithms to eventually allow them to predict the wearer's level of alertness over time.

Additionally, various medical or psychological conditions may dramatically affect alertness. Perhaps the most widespread chronic medical condition of concern is sleep apnea, which affects approximately 3% of Americans (Kryger, 1994). The disorder is characterized by cessations of breathing, followed by partial sleep arousals as the oxygen-starved brain alerts the body to gasp for air. Because these arousals can take place from tens to hundreds of times a night, many sleep apnea sufferers are unable to obtain sufficient restful sleep and thus are chronically drowsy during the day. This can impair their ability to safely operate transportation equipment and can degrade their overall quality of life. The degree of severity of sleep apnea that has a deleterious effect on driving is currently being studied.

Performance outputs of operators also belie their states of alertness. For example, it has been known for nearly a decade that motor vehicle driver drowsiness can be detected with reasonable accuracy based entirely on performance measures such as "drift-and-jerk" steering and increased fluctuations in vehicle lateral lane position (Skipper and Wierwille, 1986). Research currently underway suggests that delayed and/or excessive applications (for prevailing conditions) of brake and throttle during train handling are indicative of LOA. Secondary tasks, whether they be simple manual stimulus-response or complex verbal/cognitive, may be used to assess operator alertness. To this end, mandatory, cognitively-challenging secondary tasks are being evaluated by FRA as alertness tests/maintainers for locomotive engineers.

LOA detection systems employ measurements of operator inputs, processes, and/or outputs. However, after decision processing, the system must respond with some form of feedback to the operator, delivered in the form of a vehicle response. While there is little published research to identify the most effective forms of feedback/vehicle response, it is certainly necessary that the feedback not jolt the operator into making an undesirable, or dangerous, control response. Principal options are advisories/warnings to the drowsy operator, advisory/warnings to others (e.g., supervisors, other travelers), introduction of stimuli known to inhibit sleep (e.g., noise, vibration), and automatic vehicle controls such as automatic soft braking (for trains), emergency braking, or vehicle shutdown.

Evolution of LOA Research

The state-of-practice is basically oriented toward monitoring. Significant improvements have been made over the past 20 years (microprocessor technologies, ambulatory EEG recorders, etc.). Research projects that have collected multi-source data over a workday, or a period of several workdays, should give researchers a clearer picture of patterns of changes in operator performance and physiology.

In-vehicle (or at-workstation) real-time performance monitoring has significant cross-modal applications. Applications include operator self-assessment to provide meaningful feedback on his/her alertness level and enable the operator to seek and receive advice or instructions for an intervention. These interventions can become a part of a transport operator's (or private operator's) procedures. Examples of research studies leading to advancing the state of the practice include: a study of planned crew naps in airliner cockpits (Rosekind, et. al., 1991); field data collections on truck and bus driver fatigue sponsored by the FHWA (Harris, et. al., 1972; Mackie and Miller, 1978); the Driver Fatigue and Alertness Study currently in progress (Freund, et. al., in press); and two ongoing studies, "Fatigue and Stress in Drivers of Multi-trailer Combination Vehicles" and the "Effects of Stress and Fatigue on the Performance of Locomotive Engineers."

The emerging state-of-art is prediction of driver LOA episodes and patterns. There are two different approaches being used. One approach employs a fitness-for-duty test presented prior to, and/or during, the driving/operating period. The test measures aspects of the operator's performance related to the driving task, such as hand-eye coordination, reaction time, and cognitive processing. This approach was investigated under sponsorship of a State highway safety agency as a potential screening tool for roadside enforcement of driver hours-of-service regulations, and has been modified for in-vehicle and terminal-based driver alertness assessment (Stein, in press). While this work shows early promise, the operational role and issues of users' and employers' acceptance of a fitness-for-duty-testing approach must be assessed further using larger samples and different operator populations.

Another approach explores physiological response to stimuli. This approach is being evaluated in several studies under FRA sponsorship. Other research activities addressing prediction of LOA are the investigation of effects tied to circadian rhythms and activity/rest cycles and incremental advances in measurement technologies (Makeig and Inlow, 1993).

To make prediction useful, countermeasures must be developed. These may be defined as devices that monitor an operator's behavior or operational parameters related to execution of tasks, as well as actions to enhance an operator's level of alertness, delay onset of fatigue, or mitigate fatigue's effects. Countermeasures to LOA have been classified as "alarms" which activate after a driver's alertness level has diminished, and "maintainers" that are designed to keep alertness levels from dropping below safe levels (Mackie and Wylie, 1991).

Examples of countermeasures in the form of monitoring and warning devices, designed for installation on a vehicle or workstation, may also be utilized. For example, in a car, truck, or bus, these might include second- and third-generation lane position monitors and various collision warning systems. Within an air traffic control console, it might take the form of artificial-intelligence software to monitor aircraft flight parameters in congested airspace. On a locomotive control stand, monitors of throttle and brake control might be added.

Countermeasures can also be applied through the physical, operational, and cultural environments, alone or in combination. The multiplicity of operating conditions, and the differences among transportation operators and between professional and private operators, will provide significant challenges to those who develop training and guidance. In the area of motor vehicle safety, efforts are just getting underway on a broad scale to provide information about the risk of driving while drowsy (New York State Governor's Traffic Safety Committee, 1994).

RESEARCH ORGANIZATIONAL MODEL

The "operator alertness" holistic model shown in Figure 2 is intended to provide a frame of reference to categorize the different aspects and levels of research on operator LOA, and to discuss DOT research and safety intervention programs on this issue. The organizational missions of different DOT agencies usually require them to focus on different domains.

An example of two different, and complementary approaches to operator LOA research in the road and highway environment is that taken by NHTSA and FHWA/OMC. The NHTSA, whose organizational mission emphasizes vehicle and driver safety, has relatively little involvement in programs relating to the physical environment (i.e., highways) and to the operational environment (e.g., commercial hours-of-service regulations). Therefore, their research program emphasizes a vehicle-design solution (i.e., a vehicle-based drowsy driver detection system). On the other hand, the FHWA/OMC concentrates on the operational environment of the trucking industry, and thus performs extensive research on operational and regulatory practices such as hours-of-service and availability of rest areas for commercial drivers.

Other parts of DOT also tailor their programs to the unique needs of their industries. The FAA's program integrates LOA R&D results within design requirements for flight deck/air traffic control workstations, training courses for crews/teams, and regulatory policy governing crew interaction. The Federal Railroad Administration's (FRA) safety responsibilities lead it to focus on the locomotive cab environment including alerting devices and ergonomics, hours of service, crew calling and scheduling, and train crew/dispatcher interfaces. The maritime area addressed by the U.S. Coast Guard and the Maritime Administration (MARAD) considers an even broader focus. For example, in the case of large commercial vessels, where crews are aboard for 6- month periods, the entire work and social activities of crews are areas of concern.

In some cases, to avoid duplication of effort, individual agencies within DOT have channeled their research energies on specific elements of the holistic model, or on specific technologies. For example, eye activity monitoring is one example of technological specialization. The FAA is supporting work on video image processing approaches to operator eye activity monitoring. The NHTSA is taking the lead in supporting work on low-cost opto-electronic devices. While the ultimate outcome of the two programs is similar, the two approaches are complementary, and provide alternatives for research and future commercialization.

Another area of specialization is operator "duty hours" monitoring. Because of the large population of U.S. commercial motor vehicle (CMV) drivers subject to hours-of-service regulations, the FHWA's requirements for records of duty status imposes a significant recordkeeping burden on both drivers and their employers. In the long term, it may be worth considering reducing or eliminating the "hours of service" concept (which basically uses duty hours as a surrogate for levels of alertness) in favor of a performance-based assessment.

FHWA/OMC PROGRAM

The objective of the FHWA/OMC high-priority research program area, Driver Proficiency, is to ensure that CMV drivers are physically qualified, have the knowledge and skills necessary to operate safely, are appropriately licensed, and are alert and unimpaired behind the wheel. The program embraces a broad range of topics, including CMV driver medical qualifications, LOA/fatigue, substance abuse, and driver training.

Research results may form the technical foundations for changes to the DOT's Federal Motor Carrier Safety Regulations, which primarily govern trucks and buses in interstate commerce. Accordingly, the topics for research are highly applied. The experimental designs are designed to provide representative models of real-world motor carrier operations. Six studies are currently in progress:

Driver Fatigue and Alertness Study
The Driver Fatigue and Alertness Study is the first major field research project within the "Fitness for Duty" element of the program. It is also the first study to collect data from commercial motor vehicle drivers behind-the-wheel since the mid-1970's. The goal of this research is to provide a scientifically-sound basis for evaluating the hours-of-service requirements and to develop countermeasures for reducing driver fatigue and increasing driver alertness. A total of 80 United States and Canadian drivers, divided into four groups of 20 each, drove four schedules allowed under their respective country's hours-of-service regulations. Continuous measurements were made of driving performance, traffic conditions, and drivers' physiological states (Freund, et. al., in press).

Driver Fatigue and Stress
Operation of multiple-trailer combination vehicles (MTCVs) has the potential to significantly improve the productivity of certain types of motor carrier operations. However, their physical characteristics influence their interaction with other vehicles in the traffic stream. The physics of their multiple articulation points may affect their driveability and may make them more prone to certain types of accidents. This study will determine if operating a single trailer and two types of triple-trailer combination vehicles leads to differences in drivers' performance, stress, and alertness levels.

Fitness-for-Duty Testing
The purpose of this study is to evaluate the use of in-terminal and in-vehicle fitness-for-duty testing technologies and devices for commercial drivers. Data have been collected on driver performance, driver acceptance of the tasks, the effects of terminal and cab environment on the hardware, and system reliability and maintainability.

Sleep Apnea
Undiagnosed and untreated, sleep apnea causes sleepiness during waking hours and poses a potentially serious highway safety problem. The goals of this study are to estimate the prevalence of sleep apnea in a population of high-risk truck drivers and to estimate the level of sleep apnea at which driving performance becomes impaired.

Rest and Recovery
The objective of this study is to determine the number of hours, or range of hours, a driver needs to recover from fatigue after operating a commercial motor vehicle. For reasons of experimental control and operator safety, this research will be

conducted in a laboratory setting. Commercial drivers will operate a fixed-base, personal-computer-driven driving simulator and take computer-based performance tests. An existing software model based on activity monitoring will be modified to predict the alertness of drivers placed on various work/rest schedules.

Rest Areas

This ongoing study will determine public rest area availability and services needed by commercial truck drivers and how well the current system meets those needs/demands.

NHTSA PROGRAM

Drowsy Driver Research

The NHTSA has several research programs addressing the problem of driver . alertness. Its principal drowsy driver research program focuses on continuous vehicle-based monitoring of driver alertness. Agency-supported research is underway at Virginia Polytechnic Institute and State University (VPISU) to develop a capability for unobtrusively monitoring driver performance (Wierwille, et. al., 1994). This system entails continuous measurements of driver performance (e.g., steering wheel movements, lateral lane position measures), data processing to "decide" whether the driver is drowsy, and an appropriate warning system interface with the driver. Direct, unobtrusive driver psychophysiological measures and secondary task performance could also be integrated into the measurement/decision regimen.

An example of the synergy of different DOT-sponsored driver alertness studies is provided by a new project, being performed by North Carolina Agricultural & Technical State University (NCA&T) to apply the VPISU performance-based detection approach to the over-the-road truck driver alertness and fatigue data collected by the FHWA/OMC. Replication of the automobile-simulator-derived multiple regression results, using real-world heavy truck data, would strongly validate this countermeasure concept.

NHTSA-supported research on psychophysiological measures of driver alertness has focused on measures of eye activity. A device under development by MTI Research, Inc. detects eyelid closure using a miniaturized, glasses-mounted opto-electronic emitter and sensor. This low-cost device is only minimally obtrusive but provides continuous readings of subject alertness based on cumulative eye closure time during blinks; readings from the device correlate highly with performance on a vigilance task.

Video image processing is another candidate technology for monitoring drivers' eyes. It has the potential to be completely unobtrusive, and could be adapted for applications other than drowsiness detection (e.g., monitoring driver point of regard and attention). The challenge for this technology will be to achieve a low enough cost to be practical for commercial implementation.

Lane tracking measures will likely be essential in any performance-based drowsy driver detection algorithm (Knipling and Wierwille, 1994). Optical technologies are advantageous since they can use existing highway lane edge markings. Accordingly, NHTSA is supporting industry R&D on optically-based lateral lane position monitors. In a current cooperative agreement, Rockwell International is evaluating a prototype forward-looking machine vision lane edge sensor/processor.

Of course, detection ***per se*** is not sufficient as a countermeasure. The detection system must actuate an advisory and/or alerting signal to the driver, and the signal must be acted upon appropriately. As part of a comprehensive research program on driver warning systems, preliminary human factors guidelines for driver alertness warning systems were developed based on a literature review (COMSIS, 1993).

Follow-up empirical research will examine a variety of stimulus options such as buzzers and other sounds, voice displays, increased ventilation/cool air, stimulating aromas, and seat vibration. The required stimulus must be capable of alerting the driver without disrupting performance due to a startle response. Of course, no stimulus will sustain driver alertness for extended time periods in the face of progressive fatigue.

The NHTSA is also initiating a program to develop and test an on-road prototype drowsy driver detection and warning system for heavy trucks based on the approaches described above.

Data Acquisition System for Crash Avoidance Research

The Portable Driver Performance Data Acquisition System for Crash Avoidance Research (DASCAR) program will develop an unobtrusive and inconspicuous vehicle instrumentation suite to support experiments and field studies on driver psychophysiology, performance, and behavior. A DASCAR prototype will be completed and validated by mid-l 995. This instrumentation suite, or some variation, will be an important element of ***in situ*** studies to provide more definitive data on the role of fatigue in driver information processing errors, and for field studies of drowsy driver countermeasures.

FAA PROGRAM

The goal of the FAA Airborne Human Performance (AHP) program is to refine the aircrew performance envelope and to evaluate countermeasures to minimize performance degradation, or to enhance performance, in response to aircraft tasking.

Airborne Human Performance

The AHP program goal statement introduces two prime elements -- definition of the airborne human performance envelope and evaluation of countermeasures which offer enhancements to this envelope. Rather than exploring psychological constructs of human behavior such as cognitive modeling, interpersonal interactions, or motivational strategies, the AHP program will focus on an engineering approach. The engineering approach views the human as one of the aircraft subsystems, which when integrated with the other aircraft subsystems, contributes to the successful function of the aircraft as a system. Therefore, the attributes of this human subsystem, as well as the influence of the countermeasures upon it, must be definable and measurable.

Performance Envelope of Airborne Human Subsystem

This research element will define “normal” aircrew performance and identify envelope limits. It will focus on:

1. Extracting previous research results which can be translated accurately into the airborne environment database and establish an initial (albeit crude) operator performance envelope;

2. Identifying current research programs which potentially will expand the knowledge base;

3. Increasing the accuracy of the performance envelope while addressing short-term concerns in response to pressing National Airspace System issues; and

4. Documenting performance degradation events, define effects, cross reference existing knowledge bases, and model impact on normal performance.

Several projects are currently being funded to meet these program goals. The Automated Performance Measuring System (APMS) project evaluates the ability to directly measure and analyze airline aircrew technical performance via digital flight data recorders. This project will provide valuable information to enhance the

FAA's Advanced Qualification Program. At the same time, results from this project will provide additional knowledge concerning the human performance envelope. Fatigue research in the air carrier environment has been conceptualized. The FAA has initiated efforts to identify the impact of fatigue within each type of aviation environment: air carrier, commuter/air taxi, and general aviation. Much of this research has been completed and the efforts within air carrier operations have shifted to evaluating countermeasures (Graeber).

Countermeasures to Performance Degradation

Research under this element will systematically introduce countermeasures to human performance degradation and pilot error. An example of this process has been fatigue countermeasures implemented within air carrier operations. Several under evaluation are bunk rest for long-haul operations, planned flightdeck rest, and pre-flight strategies (Rosekind, et. al, 1991).

This project also exemplifies the long-term cost-effectiveness of a programmatic approach. The countermeasures being developed can easily be translated into other environments such as commuter/air taxi, general aviation, and even air traffic control.

MARITIME ADMINISTRATION and U.S. COAST GUARD PROGRAMS

The Maritime Administration (MARAD) and the U.S. Coast Guard collaborate on research into a variety of issues in the human factors and other areas in performing their respective functions for the marine mode of transportation. MARAD's focus is on large ships in commercial trade and on their economic competitiveness. USCG provides safety regulation for all forms of marine transportation including fishing vessels and pleasure boats.

There are many factors in the marine environment which can contribute to loss of alertness. The constant pounding of rough seas can transform the ordinary-simple act of walking into a difficult and physically-fatiguing task. Traditional watch-keeping schedules alternate on-duty and off-duty hours so that crew are available around the clock. The common 4 hours on and 8 hours off watch cycles do not allow mariners the opportunity to get a long period of rest, which can result in chronic fatigue. Port calls are often marked by a frenzy of shipboard activity which can continue non-stop for many hours. While prior studies have identified these and other factors relating to loss of alertness, there is relatively little quantitative data.

The USCG has embarked on an aggressive study to collect quantitative data on the effects of these factors on crew fatigue and performance on large ships.

Research teams will gather data on voyages with daily logs being administered to collect information on crew activities (both on-duty and off-duty), duration and quality of sleep, and affective states. Performance tests which are sensitive to changes in alertness and human adaptational states will be administered to monitor changes over the duration of the voyage. By carefully selecting the ships to be studied, certain variables (such as style of management, degree of crew cohesion, type of vessel, voyage duration) can be controlled thereby increasing the sensitivity of the experiments to the variables of interest (such as watch schedule, crew size, trade route, frequency of port calls). A series of these studies is envisioned to identify the relative strengths of the effects of the different variables on the crew's LOA and performance.

In recent years, revolutionary reductions in ship crew sizes worldwide have raised many issues that challenge traditional approaches to human tasking and training. A number of recent high-profile accidents having human factors causes (EXXON VALDEZ, etc.) have focused public and industry attention on these problems. Recent research has addressed the potential impact on fatigue and safety of operations from reductions in crew size (Marine Board, 1990; Pollard, et. al., 1990). Results could not identify a decrease in safety specifically because of having fewer crew but noted that fatigue is a major problem often because of a number of circumstances including the concentration of work hours necessary during port calls.

A major conclusion that has evolved from recent work is that attention must be given to the entire system and especially the related environments if safety is to be improved (Landsburg and Nagendon, 1994). Shipboard operations have similarities to those in other modes except for duration and isolation. Large ship crews essentially work and live isolated from society for about half the year and are on vacation the remainder. The individual's work, social, and living environments are thus quite different than for other modes. This necessitates carefully factoring in all of an individual's activities onboard and influencing activities from shoreside in assessing alertness potential and reliability. The totality of human factors thus must be considered including ergonomics, automation, scheduling, organization, and social interactions of the entire marine transportation system including the company management, shoreside managers, pilots, and vessel traffic controllers.

Several projects are underway relating to LOA that are focused on practical improvements to maritime operations. MARAD has a cooperative research program with ship operators in which fitness-for-duty testing devices are being evaluated and trial implementations planned. Shipboard watch operations do not involve frequent steering or other such activities but are highly cognitive, planning, and judgment related. MARAD thus supported Volpe National Transportation Systems Center's (VNTSC) development of a special fitness-for-duty test which used spoken statements requiring memory and alertness for proper response, and relying much less on tracking and dexterity-type abilities.

MARAD also has just initiated a Human Factors Research Program with the Federal and State Maritime Academies using the expertise of their faculties. This program is to focus cooperatively on all aspects of human factors issues including recruitment, education, training, licensing, skills and task analysis, organizational relationships, work hours and overtime policies, ergonomics, and other issues related to human factors and performance. LOA is a key element relating the addressing of all of these issues.

In addition, the Marine Board, with USCG and MARAD sponsorship, is planning to convene a "Forum on Human Performance, Organizational Systems and Maritime Safety." It will address issues and promote collaboration on human performance, organizational systems, and maritime safety.

FRA PROGRAM

The objective of the FRA's LOA research program is to improve the safety and efficiency of railroad operating personnel by identifying conditions leading to workload, stress and fatigue which are most likely to adversely affect performance, and to recommend appropriate countermeasures. Present and near-term emphasis is on locomotive engineers, train dispatchers and high-speed-train operators.

Enginemen Stress and Fatigue

FRA's full-function, high-fidelity locomotive and train handling simulator, located at the IIT Research Institute in Chicago, is being used to measure locomotive engineers' performance while they are operating under known conditions which affect stress and fatigue. Experienced locomotive engineers are being used as test subjects. A record is obtained of the activity of each test subject for a specified period prior to testing, and for duty and off-duty times during the test period. Duty and off-duty schedules fully comply with current hours-of-service requirements. Selections of test subjects, test schedules and test runs are designed to address a variety of alertness-influencing conditions. The conditions include circadian desynchronization, sleep deprivation, length of duty period, crew calling and scheduling practices, and age of test subjects. This project will be completed in late 1995.

Impairment Testing

The concept of "fitness-for-duty" testing or "alertness monitoring" of operators is an interest of FRA. FRA has sponsored the development of a device to test individuals when they report for duty to determine if they are impaired. The test should identify impairment regardless of cause, be easy and fast to administer by non-technical personnel, and be reliable. The research suggests an approach based upon the involuntary expansion and contraction characteristics of the pupil of the eye. Results of this work are currently under review. However, it is anticipated that additional testing will be undertaken to compare data obtained with the prototype device with performance data being obtained in the Enginemen Stress and Fatigue project.

Advanced Alerter

Approximately one-half of existing U.S. locomotives have an in-cab device devised to assist the engineer in staying alert. These devices require a time sensitive action by the engineer. Accident investigations in recent years have indicated that an experienced engineer may unconsciously reset the alerter without being alert. In order to address this problem, a retrofit kit is being developed for existing alerters which will require a cognitive response by an engineer to reset the device. Future locomotives **will** incorporate more sophisticated approaches to maintaining crew alertness.

Dispatcher Workload, Stress and Fatigue

FRA plans to develop test protocols for evaluating conditions which may lead to dispatcher loss of alertness. Work overload during peak periods of train operations, boredom during slow periods of operation, dispatch center environment and work schedules are among the conditions being considered. The consolidation of dispatch centers and operating territories, increases in train traffic on many territories, the introduction of high technology capability in many consolidated centers, and broader spans of supervision dictate that attention be given to these conditions.

High-Speed Train Operator Stress and Fatigue

The regular operation of passenger trains at speeds in excess of 125 mph is expected to present unique conditions fostering LOA in operators. Since the control of such trains is expected to require greater use of computers and higher order communications than conventional operations, the term "operator" is used to apply to a blending of the roles and responsibilities of conventional locomotive engineers and train dispatchers. This activity will build upon work described earlier for locomotive engineers and dispatchers.

CONCLUSIONS

Several of the DOT modal administrations have developed operator LOA programs in accordance with their own organizational missions and resources. Each of the programs is implementation-oriented and is tailored to the specific sponsoring mode. However, the holistic conceptualization presented in this paper shows that, in the aggregate, these programs address the LOA problem across many different levels of the conceptual holistic model of the interactions among the vehicle, the operator/crew, and the various operating environments of the vehicle and the operator. They address similar concerns regarding operator alertness in a vehicle (or at a workstation), fitness-for-duty or "readiness-to-perform" testing conducted prior to operating a vehicle, or at designated points within a shift, and education on countermeasures to prevent or alleviate LOA.

The different approaches described appear to be mutually-compatible -- even synergistic -- with each other. Given the recent advancements in scientific knowledge and technological capability relating to many different elements of the operator alertness model, it is likely that a variety of effective and complementary countermeasures will soon become available to commercial transportation operators and the public to help mitigate this important cross-modal transportation safety problem.

REFERENCES

Akerstedt, T. and S. Folkard. A quantitative model for vigilance regulations and its application in transport operations. Paper presented at the ***Vigilance and Transport*** Conference in Lyon, France, sponsored by the French National Institute for Transport and Safety Research (INRETS), December, 1993.

American Automobile Association Foundation for Traffic Safety. ***A Report on the Determination and Evaluation of the Role of Fatigue in Heavy Truck Accidents.*** October, 1985.

COMSIS Corporation. ***Human Factors Guidelines for Crash Avoidance Warning Devices.*** NHTSA Contract No. DTNH22-91-C-07004, 1993(a).

Freund, D.M., C.D. Wylie and C. Woodle. "The Driver Fatigue and Alertness Study: A Plan for Research." ***Proceedings, Conference on Driver impairment, Fatigue, and Driving Simulation,*** Fremantle, Western Australia, 16-l 7 September, 1993. Taylor & Francis. In press.

Garcia, Manuel de Leon Alvarez and Rosa Peraita Adrados, "Actigraphy in the Diagnosis and Follow-Up of Obstructive Sleep Apnea." from ***Revista de Neurofisiologia Clinica,*** volumen III/1 -2, 1990. (Translated by Thomas Kazlausky, Ambulatory Monitoring, Inc.)

Graeber, R.C. (ed.) ***Crew Factors in Flight Operations: IV. Sleep and Wakefulness in international Aircrews.*** NASA Technical Memorandum 88321. NASA Ames Research Center, Moffett Field, California.

Harris, W., R. Mackie, and others (1972). ***A Study of the Relationships Among Fatigue, Hours of Service, and Safety of Operations of Truck and Bus Drivers.*** Report BMCS-RD-71-2. 1972.

Knipling, R.R. and W.W. Wierwille. Vehicle-based drowsy driver detection: current status and future prospects. Paper presented at the ***Fourth Annual Meeting of IVHS America.*** Atlanta, April, 1994.

Krueger, G.P., D. Headley, T. Balkin, G. Belenky, and R. Solic, ***Effects of continuous operations (CONOPS) on soldier and unit performance; Phase II: Strategies for sustaining the soldier in CONOPS.*** Joint WRAIR/ARI report for TRADOC CONOPS Staff Study. Walter Reed Army Institute of Research, Washington, D.C., 1986.

Kryger, M. ***Sleep apnea: magnitude of the problem, signs, symptoms, and diagnosis.*** Strategy development workshop on sleep education; conference sponsored by the National Center on Sleep Disorders Research. Rockville, Maryland, June, 1994.

Landsburg, A.C. and R. Nagendran, "System Safety in the Marine Transportation Field: The Need for Human Factors Analysis," Proceedings of the 2nd Annual Mid-Atlantic Human Factors Conference, Human Factors and Ergonomics Society (Potomac chapter), Washington, D.C., p, 123-l 29, February, 1994.

MTI Research, work in progress under a grant from the U.S. Department of Transportation Small Business Innovative Research Program.

Mackie, R. and J. Miller, ***Effects of Hours of Service Regularity of Schedules and Cargo Loading on Truck and Bus Driver Fatigue.*** Report DOT HS-803 799. 1978.

Mackie, Robert R. and C. Dennis Wylie, "Countermeasures to Loss of Alertness in Motor Vehicle Drivers," ***Proceedings, 199 I Human Factors Society Annual Conference.***

Makeig, S. and M. Inlow. Lapses in alertness: coherence of fluctuations in performance and EEG spectrum. ***Electroencephalograph y and Clinical Neurophysiology. 86, 23-35, 1993.***

Marine Board of the National Research Council, ***Crew Size and Maritime Safety.*** National Academy Press, Washington, D.C., 1990.

Moore-Ede, Martin ***C. The Twenty-Four Hour Society: Understanding Human Limits in a World That Never Stops.*** Addison-Wesley Publishing Company, Reading, Massachusetts, 1993.

Najm, W.G., J.S. Koziol Jr., L. Tijerina, J.A. Pierowicz and D.L. Hendricks. Comparative assessment of crash causal factors and IVHS countermeasures. ***Proceedings of the Fourth Annual Meeting of IVHS America.*** IVHS America, 1994.

National Commission on Sleep Disorders Research, ***"Wake Up America; A National Sleep Alert." (Volume One).*** Submitted to the United States Congress and to the Secretary, U.S. Department of Health and Human Services, January, 1993.

Pollard, J.K., E.D. Sussman, and M. Stearns, ***Shipboard Crew Fatigue, Safety, and Reduced Manning.*** Volpe National Transportation Systems Center, Cambridge, Massachusetts, 1990.

Rosekind, M.R., P.H. Gander and D.F. Dinges. ***Alertness management in flight operations: strategic napping.*** SAE Technical Paper No. 912138, Aerospace Technology Conference and Exposition, September, 1991.