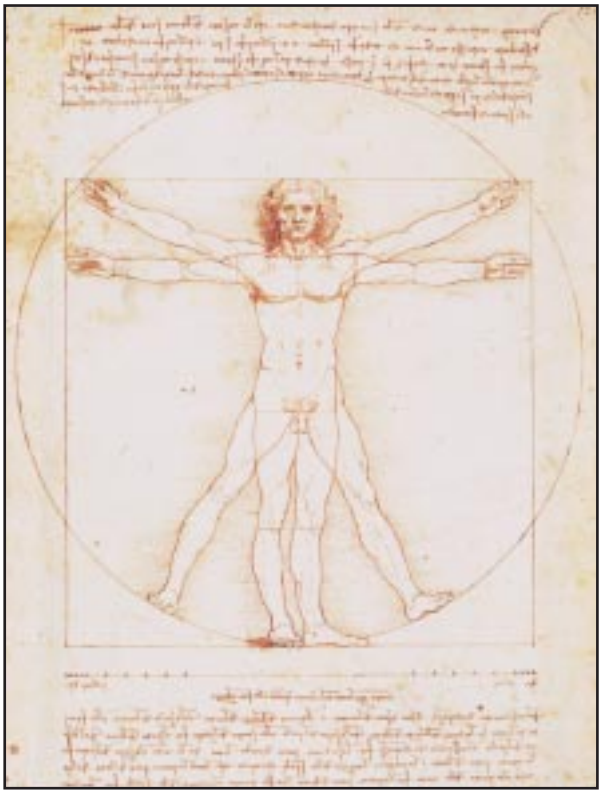
Human-Centered Systems

The Next Challenge in Transportation

U.S. Department
of Transportation



June 1999

FAA FHWA FRA FTA MARAD NHTSA RSPA SLSDC USCG

DOD NASA

About the DOT Research and Technology Coordinating Council

The Department of Transportation's (DOT) research and technology activities are coordinated through the DOT Research and Technology Coordinating Council (RTCC). The role of the RTCC is to create and stimulate an innovative, integrated departmental and interagency transportation research and development agenda that supports national transportation goals and enables an effective intermodal national transportation system.

To obtain additional information regarding the DOT RTCC, contact RTCC Chair, Dr. Fenton Carey the Associate Administrator of the Office of Research, Technology and Analysis at RSPA, at 202-366-1194.

About the DOT Human Factors Coordinating Committee

The Secretary of Transportation established the Human Factors Coordinating Committee (HFCC) in 1991 to become the focal point for human factors issues within DOT. The HFCC's responsibilities include the development and implementation of a national strategic agenda for human factors research in transportation and being a human factors information resource to the transportation community. The HFCC facilitates the implementation of human factors elements of the *DOT Strategic Plan* and supports the activities of the RTCC as well as the National Science and Technology Council's Committee on Technology and its Subcommittee on Transportation R&D.

To obtain additional information regarding the DOT HFCC, go to http://humanfactors.dot.gov

Prepared by

United States Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Operator Performance and Safety Analysis Division
55 Broadway
Cambridge, Massachusetts 02142-1093

Federal Aviation Administration • Federal Highway Administration • Federal Railroad Administration • Federal Transit Administration • Maritime Administration
National Highway Traffic Safety Administration • Research and Special Programs Administration • Saint Lawrence Seaway Development Corporation • United States Coast Guard
Department of Defense • National Aeronautics Space Administration

Artwork on Cover: Leonardo Da Vinci's Vitruvian Man from *On Architecture* by Vitruvius, published 1511.

UNITED STATES DEPARTMENT OF TRANSPORTATION
WASHINGTON, D.C. 20590

President Clinton and Vice President Gore have made safety this Administration's highest transportation priority. We, at the DOT, strive to optimize transportation safety by working toward the elimination of transportation-related deaths, injuries, and property damage. This document, *Human-Centered Systems: The Next Challenge in Transportation,* calls attention to the most critical component of our transportation systems, the human operator. We recognize that, as we increasingly incorporate new technologies into our transportation systems, the human contribution to transportation operations becomes ever more crucial.

Today's U.S. transportation system is structurally, mechanically and technologically sound. The greatest challenge is to ensure it is fully designed for human operators, maintainers, and users.

We need to employ human factors expertise in the design, development, evaluation and use of transportation technologies and systems to ensure that we do not exceed the limits of human performance, and that we use the full capabilities of the human. We compromise the capabilities of technologies when we fail to consider human performance issues associated with their use. We need transportation systems that adapt to humans instead of humans adapting to them.

Under the leadership of the DOT's Research & Technology Coordinating Council, the DOT Human Factors Coordinating Committee produced this document which highlights the activities and achievements of DOT modal administrations and other Federal agencies in human factors research related to transportation. It also provides an overview of DOT's human factors research agenda and future directions.

This document provides DOT's strategy to achieve human-centered systems in transportation that will help us build a 21st century transportation system to keep our citizens the most mobile, our economy the strongest, and our environment the cleanest in the world.

Rodney E. Slater
Secretary

Acknowledgements

This report represents the contributions of many people, modal administrations and Federal agencies. The report originated from the work of the DOT Human Factors Coordinating Committee, chaired by Alexander C. Landsburg, MARAD. Committee members include Mark D. Rodgers, FAA, Thomas M. Granda, FHWA, Ronald Knipling, FHWA/OMC, Thomas Raslear, FRA, William O. Adams, FTA, Michael Goodman, NHTSA, Donald R. Trilling, OST, Fenton Carey, RSPA and Antonio Carvalhais, USCG, and the Executive Agents, E. Donald Sussman and Mary D. Stearns, VNTSC. Ronald Simmons and James Fobes, FAA, Elizabeth Alicandri, FHWA, Robert J. Carroll, FHWA/OMC, Raymond J. Resendes, FHWA/JPO, Paul Rau, Michael Perel, Michael Smith, NHTSA, Robert M. Clarke, Caitlin Hughes, Kimberly J. Bowen, OST, Jennifer Antonelli, Norman G. Paulhus, RSPA, and Carlos Compratore, Habib Durrani, and Allen W. Penn, USCG, contributed to developing the ideas presented in the report. The DOT Human Factors Coordinating Committee also requested advice and input from Maris Vikmanis, USAF, and Charles Huettner, NASA. Carol Colman, Cambridge Systematics and Arthur H. Rubin, EG&G Services provided editorial support to produce this report.

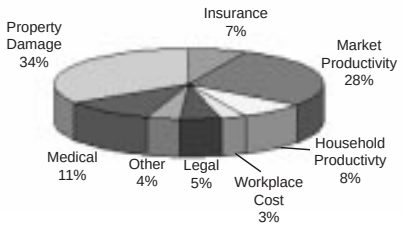
Table of Contents

Executive Summary

Opportunity

Human errors contribute significantly to most transportation crashes across all modes of transportation. Reducing these errors by increasing attention to human performance and behavior issues will reduce crashes, loss of life, injuries, property damage and resultant personal and financial costs. Such costs include not only lost days of life and functionality, but also expenses associated with emergency response and clean up, injury treatment, property and environmental damage, workplace disruption, insurance claims processing, and legal proceedings, as well as public assistance for the injured.

Economic Cost of Motor Vehicle Crashes, 1994



Total economic cost of motor vehicle crashes in 1994 was $150.5 billion.
Source: Blincoe, 1994

Awareness of the role of human performance and behavior issues in transportation is increasing at a time when new technologies are being introduced to improve transportation system safety, reliability, and productivity. However, the capabilities of these technologies are often compromised because the full range of human performance and behavior issues associated with transportation system design, use, operation, and maintenance were not considered. The use of a "human-centered systems" approach to the design, development, and implementation of technologies is necessary to ensure that the full potential of these technologies can be realized. This potential includes achieving the desired gains in safety, reliability, and productivity, as well as a high degree of public support for, and acceptance of, these technologies.

The "human-centered systems" approach focuses on human capabilities and limitations with respect to human/system interfaces, operations, and system integration. The goal is to design transportation systems that facilitate task completion, so that people can focus on task performance and not be distracted by the technology. This encompasses development of a generation of machines that are adaptable to their human operators, rather than depending on humans to adapt to machines. By incorporating human performance and behavior principles into the design, development, and operation of transportation systems, it will be possible to improve safety while

Traffic management center.

enhancing system performance, with increases in capacity, operational efficiency, and productivity.

A coordinated, proactive human factors research program is essential to ensure that the necessary data and methods are available to the U.S. industries responsible for designing and implementing advanced technologies for our transportation systems so that they can take a human-centered approach. This program should be multi-modal and multi-agency, involve the public and private sectors, and ensure synergy among the modal research programs.

Tracking eye movements.

The program includes modal-specific elements within the U.S. Department of Transportation (DOT), multi-modal programs, and interdepartmental research efforts. In the near-term, the research efforts will focus on two new multi-modal human performance and behavior initiatives: Operator Fatigue Management and Advanced Instructional Technology (AIT).

Modal-Specific Human Performance and Behavior Programs in the DOT

The DOT modal administrations focus on known or anticipated human performance problems in the civil transportation sector. Modal human factors research must respond to specific regulatory concerns and programmatic requirements. Due to lack of funding and the technical risk involved, the pursuit of fundamental research is very limited. The estimated total R&D human factors budget for DOT in fiscal year 1999 is $41.3 million, allocated as follows by mode:

Aviation: $25.1 million

The aviation program focuses on the following:

- Human-centered automation research–the role of the operator and the cognitive and behavioral effects of using automation to assist humans with task performance;
- Selection and training, where initiatives include the Model Advanced Qualification Program, an air carrier pilot training program integrating technical and crew resource management performance requirements; and pre-hiring screens for air traffic controllers;
- Human performance assessment, where research focuses on better understanding and measurement of human performance capabilities and limitations in aviation;
- Information management and display, which focuses on identifying the best ways to display and exchange information to reduce information transfer errors and misinterpretations; and
- Bio-aeronautics, where the research focuses on maximizing crew and passenger physical health and psychological integrity; issues include human protection and survival, evacuation, and aviation medicine.

Highway: $13.3 million[1]

The highway program includes efforts to identify how drivers interact with the roadway environment; to modify highway systems so that they meet the needs of older drivers; and to develop traffic management approaches to enhancing roadway safety. Also included are efforts to foster the development and assessment of crash avoidance countermeasures, and to conduct research for detecting and warning drowsy drivers.

Rail: $2.0 million

The Federal Railroad Administration (FRA) human factors research program focuses on three major areas: railroad operating practices, railroad systems design, and grade crossings. Projects are being conducted to evaluate the effects on train crew performance of automation interfaces; fatigue, shiftwork, and scheduling; workload-related stress; yard and terminal employee injuries; and traditional ergonomics. Research is also being conducted to identify and evaluate various evacuation concepts, strategies, procedures, and techniques for passenger rail vehicles and locomotives. Research is also focusing on causes of highway-rail grade crossing accidents and includes evaluation of driver behavior and driver education programs.

Maritime: $0.4 million

Coast Guard research focuses on improving crew alertness, the ability to identify the contributions of human factors to casualties, and performance-based testing to meet safety objectives. The Maritime Administration's (MARAD) Human Factors Research Program focuses on applying behavioral science principles to improving maritime transportation systems, with an emphasis on fatigue, qualifications and training, crew scheduling, and workload.

Transit: $0.5 million

The Federal Transit Administration (FTA) is concerned with human factors issues in general, and about fatigue in particular, but the organization has not been able to devote any resources to this effort. However, at the request of the National Transportation Safety Board, the FTA and the American Public Transit Association sponsored a Fatigue Awareness Symposium with the Federal Railroad Administration (FRA) in February 1998 as a first step in developing a joint Fatigue Awareness Program.

Multi-Modal Human Performance and Behavior Initiatives and Goals

The key elements of the coordinated program are two new multi-agency human performance and behavior initiatives relating to Operator

[1]Includes $8 million for National Advanced Driving Simulator (NADS).

Fatigue Management, and to the use of Advanced Instructional Technology.

Enhancing Operator Alertness through Fatigue Countermeasures and Analytical Systems - Operator Fatigue Management (OFM) Initiative.

The objective of the Countermeasures and Analytical Systems effort is to reduce loss of life, injuries, destruction of property, damage to the environment, and lost productivity in the United States by 33 percent within 20 years. The OFM initiative will provide operators with the knowledge and information to maintain and restore alertness, and by providing resources to plan, predict, and proactively address periods of reduced alertness. Through this effort, a comprehensive multi-modal, multi-agency, research program will conduct research on known fatigue countermeasures to assess the efficacy, side effects, reliability, validity, and relevance to specific modal environments. The findings will be compiled into a Fatigue Management Reference (FMR) document similar to a *Physician's Desk Reference,* and will be used to tailor fatigue countermeasures programs to the mode-unique environments, and develop model fatigue countermeasure programs for various operational scenarios. In addition, the program will develop and demonstrate an analytical system to forecast and detect decrements in alertness, and to provide effective, safe, mode-specific fatigue prevention strategies for real-time use.

Computer-based training

Advanced Instructional Technology (AIT)

The objective of the AIT Initiative is to reduce the rate of deaths, injuries, and motor vehicle crashes among operators who participate by 33 percent within 20 years. This will be accomplished by using AIT techniques, such as computer-based instruction and simulation, to enhance motor vehicle operator skills, decision-making, and safety-related attitudes. The AIT initiative will determine the behaviors of novice, experienced, and elder drivers in complex, dangerous situations. It will develop educational approaches to engage and teach appropriate attitudes, reactive skills, and preventative behaviors to drivers of all ages. Finally, the AIT initiative will evaluate and demonstrate the effectiveness of advanced information technologies in preparing operators to identify, avoid, and manage potentially hazardous situations.

Military human factors research

Interdepartmental Research Efforts: DOD and NASA

In addition to the DOT activities, several other Federal agencies, including the U.S. Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA), have major human performance/behavior R&D programs to support their missions.

DOD

The extensive DOD science and technology efforts in human systems focus on ensuring that military forces have the right people with the right training; and on system interfaces that leverage and extend the capabilities of warfighters and maintainers to ensure that fielded systems will exploit the fullest potential of the warfighting team, regardless of mission, or environment. Although the emphasis is on the human component in military systems and operations, much of the DOD program has dual use application to civilian transportation systems.

Astronaut training

NASA

NASA is responsible for conducting leading-edge research in aerospace human factors. A comprehensive program of human factors research relative to applications in the exploration of space is conducted at Johnson Space Center, with support from Ames Research Center. The NASA program of operational human factors R&D is coordinated with the FAA through the *National Plan for Civil Aviation Human Factors: An Initiative for Research and Application* and a variety of formal Memoranda of Understanding, including one on human factors. Research in selected areas of aeronautical human factors is led by the Ames Research Center and the Langley Research Center.

Next Steps

Departmental investments must leverage the investments of other Federal agencies, industry, and academia if multi-modal issues are to be addressed in a meaningful way. Projects under the initiatives are to be conducted in partnership with other Federal agencies such as DOD and NASA, as well as, where appropriate, with academia and industry. The key is to conduct research that will lead to a transportation system that adapts to the human as opposed to the current system that requires the human to adapt to it. By working together, Federal agencies and non-governmental organizations can enjoy the synergy and economies of scale that make the most effective use of research and development efforts in the pursuit of answers to the nation's most pressing transportation safety and efficiency problems.

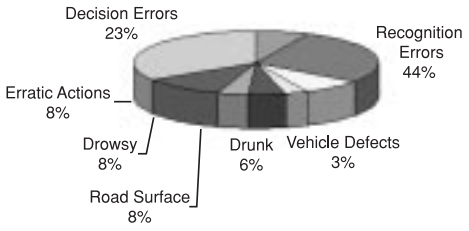
Well designed systems result in safe, efficient, and relaxed travel.

1.0 The Problem and the Opportunity

The Problem

Human performance-related problems play a significant role in the safety of U.S. transportation systems. In particular, given that approximately 70 to 90 percent of transportation crashes involve human error, it is clear that reducing or mitigating these human errors can have a significant impact on the associated human, environmental, and financial costs.

Motor Vehicle Crash Causal Factors



Source: Najm et al, 1995

Transportation accounts for roughly half of the accidental deaths in the United States and has done so for at least the past 25 years. Transportation accidents are the major source of work-related fatalities; in 1995, 41 percent of all occupational deaths occurred as a result of transportation incidents. Highway transportation provides the most dramatic example of the transportation-related safety challenges. In the last 30 years, more Americans have died in transportation crashes than in all the wars fought in U.S. history.

Currently, there is one highway death every 13 minutes and an average of 115 deaths each day. In 1995 alone, approximately 6.6 million motor vehicle crashes were reported to police. This represents only a portion of the 15 million highway crashes, involving 26 million vehicles, which are estimated to have occurred. These crashes killed 41,798 people; an additional 3.4 million people were injured, of which 428,000 were incapacitated. Many types of crashes and vehicles are involved. In addition to crashes involving passenger vehicles and light trucks, which represent the majority of deaths and injuries, 644 occupants of heavy trucks were killed and 30,000 were injured. There were 2,221 deaths involving motorcycles and 5,585 pedestrian deaths.

Traffic crashes have many costs. Each day, millions of days of life and functionality are lost to highway crashes. The National Highway Transportation Safety Administration (NHTSA) estimates that the lifetime economic costs associated with those injured and killed in highway crashes in 1994 will be $150 billion. This is equal to $580 for every man, woman, and child, or 2.2 percent of the nation's Gross Domestic Product. These costs include crash clean up, injury treatment, property damage, workplace disruption, insurance claims processing, legal proceedings as well as public assistance for the

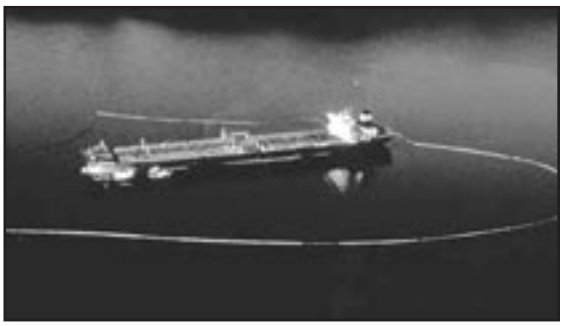
injured. Motor vehicle crashes cost taxpayers the equivalent of $144 in added taxes per household in 1994. NHTSA estimates that 9 percent of all motor vehicle crash costs are paid from public revenues, with Federal revenues accounting for 6 percent and state and local revenues for 3 percent.

New drivers are at a high risk for traffic accidents.

The risks (and subsequently, the costs) of motor vehicle crashes are not distributed equally. For example, per million miles traveled, the youngest drivers have the highest rate of involvement in police-reported crashes. Older motor vehicle operators have the highest rate of fatal crashes per mile driven. Given this risk distribution, focused efforts in human-centered transportation technologies, both in the driving environment and vehicle, may cause significant decreases in the incidence of highway fatalities and injuries.

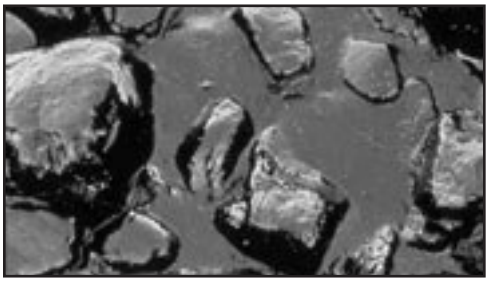
Fatal accidents and injuries also occur in other modes of transportation. There were 1,088 fatalities in all forms of aviation in 1996 and 359 serious injuries in general aviation alone. In 1996, there were 1,045 rail-related fatalities and more than 12,000 injuries (including highway-rail grade crossing accidents and railroad operations). There were 50 fatalities involving waterborne transport and 709 fatalities in recreational boating, for a total of 759 maritime-related fatalities in 1996.

The impacts of human performance-related transportation crashes and incidents go well beyond fatality and injury to include major environmental disasters. No case is more reflective of the dangers of impaired human performance than the grounding of the U.S. tank ship *Exxon Valdez* in Prince William Sound, on March 2, 1989, in which almost 11 million gallons of oil spilled from the Valdez. Oil drifted along the Alaska coastline, contaminating the shoreline of Prince William Sound, the Kenai Peninsula, the lower Cook Inlet, the Kodiak Archipelago, and the Alaska Peninsula. Areas ruined by the oil included a national forest, four national wildlife refuges, three national parks, five state parks, four state critical habitat areas, and a state game sanctuary. Oil eventually spread to shorelines nearly 600 miles southwest of Bligh Reef, where the spill occurred. An estimated 1,000 miles of shoreline was affected by the spill. Although damage to the vessel and cargo amounted to more than $28 million, the cost of cleaning the spilled oil



In 1989 the Exxon Valdez spilled 11 million gallons of oil largely due to impaired human performance.

during 1989 alone was almost $2 billion, making this probably the most expensive fatigue-related accident in history.



Oil spill from the Exxon Valdez cost more than $2 billion to clean up in 1989 alone.

The National Transportation Safety Board implicated impaired human performance in four of the primary causes of the Valdez grounding, as follows:

- The failure of the third mate to maneuver the vessel properly due to fatigue and excessive workload;
- The failure of the master to provide a proper navigation watch because of impairment from alcohol;
- The failure of Exxon Shipping Company to provide a fit master and a rested and sufficient crew for the *Exxon Valdez*; and
- The lack of an effective Vessel Traffic Service because of inadequate equipment and staffing levels, inadequate personnel training, and deficient management oversight.[2]

The Opportunity: Enhance Safety and Capacity by Using a Human-Centered Systems Approach

A heightened awareness of the role of human performance and behavior issues in transportation safety is occurring at a time when a variety of new technologies are being developed and introduced into transportation systems to enhance their capabilities. For example, next generation Air Traffic Control (ATC) and flight deck systems will employ technologies that allow greater air traffic density while reducing the likelihood of crashes. Similarly, intelligent transportation technologies could allow increases in highway traffic density while enhancing safety.

Traffic management centers at Air Traffic Control Centers.

Properly employed, these new technologies can dramatically improve transportation safety, reliability, and productivity. They can expand the accessibility and functionality of our transportation system. They also can increase the competitiveness of the U.S. transportation industry by improving the efficiency and safety with which we move passengers and goods.[3]

[2] Remarks by Jim Hall, Chairman, National Transportation Safety Board, before the Washington Traffic Safety Commission Symposium on Driver Fatigue, Bend, Oregon, November 21, 1996.

[3] For example, in recent years, foreign-flag ships have been able to reduce their crew levels dramatically with the addition of automation giving them a considerable operating advantage over equivalent U.S.-flag vessels, which typically operate with more crew. Without increasing attention to human-centered technologies and accurate assessment of safety implications, U.S.-flag shipping cannot be competitive in the international marketplace.

To date, the full potential of advanced technologies has not been realized because of a failure to consider fully the human performance and behavior issues involved in their use by operators, crew, maintainers, and passengers.[4] The major areas of human factors-related concerns associated with transportation systems include:

- Fatigue and workload;
- Hours of service;
- Training and certification;
- Automation;
- Passenger security;
- Aging and mobility;
- Information overload;
- Substance abuse; and
- Adequate staffing

New technologies can address some of these concerns. However, the technologies also may contribute to exacerbating these problems unless their implementation is designed using a human-centered systems approach. For example, new transportation technologies have the potential to increase the amounts of information available to transportation system operators, possibly resulting in information overload. Automation and advisory systems will help operators make decisions that are critical to safety and efficiency. The impact of these changes on the way that information is processed by the operators must be considered during the system design, including the workload impact of increasingly sophisticated information display and management systems.

In addition, as new technologies take over the tasks traditionally performed by transportation system operators, the operator's role will change; this will affect the determination of appropriate staffing levels. The implementation of these new technologies also will affect the knowledge, skills, and ability requirements for transportation system operators, and thus will require changes to training and licensing procedures.

It is evident that the ability to achieve the full potential of new technologies will depend, in large part, on the degree to which human performance and capabilities are incorporated as a central element in these new systems. Also, public acceptance of new technology applications depends on their ease of use, their simplicity of design and the quality of the human-system interface. These goals can be achieved only by ensuring that all aspects of human performance and behavior are considered in system design, implementation, and operation.

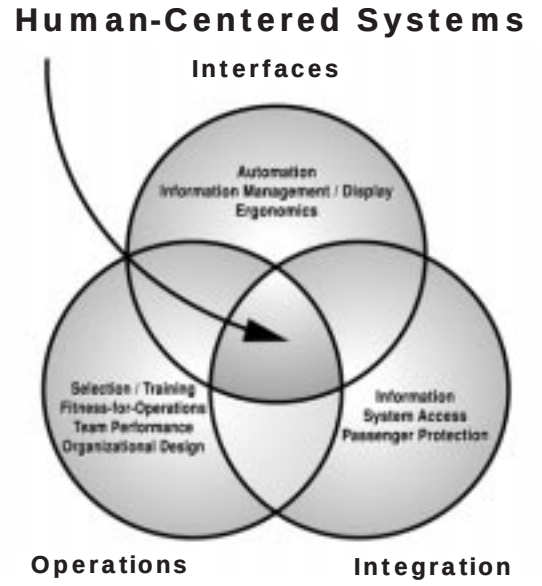
The "human-centered systems" approach recognizes that technology can only be as effective as the humans who must use it. Designing

[4] Beniger, J.R., *The Control Revolution,* 1986.

technology from a human-centered perspective is as critical to improving transportation system performance as is vehicle design. Optimal human performance in any transportation system has the potential to leverage, extend, and maximize the investment in technology.

The success of "human-centered technology" comes from putting people first and recognizing that the human contribution is a critical part of technology development, system implementation, and operation. The "human-centered systems" approach includes three components:

- Human-centered interfaces - focuses on design, product, and systems development with full consideration of human capabilities and limitations.
- Human-centered operations - focuses on ways to increase the safety and effectiveness of system operations by improving procedures, training, and selection.
- Human-centered systems integration - focuses on systems design, construction, and implementation that fully include the human user in the assessment of safety, security, environmental risk, comfort, efficiency, economics, and choice.



2.0 The Vision and the Mission

The Vision

Due to the increased capability and ubiquity of advanced technology in transportation, the transportation R&D community faces the growing challenge of ensuring that humans can perform optimally in an increasingly advanced technological transportation system. The response to this challenge is based on the following vision:

> **Transportation technology assists and facilitates, rather than distracts and discourages, so that people can focus on performing their tasks effectively and not on mastering the technology.**

The Mission: Create a Synergistic Departmental Human Factors Research Program

Definition of Human Factors Research

Human factors is a multi-faceted discipline that focuses on issues of performance and behavior related to human interactions with equipment, vehicles, operations, or control systems.[5] The primary goal of human performance and behavior research in transportation is to ensure that transportation systems are tailored to account for user needs, capabilities, and limitations.

Program Overview

Emerging areas, such as human-centered technology, usually require Federal leadership to focus on long-term, high-risk, or cutting-edge research. The industrial base for advancing human performance research is too fragmented, and the leap from R&D to implementation is too great, for the private sector to support sufficient developments in human performance research. Federal sponsorship of R&D on the design and operational aspects of human contributions to transportation will promote technology development. The Federal role is to:

- Reduce risks and front-end costs by establishing the knowledge base and concept feasibility for industry;
- Serve as a catalyst and facilitator; and
- Foster technology transfer for the end-users.

[5] The discipline of human factors is based on the "...knowledge concerning the characteristics of human beings that are applicable to the design of systems or devices of all kinds...the consideration of such knowledge in the assignment of appropriate functions for humans and machines...and the use of such knowledge to achieve compatibility in the design of interactive systems of people, machines, and environments to ensure their effectiveness, safety and ease of performance." Source: *Human Factors and Ergonomics Society Directory and Yearbook,* 1997-1998.

A coordinated, proactive research program is essential to ensure that the necessary data and methods are available to the U.S. industries responsible for designing and implementing advanced technologies for our transportation systems. A program that crosses modes and involves both the public and private sectors can achieve benefits that are too widely dispersed and will be realized too far in the future for any single organization to recover its investment. A coordinated program ensures synergy among the modal research programs, and provides a central focus for articulating the importance of human performance and behavior research within the Department. Such a program also affords protection from risks that are too great for any organization to bear independently.

The coordinated program will be an integrated, synergistic program with the following elements:

- **Modal specific - each mode will continue to conduct focused, applied programs designed to support their unique needs.**
- **Cross-modal - new initiatives will sponsor broadly applicable projects that complement the modal programs and can be tailored for use by the modes.**
- **Interagency - all of the U.S. DOT's human factors research programs will leverage the resources of other Federal agencies.**

3.0 Program Goals and Benefits

A coordinated human factors research program supports long-term national transportation goals that include:

- Ensure safer, more efficient, and more productive transportation products and services;
- Provide reliable, safe, dependable transportation systems that will enable efficient U.S. industries to achieve or maintain world-class competitiveness;
- Improve the integration of national transportation resources to provide "seamless" transportation to customers using multiple modes; and
- Provide mobility for diverse populations and ensure the accessibility of transportation technologies and services.

The mobility impaired population need access to transportation

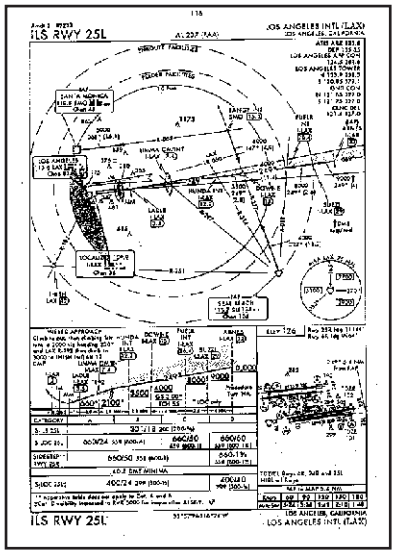
By incorporating human performance and behavior principles into the design of transportation systems, it will be possible to improve safety while enhancing system performance. The benefits of human-centered transportation research include the following:

- A decrease in the number of human errors affecting safety;
- A reduction in the fatalities, injuries, environmental impacts, and property damage associated with transportation accidents;
- An increase in the capacity of the existing transportation infrastructure;
- Enhanced transportation product effectiveness, efficiency, comfort, convenience, and user acceptance;
- Improved operational efficiency and productivity for transportation operators;
- Better human/machine relationships through use of advanced information and human factors technologies;
- Implementation of human-centered processes for transportation systems design and operation;
- Better assessments of complex performance issues and development of optimal resolutions to enhance safety and efficiency;
- Development of a generation of machines that are adaptable to their human operators, rather than depending on humans to adapt to machines.

Courtesy of ITS Joint Program Office

Attention to human-centered technologies in transportation also will contribute to U.S. leadership in transportation products and services. Currently, the United States is a leader in systems integration technologies, which will be key to achieving a competitive edge in the future.[6] By linking our strength in systems integration to human performance, the "human-centered systems" concept will contribute to the commercial success of U.S. transportation systems.

[6] Forum on Future Directions in Transportation R&D, Washington, D.C., March 6-7, 1995



Original approach chart.

New Volpe Center approach chart gives pilots quicker access to critical approach information.

Examples of Benefits

• FAA: Enhanced Airline Approach Charts

The National Transportation Safety Board implicated cluttered, difficult-to-read approach chart design as a contributing factor to nine aircraft accidents. In partnership with the aviation industry and pilot groups, the FAA performed human factors studies to develop new approach chart designs. The participants evaluated the new designs in the laboratory, in certified simulators, and in the air. In April 1995, the Air Transport Association adopted the new chart design, which is used by the 16 commercial air carriers. Jeppesen Sanderson, the major U.S. manufacturer of aviation charts, has replaced their airline charts with the new design. The Air Force has adapted the new format to electronic presentation and is evaluating it for military applications. This program was conducted by the FAA's Chief Scientific and Technical Advisor for Human Factors.

• FAA: Safe Use of Satellite Communications in Air Traffic Control

Before 1990, the FAA had a moratorium on the use of satellite communication systems for critical air traffic control communications, despite the fact that satellite communications often provide clearer transmissions at lower costs than land lines. The moratorium addressed the potential danger of blocked transmissions due to stepped-on messages resulting from the satellite-imposed transmission delays. FAA human factors research assessed the risk associated with satellite procedures and the conditions under which such risks would be most critical. The research found that significantly more pilot-controller/controller-pilot "step-ons" were recorded for satellite conditions only under the highest communication workload levels. As a result, the FAA ended the moratorium for most applications, maintaining it only for sites such as major TRACONs and high-density center sectors, where continuous, rapid controller/pilot communications occur.

• Coast Guard: Reducing Alcohol-Related Boating Fatalities

Although it generally was believed that alcohol intoxication was the cause of many recreational boating fatalities, there were no good estimates of the true risk of fatality due to intoxication. Congress asked the Coast Guard to quantify the risk and to develop methods of supporting law enforcement agencies in dealing with this problem. The resulting Coast Guard Human Factors research program included case-by-case fatality surveys and extensive field exposure studies.

Alcohol intoxication contributes to boating accidents.

This research determined that the fatality risk was more than 10 times greater for an intoxicated boater than for a sober boater. The Coast Guard study also evaluated and adapted non-invasive field sobriety tests so that they could be used for marine law enforcement.

• MARAD: Development of Simulation to Improve the Effectiveness of Bridge Crew and Pilot Training

In 1973 the Maritime Administration brought on line the first computer generated image (CGI) maritime ship handling simulator in the world, the Computer Aided Operations Research Facility (CAORF) at the U.S. Merchant Marine Academy in Kings Point, New York. CAORF focused on research in its early years of operation. Results from this research resulted in a better understanding of the human elements and their importance in ship bridge operations. Although full-size ship bridge simulators were expensive to operate, ship owners learned the importance of simulator training based on the results of this early human factors research. The focus of training using simulators evolved into bridge resource management programs based on the success of Cockpit Resource Management (CRM) research sponsored by NASA and the FAA and adopted by the airline industry. These research efforts have resulted in the development and operation of numerous full-scale ship bridge simulators that are regularly used for education and training of commercial and military mariners and ship pilots (there are over a dozen nearly full-scale ship handling simulators in the United States alone). Such training and refresher retraining is now considered not only helpful but necessary by all to achieve safety of maritime operations.

Ship's bridge simulation.

• NHTSA: Establishing the Safety Benefits of the Center High Mounted Stop Lamps

NHTSA based its regulation requiring Center High Mounted Stop Lamps (CHMSL) on research tests showing that rear-end crashes for company fleets equipped with CHMSL were reduced by 35 percent. These lamps help drivers detect and respond quickly to braking by lead vehicles. NHTSA has mandated CHMSL on all new passenger cars since the 1986 model year and on all light trucks since the 1994 model year. Recent analyses of police-reported crashes in eight states found that CHMSL reduce rear-end crashes by about 4.3 percent. These benefits far outweigh the modest cost of the lamps.

The use of high-mounted stop lamps have decreased the incidence of rear-end crashes.

4.0 Modal-Specific Programs within the Department of Transportation (DOT)

Overview

Current DOT research is described in published documents, such as the *National Plan for Civil Aviation Human Factors: An Initiative for Research and Application*, a joint effort of the FAA/NASA/DOD (March 1995) and the Coast Guard's *Human Factors Plan for Maritime Safety* (February 1993). The FAA human factors program conducts research to support the development and implementation of equipment, training, and procedures that enhance the safety and efficiency of national airspace system (NAS) operations. The Coast Guard plan focuses on safety issues and organizational design.

DOT's human factors research is captured in published documents.

At the Maritime Administration, the focus is on productivity and competitiveness through safe, pollution-free construction and operations. The FHWA and its Office of Motor Carriers and the NHTSA focus on regulation, achievement of crash and injury reduction, and improved mobility for all citizens. The FTA is focusing on education for both transit agency managers and employees on the dangers and long-term expense and consequences of fatigue. The FRA human factors research program conducts research on railroad operating practices, railroad system design, and grade crossings to improve the overall safety of railroad operations, with a particular emphasis on reducing fatigue among railroad employees.

... the Plan focused on five major core research areas or research thrusts. These areas are:

Human-Centered Automation:
Establishment of human interface design principles and criteria for automated and advanced systems.

Selection and Training:
Establishment of criteria and techniques for efficiently acquiring and training aviation personnel.

Human Performance Assessment
Establishment and utilization of measures to assess individual, crew, and organizational human performance in aviation systems.

Information Management and Display:
Establishment of critical human performance parameters required to effectively transfer information in the aviation system.

Bio-aeronautics:
The bioengineering, biomedicine, and biochemistry associated with performance and safety.

Excerpt from the National Plan for Civil Aviation Human Factors: An Initiative for Research and Application

Aviation

The aviation community has identified the national aviation human factors research needs; these are articulated as the five national research thrusts. This national aviation human factors research program responds to internal and external customers, is technically cohesive, and is thoroughly coordinated. The research thrusts cut across aircraft flight deck and cabin, air traffic control (ATC), airway facilities (AF) systems and services management, aircraft maintenance, aviation security, and aviation operations. The five research thrusts transcend organizational boundaries and agency-specific requirements to provide the information necessary to achieve expectations for NAS safety and productivity. Aviation-related activities focus on reducing the national aircraft accident rate by 80 percent within ten years.

• Human-Centered Automation

Human-centered automation research focuses on the role of the operator (active or passive), and on the cognitive and behavioral effects of using automation to assist humans in accomplishing their assigned tasks with increased safety and efficiency. The research in this area addresses the identification and application of knowledge

concerning the relative strengths and limitations of humans in an automated environment. It investigates the implications of computer-based technology to the design, evaluation and certification of controls, displays, and advanced systems.

• Selection and Training

Initiatives in this area include the Model Advanced Qualification Program, an air carrier pilot training program integrating technical and crew resource management performance requirements; and pre-hiring screens for air traffic controllers, designed to reduce the on-the-job training required. In addition, conducting research on the following issues related to selection and training should improve the effectiveness and efficiency of the NAS:

- Understanding the relationship between human abilities and aviation task performance;
- Enhancing the measures and methods for the prediction of future job/task performance;
- Developing a scientific basis for the design of training programs, devices, and aids;
- Defining criteria for assessing future training requirements; and
- Identifying new ways of selecting aviation system personnel.

The beneficiaries of research findings on selection and training are flight crews, air traffic controllers, Air Force systems management personnel, aircraft maintenance technicians, airport security personnel, and others in the aviation community who contribute to safety personnel and efficiency through staffing and training decisions.

• Human Performance Assessment

The cognitive and interpersonal skills of individuals, team characteristics, and organizational factors directly affect the safety and efficiency of aviation operations. Research under this thrust is directed toward improving the understanding and measurement of human performance capabilities and limitations in aviation. This research will improve safety and productivity through better equipment design, training, and system performance.

• Information Management and Display

Research conducted under this thrust seeks to improve safety and performance by addressing the presentation and transfer of information among components in the NAS. These components include controller workstations, flight deck, operational and airway facilities, as well as all of their interfaces. The research focuses on identifying the best ways to display and exchange information, and to reduce the frequency and impact of information transfer errors and misinterpretations.

Airplane evacuation

• Bio-aeronautics

This research area focuses on the bioengineering, biomedicine, and biochemistry associated with performance and safety. The objective is enhancement of personal performance and safety by maximizing crew and passenger health and physiological integrity. Examples of bio-aeronautics issues include human protection and survival, air quality, restraint systems, and evacuation. Aviation Medicine research, which identifies human failure modes and develops formal recommendations for counteracting measures, is included in the bio-aeronautics area.

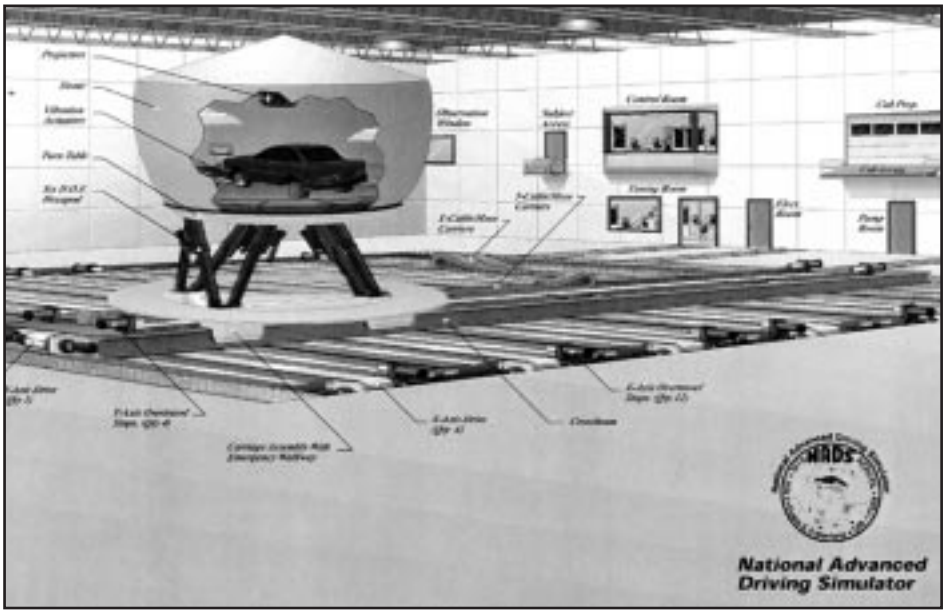
Prior to the Pan Am 103 tragedy, the human component and contribution to aviation security was not seriously considered in terms of its impact on overall system effectiveness. This catastrophic event led to the formation in the United States of the President's Commission on Aviation Security and close scrutiny of the domestic and international aviation security system. One primary recommendation from the Commission's report was the need to better address human factors and operator performance.

Given this reality, specific mandates in the Aviation Security Improvement Act of 1990 established the FAA's Aviation Security Human Factors Program. The program's mission is to review and improve human performance in civil aviation security. Current research and development efforts encompass all significant human roles, responsibilities, activities, and impacts within the aviation security system. Systematic consideration of aviation security human factors optimizes the human contributions within present and advanced technology security systems, while accommodating operator constraints. The consequential gains in system performance translate into increased safety for all users of the international aviation security system.

Highway

Highlights of the human factors-related surface programs include the following:

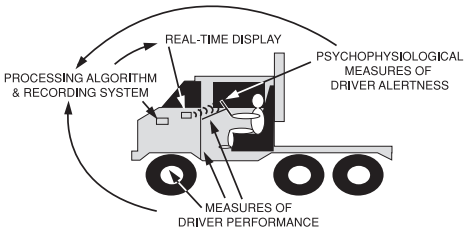
- Highway Safety – research program that includes studies investigating how drivers interact with the roadway environment. The ultimate goal of this program is to design roadways that improve safety by accounting for driver needs and capabilities. Researchers are conducting studies on determining the causes of driver maneuvering errors, driver identification of highway hazards, driver behavior in construction and maintenance zones, and driver responses to traffic control devices. Research products include modeling tools, engineering guidelines, and highway design handbooks.
- Development of highway design guidelines and modeling tools to improve the safety of the nation's highways by assuring that the system meets user needs.



NADS simulator.

- Older Drivers – efforts to modify the highway system to meet the needs of an increasingly older driver population. The FHWA High-Priority Area, Improved Highway Travel for an Aging Population, has addressed the needs and capabilities of older drivers and pedestrians. The FHWA has conducted studies to identify the needs of older road users, including maneuverability requirements, pavement markings, and signage needs. The main product of this research is an Older Driver Highway Design Handbook, which will guide engineers and designers in meeting the needs of older drivers when constructing or repairing roadways. In its research, NHTSA also is emphasizing the importance of accommodating the older driver in vehicle design, including the development of crash avoidance technologies. The emphasis has been on factoring in the capabilities and limitations of older drivers to achieve increased mobility while maintaining acceptable safety margins.
- Advanced Traffic Management Systems (ATMS) – traffic management approaches to enhancing roadway safety include reducing congestion-related crashes and the rapid clearing of minor incidents, such as flat tires. The Human Factors ATMS program works to optimize the operational effectiveness of the traffic management center, which functions as a major component of this approach. Strategies include reducing operator error and designing user-friendly equipment, software, and procedures. Guidelines for traffic management center designers and operators are being produced to ensure the incorporation of human factors principles and findings.
- Intelligent Vehicle Initiative (IVI) – initiative aimed at accelerating the development, availability, and use of driving assistance and control intervention systems to increase safety by reducing motor vehicle crashes, and to increase traffic throughput. By integrating driving

In Vehicle Alertness Monitoring: System Concept



Source: Knipling, 1998.

assistance and motorist information functions, IVI systems will help drivers operate vehicles more safely and effectively. The operational goal of IVI is to begin on-road field testing of vehicles by 2001.

- Driver/vehicle interface for ITS – efforts to foster the development of well-designed, fully integrated driver information systems that filter, organize, and communicate driving-related information; key issues are workload and driver acceptance. The capabilities of older drivers must be considered in the design of any such information systems.
- Crash avoidance countermeasures – efforts to foster the development and assessment of a variety of crash avoidance countermeasures to address various crash situations and conditions. These situations and conditions include rear-end, backing, drowsy driver/run-off-the-road, degraded visibility, lane change/merge, intersections, and adaptive cruise control. Principal issues are methods of warning, integration with other information systems, and consumer acceptance.
- "Drowsy driver" research – includes efforts to develop in-vehicle technology for detecting and warning drowsy drivers. Initial development is being conducted within the context of heavy vehicles, but the technology also is applicable to other surface transportation modes, including light vehicles and mass transit. Efforts also are directed at understanding the timelines of drowsiness for various at-risk populations, such as shift workers, students on break, and military personnel on leave. The "Commercial Motor Vehicle Driver Fatigue and Alertness Study" was the most comprehensive over-the-road study of commercial driver alertness ever conducted. It was a collaborative effort involving the FHWA, Transport Canada, a major industry association, and three motor carriers.
- Education and licensing of younger drivers – efforts to identify and communicate best practices for the education, training, testing, and licensing of novice drivers, including development of CD ROM-based risk-management training programs, and evaluation of graduated licensing systems.

Research and Locomotive Evaluator/Simulator (RALES)
Courtesy of IIT Research Institute, Chicago IL

Rail

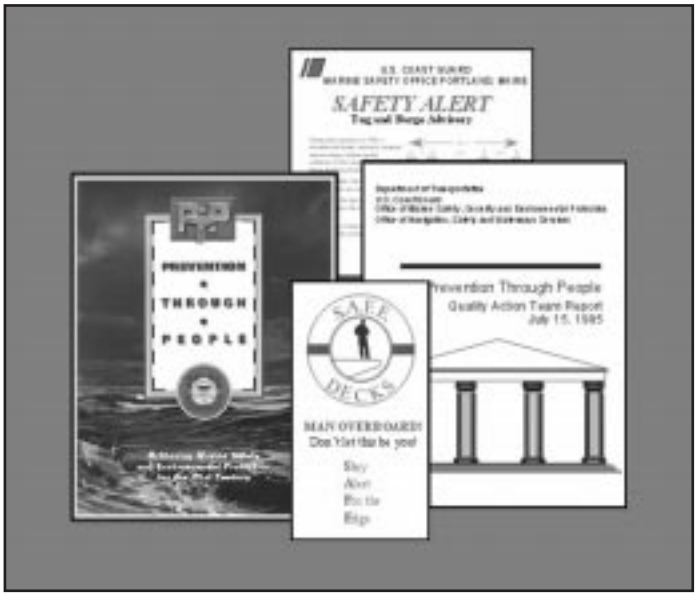
FRA's rail-related human factors research focuses on the following three major areas:

- Railroad operating practices research. A major emphasis of railroad operating practices research is fatigue. For example, diary data of locomotive engineer work/rest cycles are being evaluated to help develop models of fatigue that could be used as a tool in the design of improved work schedules. Projects are also being conducted to better understand dispatcher workload, stress and fatigue. Research activities in railroad operating practices also include organizational

Courtesy of GE Harris Railway Electronics, Melbourne FL

and cultural studies to better understand the safety culture of railroad operations, and to help implement new behavior-based safety programs as a means of improving the overall safety culture of railroad employees. Other on-going and planned research initiatives in this area include studies on job analysis, selection and training, and the teaming of operating personnel.

- Railroad systems design. Research initiatives in this area include cognitive task analyses of dispatchers, locomotive engineers and other employee groups to help classify the information requirements and other cognitive demands of complex decision-making in a dynamic work environment. Mental models will then be developed to help improve advanced information displays, communication technologies, and other decision aid systems. Results from cognitive task analyses will also be used to help design and evaluate the variety of railroad automation systems, such as Positive Train Control (PTC) and digital communications, on human performance. Other research initiatives in this area include ergonomics research, such as evaluations of the locomotive cab design for performance and safety-critical features and maintenance-of-way employee safety, and passenger car design for emergency evacuation procedures. On-going research, for example, is being conducted to evaluate whether performance-standards (similar to those used by the FAA) would be an appropriate replacement for existing prescriptive rules on the number and configuration of emergency exits in passenger cars.



The PTP program conveys the importance of people in maritime operations.

- Grade crossing research has been focusing on optimal acoustic warnings of locomotive and stationary crossing horns and the design effectiveness of various reflectorization patterns on locomotives and rail cars. Current and future grade crossing research focuses on developing a better understanding of driver behavior at railroad crossings and improving the effectiveness of driver education programs.

The FTA, with the FRA and the APTA, co-sponsored a symposium on fatigue in mid-February 1998. As the next step to developing a one-day seminar on fatigue, a panel of experts was convened in late March 1998. This panel included representation from the NTSB, FHWA, FRA, FAA, APTA, the Community Transportation Association of America (CTAA), the Transport Workers Union of America (TWU), the Amalgamated Transit Union (ATU), New Jersey Transit (NJT), the Volpe National Transportation Systems Center (VNTSC), the Transportation Safety Institute (TSI), and the FTA. The results of this seminar have been incorporated into the curriculum of the TSI's Transit Division.

Maritime

The major Coast Guard human factors effort is the "Prevention Through People" (PTP) program. The objective of this program is to provide information to the maritime community about the role of the human element in all maritime operations, both afloat and ashore, to promote the need for increased preventive measures, and to promote a human-centered approach to the design and operation of marine systems. Other human factors research conducted by the Coast Guard includes the following:

- Improving crew alertness – Studies are being conducted to measure and evaluate the effects of Coast Guard and commercial maritime work environments on human alertness and performance. This research is intended to develop tools for preventing, controlling, detecting, and managing human-related factors, such as fatigue, to improve mariner alertness and performance.
- Human factors in casualty investigations – Although human factors routinely are identified as primary contributors to marine casualties, current databases often do not provide data that are sufficient for conducting root cause analyses. Studies are being conducted to identify deficiencies in the marine casualty databases, and to improve the ability of investigating officers to identify human-related casualty causes.
- Performance-based testing – This is an effort to develop tools for the Coast Guard to meet its maritime safety objectives. This includes ensuring that Coast Guard qualification and training requirements for mariners incorporate the best performance assessment practices; developing analytical tools and methods for understanding how operational characteristics affect minimum crewing requirements; and developing tools for improving the coordination and communication among pilots and bridge teams.

The objective of the MARAD's Human Factors Research Program is to apply behavioral science principles to improving the safety, environmental friendliness, and efficiency of maritime transportation systems. Improvements are necessary because of the high probability of human error, the extreme competitiveness in the trades, the rapid introduction of automation advances, pressures to reduce staffing levels, and the significant safety risks and potential environmental damage associated with maritime accidents. Research initiatives are accomplished largely through public/private partnerships involving industry leadership, government, and academic institutions. Key areas of cooperative research include portable navigation aids for pilots, master-pilot information exchange, and potential improvements to mariner licensing. MARAD and the Coast Guard are working to develop a safety incident reporting system that will focus particularly on human factors issues. Because all accidents are rare occurrences, identifying precursors is mandatory for accident prevention. Other areas of interest include fatigue, crew scheduling, and workload.

5.0 Multi-Modal Human Performance and Behavior Research Needs and Goals

The key elements of the coordinated program are two new multi-agency human performance and behavior initiatives relating to fatigue detection and alertness enhancement: the Operator Fatigue Management (OFM) Initiative and Advanced Instructional Technology (AIT) Initiative.

The OFM is intended to improve transportation safety by developing a fatigue management system to disseminate knowledge, strategies, tools, and technologies to forecast and detect compromised operators and to maintain and/or restore alertness in a proactive manner. The strategic goal of OFM is to reduce the economic impact from fatigue-related transportation injuries, fatalities, and property and environmental damage or loss by one-third within 20 years of the implementation and application of OFM findings, products, practices, and systems. This will be accomplished by providing operators with the knowledge and information to maintain and restore alertness, and by providing resources for system designers and operators to plan, predict, and proactively address projected periods of reduced alertness.

The desired outcome of AIT is to reduce the rate of motor vehicle crashes, deaths and injuries among operators who participate by 33 percent within 20 years. This will be accomplished by using AIT techniques to enhance vehicle operator skills, decisionmaking, and safety-related attitudes.

Potential additional future multi-agency projects may include efforts relating to the following issues:

- Operator education, qualifications, and training
- Human/systems interfaces
- Cognitive workload
- Situational awareness
- Diversity, aging, and mobility requirements
- Effects of prescription drugs on performance
- System-induced errors
- Cultural change toward increasing responsibility for system safety.

As the agencies with the most critical responsibilities as providers and users of transportation services, the lead agencies for these initiatives would be the DOT and the DOD. In addition, the efforts should involve partners from academia, private industry, non-government safety groups, and other Federal and state agencies.

The Operator Fatigue Management (OFM) Initiative

Background

Transportation operators working in occupational environments requiring shiftwork rotations from daytime to nighttime schedules, extension of work hours beyond eight hours per day, high physical or mental stress, experience fatigue and decrements in alertness that adversely impact performance and safety. Casualty investigation data reveal that the human element is a primary causal factor in 60 to 80 percent of all mishaps consistently across all modes of transportation. To control the incidence and severity of casualties in transportation systems, it must be possible to forecast and detect periods of reduced alertness, and to develop countermeasures that will enhance and maintain alertness at appropriate levels. Although the scientific knowledge of human alertness has improved greatly in recent years, the knowledge is often underutilized or misused because no systematic process is available to assess the level of risk, identify the risk, and provide effective mechanisms to reduce or eliminate the risk.

A system modeled on medical analytical systems is required to fully export the fatigue and alertness research to the operational field. For example, medical personnel use factors such as cholesterol level, diet, lifestyle, and family history to establish a risk for heart problems. Depending on the level of risk, and factors involved, various interventions can be used to address the risk (such as dietary changes, exercise, stress reduction, smoking cessation, or medication). In addition, individuals are educated to look for certain cues (such as numbness, shortness of breath, and chest pain) that can help them to detect the onset of a heart attack and to take appropriate action. A similar system is needed to synthesize all that is known about human alertness into an analytical system for transportation system operators, managers, and designers to use in real time.

A human operator is susceptible to stress and fatigue.

Elements of an analytical system are available. For example, there are computer models that can forecast fluctuations in alertness as a function of previous sleep, time since last sleep (period of wakefulness), and circadian rhythmicity. The problem is that these models account for neither the effects of work-related or environmental factors, nor the restorative benefit of countermeasures. Another element is the ongoing research in fatigue detection that has identified, and is validating, various tools for detecting the onset of reduced alertness. Finally, research on fatigue countermeasures has produced numerous recommendations and strategies to prevent degradation in alertness and performance. These countermeasures range from simple recommendations, such as napping, to more drastic, riskier recommendations employing pharmacological interventions, such as stimulants and sleep aids. Usually, the selection and implementation of countermeasures is left up to the individual. All too often, operators use countermeasures that are inappropriate, implemented improperly,

or have never been systematically evaluated with respect to their efficacy, side effects, reliability, validity, or relevance to specific occupational environments. The use of such countermeasures may result in a false sense of security and complacency, and may compromise safety and performance.

A comprehensive multi-modal, multi-agency, research program is envisioned that will:

- Conduct research on known fatigue countermeasures to assess their efficacy, side effects, reliability, validity, and relevance to specific modal environments. The findings would be compiled into a reference document similar to a *Physician's Desk Reference*; and
- Develop and demonstrate an analytical system to forecast and detect decrements in alertness, and to provide effective, safe, mode-specific fatigue prevention strategies for real-time use.

Outcome

The desired outcome of this effort is to reduce transportation-related loss of life, injuries, destruction of property, damage to the environment, and lost productivity in the United States by 33 percent within 20 years. This will be accomplished by providing operators and managers with the knowledge and tools (including computer-based software and a reference manual) to forecast, detect, and maintain or restore alertness in a proactive manner.

Goals

The major goals of the effort will be to:

- Develop a national inventory of fatigue countermeasures for transportation operators, managers, and systems personnel. This inventory will be written like a *Physician's Desk Reference* for pharmaceuticals, where each countermeasure is discussed in terms of the efficacy, duration of effect, side-effects, appropriate application, and implementation procedure. This reference would feature separate chapters for each mode and address contributing factors, detection, and prevention of fatigue and loss of alertness. A condensed "quick guide" version would be developed for operators. These references could be used to tailor fatigue countermeasures programs to the mode-unique environments, and develop model fatigue countermeasure programs for various operational scenarios.
- Develop and demonstrate an analytical system that will forecast and detect alertness decrements, and provide safe and effective mode-specific fatigue prevention strategies that can be used by operators and managers in real time. This tool could be used to plan operations, design and evaluate alternative work schedules, as a fitness-for-duty test, and to assess the feasibility of critical or risky operations. In general, this should become a practical tool that industry can use to improve safety.

Program Plan

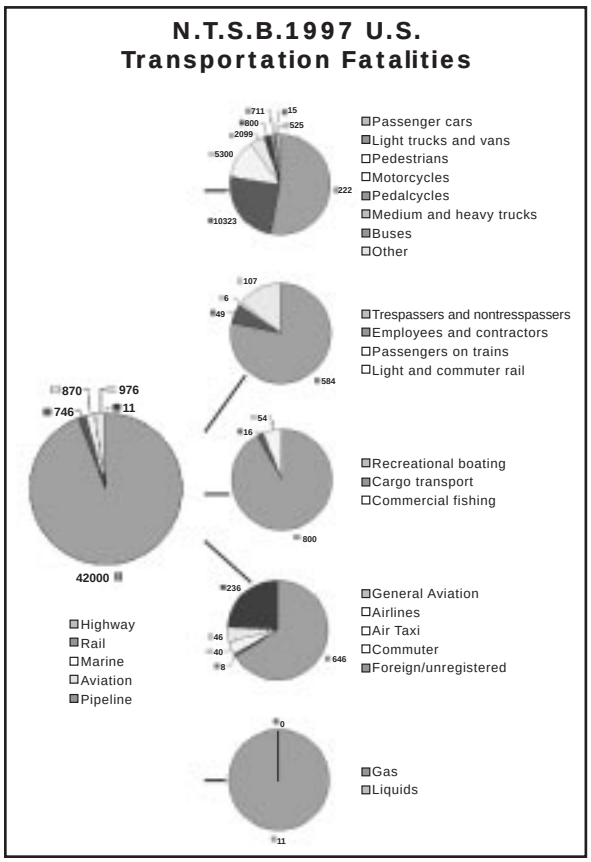
This research effort will be a multi-modal and multi-agency program. The research program is intended to produce products that individual modes cannot support independently. The lead agency on this effort will be the DOT, with partnerships sought with subject matter experts from the DOD, academia, non-government safety groups, and various federal and state agencies. The development and execution of the research program is expected to require several years. However, intermediate useful products can be expected at the end of each research year.

The envisioned effort would consist of two phases.

- Phase I, assess the efficacy of known fatigue countermeasures, publish a "DOT Fatigue Management Reference," and begin assessment of "promising" Fatigue Management approaches.
- Phase II, the OFM Program will develop, test, and demonstrate Fatigue Management Analytical Systems (FMAS), validate "promising" Fatigue Management Approaches, and deploy enhanced editions of the FMR.

Advanced Instructional Technology (AIT) Initiative

Background



Annual transportation fatalities in excess of 40,000 represent by far the single largest source of transportation deaths in the United States. Poor operator performance is believed to be the major factor in these ..fatalities. In addition, safety-related aspects of operator performance vary among different population segments. Different challenges are associated with improving the performance of each segment of the operator population. The youngest drivers, who have the highest risk of fatalities per vehicle mile, must quickly develop the skills, experience, and judgment required to understand and avoid dangerous situations. The growing population of older drivers, who depend on the automobile for mobility, requires both "age-neutral" evaluation procedures and better methods of compensating for their changing cognitive and physical capabilities. The latter would involve modifying both the driving environment and vehicle design.

A "Smart Skilled Operator" must be educated and trained to be a safe operator. Safe operators take personal responsibility for the safety of not only their own vehicles but also for the safety of other vehicles–in essence, for the transportation system itself. One approach to the goal of increasing the number of safe

operators is to develop and implement a set of procedures that provides a lifetime of learning opportunities for operators. Such an initiative would require the development of a variety of educational and informational tools and procedures, and would use many different types of technologies.

It is envisioned that one major component of such an effort would involve the use of Advanced Instructional Technology (AIT), which are among the most promising of the new technologies available for transportation system and operator education, training, and evaluations. These systems range from simple, inexpensive desktop computer-based instruction (CBI) programs to elaborate, full-mission simulators. The military and the transportation industry use AIT techniques for operator training. For example:

- The Air Force uses aircraft simulators to compress the time needed for their pilots to reach full proficiency, to improve their flying ability and safety, and to evaluate their performance.
- The commercial aviation industry uses such systems to familiarize pilots with emergency situations and to train pilots in the appropriate responses to these situations. Simulation also is used in commercial aviation to meet requirements for recurrent pilot training.
- Railroads use AIT to train locomotive engineers to operate their equipment and to become familiar with the routes or terrain on which they operate.

Continuing improvements in the capabilities of relatively inexpensive AIT systems are expected to make them cost-effective for training non-commercial motor vehicle operators, such as automobile drivers.

The first project under a department-wide multi-modal transportation human factors program is a multi-agency program to evaluate the use of AITs such as CBI and simulation in the improvement of operator skills. To be successful, the AIT program must build on the experiences, technologies, and accomplishments of all the DOT modal admin-istrations and other Federal agencies, particularly the DOD and NASA.

Although the lead agencies for the AIT Initiative will be the DOT and the DOD, it will be a team effort, drawing research partners from the academic community, private industry, non-government safety advocacy groups, and other Federal and state agencies. Other potential partners include elderly advocacy groups, which could provide access to and counsel from older driver populations; state Departments of Motor Vehicles, which could help with research program development; insurance companies which could help to plan evaluation procedures; designers of simulators and other learning technologies; DOD and NASA researchers; and automobile manufacturers who will be invaluable for AIT technology development.

Further, it is anticipated that the lessons learned will be applicable to the broader range of civil and military systems using AITs.

In particular, the DOD role may extend far beyond technology transfer. One of the largest sources of military injuries in both peacetime and wartime is transportation accidents. Military bases represent a critical source of research subjects. The military subject pool has the potential to provide a population of younger "high-risk" drivers under the controlled conditions that have been lacking in many prior studies.

Outcome

The desired outcome of AIT is to reduce the rate of crashes, deaths, and injuries among operators who participate by 33 percent within 20 years. This will be accomplished by using AIT techniques to enhance vehicle operator skills, decisionmaking, and safety-related attitudes.

Research Goals

The major goals of the research are as follows:

- Develop, and validate the effectiveness of AIT systems that can improve the operational safety of operators through lifetime education and training and adapt them where appropriate.
- Demonstrate the effectiveness of such systems in reducing crashes through a decrease in unsafe behaviors.

Approach

The approach of the AIT initiative will be to:

- Determine the different behaviors shown by novice, experienced, and elder operators when presented with various complex and dangerous situations;
- Develop educational approaches for drivers of all ages to engage and teach appropriate attitudes, reactive skills, and preventative behaviors while instilling in the individual a responsibility for safe societal operations of transportation systems; and
- Evaluate and demonstrate the effectiveness of information technologies such as simulator and other CBI training systems in preparing operators to identify, avoid, and manage potentially hazardous situations.

Program Plan

The program will include two phases. Phase I will consist of demonstrations of promising systems; short-term evaluations will be conducted and documentation produced to identify "what works." Phase II will serve to improve the curricula developed in Phase I, follow up on short-term studies, and conduct long-term studies using the improved curricula.

6.0 Interdepartmental Collaboration/ Leveraging Other Federal Programs

In addition to the DOT modal and multi-modal activities, several individual Federal agencies, including those in the Department of Defense (DOD) and NASA, have human performance and behavior R&D needs. Each of these agencies has developed an active program in response to those needs. Ongoing agency R&D programs address various aspects of human behavior, with each agency tailoring their programs to meet focused, mission-specific needs.

Department of Defense (DOD)

The overall program is organized in the following seven areas:

- Labor and personnel technology - addresses the recruitment, selection, classification, and assignment of people to military jobs. It seeks to reduce the attrition of highly qualified personnel.
- Training systems technology - improves the effectiveness of individual team, crew, unit, and joint training instruction, improves the flow through the training pipeline, and provides skill practice and mission rehearsal opportunities.
- Information management and display - develops methods and media for delivering task-critical information to individuals, teams, and organizations.
- Performance-aiding - produces technologies to minimize human error, overcome sensory and physical limitations, and improve mission performance.
- Life support - addresses technologies that protect and sustain the operational warfighters in combat and non-combat operational environments.
- Design integration - develops design tools, performance metrics, crew system design processes, and related technologies for integrating the human into operational systems so as to maximize safety and effectiveness.
- System supportability - develops technology for improving the operational and logistical support of operators and weapon systems.

National Aeronautics and Space Administration (NASA)

Highlights of human factors-related research being performed by NASA include the following:

- Research concerning human survival and performance in space-related environments.

- Aeronautics research into the human role in air traffic productivity.
- Aviation safety related to pilot error and system design for commercial and private aviation.
- Advanced avionics design for the next generation of general aviation aircraft.

NASA recently initiated the Advanced Air Transportation Technologies (AATT) program, which has a significant human factors component. These programs are driven by increases in air traffic, changes in the international mix of aviation over U.S. airspace, integrating new technologies, and making the best use of the shift from air traffic control to air traffic management.

The AATT program, led by NASA Ames, is focused on improving the throughput of the nation's air transport system. This is a systems-level effort to integrate NASA's new and upcoming technologies into the national aerospace system to ensure that it is capable of coping with current and anticipated future demand on the system. A major goal of the program is the development and delivery of integrated productivity tools and better ways to model air traffic.

The Aeronautics Safety Investment Strategy Team (ASIST) program, led by NASA Langley, is similar in structure to the AATT program, but it is focused on integrating safety technologies into the national aerospace system, rather than on productivity-related technologies. Its human factors efforts concentrate on the relations between human error and aviation fatalities and incidents.

The Advanced General Aviation Technical Experiment (AGATE) functions as a joint partnership involving the industry, the NASA, and the FAA with the purpose of developing a new generation of general aviation (GA) aircraft. The human factors efforts in this program focus on extending aircraft usability to a broader segment of the population through enhanced display and controls.

Existing Long-Term Interagency Human Factors Research

Human Fatigue Resource Directory

The Fatigue Resource Directory (FReDi) is intended to provide members of the transportation industry with current information on resources available to address fatigue in transportation *http://www.hf.faa.gov/dot/fatigue/*. The Directory is comprised of an on-line, searchable database with information on many projects being conducted by government organizations, as well as by academic institutions, private industry, and non-profit organizations.

7.0 Next Steps – Operator Performance Enhancement Initiatives

Modal programs are designed to serve modal system users in their unique environments. However, the U.S. DOT's predominantly modal structure and funding mechanisms limit innovative, multi-modal research or long-term, high-risk, high-payoff research programs that have benefits relevant to all modes. Human performance and behavior, like most of the potential cross-cutting transportation research topics, is interdisciplinary and complex. This challenge has not been addressed systematically in the past. Achieving meaningful results will require making a long-term commitment of resources.

By working together as "ONE DOT," the agencies of the U.S. DOT can enjoy the synergy and economies of scale that will enable them to make the most effective use of the available research and development funds in the pursuit of answers to the nation's most pressing transportation safety and efficiency problems. The key is to conduct research that will lead to a transportation system that adapts to the human as opposed to the current system that requires the human to adapt to it. Departmental investments also must leverage the investments of other Federal agencies, industry, and academia, if multi-modal issues are to be addressed in a meaningful way. Projects should be conducted in partnership with other Federal agencies such as DOD and NASA, as well as, where appropriate, with academia and industry.

Significant benefits will be realized from cross-cutting efforts in the human factors area. Creating a coordinated Departmental Human Factors Research Program will strengthen the modal programs, provide cross-cutting products that are useful to multiple modes, and will leverage investments by other agencies in human factors research.

The goal of this DOT research initiative is to reduce transportation incidents by as much as one-third by the year 2020 by focusing on two critical areas:

- Managing operator fatigue to sustain alertness, and
- Upgrading operator abilities and skills, especially those related to recognizing and responding to imminent crash threats.

This DOT research initiative will develop advanced technologies to mitigate human error and upgrade skills specifically for new operators and older individuals through the application of advanced instructional technology.

Funding and implementing the Operator Fatigue Management Initiative and the Advanced Instructional Technology Initiative will be a first step in establishing the kind of cross-cutting research that has a long-term payoff for one or more of the transportation modes. The progress and results of these initiatives should be documented and disseminated as appropriate to all interested parties.

References

Beniger, James R. *The Control Revolution: Technological and Economic Origins of the Information Society.* Cambridge, Harvard University Press, 1989.

Blincoe, Lawrence J. *The Economic Cost of Motor Vehicle Crashes, 1994.* DOT HS 808 425. National Highway Traffic Safety Administration (NHTSA), U.S. Dept. of Transportation, 1996.

Forum on Future Directions in Transportation R&D. Co-sponsored by the Transportation Research Board and the NSTC, Washington D.C., March 6-7, 1995.

HFES Directory and Yearbook, 1997-1998. Human Factors and Ergonomics Society, Santa Monica, Calif., 1998.

Hall, Jim. Chairman, National Transportation Safety Board. Remarks read at the Washington Traffic Safety Commission Symposium on Driver Fatigue. Bend, Oregon, November 21, 1996.

Hofmann, M.A. and G.M. Hewitt. *National Plan for Civil Aviation Human Factors: An Initiative for Research and Application.* Federal Aviation Administration, March 1995.

Knipling, R.R. "The Technologies, Economics and Psychology of Commercial Motor Vehicle Driver Fatigue Management." Paper presented at ITS America's 8th Annual Meeting and Exposition, Detroit, Mich., May 4-7, 1998.

Najm, W.G., M. Mironer, Jr., J. S. Wang, and R.R. Knipling. *Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures.* DOT HS 808 263. NHTSA, U.S. Dept. of Transportation, June 1995.

Sanquist, Thomas F., John D. Lee, et al. *Human Factors Plan for Maritime Safety.* CG-D-11-93. U.S. Coast Guard Research and Development Center, Groton, Conn., February 1993.