REPORT

Prospectus on Multi-Modal Aspects of Human Factors in Transportation

T. J. Triggs
R. Doyle
V. Drago

Prepared for

Research and Special Programs Administration
Volpe National Transportation Systems Center
Cambridge, MA

February 1991

Prepared by

Battelle Human Affairs Research Centers
Seattle, WA

Battelle

Prospectus on Multi-Modal Aspects of Human Factors in Transportation

T. J. Triggs
R. Doyle
V. Drago

Prepared for

Research and Special Programs Administration
Volpe National Transportation Systems Center
Cambridge, MA

February 1991

Prepared by

Battelle Human Affairs Research Centers
Seattle, WA

EXECUTIVE SUMMARY

This prospectus identifies and discusses a series of human factors issues which are critical to transportation safety and productivity, and examines the potential benefits that can accrue from taking a multi-modal approach to human factors research.

It is now recognized within the Department of Transportation that human-related factors are the largest contributors to transportation accidents. Efforts to moderate the influence of such factors need to be increased given that additional challenges to the safe operation of transportation systems are developing. Examples of such challenges include increasing congestion in the skies, on public roads, and in navigable waters.

Research in transportation human factors has been characterized by a lack of integration across the various modes. A strong case can be made that the efficiency and impact of human factors research can be enhanced by a systematic examination of what the transportation modes share in terms of human factors needs. In the conduct of research, a multi-modal formulation will encourage the adoption of a programmatic orientation towards longer-term and large-scale issues. Such an approach will provide the government with a long-range technical agenda that will guide research planning. The prospectus recognizes that not all human factors research areas readily lend themselves to a cross-modal approach and provides illustrative examples.

This report identifies and describes critical current and emerging human factors issues. They were identified based on three considerations: relevance to transportation, significance to operational safety, and likelihood that research will yield substantial benefits. The human factors issues selected to be of primary concern are:

- Fatigue

  The degrading effects of fatigue have been recognized as a major contributing factors to accidents in all transport modes.

- Drugs and Alcohol

  The topic of substance abuse is currently receiving significant public attention and there is a strong need for effective countermeasures.

- Automation and High Technology

  The advent of high technology is having profound effects on how humans function in transportation systems, and major research issues abound in this area.

- Aging

  The age of operators and users of our transportation systems is increasing, and questions exist concerning the effect of human

performance shifts that accompany aging in transportation system performance.

- Crew Sizing

  Concerns with transportation efficiency are leading to an increasing focus on human factors associated with crew sizing across the various modes.

- Organizational Factors

  The organizational context within which transportation operators perform is now understood to have a vital effect on system efficiency and safety, but the issues have received relatively little systematic attention.

In addition, some important emerging issues are also identified and discussed. These are:

- Human Performance Modeling

  Increasing attention is now being devoted to the use of human performance modeling to aid the prediction of transportation system functioning. There is a significant need to improve the efficacy of such modeling.

- Multiple Task Management

  There is a need to understand how transportation operators manage workload and multiple tasks at a strategic level.

- Allocation of Functions

  Significant new issues are emerging concerning allocation of functions between operators and machines as systems become increasingly automated.

- Unanticipated Emergency Handling and Training

  System operators need to be prepared to handle unanticipated emergencies for which they have not been specifically trained. The training of cognitive skills in severe incidents is a major research issue.

- Human Performance Aspects of Safety Data Bases

  Considerable scope exists for developing methods to aid how we understand the contribution of human error to transportation accidents.

- Human Factors in Maintenance

  Maintenance quality is now receiving considerable scrutiny in the transportation industry, and the importance of human factors issues is now appreciated.

While the prospectus serves to advocate the cross-modal approach, it is important to recognize that not all human factors issues are necessarily cross-modal. For example, a specific problem of an immediate nature in a single transport mode will often not lend itself to being part of a coordinated multi-modal activity. An explicit cross-modal research prioritization methodology could be of great benefit in maximizing the impact of human factors research. In particular, the process of prioritization must be accessible to, and understandable by, policy makers.

TABLE OF CONTENTS

INTRODUCTION

INTENT OF THE PROSPECTUS

The role of human factors in the performance of the overall transportation system has received considerably increased emphasis in the last several years. The recognition of the contribution of human error to transportation accidents, the perceptions of the need for increased efficiency in transportation operations, the changing demographics in the community, and an increased focus on user requirements have all contributed to the current high profile of human factors. Certain major transportation accidents have enhanced this recent appreciation of the vital role of the transportation operator and the importance of human factors issues. The U.S. Department of Transportation has significant initiatives underway that reflect this heightened concern with issues relating to the human element in transportation systems. The report of 1989 to the Secretary of Transportation, entitled "What America is Saying About Transportation: Innovation and Human Factors Cluster Outreach Report," details the widespread view in America of the significant role human factors can play in increasing the safety and productivity of the transportation system.

Specifically, this prospectus has been prepared to give an overview of the approach for use in policy-making concerning the coordination of research in transportation. An important goal should be to maximize the value of human factors research in transportation by focusing on cross-cutting issues. The prospectus highlights the most important current issues in transportation human factors and emphasizes their cross-modal nature. Six primary cross-modal research issues are discussed. These are Fatigue, Drugs and Alcohol, Automation, Aging, Crew Sizing, and Organizational Factors. Addressing these areas systematically with a multi-modal orientation has the potential of yielding significant improvements in transportation operations. A listing of secondary human factors topics is presented that will assume more importance in the future.

THE OVERALL TRANSPORT CONTEXT

Several factors in the transportation arena are important forces for change and contribute significantly to the human factors issues now confronting the industry as a whole.

- The impact of new technology

  The current rapid introduction of advanced computer-based technology into the transportation field presents a new set of problems associated with the human operator. Some technology will improve the operation of already existing modes, as in road traffic control systems, while other technology makes possible the development of new transport systems, such as in the high-speed magnetic levitation initiative. In both cases, the tasks of human operators in the system will change from those of conventional systems.

- The changing composition of system users

  The population in the United States is growing older. During the 1990s fewer young workers will enter the workforce, and the average transport user/worker's age, as in other industries, will increase. Additionally, there will be a general bifurcation of skill requirements. Some new jobs in the industry will require only minimal level of skill and training. This should result in general increased employment opportunities for minority groups and recent immigrants. On the other hand, many of the types of employment that will be generated in the increasingly sophisticated transportation system of the future will demand much higher levels of skills and training than previously.

- Challenges to safety

  Increased requirements for productivity pose potential threats to safe operations in several transportation modes. For example, increasing use of narrow sea lanes, reduction in operational crew sizes, or the developing congestion in the skies or on freeways must not be allowed to increase the probability of operational errors that lead to accidents. Human operators will have to be able to operate at high levels of performance despite tighter operational constraints.

THE MULTI-MODAL APPROACH

AN OVERVIEW OF HUMAN FACTORS

In order to provide a background to the cross-modal issues to be discussed in detail, this section provides a short overview of human factors.

"Human Factors" refers to the systematic application of information about human capabilities and limitations to the design of equipment, procedures, and systems. A major concern of the field is the interface between humans and machines in large-scale systems, such as in the transportation field. Human factors specialists can contribute significantly to the analysis, design, evaluation, and maintenance of such systems. In these tasks, such specialists draw on empirical results and theory. Frequently, in the transportation arena, the results on which the specialists base their work have been drawn from research settings relatively close to the specific application. As a result, some findings have not been widely disseminated, nor have they been capitalized upon in other arenas.

The human factors field is multi-disciplinary, drawing on areas such as experimental psychology, biomechanics, sociology, engineering, and operations research. A well-supported assumption of professionals in the field is that human-related errors are typically the result of poor system design, inappropriate use of operators, inadequate training, or flaws in the organizational aspects of the operation. A related fundamental assumption is that, in order to improve the reliability and safety of transport systems, it is important to go beyond the mechanical and functional aspects of the system to consider the capabilities and limitations of the human operators.

The initial experience in the human factors field was mainly associated with the design of the immediate workplace of the individual operator directly controlling a system, such as an aircraft cockpit. Designing specific displays, configuring groups of displays, and coding displays and controls to take account of the operator's response tendencies are examples of human factors topics receiving early attention. Human factors specialists were guided by some general principles developed out of human information processing research.

Over the last 25 years, the scope of human factors activity has broadened. In critical operational tasks, there has been a greater emphasis on the human acting as a monitor of complex operational systems. More attention has been given to the decision-making role of operators, with a greater focus on their thinking or cognitive activities. This change in the role of the individual operator from a controller to a supervisor occurred slowly at first, but has gathered pace in the last decade. It has been found that changes in transportation technology and moves towards automation have fundamentally altered both the demands placed on humans by operational tasks and the types of human-related errors that occur. Most recently, there has been interest, through developments in cognitive/computer science, in using expert systems and decision aids to assist the operator. There have also been some recent systematic attempts to incorporate what is known about team behavior into the design and operation of multi-operator systems. Currently, there is a developing interest within the human factors field in the influence of management and organizational structure on the performance of individual operators and the occurrence of human error. These issues of organizational effectiveness are being increasingly regarded as a substantive human factors topic.

With the dramatically increased reliability of engineering components in transportation systems, the safety improvements that can be realized through technological fixes are now dominated by the improvements that can be brought about by attention to human performance issues.

HUMAN FACTORS RESEARCH IN THE DEPARTMENT OF TRANSPORTATION

Human factors has come of age in aviation, where primary emphasis is on safety enhancement. The Aviation Safety Research Act of 1988 specified human factors as a lead area for research. The need for an increased level of effort and better coordination of human factors efforts was highlighted by the U.S. Congress Office of Technology Assessment report entitled "Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment," published in 1988. The FAA issued its draft National Plan for Aviation Human Factors in November, 1990 which outlines a large coordinated research plan for the 1990s.

While in general human factors research in marine operations has not been very active, it is now receiving increased emphasis. There are now recognized needs in several areas, with the U.S. Coast Guard developing a human factors program as part of an increased level of effort at its R&D center. This increased effort is in response to the need to comply with the requirement of the Oil Pollution Act of 1990. Over the last few years, the spotlight has been turned on the question of how fit merchant vessel operators are to make the high-level decisions. Risk management and prevention of extraordinarily costly accidents such as the Exxon Valdez accident have raised the visibility of the general fitness-for-duty issue. Other human factors areas that have been allocated high priority by the Coast Guard relate to the study of automation of both the bridge and engine room. There is also a recognized need to conduct vessel casualty analyses to determine human factors involvement in incidents and accidents. The area of manning requirements is also regarded as important, and a need to develop a theoretical and empirical basis for the whole range of vessels regulated by the Coast Guard.

Current interests at the FRA include drugs/alcohol and fatigue. The FRA locomotive simulator is a particular focus for this activity. Other research interests include locomotive crew selection techniques, grade crossing safety, and dispatcher performance. At UMTA, the Section 15 performance data reports require the establishing of a database of accidents and incidents that is used for the identification of human performance problems. For example, human factors in bus safety has been a topic of interest. There is also some research interest at UMTA on improving relationships and communications between management and employees.

In highway research, the FHWA has a continuing interest in fatigue on the road, particularly for long-distance truck and bus drivers. This agency is also sponsoring research relating to the influence of aging on road user behavior and of high technology in driving. The NHTSA is proceeding with research programs in related areas. Human factors research programs are underway on the effects of high technology and warning systems on driver workload and distraction. NHTSA is also actively engaged in human factors programs related to alcohol and drug countermeasures, seat belt usage, driver training, and the elderly driver.

SOME OBSERVATIONS CONCERNING TRANSPORTATION SAFETY

Across all modes, the Department of Transportation is committed to safety as its first priority. The Department will expand its efforts during the 1990s to improve safety. The public has a high expectation that commercially-available public transportation modes will achieve and sustain high levels of safety. Currently, this expectation is reasonably met as passenger modes are relatively safe, but there is room for improvement. In addition, the public also expects that high visibility, multiple-fatality accidents and catastrophes will be substantially avoided in passenger-carrying transport. At present, additional "challenges" to the safe operation of systems are developing, such as increasing congestion in the skies and on freeways. These threats must not be allowed to bring about reductions in safe operations.

The National Transportation Safety Board reported that U.S. transportation fatalities dropped by 3% in 1989. The main factor in this reduction was the decrease in public road fatalities, which account for 95% of the deaths. Last year, road fatalities fell by just over 3%, from 47,082 to 45,454 (of which about 8,000 were pedestrians). Deaths resulting from collisions at grade crossings between trains and road vehicles increased by 15% to almost 700, while rail fatalities overall were up by 7%. Private aviation contributed substantially to the overall aviation fatality figure of 1,158. This figure was very close to that of 1988. There was a decline in marine-related deaths of nearly 8% in 1989, from a figure of 1,026 to 944. Recreational boating accounted for 945 of the deaths in 1988. Fatalities decreased in both commercial shipping and recreational boating in 1989.

Almost half of the accidental deaths per year in the United States occur on public roads, the majority of these associated in some way with motor vehicles, making motor vehicle accidents are the leading source of accidental death overall. Young people are very highly involved in fatal accidents, with almost three quarters of accidental deaths for those between 15 and 24 years of age resulting from motor vehicle fatalities.

Since World War II, the rate of motor vehicle deaths, whether related to drivers, vehicles or miles traveled, has undergone a significant decline. However, this has been matched by a generally steady increase in the number of vehicles and drivers, and in the number of total miles driven each year. Because of this increase in the amount of exposure that road users have to hazards on the road, highway deaths continue to be a very significant public health problem as the number of fatalities in the population remain at a high level. In response to this, the President has nominated a goal for the reduction of traffic-related fatalities from 2.3 fatalities per 100 million vehicle miles in 1988 to 2.2 in 1992. Continued reductions in such statistics will have to come in large measure from human factors improvements. Researchers have concluded that, in general, human-related factors are the largest contributor to automobile accidents, being represented in over 90% of accidents.

In the U.S. heavy trucking industry, about 9 out of every 10 accidents are claimed to be driver-related in the United States. Whether the rate of accidents is considered on a per-mile or a per-vehicle basis of exposure, heavy commercial vehicles have a very significant accident involvement rate compared with automobiles. On a per-mile basis, heavy articulated trucks are over-represented in accidents by a factor of 3 in the United States. Such over-representation also has been documented in other countries. There is evidence that, in truck driver fatality accidents, alcohol and other drugs are significant contributors, while fatigue is cited most frequently as a causal factor. Drugs/alcohol and fatigue are also considered serious threats to safety in commercial operations in other transportation modes.

The links between aviation safety and human factors issues are strong. The accident data since 1978 indicate that approximately 85% of general aviation accidents and 65% of commercial jet accidents have involved human error as a significant contributing factor, principally from aircraft crew involvement. In terms of aviation incidents that have implications for or threaten safety, the Aviation Safety Reporting System data show that at least 70% of reported events are associated with human error. The increasing emphasis on human error can be attributed in part to improvements in other aspects of the aviation system. Overall, material failure has diminished in relative importance despite some graphic accidents in 1989-90. The jet engine, for example, is remarkably reliable. Improvements in radar, weather forecasting, and computer use have reduced the contribution to accidents of the non-human factor type.

It is projected that by 1998 as many as 650-800 million passengers will be transported by air in the United States, representing an almost 50% increase over recent years. Aviation safety has a high public profile and, because they are so graphic, commercial aviation accidents tend to evoke more community concern than equivalent losses of life in other modes, for example, on public roads. While commercial aviation has achieved what can be considered to be high levels of safety, the huge projected increase of passengers and freight in commercial operations impose a significant challenge to air safety. Sustained attention to system improvements are essential to ensure a continuing reduction in accidents.

Freight modes operate in a very competitive environment. The commercial pressures mean that safety considerations do not always dominate, and in that sense there is scope for improvement. The transport of hazardous materials is of considerable concern to the community. Good organizational cooperation is required across responsible groups in this area. Also, the procedures necessary for the prevention of accidents and for the mitigation of their effects when they do occur need to be based on well-formulated human factors principles and good emergency preparedness system design.

The non-commercial transport modes--the passenger vehicle, the light aircraft, and recreational boating--do not achieve the same high levels of safety performance of public transport systems. A major source of this difference is in the effort spent on operator selection/training and regulation in the transportation industry. In particular, where operators are not professionally trained, human error and lack of judgment play a disproportionate role in accidents. Exposure to risk overall is also greater for non-commercial transport, primarily because of passenger vehicle use. Private transport continues to warrant detailed scrutiny and human factors research efforts, particularly as operational circumstances and the environment change. The implementation of high technology in vehicles may introduce an additional factor that could militate against safety when this technology influences human operator workload or introduces distractions.

PRODUCTIVITY IN U.S. TRANSPORTATION

Although safety is critical, the U.S. transportation system must also maintain an enhanced level of productivity in order to remain competitive in the world economy. The transportation industry needs to be profitable, provide reliable service, and have flexibility. There are some signs, however, that the system is beginning to fall short of reasonable productivity goals just at a time when inefficiency cannot be afforded.

Human factors engineering has had a long association with activity designed to improve efficiency and productivity through its relationship with ergonomics and industrial engineering. A large-scale national program on human factors in transportation should yield significant gains in productivity as well as in the Department of Transportation's top priority area of safety. Much of the productivity and efficiency improvement can be expected to occur from innovation and the introduction of high technology. In particular, the Department has indicated its commitment to the reduction of congestion in the highway and aviation systems by these means. For example, there is a strong commitment to implementing the National Aerospace System Plan, and installing a new generation of air traffic control.

The Department of Transportation has indicated its support for exploring new transportation technology, for example, new high-speed passenger rail service, intelligent-vehicle/highway systems, tilt rotor aircraft, magnetically-levitated trains, and ship control room technology. Significant human factors issues will be involved in the introduction of such innovations.

MULTI-MODAL RESEARCH BENEFITS

Implementation of the multi-modal approach should result in several advantages, which are discussed in the following sections.

Gains to DOT from Cross-Modal Programs

The quantity of research directed at human factors issues in transportation has increased dramatically over the last 20 years. In transportation research, much of the early seminal work related to aviation. Subsequently, road user behavior research received greatly increased attention, primarily because of concerns with the road toll. In contrast, human factors research and development in the marine and rail areas has generally only been conducted at a relatively low level of activity.

Research in transportation human factors has been characterized by a lack of integration across the various modes. The large body of research and knowledge tends to be made up of relatively unconnected elements, or clusters of activity, within an individual transport mode. Examples where research on an issue has been deliberately conceived and addressed at such a level that the benefits could be shared across transportation types are uncommon. There has been insufficient awareness of research programs across agencies, which has led to duplication of efforts in some instances.

The efficiency and impact of human factors research can be enhanced by a systematic examination of what the transportation modes share in terms of human factors needs. Structuring issues in ways that cut across modes should provide a framework for the cost-efficient and coordinated use of financial resources. Focusing on a smaller number of major research issues when considering relative requirements for funding should assist the Department in making strategically appropriate decisions and may increase the organizational commitment to the systematic application of human factors. In general, the overall benefits from research that are likely to accrue to the transportation system can be more readily estimated if addressed on a cross-modal basis than by considering a larger array of single-modal projects. Such cross-modal research should facilitate inter-modal system planning and linking. For example, the user needs to be better served in the linking of air and surface transport. Furthermore, when an issue is conceived multi-modally, the needs of, and potential benefits to, each individual modality can be compared. This should aid judgments concerning allocation of research and implementation resources to the agencies associated with the various modes. A top-down multi-modal orientation will promote a higher level of visibility for human factors concepts. Higher visibility should encourage the earliest possible inclusion of human factors findings and concepts in the design process.

A cross-modal conceptualization of human factors issues and applications should also encourage the broad application of technology innovation associated with the human operator.

Promotion of Human Factors Research by a Multi-Modal Approach

A multi-modal approach can also assist in the actual conduct of research. Such a framework should aid the formulation of a research agenda that addresses continuing theoretical questions, system performance measurement issues, and/or substantive operational problems relating to system design. Because it provides a unifying theme, a cross-modal conceptualization of an issue will also encourage researchers to adopt a programmatic orientation, rather than one that focuses on specific detailed research questions in isolation. Such a programmatic view should improve the communications among human factors professionals across the various transport modes, so that transfer of ideas and concepts do not need to await formal publication. Communication among researchers can also be fostered by the establishment of multi-modal program steering committees with representation from across the transport modes.

An identification of common needs provides a foundation for cooperative research across transport modes. A recognition of shared interests should be a desirable by-product of an explicit cross-modal approach, and should lead to enhanced opportunities for cooperative investigations across different research groups.

Advantages of the Multi-Modal Approach to Groups with Special Interests

Development of a coherent multi-modal approach to research issues will provide a statement of an overall mission relating to human factors needs. The advantages that result will depend on what interested party is being considered.

The prime advantage to the government of a multi-modal approach will be the availability of a long-range technical agenda that will guide research planning. It will provide a framework both for determining funding needs (as well as how such funds should be allocated) and for overseeing programs of research. Such a planning document will provide a means to the Department of Transportation to communicate research needs to government laboratories, the industry, and the non-government research community. Such communication should promote the development of synergy in the associated research and development activities.

The transportation industry (and related industrial organizations) will be provided with a set of macro-issues in the human factors area that indicates the general system problem areas being addressed. This is important, as research problems in operational and system design are often not considered in a proactive fashion. The problems are left unaddressed until they must be confronted by the industry contractors at the time of implementation. This means that appropriate or optimal solutions are not properly devised. A forward looking multi-modal approach will provide the industry with a benchmark of what general issues are receiving attention, along with a structure on which it can base input to the Department of Transportation concerning these or other outstanding operationally-significant issues. Such feedback is important in the continuing evolution of the approach. Involvement in the planning process and responding to plans should encourage such interested parties to become associated with the Department's activities.

Academic institutions make their major contribution through longer-term, systematic, research programs. Their major contribution derives from the intellectual resources that can be brought to bear on transportation problems. A multi-modal approach and the associated planning activities will allow this sector of the community to tune its programs to the Department's and industry's needs.

The documentation associated with the multi-modal approach will provide a means for keeping the public and the media informed in a structured manner concerning human-related issues in transportation in general and will provide a framework for public debate.

<u>SELECTION CRITERIA FOR MULTI-MODAL ISSUES</u>

Several criteria have been used to guide the selection of the multi-modal human factors issues proposed.

- An issue must be of one of relevance and concern to more than one transport mode.
- There should be reasonable agreement among human factors researchers that it represents a significant problem.
- An issue must be judged to be relevant to transport system design and functioning by professionals concerned with real world transport operations, as well as human factors researchers.
- Research stemming from the issue should be capable of contributing theoretically in areas relating to human performance.
- The issue should be such that progress can be made within the resources available, in a reasonable time frame, and with some real chance of success.

MAJOR CROSS-MODAL HUMAN FACTORS ISSUES

A number of macro human factors issues that can be judged to have significant implications for the current and future performance of transportation systems will now be discussed. These topics can be deemed to be strongly deserving of research support, where with the appropriate focus, a research effort will be able to contribute to improved performance across transport modes. The listing is divided into two groups. The first consists of those with highest priority. The additional listing is for topics that can be deemed to be important, although not at the same level of priority, but are not being given research emphasis at present.

FATIGUE

There has been an increasing realization in recent years of the potential degrading effects of fatigue on the operator's performance and information processing. Fatigue has been named as a major contributing factor to accidents in all transport modes, and potential countermeasures to the fatigue problem are common across modes. By the fatigue problem, we refer to mental fatigue, rather than physical. Much still needs to be learned about the theoretical aspects of fatigue and its effects on human performance.

All long-haul freight transportation modes require their operational staff to work long days and weeks, frequently work at night, work highly variable shifts, and occasionally work very intensively. Such conditions promote fatigue and sleep-loss. Of all the modes, the merchant marine probably demands the most in terms of sustained periods without sleep, but lack of sleep can be a major problem on occasion in all modes. To illustrate the extent of the problem of fatigue from extended transport operations, data from road accidents indicate that the risk of heavy truck drivers having an accident approximately doubled when their driving time exceeded eight hours compared with those who had driven for a shorter period. The importance of the fatigue in trucking issue is reflected in the current program being funded by FHWA. Severe train accidents have also been attributed to train crews being inattentive due to fatigue or asleep, while similar concerns have been raised concerning the marine environment. Accident statistics in aviation over a large number of years have consistently shown a higher accident rate for long-haul operations versus short-haul. The impact of both long periods of duty and time zone changes on crew fatigue (circadian desynchronization) have been judged to be significant factors in this difference.

While a wide range of fatigue countermeasures have been discussed across transport modes, a general requirement is the development of a general alertness indicator. Originally, this was recognized as a critical problem with locomotive engineers, but increasingly it is understood to be an issue for operational personnel in all the transport modes. While a number of physiological, operational task, test battery and subjective types of measurement have been proposed in the past, no single measure of fatigue has yet gained extensive support. The potential payoff from successful development of such an indicator in terms of safety in the transportation field would be enormous. The high profile of this problem is reflected in the involvement of state agencies. For example, the Arizona Department of Public Safety is currently conducting research to check the feasibility of testing drivers of commercial vehicles for fatigue at designated locations. Developing techniques for continuously monitoring drivers is the current focus of programs in other countries, such as Australia. It is important to distinguish here between methods of monitoring fatigue and methods of predicting fatigue. While both have challenges associated with implementation, the task of predicting fatigue is the more difficult problem.

Concern with designing optimal shift schedules is a problem shared across the transport modes. It is known that human error as a result of fatigue is a function of duty time, time of day, and shift schedule, but the exact relationship requires additional clarification. Of recent interest in the trucking industry has been the effect of the driving/rest pattern over days to evaluate the tendency for fatigue effects to accumulate. This is also of relevance to other transport modes. Questions remain concerning the efficacy of sleep or rest obtained while involved in operations. Use of sleeper berths in long-haul trucking operations has been shown to adversely affect safety, while questions have been raised concerning how rest should be taken by trans-ocean aircraft crews. This is a developing issue as aircraft have now been introduced with flight durations extending beyond 14 hours.

New challenges exist in the area of fatigue in association with other human factors issues. There is a general push for reduced crew sizes in the transportation arena. For example, commercial aircraft are now all being designed for two-pilot crews. There is little accumulated experience with this crew configuration for long-haul flight operations. Staff reductions are also an issue in marine and rail operations. Such changes may lead to performance decrements due to fatigue because of increased demands on operational staff. The introduction of advanced technology affects fatigue, providing both a challenge and an opportunity. The introduction of new technology into operational situations can increase the probability of boredom, vigilance decrement, and sleepiness. This is particularly true if the new technology leads to reduced social interaction as is frequently the case. Social exchange provides an important antidote to loss of alertness. However, there is potential for taking advantage of the computer capacity typically being added to operational situations. The computer-based system can be used to stimulate an operator's alertness and performance readiness. Alternatively, the computer can monitor the performance or state of alertness of the crew and alert them when decrements are noted.

In sum, the fatigue area represents a significant opportunity for a major multi-modal research effort.

DRUGS AND ALCOHOL

Concern has been growing concerning the fitness of an operator to perform his/her duties following the ingestion of alcohol, drugs, or combinations of these. The topic of substance abuse is receiving a great deal of public attention because of graphic events in some transport industries. One example of this is the recent wide publicity associated with significant alcohol abuse by airline crew members. Also, the detailed scrutiny that the legal profession, environmentalists, the petroleum industry and safety professionals has given to the performance degrading effects of substance abuse of merchant fleet operators has flagged this area as one of critical concern. Recent oil spills in Alaska and in the Galveston area have resulted in the courts holding corporations responsible for such spills, and at times charges of criminal negligence have been laid against ship officers. As a result of these specific transportation-related events and a general increasing concern with the problem in government, industry, and the community, drug and alcohol testing is now under serious consideration in many modes of transportation. The National Transportation Policy commits the Department of Transportation to more effective anti-drug and alcohol programs.

It should be noted that drugs and alcohol constitute only part of the generic fitness-for-duty problem. This overall issue has two main components. The first involves the state of the operator to perform his/her work when first training, level of ability, and pre-existing fatigue. The second component concerns the issue of degradation in an operator's performance over the period of a shift. Time-on-task is a principal factor for this sub-issue.

The techniques for detecting the taking of alcohol are now relatively well advanced, but the situation for drugs is not nearly as well established. With alcohol, it is possible to conduct real-time testing with the breathalyzer, while good behavioral screening tests, such as eye gaze nystagmus that can detect even minor alcohol involvement, are available. Furthermore, a good understanding has been developed concerning the dose-response relationships associated with alcohol, so that the impairments in human performance that result from different levels of alcohol in the blood can now be regarded as well defined. In contrast, much less is known about the impact of drugs. There are no satisfactory behavioral or real-time tests. Drug tests are expensive and time consuming, with significant time delays, typically up to 48 hours, before the test results are available.

Dose-response relationships for drugs have not been well established for either short- or long-term effects, particularly where more than one drug is involved. These considerations mean that operational fitness-for-duty rules, to be effective, must be based on a total absence of drugs, which may not be practicable for all transportation environments. Further, relatively little is known about the effects of drugs (both legal and illegal) when working in concert with alcohol. This raises important fitness-for-duty questions as in many cases of substance abuse drugs and alcohol are found in combination.

While much still needs to be learned about the short-term and synergistic effects of drugs, it also needs to be stressed that the links among drug type, amount of use, and longer-term impairment are at present ill defined. This is an important consideration as some testing techniques provide information only about relatively recent use. Thus, some longer-term impairments may be present even if negative test results are obtained. While most scrutiny has been given to the effects of illegal drugs on performance, some attention has been devoted to impairment produced by legal drugs. However, despite this work, there continue to be issues of relevance to the transportation field in the area of legal drugs. For example, the influence of long-term use of anti-depressants on actual operator performance has not been investigated in any detail.

The transportation industry is characterized by the use of small teams or single operators who are not under the direct supervision by their management much of the time. Thus, some of the "problem indicators" associated with substance abuse nominally available to supervisors in large scale organizations are not fully present in operational segments of the transportation industry. This raises several multi-modal issues about how transportation modes should respond to this difference. Important human factors questions need to be addressed. These include how best to select operational personnel prior to employment to minimize fitness-for-duty problems, how to train transportation workers to be more conscious of their roles and responsibilities, and, in the team context, how to train and prepare individual team members to control and act against other team members when substance abuse is detected.

AUTOMATION AND HIGH TECHNOLOGY

The "revolution" that is taking place in high technology is influencing transportation systems in the same dramatic way as it has manufacturing, office, commercial and financial systems. This revolution needs to be tempered with a concern for the way in which the technology will affect the role of the human operator, the user of the system, and the safety and efficiency of system operations. As automation and new information sources continue to change how the human functions in transportation systems, general research issues abound in this arena.

The replacement of human functions by machines as new technology is introduced has been a matter of some controversy and continuing debate in all transportation modes. Automation is seen as one way of removing human vagaries from the operation of the system and replacing these with reliable machine operations. While offering potential for reducing human error, automation can also augment human monitoring with reliable warning systems. On the other hand, some professionals have regarded the introduction of automation as reducing the role, status, and satisfaction of the human operator and as a potential threat to safety. Automated systems have demonstrated that, on occasion, they can promote new types of human error in their operation. Also, the expectations that automation will reduce crew workload have not always been met. Manual control tasks are typically reduced by the introduction of automation, but this is likely to be accompanied by an increase in the human's need to plan and monitor the operation of the system with an associated increment in cognitive workload and, in some cases, with potentially increased distraction from the primary tasks of the operator.

The thrust towards automation will continue to be extensive across the transportation field during the 1990s and systematic programs in some modes are currently being developed. In aviation, both NASA and FAA are mounting increased and cooperative efforts to reduce the potential for operational human error with a significant emphasis on the role of technology. NASA has developed a program plan specifically oriented towards automation in the context of aviation safety that addresses flight and air traffic control operations. The FAA Draft National Plan for Aviation Human Factors also addresses issues concerned with the implementation of technology. This plan expresses a need for inter-agency cooperation on such issues. The January 1991 National Forum to address the impact of new technology on human factors in aviation is an example of such cooperation. The conference was co-sponsored by the American Institute of Aeronautics and Astronautics, NASA, FAA, and the Human Factors Society.

The Federal Highway Administration and the National Highway Traffic Safety Administration have expressed common interests in the role of high technology to augment driver performance on the road by providing information related to navigation, warnings, and collision avoidance. These highway efforts are related to the very major programs of the European Economic Community concerning computerized aids to drivers, such as PROMETHEUS. In the U.S., we have entered the era of intelligent vehicle highway systems so that issues involving human performance in automated and semi-automated systems must now be addressed. Current initiatives by the FRA (in connection with MAGLEV), UMTA, and the Coast Guard all have relevance to the automation issue.

A number of challenges confront the human factors specialist when automation issues are addressed. To a large extent, the general issues can be considered as multi-modal problems. Advanced technology should adjust the composition of the human operator's tasks towards more planning, sequencing, and cognitive processing. What is lacking at present is a well-developed and comprehensive general guiding philosophy for designing human/automated systems. Certainly, experience to date shows that regarding the automation process as merely the adding of a collection of devices is not viable.

A related major human factors issue for the 1990s involves the collaboration of human and artificial intelligence (or expert systems). Development of such systems is likely to extend the role of automation in transport systems dramatically. Interest in expert systems will encourage research addressing issues associated with understanding the factors influencing the reliance and "trust" operators place on such devices, and how responsibility is shared between the human and the system. Research is also needed to evaluate the processes governing human intervention in vehicle control in the presence of expert systems. It has been noted that when fatigued, humans are less willing to intervene in system operations, and automation may heighten this tendency to surrender control. How operators perceive their degree of control and authority when involved with automated systems is an important issue. Artificial intelligence has the potential in time eventually to aid reductions in crew complements, given its capacity to act essentially as an associate of human crew members.

Another crucial and continuing multi-modal research issue is that of a crew's ability to perform safely and effectively when the mode of system operation reverts from automatic to manual. This is a particularly critical problem for circumstances where the changeover occurs suddenly and unpredictably, but may also be a problem for some "normal" transition points, such as when a road vehicle exits from an intelligent highway. To date, there are few research findings to guide designers on this problem, and it is an issue deserving of significant attention in years to come.

AGING EFFECTS

The workforce in our society is aging. Demographic trends indicate that the average age of operators and users of our transportation systems will continue to increase. Based on these trends, predictions have been made of shortages in available staff to operate systems. Questions have been raised about the overall functioning of systems in terms of safety and efficiency given the changes in human performance ability that accompany aging. The potential influence of aging (and other demographic trends) on system performance is profound. Much needs to be learned concerning the effect of aging on real world performance in complex systems.

To illustrate how the changing population will affect the mix of people operating and using transportation systems, consider the highway system. The profile of the U.S. driving population has undergone quite marked changes in recent times as the population ages and other demographic shifts occur. This aging trend will continue well into the 21st century. During the last 10 years, drivers aged 65 and older showed an increase in number of about 25%, and those aged 69 and older by more than 65%. The number of young drivers actually decreased despite an approximately 25% increase in the total number of drivers. The average age of truck drivers has increased and shortages in licensed truck drivers are predicted in the 1990s. Such a trend will be likely to create pressures to encourage aging drivers to continue to operate. This in turn raises questions concerning safety. Both human factors engineering in system design and personnel screening tests can play a role in accident reduction.

A necessary antecedent for good human factors design activity is information about the capabilities and limitation of the population under consideration. There is still a shortfall in such information for the aged. However, even in the absence of highly systematic data, transportation problem areas for the aged can be identified. For example, aged drivers have difficulty in night driving. A research program to identify improvements in roadway delineation for the aged population, coupled with efforts to reduce glare from headlamps to improve night visibility could lead to substantial improvements in this area. Many other human factors research opportunities exist in the transportation field to improve the system design characteristics for the older user.

Based on our current knowledge of sensory, perceptual, cognitive, and psychomotor performance, there are no purely age-based restrictions that can be applied with equity to an individual's continuing employment or involvement in transportation. Some other form of screening to identify those who are threats to safety is required. The question of when people should be excluded from the operational work force or from being operators of personal transportation is an issue across transportation modes. Because of increased awareness of the place of the aging population in the community, any restrictions, exclusions, or grading of the right to operate must be fair, justifiable, and able to withstand scientific and political scrutiny.

The aviation field provides an example of the importance of this issue. There has been a long-standing, continuing, and vigorous debate associated with the FAA Rule concerning mandatory retirement of pilots at age 60 that was imposed in 1959. While motivated by safety concerns, the selection of the 60 years of age cutoff has been challenged frequently on the basis that many pilots above 60 retain the qualifications and abilities necessary for safe operations. There are no aviation data indicating a downturn in safety as pilots age. All commercial pilots are subject to frequent evaluation of their medical status, as well as their cockpit performance based on company and FAA checks. It has been argued by some that this should provide a sufficient basis for determining the ability to continue employment as a pilot. No other performance tests have been accepted as a tool for such evaluations.

Yet, pilots are a highly selected and trained group of operators, and it cannot be assumed that other transportation modes will show the same pattern of maintenance of safety as the operators age. In the area of driving, for example, there is now considerable evidence that the basic skills necessary for safe driving begin to deteriorate at about age 55, and markedly so after 75. This is reflected in highway accident statistics. While some drivers at 75 are just about as safe as they ever were, making up with judgment, caution, and attitude whatever they may have lost in sensory abilities and basic performance skills, the data show that after age 75, older drivers overall are about twice as likely to be involved in a crash per mile driven as the general driving population.

To date, the relationships between the degradation of specific aspects of human performance and diminished skill in operational circumstances have not been clearly established. Because the functional differences between people increase with age, age by itself is a poor predictor of performance and generally should not be the basis for restricting approval to operate. This points out an important need, relevant to all transport modes, to establish the relationship between human performance capabilities, of the perceptual cognitive and psychomotor types, and safe and efficient performance in the operational environment. Understanding of these relationships would lead to development of appropriate screening tests. A coordinated multi-modal program in this area with cooperation with other federal agencies, for example, the National Institute on Aging and other Institutes of the National Institutes of Health, and the Veterans Administration, should yield significant benefits.

In addition, while a great deal is known about age-related changes in memory functioning, more needs to be learned concerning some sensory aspects related to transportation. Research should be conducted to develop validated tests of visual performance in addition to the normal battery of visual tests such as static acuity. There is evidence that such additional tests should include glare sensitivity, contrast sensitivity, and dynamic visual performance.

CREW SIZING

Cost containment considerations have led to an increasing focus on crew size issues, and whether tasks and missions can be satisfactorily performed by smaller personnel complements. This topic has received scrutiny in all transportation modes, but it remains as a major general issue. Associated with this general area is team performance, where the essential question is how individual functions can be combined and integrated so as to yield excellent, reliable team and system performance with as small a complement as possible. Team coordination can be identified as a critical issue based on the finding that approximately 60% of all fatal commercial aviation accidents could be attributed, fully or in part, to poor crew interaction.

The transportation industry has been very active in recent years in addressing crew complement issues. Examples involving air and sea transportation illustrate these concerns. Almost a decade ago, the President's Task Force on Aircraft Crew Complement cleared the way for future commercial aircraft to be designed to operate with two pilot crews rather than three. However, the development in air traffic requiring more economical use of airspace with more precise lateral and vertical navigation and careful speed control has increased the programming and monitoring demands on flight crew, as well as on Air Traffic Control personnel. It has been suggested that the issue of cockpit crew size may again need to be addressed because of such challenges.

In maritime operations of U.S. flagged deep-water vessels, crew sizes have been reduced over the last 20 years from an average of approximately 40 people to about 20. There are some indications that this change has been accompanied by an overall reduction in the rate of injuries. Such a reduction in accidents is supported by other results.

A recent National Research Council Report for the Coast Guard suggests that incremental crew reductions in the fleets of other countries, backed by some experiment and analysis, do not appear to have compromised safety. However, to date the U.S. Coast Guard has not collected data that permit a definitive evaluation of the relationship between crew size and the likelihood of an accident. There is now a recognized need to conduct vessel casualty data collection and analyses to determine human factors involvement in incidents and accidents.

The transportation industry lacks a set of systematic, scientific methods for determining and justifying crew size requirements in a wide range of operational settings. Development of such methods in a multi-modal context will require a wide range of factors to be addressed. While one major thrust of modern job design is to reduce crew complements by combining functions, unreasonable workload and fatigue of individual operators need to be avoided. The equipment design, level of automation, and procedures required for the range of operational functions will influence the acceptable minimum crew size. Task requirements in normal, degraded mode, and emergency conditions need to be considered in terms of how crew size will affect human error rates. Temporary augmentation of a team of operators under peak-load conditions represents one means of keeping overall crew size down, but the efficacy of such augmentation needs to be assessed. Human performance modeling techniques have potential in these areas that has not yet been fully tested. There exists considerable scope for further development of predictive models relating to multi-person systems.

An additional general question in this area is the degree to which establishing better crew coordination and communication through the application of improved training and task design can be used as a basis for reducing crew complements. Dimensions of team performance such as proper delegation of tasks, sharing of workload, assignment of responsibilities, and communication of plans are likely to become more important with reduced crew sizes. Experience in the aviation industry should prove to be generally useful in this area.

In all transportation modes, there are potential tradeoffs between the efforts and costs devoted to selection of proficient employees and their training, the procedures used to motivate staff, and the crew complement required. Understanding of how these factors interact can aid efforts to develop general crew sizing methods.

ORGANIZATIONAL FACTORS

Quality of performance within an organizational context now appears to be a significant thrust in a number of sectors within the community (for example, the emphasis on Total Quality Management). There is an increasing realization in industry that factors such as the organizational structure, culture and norms can have a major influence on the efficiency and safety of operations. As new transportation systems are introduced and older systems refined, the organizational context should now be perceived as a vital generic factor in determining performance.

To date, very little systematic attention has been given in transportation to how organizational and management factors can influence the performance of operational personnel. This general issue in transportation is still very much in its infancy, but its implications for safety and efficiency are enormous. Some in-depth investigations have strongly suggested, for instance, that inadequacies in management and organization were major contributing factors to the occurrence of some accidents. Research on related topics has been conducted in recent years in other industries, such as nuclear power, but significantly more basic knowledge is required, specifically oriented towards transportation.

A wide range of factors is likely to have an influence on the potential likelihood of operational errors by individuals or teams. Organizational structure involves issues related to span of control, allocation of authority, and policies and management practices concerning human resources, while the cultural factors include norms in the workplace, uncertainties concerning work policies and practices, and implicit or explicit conflicts. In general, however, it can be stated that organizational and administrative factors applying across functional areas are likely to be more important for long-term safety and efficiency than what occurs within any narrow individual function.

There is a need to identify within the transportation industry an appropriate family of macro, organizational-level indicators of emerging potential safety problems. Basic knowledge is required to support the development of improved methods to define and quantify organizational factors. These then need to be linked to dimensions of operator performance. When such relationships are established, guidelines can be developed for management and organizational development staff so they can systematically address the improvement of safety, operational personnel job satisfaction, crew performance, and productivity. In particular, the availability of such information should considerably enhance the ability of the transportation industry to respond appropriately at an organizational level when new technologies or systems are introduced. Ideally, quantitative models linking organizational and management factors to system performance would be available to support planned organizational changes.

INTERACTIONS BETWEEN ISSUES

The human factors issues just discussed have been identified as important cross-modal research topics in transportation. It should be emphasized again that some of these issues are now independently addressed within the Department of Transportation. For example, several of the modes have independent research activities in the fatigue area. However, there are likely to be important interactions and overlaps between the issues. For example, while the task demands resulting from the introduction of new technology may be adequately accommodated by younger operators in terms of setting up and monitoring, they may exceed the capabilities or the mix of skills of older operators. This represents an issue concerning both high technology and aging. There is a potential interaction of the fatigue and staffing issues, in that avoidance of undue fatigue is one of the factors governing the appropriate minimum crew complement in various transportation modes. Where such interaction occurs between active research areas, added attention must be given to monitoring and coordinating the research activities in the two areas.

IMPORTANT EMERGING HUMAN FACTORS ISSUES

HUMAN PERFORMANCE MODELING

In recent years, increasing attention has been devoted to the development of computer-based models incorporating both human performance parameters and system characteristics. Specific examples of such modeling approaches include SAINT,[1] HOS,[2] and the optimal human control model. While such efforts serve other purposes, a principal justification for these models is their role in predicting the effects of human performance on system output in the design or pre-implementation stages of system design. The contribution of such efforts to transportation human factors is recognized as potentially very great. Ideally, the system designer would have tools available to allow the prediction of human performance in the same way that hardware and software performance can be predicted. However, what has been achieved to date can be judged to fall well short of this ideal.

---

[1]Systems Analysis of an Integrated Network of Tasks.

[2]Human Operator Simulator.

There are a number of continuing and new research problems that need to be addressed in this area.

- Much still needs to be done to determine the generality and validity of the available models.

- The types of human performance incorporated in the models need to be significantly expanded. For example, the cognitive behavior of operators when monitoring and supervising system functioning has not been incorporated in modeling efforts to the degree necessary.

- There continues to be a real need for models that adequately address performance in large-scale, multi-person systems. Given the critical role of crew interaction and performance in system safety, multi-person modeling is a centrally important requirement. It is not at all satisfactory to base predictions of the performance of groups on extrapolations of the performance of single operators, but system developers have effectively not had other tools available. Both qualitative and quantitative model developments of multi-person systems are required.

- Social and organizational factors have largely been ignored in modeling efforts to date.

- More research is required to determine the relative efficacy of various classes of models.

- The effects of stress and emergencies have typically not been explicitly built into the modeling efforts.

- Greater efforts are required in making the models accessible to the transport system design team members, who are the ultimate users. To date, the available computer-based models of human functioning in systems have not fulfilled their promise as practical design tools. This is a multi-modal human factors problem in that relatively little research funding has been provided to date to address the topic of "model transfer" where finished products of modeling research are made available to the end user.

MULTIPLE TASK MANAGEMENT

Over the last decade, a very significant research effort has been expended on the topic of human workload and multiple task performance primarily because of concerns in the transportation area, particularly aviation. While much has been learned, this research has demonstrated the complexity and the multi-dimensional quality of the workload concept, as well as the difficulty of developing standard measurement tools. We do not recommend this continuing topic as one of the multi-modal human factors issues here, as it does not satisfy the criterion of having a reasonable probability of further success from the expenditure of additional research funds.

However, a new related issue is emerging as one that is highly relevant across transportation modes and deserving of attention.

This issue is multiple task management. There is as yet relatively little understanding of how an operator manages or should organize the conduct of a multiple set of tasks. When a set of tasks presents simultaneous demands, an operator must "manage" his/her overall performance by assessing and allocating priorities and deciding on the relative tradeoffs of performance across the various tasks. Such a requirement can be defined as multiple task management or the strategic management of workload. It is a highly complex, cognitive activity, subject to frequent interruption and recasting as new tasks demands occur. There has effectively been no human factors research conducted on this meta-level topic, and it is an important issue in transportation across the modes, particularly for emergency or degraded operating conditions. In the multiple operator environment, management of the strategic allocation of tasks poses a very special challenge to the individual responsible for coordination of the efforts.

A multi-modal research program on strategic management of task load addressing generic types of transportation tasks could make an important human factors contribution to the design and operation of systems.

ALLOCATION OF FUNCTIONS

A long-standing human factors problem in the design of systems is the allocation of functions between the operator and the machine. The approach to this issue has changed substantially over the years. Initially, listings of the functional advantages and disadvantages of both people and machines were prepared as guides to the system designer. Such an approach was basically governed by the general observation that humans are flexible but inconsistent, while machines are inflexible but reliable in their operations. It was recognized, however, that such lists were not satisfactory for addressing specific system requirements and performance criteria. This list approach was replaced by other rules-of-thumb and techniques to decide how technology should be functionally incorporated in the system design. However, the fundamental difficulty with all of these approaches has been that a coherent set of tasks for the individual human operator does not always result.

As systems become increasingly computer-based and automated, a new form of functional allocation has been discussed. Referred to as dynamic or flexible allocation, this method involves the human in allocating functions to the automated system based on its current state and the likely demands in the immediate future. Such a dynamic approach can be seen as an extension of earlier approaches based on the availability of high technology. Because of the flexibility provided by system operations being increasingly incorporated in the software of the system, allocation of functions need not be fixed throughout all phases of system operations. For example, the division of tasks on a ship's bridge could be quite different in crowded sea lanes near land than on the high seas.

The issue of allocation of tasks in automated and semi-automated systems is an important cross-modal issue that, at present, is not receiving a systematic research emphasis. The problem is one of real significance for transportation systems, particularly as it has implications for the degree of acceptability of automated systems to operators.

UNANTICIPATED EMERGENCY HANDLING AND TRAINING

In transportation, as in other industrial fields, low probability, high-risk incidents can occur. These accidents must be managed and controlled to minimize risk to passengers and crew. Operational staff, search-and-rescue personnel, emergency response teams, and hazardous waste handlers could all be centrally involved in such incidents. The high level of concern with hazardous waste is reflected in the passage by the U.S. Congress in 1990 of the Hazardous Materials Transportation Act (S.2936). Further, the Commercial Vehicle Safety Alliance is supporting research concerning issues in the highway transport of highly toxic materials.

Across most segments of the transportation industry, many of the emergency scenarios have been considered in detail. As a result, techniques either to prevent accidents or to mitigate their consequences have been developed. These techniques frequently require the human operators to follow pre-established procedures. In aviation, in particular, pilots are highly trained in responding to a wide range of emergencies. However, across the transportation industry, emergencies of a quite unanticipated type do occur on occasion with significant safety and cost implications. For these situations, specific procedures will probably not have been developed to respond to the event, and focused training will not have been provided to prepare the operators. Examples include shifting loads or holed hulls in ships, complete loss of aircraft hydraulics, and derailments of trains resulting in collisions with pipelines.

In these unprepared circumstances, little or no guidance is available to the crew or emergency personnel in dealing with the severe event. Operational personnel are in an inherently different type of problem situation during such severe accidents. These personnel must perform tasks for which they have not been specifically prepared. Compared with "standard" emergencies, unanticipated events are likely to be associated with significant uncertainty, an inability to rely on written or formal procedures, and a need to devise novel or adaptive mitigation strategies in order to respond appropriately. In handling such severe situations, the cognitive performance required of the operator will involve components of problem detection, diagnosis of the situation, and devising of countermeasures. While it is known in general that training on strategy and content can improve the performance of operators in diagnostic and mitigation situations, this remains a fertile research area. Much can be learned from the study of expert crew, as research on expertise has demonstrated that highly skilled operators in particular domains exhibit characteristic behavior in problem-solving situations. How such information on behavior patterns can be used to determine good training methods for cognitive skills in severe accidents is a research topic of real significance.

Training for these situations needs to develop the conceptual ability of personnel to diagnose unfamiliar states, and to generalize potential responses to new situations. The necessity of diagnosing unusual situations and devising novel accident mitigation strategies that are not part of well-defined and practiced procedures places significant demands on operational crew. Additionally, these demands are coupled with the stress associated with the recognition that potentially catastrophic effects may result. Training approaches to reduce the cognitive impairments that are know to result from such stress constitute an additional research topic of real cross-modal relevance.

It is likely that intelligent training technologies that represent an extension of "conventional" transportation simulators will have promise in cognitive skills and stress management training for unanticipated emergencies. Such technologies are based on artificial intelligence, incorporate dynamic system models in simulators, and allow the trainee to explore the system realistically in a variety ways. They would typically involve some form of explanatory capability that allows a meaningful dialogue between the trainee and the instructional system. Ideally, such a system permits a diagnosis to be made of the trainee's actions so that appropriate feedback can be provided.

These specific cognitive understanding and training research areas can potentially contribute to each of the transportation modes.

HUMAN PERFORMANCE ASPECTS OF SAFETY DATA BASES

Administrative authorities in all modes of transport recognize the importance of assembling and maintaining accident and incident data bases. Despite this common interest, the various modes differ widely in the form, detail, level, and completeness of their accident data sets. Even within a single transportation mode, there exist differences in definitions and categories of accidents and in the methods used for analysis by different investigators. There is even greater disparity across modes, making cross-modal comparisons at best difficult and at worst impossible. Furthermore, considerable scope remains for the further development of the formal analysis techniques and exploratory (or visualization) methods applied to the data bases. Data analyses are still largely based on simple tabulation of data, two-dimensional contingency tables, or trend analysis. Substantive progress in this area of transportation safety analysis has been slow. While often useful, elementary methods place limits on the ability first to generate and then to evaluate hypotheses concerning contributing or causative factors associated with human errors in accidents. There has only been limited attention to the issue of exposure to risk. Developing an understanding of how exposure indices should best be constructed is an important topic in transportation safety research and deserves further attention.

It is highly likely that an accident data research program, based on a cross-modal human factors orientation, will yield considerable benefits.

- Such a program would foster an environment where cross-modal transfer of ideas and methods could take place.

- The program would provide an opportunity to move towards a standardization of classification schemes relating to accidents/incidents with consequent benefits for cross-modal and intra-modal comparisons.

- The program would have as a major goal the development of a more sophisticated general set of methods for conducting safety analyses.

- If well organized, such a program would encourage the conduct of cross-modal studies where data bases related to particular contributing factors can be linked. An example would be an evaluation of the contribution of fatigue and shift schedule to human error and accidents across the transport modes. This is likely to provide a more complete and thorough understanding of the operational contribution of this factor to transportation safety.

- Improved methods for structuring transportation accident data and analyzing such data may allow the development of general safety models. To date, little progress has been made in developing such models that allow accident risk to be forecasted in a realistic way as changes in the system are introduced. If developed, these models would allow predictions to be made of the likely effectiveness of proposed countermeasures. At present, this capability does not exist, but would be extremely valuable. However, the development of general safety models should be a reasonable goal. Despite the seeming randomness of individual accidents, aggregate data have relatively stable characteristics, but have demonstrated a responsiveness to the application of system changes.

This general topic reflects an important need, where prospects for success appear to be high. Improved data bases would allow better comparability of data from various sources, an increased understanding of the factors contributing to human error and how these factors interact, and, finally, an improved estimation of the potential effects of proposed accident countermeasures and changes in system design.

HUMAN FACTORS IN MAINTENANCE

The general topic of maintenance has received relatively high visibility in the transportation industry in recent years. The need to maintain truck fleets that are responsible for the transport of hazardous waste, environmental concerns with shipping, and the aging commercial aircraft fleet have all contributed to the concern with maintenance. The role of human factors in maintenance activities covers a wide range of activities, including human/machine interface design, personnel qualifications and staffing, job performance aids, training, and management and organization. It is recognized that human performance is strongly linked to the effectiveness and efficiency of transport system maintenance. One area of particular relevance to maintenance practices is that of human factors in nondestructive testing. This class of techniques is used to detect material flaws and cracks in metal and other materials and is used widely in transportation.

There is a paucity of evaluation data concerning the efficacy of nondestructive techniques in detecting flaws. Those data that have been collected have frequently been in a form that does not allow the appropriate relative operating characteristic form of analysis. There is concern that while the technical principles behind the methods are sound, they do not necessarily yield very high levels of detection in practice. A cross-modal research program aimed at identifying the human-related factors influencing overall performance of such systems in field operations should provide a basis for recommendations to improve the detection of flaws.

IMPLEMENTATION OF CROSS-MODAL APPROACH

UNI-MODAL VS CROSS-MODAL APPROACH

While a cross-modal approach has been strongly advocated here, it is important to recognize that not all issues lend themselves to a cross-modal approach. Some are uniquely uni-modal. In general, where there is a requirement to determine a particular value for a specific standard or regulation, a multi-modal program would not be indicated. As an example, the need to assess the perception-reaction time for older drivers to be used in revised geometric road design standards is an issue for only a single transport mode. The necessary methods and data would not transfer to the other modes, nor would there be any direct benefit from a macro cross-modal program. Also, a multi-modal program is probably not appropriate where there is a short term requirement or where immediate answers are required. Additionally, some research issues may be judged to be of high priority given the immediate needs of a single transportation mode. However, from a multi-modal perspective, they may only be viewed as having low priority. It will be important to recognize a continued need to devote some research funds to this type of high priority, uni-modal problem area.

Some issues have only been weakly linked across transport modes, despite the fact that the substantive problems in different modes appear to be related as has been the case in visual guidance for approach to landing in aviation and for night time highway delineation. Additionally, there was little synergy between the research conducted on signaling systems for railroads and highway traffic signals. In both of these examples, one contributor to the lack of cross-fertilization is likely to have been an absence of coherent transferable theoretical work. In such cases, a multi-modal program would be difficult to justify.

It can be said that human factors research in transportation has not been well coordinated in the past and has generally not experienced high-level, long-term programmatic support. Despite this fact, there are cases where research conducted within the context of a single mode has been of sufficient generality with enough theoretical significance to have influenced research and application in a major way within other transport modes. Three areas of aviation human factors research provide examples of eventual strong linking of results and concepts to road researchers. These three research topics are visual sampling, oculo-motor processes, and the effects of distraction. It is in areas such as these that coordinated, cross-modal research programs are most likely to yield effective and timely outcomes. Funding of research on a uni-modal basis in such areas is likely to lead to less efficient problem solution, and will impede responding to the broader needs of the transportation community.

THE PRIORITIZING OF CROSS-MODAL RESEARCH

The major human factors areas discussed earlier are high profile topics for which strong support for cross-modal programs can be justified. However, the prioritization and relative funding levels in an overall program will need to be determined. In addition, in any continuing program additional human factors areas will have to be selected from a list of potential topics. The areas nominated earlier in this prospectus as issues likely to assume more importance in the future would be candidates for this listing.

The criteria discussed earlier in the prospectus provide an initial basis for the selection of the human factors issues to be addressed in a multi-modal program. However, there is a pressing need to develop a more complete and appropriate methodology for determining prioritization. Setting up a formal procedure for developing priorities is necessary to promote agreement across interested parties and to avoid conflict. The procedure needs to be such that it can be understood by, and can be justified to, decision makers concerned with the allocation of resources. Ideally, the issue prioritization method developed should be sufficiently objective that it can be understood and appreciated by policy makers who are not involved technically in the human factors field.