TRANSPORTATION RESEARCH

CIRCULAR

Number E-C085 January 2006

Railroad Operational Safety

Status and Research Needs

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH CIRCULAR E-C085

Railroad Operational Safety

Status and Research Needs

Transportation Research Board
Vehicle User Characteristics Committee
Railroad Operational Safety Subcommittee

January 2006

Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001
www.TRB.org

TRANSPORTATION RESEARCH CIRCULAR E-C085
ISSN 0097-8515

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Acknowledgment

This document is a report of the September 10–12, 2002, Midyear Meeting of the Transportation Research Board's Railroad Operational Safety Subcommittee, AND10(1). The success of this meeting was due to the dedicated efforts and resources of a wide variety of people, all involved in the science of making railroad operations safer through better understanding of the role of human factors. The groundwork for this meeting was laid during the 2001 annual subcommittee meeting, when meeting topics were selected and a core set of volunteers enlisted, to begin the intricate process of meeting planning and organization.

The following is a list of the key functions in organizing the meeting and those people responsible for making sure they were accomplished:

- Task Force Lead and Conference Organizer: Stephen Popkin
- Subcommittee Chair: Don Sussman
- Subcommittee Secretary: Stephen Reinach
- Venue Coordination: Richard Pain and Stephen Reinach
- Fundraising: Judith Gertler and Vijay Kohli
- Promotion: Roy Gelder and Faye Ackermans
- Invited Speaker Liaison: Fred Gamst

These volunteers engaged in 18 months of planning and coordinating activities that included identifying meeting agenda items and defining roles to be fulfilled. Given the scope of the effort, additional subcommittee members and outside experts were recruited to help share the workload. This work included facilitating the development of research problem statements; providing invited presentations; serving as breakout discussion session panelists, facilitators and note takers; and subsequently compiling the manuscript. The following are the people who served in this capacity:

- Research problem statements facilitator: Thomas Rockwell
- Invited speakers: Göran Kecklund, Neville Moray, Ann Mills, Victor Riley
- Breakout discussion session panelists: Michael Coplen, Federal Railroad Administration (FRA); Grady Cothen, FRA; Tim DePaepe, Brotherhood of Railway Signalmen (BRS); Peter Hall, Amtrak; Robert Harvey, Brotherhood of Locomotive Engineers (BLE); Scott Kaye, FRA; Al Lindsey, Burlington Northern Santa Fe Railway (BNSF); Larry Milhon, BNSF; Stephen Popkin, Volpe; Thomas Raslear, FRA; Mark Ricci, BLE
- Breakout discussion session facilitators: Joyce Ranney, Tom Sheridan, Don Sussman
- Breakout discussion session note takers: Judith Gertler, Jordan Multer, Stephen Reinach
- Report preparation: Stephen Popkin, Don Sussman
- Manuscript editor: Jane Saks

Despite the hundreds of volunteer hours served, this meeting would not have been possible without the generous support of the following organizations:

- Federal Railroad Administration
- Association of American Railroads
- CANAC Corporation
- Cattron-Theimeg International, Ltd

Special appreciation is also given to Richard Pain and the staff at the Transportation Research Board, who helped with every meeting detail and provided the Beckman Center in Irvine, California, as the meeting venue. Many of the attendees remarked that this setting was ideal in allowing them to clear their thoughts and focus on the issues being presented.

Lastly, the attendees are to be congratulated on their level of enthusiasm and preparation upon arriving at the meetings, and the level of effort they put into ensuring the sessions and end products exceeded expectations.

Executive Summary

Stephen Popkin
Jane Saks

This report summarizes the proceedings of the Midyear Meeting of the Transportation Research Board's (TRB) Railroad Operational Safety Subcommittee, AND10(1), held September 10–12, 2002, at the Beckman Center in Irvine, California.

BACKGROUND

The primary purpose of this 2002 Midyear Meeting was for key stakeholders to have an opportunity to discuss the most significant human factors-related research areas facing the railroad enterprise. At the first formal subcommittee meeting held during the TRB Annual Meeting in January 2000, attendees were asked to select and rank the top human factors-related research areas in which they and their organizations were most interested. This 2002 meeting was designed, in part, to address in detail the three highest ranking topics.

The two goals of this meeting were

1. To develop and rank research problem statements (RPSs) and
2. To bring together national and international members of the rail transportation enterprise to discuss three major topics believed critical to railroad operational safety:
   - Fatigue and vigilance,
   - Safety culture, and
   - The impact of advanced technology on railroad operational safety.

Internationally recognized speakers with non-railroad backgrounds were selected to provide a fresh perspective and an international flavor.

DAY 1: RESEARCH PROBLEM STATEMENTS

The initial activity (the agenda is found in Section 1.6 and a detailed agenda is in Appendix A) was the development of RPSs. Professor Thomas Rockwell led the process. He had subcommittee members first identify and discuss a comprehensive list of human factors research topics to be addressed in the rail enterprise, and then develop a "top 10" list through a consolidation and prioritization exercise. The originators of these top 10 research problem statements were then instructed to develop the statement in greater detail.

Following are the 10 most highly rated RPSs generated at the meeting:

1. Measurements of effectiveness of safety interventions of all kinds: relationship between fatigue and operator performance; non-accident performance measures that can help predict incidence of safety problems; human performance measures to be validated with simulators and revenue service;

2. Impacts of safety culture on safety performance: extent to which labor management perceptions of safety culture affect safety practices and decision making;
3. Ways to deliver information more effectively (technologies, information structure, etc.) e.g., how to tailor information about fatigue management for different audiences;
4. Use of wrist actigraphs and feedback to improve sleep hygiene and planning for countermeasures; comparisons with low-tech methods of improving sleep hygiene;
5. Simulator studies examining effects of positive train control on crew performance;
6. What technology is available to enhance alertness;
7. Evaluation of the sensitivity of fatigue models to performance-related measures; relationship between fatigue and operator performance;
8. Incidence of fatigue in train crews based on work schedule data;
9. Criteria for deciding the allocation of control functions between humans and computer; and
10. Way to predict human error resulting from new equipment, policies, and procedures.

DAY 2

Invited Speakers

Four internationally known speakers made presentations on the second day. Three of the speakers were human factors experts with backgrounds independent of the railroad enterprise. They were Dr. Göran Kecklund, Dr. Victor Riley, and Professor Neville Moray. They were selected to provide an expanded viewpoint and an international flavor. Their talks were the basis for in-depth discussions of three topics critical to railroad operational safety—fatigue and vigilance, safety culture, and the impact of advanced technology on railroad operational safety.

The fourth speaker was Dr. Ann Mills, who leads the human factors team at the Rail Safety and Standards Board in the United Kingdom. Her luncheon address described the Human Factors Research Programme currently under way in the United Kingdom.

Dr. Kecklund, of the Karolinska Institute in Stockholm, Sweden, discussed the problems inherent in measuring and controlling fatigue while maintaining vigilance in train crews. He discussed the outcomes of their recent TRAIN study, which examined the work schedules of Swedish Locomotive Engineers.

Dr. Riley, president of User Interaction Research and Design, Inc., discussed the implications of adapting new technology in a railroad environment. He focused on the risks and opportunities inherent in the adoption of new technologies.

Professor Moray, emeritus professor of psychology at the University of Surrey, talked about the implications of organizational style and safety culture on human errors, incidents, and crashes in the United Kingdom.

Breakout Discussion Groups

On the afternoon of the second day the attendees broke into three discussion groups, each covering one of the three mentioned presentation topics. Each group was led by a discussion facilitator and supported by a panel of experts drawn equally from railroad labor and management, Department of Transportation staff, and the invited speakers.

This meeting brought together national and international experts from the railroad enterprise, labor unions, academia, private research organizations, and the government. The intended outcomes of this activity were to

- Gain a better understanding of three human factors areas—employee fatigue, organizational safety culture, and the impact of new and rapidly developing technologies;
- Capture the safety concerns for each stakeholder group and the underlying rationale for each concern;
- Understand what each stakeholder group is focusing on with regard to safety;
- Discuss what each group should be focusing on; and,
- Discuss areas of potential collaboration on each topic.

DAY 3

Observations

The safety concerns of each stakeholder group were discussed thoroughly and openly. Discussions led to an understanding of what each stakeholder group is focusing on with regard to safety. The topic of what each group could be focusing on was also discussed. In addition, the groups identified areas of potential collaboration on the topic. The meeting ended with a plenary session where each discussion group reported their observations. The comments were surprisingly similar across stakeholder groups.

Although several collaborative efforts are already under way in the railroad enterprise, participants identified a variety of possible new opportunities to work together collaboratively. These include

- Running various pilot projects;
- Determining ways to collect and analyze data;
- Planning how to change the reporting atmosphere and railroad enterprise culture to allow more open and accurate reporting and sharing of information at all levels: legislative, regulatory, management, and labor;
- Reducing other barriers to collaboration (i.e., reestablish trust between employees and front-line supervisors);
- Developing rules for the application of new technologies; and
- Sharing information through web sites and paper publications.

ONE-YEAR FOLLOW-UP

The goals and outcomes of this meeting were revisited one year later at the 2003 Midyear Meeting in Washington, D. C. The greatest accomplishment was reported to be the synergy created by the broad range of interests on the subcommittee, and the quality and openness of the dialogue that took place. Further, the international speakers provided an appreciated worldwide perspective.

This meeting was seen as a good first step at creating a dialogue among stakeholders—government, labor, railroad management, and researchers—with regard to human factors issues. In terms of next steps, the participants suggested that the subcommittee continue to provide a forum for the discussion of research needs and their funding and implementation. A need was also expressed for a continuing discussion among all railroad enterprise segments to improve human performance–related safety in railroads. As research areas often have common characteristics and goals, there is a need to share human factors information with all stakeholders, nationally and internationally, to "leverage our knowledge."

The complexity of most issues will require many different overlapping approaches, as well as good communications and information sharing to achieve the synergies between problem areas.

NEXT STEPS

The purpose of the Railroad Operational Safety Subcommittee is to discuss, identify, stimulate, and monitor key human-centered research areas. It attempts to move the railroad enterprise forward but is not a research or funding body. It provides "food for thought" and stimulates government and private-sector research. The subcommittee tracks and collects research, and distributes research reports to members and other stakeholders.

There appears to be considerable support for continuing a forum for open dialogue across safety areas with all stakeholders at an international level.

Contents

1. Introduction

This report summarizes the proceedings of the Midyear Meeting of the Transportation Research Board's (TRB's) Railroad Operational Safety Subcommittee (AND10-1), held September 10–12, 2002, at the Beckman Center in Irvine, California, and its follow-up activities. The primary purposes of this meeting were to bring together national and international members of the rail transportation enterprise and engage them in two important discussions:

1. To develop research problem statements (RPSs) and
2. To discuss three major topics believed to be critical to railroad operational safety:
    - Fatigue and vigilance,
    - Safety culture, and
    - The impact of advanced technology on railroad operational safety.

1.1 RAILROAD OPERATIONAL SAFETY SUBCOMMITTEE (*1*)

Origins of Subcommittee

The idea for a public venue to share and stimulate human-centered railroad operational safety research began in 1999. Multiple organizations were conducting railroad operational safety and human factors research. However, there did not appear to be a public venue or forum for disseminating this research outside these organizations. TRB appeared to be a natural fit for such an effort.

However, upon closer examination, there were no readily available committees to address railroad operational safety research. There was a grade-crossing safety committee, but this addressed a different aspect of rail safety. Further, there were several railroad and rail transit committees, but nothing that explicitly addressed human factors in railroad operations.

To address this need the subcommittee was formed under TRB Vehicle User Characteristics Committee (AND10, formerly A3B02). This parent committee was chosen because it is concerned with the needs, capabilities, and limitations of vehicle users as these considerations affect the design, operation, and maintenance of personal, commercial, and public transportation systems embracing highway and rail operations. The objectives of this committee are to maximize the performance, safety, comfort, and efficiency of such systems.

The first formal business meeting as a subcommittee was held during the 79th Annual Meeting of the Transportation Research Board in Washington, D.C., in January 2000. Twenty-two people attended the meeting, with representatives from railroad companies, labor unions, American and Canadian governments, academics, and consultants.

Objective of the Subcommittee

The objective of the Railroad Operational Safety Subcommittee is to define, support, and disseminate the results of research that will enhance the performance, safety, efficiency, and comfort of those who are involved in railroad and other fixed guideway operations or users of fixed guideway transportation.

Emphasis is placed on the human role in the operation and control of locomotive rolling stock and other vehicles; the comfort and safety of fixed guideway transportation users; and the impact of these systems on the community. This includes, but is not limited to, train and engine crews (also known as train operators), railroad and transit dispatchers, railroad tower operators, those working in switching yards, those who maintain the track and signal systems along guideways, passengers and commuters, and, in some cases, abutters.

The subcommittee members come from both the United States and abroad and are drawn from local, state, and federal government agencies; major universities; consulting companies; railroads, light rail and other transit systems; maglev developers; labor; and suppliers and manufacturers of fixed guideway equipment.

A focus on operational safety is in large part a focus on human performance. Human error is often cited as the cause of the great majority of railroad incidents, derailments, crashes, employee injuries, and other losses. However, human errors often do not originate in the locomotive cab or at the dispatcher's workstation. They may originate from or be potentiated by organizational factors, system design, workspace layout, or other decisions occurring well before the actual accident.

1.2 THE MEETING

At the first formal subcommittee meeting held during the 79th TRB Annual Meeting, attendees were given (and also later the entire subcommittee received via e-mail) a list of nine human factor–related research areas. They were asked to select the top three in which they and their organizations were most interested and rank them. Three key topic areas (by rank) were identified for further exploration and later renamed as

- Fatigue (33 total votes),
- Safety culture (30 total votes), and
- Technology (24 total votes).

On the basis of that information, the organizers of this 2002 Midyear Meeting focused on two goals:

- Identify, prioritize, and document RPSs that can provide the objective data required to reduce or eliminate safety critical human errors in railroad and other fixed guideway transport and
- Gain a better understanding of three areas believed to be basic to safety–critical human error, employee fatigue and vigilance, organizational safety culture, and the impact of new and rapidly developing technologies.

The outcomes of this meeting were to

1. Identify research opportunities for the railroad enterprise (*2*),
2. Document the role of human factors-based rail operational safety within TRB, and
3. Emphasize the role of human factors in railroad safety.

1.3 THE AGENDA

The meeting covered 3 days, beginning the afternoon of September 10, 2003, and ending at noon, September 12, 2003. It was divided into two sections. The first half-day was spent defining and writing RPSs. The members spent the next day and a half in one of three discussion groups, each covering an area believed to be critical to railroad operational safety.

Agenda

September 10, 2002	Introduction to Meeting
	RPSs
September 11, 2002	Fatigue and Railroad Operations: A European Perspective
	Safety Culture in Modern Railroads
	Technical Advancements
	Audience Discussion
	Lunch Speaker: Railway Safety in the United Kingdom
	Concurrent Panels on Fatigue, Safety Culture, and Technology
	Reception
September 12, 2002	Fatigue Report
	Technology Report
	Safety Culture Report
	Discussion of Next Steps and Concluding Remarks

A detailed agenda can be found in Appendix A.

1.4 THE SPEAKERS

The organizers of this meeting selected speakers (some from outside the railroad enterprise) to help participants think "outside the box." The three discussion leader speakers were experts in their specific human factors disciplines but were not necessarily familiar with U.S. railroad operations. Their presentations provided a different perspective on similar problems encountered in the U.S. railroad enterprise. In addition, the planners invited international colleagues who, while performing the same kind of work as being conducted in the United States, may be encountering different problems and perhaps also coming up with new solutions.

It was hoped that listening to international speakers enabled subcommittee members to gain a broader view of railroad operational safety. Perhaps that prompted some members to develop new research areas and methods, as well as think of new solutions to existing problems.

Göran Kecklund of the Karolinska Institute in Stockholm, Sweden; Victor Riley of User Interaction Research and Design, Inc.; and Professor Neville Moray, Emeritus Professor of Psychology at the University of Surrey, England, were invited to provide the basis for in-depth discussions of the three topics listed above, critical to railroad operational safety.

Ann Mills, who leads the human factors team at the Rail Safety and Standards Board in the United Kingdom, provided a luncheon address describing the Human Factors Research Programme currently under way in the United Kingdom.

1.5 OVERVIEW OF THE MEETING

Research Problem Statements

TRB describes its role in preparing RPSs as follows:

> An important function of the Transportation Research Board is the stimulation of research toward the solution of problems facing the transportation community. One of the techniques employed by technical committees in support of this function is the identification of problems, and the development and dissemination of research problem statements. The aim of this activity is to provide information to governmental agencies, research institutes, industry, the academic community and others in allocating scarce resources to the solution of transportation problems.

The first day of the meeting, led by Thomas Rockwell, was spent discussing RPSs. Subcommittee members first identified and discussed a comprehensive list of human factors research topics to be addressed, and then developed a top 10 list through a consolidation and prioritization exercise. The originators of these top 10 RPSs were then instructed to develop the statement in more detail. The process is described more fully in Section 3.1.

Invited Speakers

During the morning of the second day the attendees listened to the presentations of three invited speakers. Göran Kecklund, Victor Riley, and Neville Moray provided the basis for in-depth discussions of the three topics listed above, all critical to railroad operational safety. Ann Mills of the Rail Safety and Standards Board, Human Factors Research Programme, provided a luncheon address describing the Human Factors Research Programme currently under way in the United Kingdom.

Breakout Discussion Groups

On the afternoon of the second day the attendees broke into three discussion groups each covering one of the three major issues believed critical to railroad operational safety:

- Fatigue and vigilance,
- Safety culture, and
- The impact of advanced technology on railroad operational safety.

Each group was led by a facilitator and was supported by a panel representing each stakeholder group. Panel members were drawn from railroad labor and management, department of transportation (DOT) staff, and the three invited speakers. The groups were facilitated and supported by the Volpe National Transportation Systems Center and Foster–Miller technical staff.

Panel Discussion

The panel members each presented their constituency's point of view on the topics:

- The most critical safety issues,
- What their organization is doing about them,
- What safety issues they need to address, and
- How stakeholders might collaboratively address these issues.

Audience Discussion

Breakout discussion group participants were asked to discuss what they had heard that day and respond to the following questions.

- Why is this an important issue for you?
- What safety concerns are going to be most important to you in the next 10 years?
- Do you have additional safety concerns?

Breakout discussion group participants discussed how concerns arise in their organization. They were asked:

- How do you find out about problems?
- How do you document problems?
- How do you convince the organization that the problem is important?
- To what extent do you have ongoing research?
- What kind of data do you need to document the problems? Why?
- How do you make the case to your senior management, members, or the governing board to get support?

They were asked how learnings are shared in their organizations.

- What has worked and what has not worked when addressing concerns in your organization?
- What advancements have been made in this area?
- How were they achieved? What approaches have you tried?

Documentation of Concerns

Breakout discussion group participants were asked what concerns they had about the issue. They were then asked to make sure that all of the following views were represented:

- Labor,
- Industry management,
- FRA,
- Vendors and suppliers, and

- Researchers and academics.

Identify Areas of Potential Collaboration

Breakout group participants discussed areas where stakeholders could collaborate in the future. They ware asked to discuss the following questions:

- Which areas are you or your organization interested in working on?
- What are areas of potential collaboration?
- What are potential barriers to collaboration?
- How could those barriers be addressed?

1.6 FORMAT OF THIS REPORT

This report includes two background pieces:

- U.S. Railroad History Relating to Fatigue, Safety Culture, and Technology, Frederick C. Gamst; and
- Overview of British Human Factors Research Program, Ann Mills's luncheon address

Each of the three invited speakers provided reports on their presentations, which are also included. Each topic is followed by a report on the breakout group discussion for that area.

- Fatigue and Safety in the Railroad Industry, Göran Kecklund;
- Culturing Safety for Railroads, Neville Moray; and
- Technology, Victor Riley.

Each of the papers submitted as part of these proceedings reflects the opinions and voice of its author.

Notes

1. The subcommittee was formally elevated to task force status within TRB in 2005.
2. For the purposes of this report the term "railroad enterprise" includes railroad labor, management, manufacturers, suppliers, and government agencies such as the FRA.

2. Letter from Alan Rutter

The Honorable Alan Rutter, Administrator of the FRA, expressing his support for the meeting, provided the following letter.

U.S. Department of Transportation
Federal Railroad Administration

Administrator

1120 Vermont Ave., NW.
Washington, DC 20590

SEP 9 2002

Dr. E. Donald Sussman, Ph.D.
Chair, Subcommittee on Railroad Operational Safety
Transportation Research Board
National Academy of Sciences
500 Fifth Street, NW
Washington, DC 20001

Dear Dr. Sussman:

I'd like to thank the Transportation Research Board (TRB) for inviting me to attend the TRB Workshop on Fatigue, Safety Culture and Technology in Irvine, California on September 11. Although my schedule did not allow me to be away from Washington at this time, I would like to have you share the following comments with the attendees at this important workshop.

The Transportation Research Board's Subcommittee on Railroad Operational Safety and the Federal Railroad Administration's (FRA's) Human Factors R&D Program are very important in shaping safety and policy at the FRA and in the railroad industry. The FRA is fully committed to working with our industry stakeholders on non-regulatory R&D activities such as these. We are happy to co-sponsor this meeting in which representatives from management, labor, consultants, government, and universities will generate broad research ideas that will guide future R&D in the railroad industry and FRA.

Safety trends in the railroad industry indicate last year set all-time records in several areas, including the lowest accident/incident rate on record, the lowest number of railroad fatalities (22) and injuries (7,575), and the lowest overall employee casualty rate (3.19 per 200,000 employee hours). These improvements were most rapid in the 1980's and then tapered off in the 1990's, suggesting further improvements may be challenging. Furthermore, despite a 12 percent decrease in human factors caused accidents in 2001, human factors caused injuries and incidents still constitute merely one-third of all railroad accidents and one-half of all yard accidents.

For these reasons, human factors research remains one of the top safety issues at the FRA. Only by understanding the role of human factors in railroad accidents and incidents can human factors injuries and fatalities be eliminated. Your input in this process is critical.

FRA's Office of Research and Development

FRA has a strong commitment to Research and Development. R&D is the starting point for innovation, and innovation plays an important role in shaping the future of railroad safety. Our

R&D Program's primary mission is to support FRA's safety program and the Office of Safety. It does this largely by conducting innovative research and demonstration projects with partners in the railroad industry to help improve the safety, efficiency, productivity and mobility of the nation's railroads.

FRA's Human Factors R&D Program

The Human Factors R&D program has three separate activities:

1) First, it conducts research and demonstration projects in a wide variety of human factors areas, such as fatigue modeling, behavior-based safety, grade crossing safety, and digital communications;

2) Second, it provides technical support to FRA's Office of Safety, especially to our partnership efforts in areas such as the Safety Assurance and Compliance Program (SACP), the Railroad Safety Advisory Committee (RSAC) working groups, the SOFA Working Group, and the North American Rail Alertness Partnership (NARAP); and

3) Third, it collaborates with inter-agency, inter-department, and other non-governmental research institutions on applied research, evaluation, and the development and application of human factors standards, leveraging knowledge and resources in the process. Its program managers actively serve on a variety of outside panels and committees, such as DOT's Human Factors Coordinating Committee (HFCC), the National Institute of Health Sleep Disorders Research Advisory Board, TRB Human Factors Workshop Planning Committee, and the National Human Research Protections Advisory Committee.

This TRB Subcommittee will play an integral role in helping FRA achieve its Human Factors R&D Program goals. Collaborative efforts like these are essential to further improve the industry's outstanding safety record. I believe all the industry stakeholders – especially the FRA, railway labor and railway management – are committed to these safety ideals. Your hard work at this conference will go far in shaping how we achieve these ideals. Already, you have identified three of the most important safety areas facing the railroad industry today: human fatigue, safety culture, and the challenges associated with the introduction of emerging technologies.

Human Fatigue

Human fatigue remains a challenge in our dynamic operational environment. Working together, rail management and labor, the Association of American Railroads, the American Short Line Regional Railroad Association, the National Transportation Safety Board, and the FRA have helped forge the North American Rail Alertness Partnership (NARAP), which is now a national model for dealing with fatigue. Through NARAP, you have helped advance the science of, and practical countermeasures for, fatigue.

Individual countermeasures alone, however, cannot address all of the fatigue problems faced by the industry today. A comprehensive, quantitative approach that is cost effective and non-prescriptive in nature is needed to eventually eliminate fatigue as a major causal component in railroad accidents.

The FRA, for its part, will continue to evaluate methodologies, tools, and programs for effective fatigue management. We encourage railroads to propose pilot waivers to the hours-of-service legislation for systems that can demonstrate scientifically valid and safer ways to manage fatigue than just simply following the hours-of-service law. I hope that all railroads and labor leaders consider this opportunity to develop robust fatigue management and mitigation programs that incorporate innovative approaches, knowing that the FRA will stand behind you.

Safety Culture

The concept of safety culture was first coined after some of the major industrial accidents of our time: Three Mile Island, Chernobyl, Bhopal, and the Clapham Junction collision in England. Public inquiry in these situations pointed to organizational culture as a factor in the disasters.

What is "safety culture"? It is the collection of values and attitudes about safety that permeate an organization. It directly influences how employees react to potential hazards. Safety culture determines the vigilance of everyone in an organization about their safety and the safety of others. Vigilance varies from one organization to another depending on the safety culture. The willingness of workers to speak up to their supervisors when they spot something hazardous, and for their supervisors to cooperate with them on getting it fixed, depends largely on safety culture. Having the right rules and procedures, having those rules and procedures respected and followed, involves a strong safety culture.

Because it permeates safety in untold ways, safety culture is one of the most important areas of research in our Human Factors R&D Program. As such, a better understanding and clarification of those safety culture factors that influence human error is needed. Our program managers are actively developing research partnerships with industry and labor to help identify some of the cultural and contextual barriers to safety improvement, and to help implement new methods for continuous sustainable improvements in organizational safety performance. We encourage your active participation in these endeavors.

Human Factors and Emerging Technologies

A theme running through virtually all of the R&D program elements is the use and introduction of new technologies. The FRA and the railroad industry are working on systems that would integrate the sensor, computer, and digital communications technologies into train control, braking systems, grade crossing protection, track and equipment defect detection, and scheduling systems. Perhaps railroad human factors' greatest role for ensuring safety lies in the design, usability testing and risk assessment of these new systems.

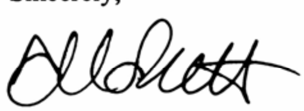
Positive Train Control systems hold great promise that trains can be operated with greater efficiency and greater safety. New technology, however, often shifts individual workload from manual tasks to more cognitive tasks. To safely monitor and operate modern locomotives, which look more and more like the cockpit of an airplane, different skills and cognitive abilities are required. As system reliability and component failure becomes increasingly important, so too does human reliability within the system and human recovery from failure when things do go wrong.

The FRA is helping to develop and demonstrate the utility, reliability, safety *and* cost-effectiveness of new technologies in the industry. To ensure that new technology is safe and efficient, design-induced human error needs to be eliminated. Evaluations need to be conducted with human factors principles incorporated into the design of these systems at the very beginning of the design process.

Close

Again, I wish to thank the TRB Subcommittee A3BO2-1 for organizing this important workshop, and our industry stakeholders for participating. The FRA is fully committed to collaborative safety research like these and other partnership efforts with the industry to continually improving the safety of our nation's railway system. I personally commend your past safety efforts, and look forward to future successes as well. With the TRB circular generated from this activity we hope to have a clearer vision for railroad human factors safety research in the future. With these and similar partnership efforts we also hope to better evaluate the utilization and impact of railroad R&D on safety in the railroad industry. Thank you.

Sincerely,



Allan Rutter
Administrator

3. Process Used to Generate and Evaluate the Research Problem Statements

3.1 INTRODUCTION

Research problem statements (RPSs) are an important product of all Transportation Research Board (TRB) committees. They are one mechanism used to promote and encourage transportation research. They represent the best thinking of a group of experts in a particular field of transportation. RPSs do not reflect any organization or resource issues. Instead they are an indication of what the committee members identify as research that will be most beneficial in a particular transportation arena at a particular time.

RPSs are posted on the TRB website for all to use. In the past, RPSs have been used by federal agencies as they developed their research agendas. State departments of transportation (DOTs), universities, and the private sector use them similarly. They are a source for graduate students looking for thesis topics. On rare occasions, they are referenced in legislation. Committees are free to distribute and disseminate RPSs as they wish.

The TRB requires each committee to generate a list of needed research projects, described in RPSs. These problem statements are based on the technical judgment of the committee members. While these research ideas may be of interest to mission agencies—such as U.S. DOT and FRA—there is no requirement that they be funded.

The process used by TRB Railroad Operational Safety Subcommittee to generate and evaluate candidate RPSs was a modified “nominal group technique” procedure. Each committee member was asked to bring to the Midyear Meeting a number of proposed research projects deemed necessary to advance the state of railroad operational safety. Each project took the form of an RPS that could be described in one to three sentences. Members who could not attend the meeting were asked to submit their ideas to the committee chair.

At the meeting of the committee, a facilitator asked each member in sequence to propose a different RPS. A recorder wrote each RPS on a flip chart and assigned an identifying number. Clarification was often necessary so that the proposed RPS could be stated succinctly. If necessary, terms were defined, so that all members understood the RPS. The generation of proposed RPSs was continued until all members had expressed their ideas. In all, 52 RPSs were collected. As it was a brainstorming session, negative responses or justifications were not permitted during this process.

Next, the facilitator asked whether any of the displayed RPSs could be logically combined. Such combinations required approval both by the members who introduced the RPSs as well as by the committee at large.

After statements were clarified and combined, the synthesized RPSs were evaluated by an anonymous ballot rating system. Members selected the top seven RPSs, which in their judgment were the most important. A seven was assigned to the RPS of greatest importance, a six to the next, and so on until a one was assigned to the seventh most important. The ballots were collected and tabulated, and each of the proposed RPSs was given a total score.

3.2 NEXT STEPS

After absent committee members had a chance to vote by e-mail, scores were finalized. The author of each of the top 10 RPSs then edited the statement, formatted it as required by TRB, and defined the needed research, including the estimated time and costs.

3.3 TOP 10 RESEARCH PROBLEMS

Table 3-1 lists final RPSs in ranked order. The first column includes descriptions of each of the problem statements that compose it. The second column shows the number of votes that final statement received. Each voter awarded seven points to his or her favorite RPS, six to the second favorite, and so forth.

The last column shows the source of each of the final combined RPS (in Appendix A). For example, *Technology A* refers to the Technology category, item A. "Other D" refers to the Other Category, Item D.

TABLE 3-1 Top 10 Research Problems

Top Research Problems	# of Votes	Combined Problems
1. Measurements of effectiveness (MOE) of safety interventions of any sort. Relationship between fatigue and operator performance. Nonaccident performance measures that can help predict incidence of safety problems. Develop human performance measures to be validated with simulators and revenue service.	46	Technology A Culture K Other D
2. Impacts of safety culture on safety performance. Extent to which labor–management perception of safety culture affects safety practices and decision making.	34	Culture J Culture M
3. Explore ways to deliver information more effectively (technologies, information structure, etc.) How to tailor information about fatigue management for different audiences.	28	Technology B Fatigue G
4. Use of wrist actigraphs and feedback to improve sleep hygiene and planning for countermeasures. Use of wrist actigraph in promoting sleep hygiene. Comparisons with low-tech methods of improving sleep hygiene.	25	Fatigue A Fatigue B
5. Simulator studies examining effects of PTC on crew performance.	24	Technology C
6. What technology is available to enhance alertness?	23	Fatigue J
7. Sensitivity of fatigue models to performance-related measures? Relationship between fatigue and operator performance.	23	Fatigue R Fatigue U
8. Incidence of fatigue in train crews based on work schedule data.	23	Fatigue Q
9. Criteria for deciding the allocation of control functions between humans and computers.	23	Technology D
10. How can we predict human error resulting from new equipment, policies, and procedures?	21	Other G

4. U.S. Railroad History Relating to Fatigue, Safety Culture, and Technology

FREDERICK C. GAMST
Retired

4.1 BIOGRAPHY

Frederick C. Gamst received his A.B. in anthropology from the University of California–Los Angeles, and his Ph.D. in anthropology from the University of California–Berkeley. He is a fellow of the American Anthropological Association Society for Applied Anthropology, Royal Anthropological Institute, and American Association for the Advancement of Science. In 1995 he received the Conrad Arensberg Award for his contributions to the anthropology of work, industry, and organizations. In 2002 he was honored with a Festschrift presentation at the 100th Annual Meeting of the American Anthropological Association, honoring his life's work. He has taught at Rice University and the University of Massachusetts–Boston, where he served as departmental chair and graduate dean, and is now professor emeritus. He is also an adjunct professor at the University of Wyoming.

Gamst, now retired, has 49 years of direct experience with the U.S. railroad industry as operating employee, researcher, and consultant (to carriers, rail unions, and regulators). His interests in industrial and organizational anthropology include the social relations and organizations of railroad work (in its operational and labor relations settings) and the social and human factors of human–machine systems, work tasks, and work structures. He has served as an expert witness for rail carriers and unions. He was a member of the Joint International Observer Group for Monitoring the Election Processes in the Oromo Region of Ethiopia and was Chairperson for Curriculum/Education for the Commission on the Study of Peace, International Union of Anthropological and Ethnological Sciences. He is past president and member of the board of directors of the Society for the Anthropology of Work of the American Anthropological Association.

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4.2 THE MEETING IN CONTEXT

The meeting of the Transportation Research Board's (TRB's) Railroad Operational Safety Subcommittee was held September 10–12, 2002, at the Beckman Center in Irvine, California. It was highly successful and informative. Three themes provided the focus: human fatigue and vigilance, the impact of advanced technologies on railroad operational safety, and safety culture and error analysis. Each of these topics has a history in U.S. railroading. Before contexts for the three themes were provided, there was a brief discussion of the overarching historical backgrounds of each.

My context comes from 49 years of various associations with the railroad industry, including on-the-job, field, interview, focus group, survey work, and human factors research, as well as reading the railroad industry's management journals from 1832, and rail labor organization journals from 1867 through the present. Let us review the salient highlights in our industry.

And then they're perfect monsters/To the ones we used to run.
The boys they tell me some of them/Weigh over fifty ton.

"The Veteran [Retired] Engineer"
Locomotive Engineers Journal, Vol. 25, 1891, p. 32

4.3 THE RAIL WORLD

In the Beginning Was . . . the Rail

The railroad industry, hoary with tradition, recently entered its fifth century (*1*). It began with animal-powered surface railed roads supporting flanged-wheeled freight cars, first in 1604 in the English Midlands and soon thereafter carrying coals from the area of Newcastle-on-Tyne. From England railroad technology diffused across the globe. After 1840 the railroads facilitated the Industrial Revolution—a period, not coincidentally, also called the Railroad Age.

The transfer of technology is elemental in world industrialization. The industrial revolution in North America depended largely upon industry, first diffused from and then developed as a continuation of technology in Great Britain. Railroads were no exception. The technology and operations of British railroading began its channeled diffusion to North America in 1795 with the construction and operation of a wooden gravity railroad on Boston's Beacon Hill. During the period 1795 through 1830 North American railroads grew exponentially, from a few, short, local lines of wood into the beginnings of a continental network of iron and then steel (*2*). Railroads conquered the vastness of time and space across the enormous continent of North America. Accordingly, dispersed farming, mining, forestry, manufacturing, settlements, and commercial centers became practicable and profitable. The United States and Canada, as we know them today, could be born.

Government and the Railroads

An understanding of the three conference themes, in part, means understanding the U.S. government's historically strong and formative interaction with the railroads. The railroads and the federal government grew in relation to one another. During the past century both the technologies related to railroad operational safety, and human fatigue and vigilance became matters shaped by federal action and inaction (*3*).

Beginning in the late 1820s, the U.S. government loaned Army engineering officers to the pioneering U.S. railroads to oversee surveys and construction. State and federal land grants nourished construction of these and later railroads. The governmental right of eminent domain, granted to the railroads, enabled them to take private land for their rights-of-way (ROW), with an obligation in return to provide stipulated services on such ways. During the Civil War the federal government both built and took from the Confederacy a system of military railroads. Equally important, it fostered the establishment of the transcontinental railroads to serve the two goals of national security and economic development. After 1887 the Interstate Commerce Act (ICA) and its amendments regarding railroad business and safety greatly furthered the partnerships of railroads and government. Special federal acts regulated railroad technology. From 1918 to 1920 the United States controlled and operated the railroads. In the 1970s, the United States engaged in quasi-nationalization of passenger Amtrak and freight Conrail—about one-quarter of U.S. rail service. Several spun-off short lines came under partial control of various states.

Federal regulation of commercial transportation is arguably the most significant government involvement in the national economy. In the later part of the 19th century the crucial railroad industry shaped and was shaped by American law and public policy. Despite private ownership, given the economic centrality of railroads, government has long viewed them as a public trust subject to its peculiar strict regulation. The courts under federal (and state) law have treated railroads as a quasi-public utility. The nation remains dependent on the railroads. Although the United States has allowed strikes by unions and lockouts by management in other economically important industries, such as steel, coal, airline, electricity, and package transportation, the railroads are so strategically important that government does not permit them to undergo short-term labor-management actions.

Two Eras of Government Regulation of Railroads

Public pressure resulted in two eras of federal railroad regulation. The first era spanned 1893 through the 1920s and saw a number of narrowly drafted laws concerning new technology for specific safety problems, such as couplers, power brakes, ash pans, and speed-control systems. In this first era, federal law resulted in a timely, universal implementation of new technologies conducive to improving rail safety. The Interstate Commerce Commission (ICC) had been regulating business aspects of railroads; thus, Congress readily gave the agency additional safety functions. Before federal preemption some states regulated rail safety (*4*). The federal government addressed the various specific problems of safety through requiring a standardized use of then new technology. The rail safety laws concern common carriers by rail (within the original jurisdiction of the ICC) and not railroads of industrial plants and transit systems (*5*).

In 1886, in a reversal decision, the U.S. Supreme Court in *Wabash Railroad Company v. Illinois* ruled that only Congress has the authority to regulate interstate commerce. The stage was then set for massive federal intervention in the railroad industry. The “railroad problem” widely discussed in the press was now partially a federal one. Congress acted immediately to intervene in the industry (*6*).

The subsequent ICA created the ICC, America’s first independent regulatory agency. At first Congress empowered this agency only to protect the public from the railroads’ discriminatory and monopolistic practices in providing and pricing transportation. Through its federal preemption of state lawmaking, the ICA also shielded the railroads from the differential powers of the various states to enter into railroad affairs. In other words, laws, regulations, and orders regulating railroad activities had to be nationally uniform to the extent practicable. A state, however, can either enact or keep in effect a law, regulation, or order regulating railroad activities to eliminate or reduce an essentially local problem if it is compatible with laws, regulations, or orders of the federal government and if it does not unreasonably burden interstate commerce. As the ICC matured, it protected the industries it attempted to regulate, from both the pressures of the market and the forces of state and federal government (*7*). Not just railroad carriers and rail labor unions, but also the federal ICC (and later the National Mediation Board and FRA) became an integral part of the American railroad industry.

On December 26, 1917, President Wilson issued a proclamation taking control of every system of transportation as of midnight on December 31, 1917. The federal government thereby controlled and operated the American railroads through a United States Railroad Administration (USRA). The USRA was under a director general of railroads. The Transportation Act of 1920 restored the railroads to private ownership and control on March 1, 1920. Congress, however, toyed with nationalization of the railroads in the Plumb plan (*8*).

Over a century and a half the organizational environment of the railroads constantly changed—dramatically so. From fledgling local carriers by “railed” road competing with coaching, wagons, canals, and coastal shipping, the railroads became a near monopoly in transportation. Congress, through the ICA of 1887, attempted to redress the market balance in favor of the public.

The second regulatory era began around 1965 and was well under way in 1970 with a number of laws granting federal executive agencies broad authority to oversee all matters of safety on railroads. During 1965 and 1966 the Congress transferred all of the safety oversights of the ICC to the U.S. Department of Transportation (USDOT). The Federal Railroad Safety and Hazardous Materials Transportation and Control Act of 1970 (*9*) especially codified, in matters of rail safety, the broad regulatory and administrative powers of the FRA (*10*).

Congress’s remedy to the inequities of the ICA was the Staggers Rail Act of 1980, a monumental change in railroad regulation. Through Staggers, Congress largely ended governmental economic regulation of railroads and many of their common carrier obligations. Staggers allowed railroads to set freight rates in response to market conditions with little ICC oversight. Congress nearly eliminated the power of the ICA over railroad business and the railroads became physically sounder and financially stronger. In 1996 the Surface Transportation Board continued some railroad functions of the sunsetted ICC. Not curtailed was federal regulation of railroad safety, strengthened during the second era.

4.4 HUMAN FATIGUE AND VIGILANCE

> The shrill whistle blew on the freight for the West,
> When the rumble was heard on the midnight express.
> Asleep at the switch, and no warning light
> To signal the trains that rushed through the night.

“Asleep at the Switch”
Charles Shackwood
E. T. Paul Music Co., New York, 1897

Fatigue and Sleepiness

Göran Kecklund, in his conference theme presentation on fatigue, introduced the subject by noting scope: “It is likely that fatigue is a common contributing factor in railroad accidents and human errors.” As mitigation, he recommended, “Introduce at least 12 hours rest between shifts to avoid serious lack of sleep and critical fatigue." This comes from his research with the predictable work schedules of European locomotive engineers. The recommendation is even more appropriate for the unpredictable, regressive, irregular work schedules of North American operating railroaders.

Operating railroaders are those who crew trains and locomotives: brakemen, conductors, locomotive engineers, remote control operators, and switchmen.

To begin, it is useful to define basic concepts. Fatigue is forms of weariness, varying to the point of exhaustion, caused by physical or mental exertion. Fatigue does not result merely from the quantity of time spent at work. It also relates to duration and quality of sleep, shift work and work schedules, circadian rhythms, and time of day (*11*). Such a broad view of fatigue frees us from classic definitions that limit fatigue solely to characteristics related to work. For example, Norman Maier held that "fatigue may be defined as a reduction in the ability to do work because of previous work" (*12*). Work schedules interfere with sleep and result in sleepiness mainly if they disturb normal nighttime sleep (*13*).

Sleep deprivation is a lack of sufficient sleep, and sleep debt is an accumulated lack of sufficient sleep. Both are factors in fatigue. An extreme consequence of sleep deprivation is night shift paralysis, an inability to make voluntary movements for a few minutes (*14*). Sleepiness is one possible result of fatigue and drowsiness to and including the point of involuntary sleep—microsleep. It results mainly from a combination of circadian rhythmicity and sleep loss (*15*).

Irregular shifts, such as those found in much railroad operating work in North America, are irregular far beyond the usual meaning of the term. They are erratically variable, including both unpredictability and regressivity at times. They do not have the predictable patterns of fixed and rotating shifts, and contribute to fatigue apart from sleep deprivation and debt. They are regressive in that the starting times of shifts often rotate in reverse, that is, in each 24-h period the worker goes on duty earlier than in the previous 24 h. The shifts, therefore, are out of synchronization with the circadian rhythm. Thus the schedules are regressively variable with respect to circadian rhythmicity.

Such fatiguing schedules yield benefits to employer and employee. This long-standing practice allows a carrier to have highly flexible and maximal use of operating employees. It maximizes employee income because more paid time can be worked, compared to a 24-h cycle, and also allows the individual to assemble large contiguous blocks of off-duty time. I have been repeatedly told by many scores of employees on freight trains that they prefer to work to the maximum amount allowed and then, if financially feasible, take leisure days of their own choosing. Here then are issues of lifestyle and personal finances. In all, the work schedules of North American operating railroaders are often unpredictable and regressively irregular.

Fatigue from sleep deprivation in North America constitutes a growing menace (*16*), and the entire industrial world encounters this rising tide of drowsy hazard. The "man failure," so regularly cited in railroad and other industrial accidents, often can be directly translated as sleep deprivation. It is not only alcohol and other drug impairment that we must scrutinize for the source of rail accidents, but also sleep impairment.

Fatigue and Sleepiness on Railroads

Turning to railroads: we have long been aware of the outlines of sleep deprivation in the industry. The concern about rested employees dates to before the time of enacting the laws contained in the Hours of Service Act of 1907 (*17*). In the first era Congress addressed human fatigue with the Hours of Service Act. The act limits the time on duty (originally to 16 h, then to 14 h, and today to 12 h) of rail employees engaged in or connected to the movement of trains in interstate commerce. Covered by the act are both operating employees and other employees (such as train dispatchers, train controllers, operators, and later, signal maintainers) who by any mean dispatch, report, receive, transmit, or deliver orders and directives pertaining to or affecting the movement of trains. Congress heavily revised the act in 1969 and recodified it in 1992 (*18*). Today, under the act, a covered employee can work 8 h on, 8 h off, indefinitely. Actually, train crewmembers can work 11 h and 59 min on and 8 h off, indefinitely. The editor of *Railway Age* noted "The wreck of a New Jersey Transit train on February 9, that killed three and injured 162, has raised questions about the practice of split shifts for engineers and about whether the 89-year-old Hours of Service Act should be modified" (*19*). Congress drafted the act before anything was known about circadian rhythms and the human and social factors of sleep.

For just one example in my files, in 1878 the Brotherhood of Locomotive Engineers (BLE), commenting on a derailment of a "wild cat" (extra) passenger train editorialized, "It need no argument to prove that it is utterly impossible for any man to remain on duty 48 hours with only 4 hours for rest or sleep." The BLE advocated at least 6 h rest between runs (*20*). The time served prior to the act "keeps [engineers] out longer than [they] can safely work" (*21*). In 1899 an "old engineer" reported 25 to 35 h on duty during round trips, "doubling back" totaling 300 mi (*22*). The act has its limitations. In 1918 a railroader wrote "Five hours sleep is the most one can get out of an 8-hour [rest] layover under the most favorable of circumstances." The railroader hoped that the USRA would rearrange the work and rest periods (*23*).

U.S. hours-of-service regulations (as opposed to the hours-of-service laws that govern the railroad industry) apply to airline crews and dispatchers, maritime crews, truck and bus drivers, and nuclear power plant operators. Congressional consideration of extending the act to independent contractors and to railroads (such as that providing signal maintenance, work now covered by the act for signalman employees) provoked intense opposition from suppliers, contractors, and short lines. The Railway Progress Institute held that such extending would impair safety (*24*).

The Hours of Service Act has great limitations regarding safety. As Michael Coplen and Donald Sussman explained: "[T]his act does not limit employees' weekly or monthly work hours, restrict the irregularity or unpredictability of on-call work schedules, or restrict mandatory commuting distances without compensatory time off. Extensive night work, irregular work schedules, extended work periods with few or no days off, and the policies, procedures, and agreements that encompass these work scheduling practices, all evolved within the limited provisions of this act" (*25*).

Fatigue-related incidents undoubtedly are more frequent than the limited data on the subjects indicate (*26*). For example, one night at the entering end of a yard a fatigued engineer of a freight train "let off his crew." He then "crawled" along a 1.5-mi yard receiving track at less than 10 mph and eventually dosed off, to be startled awake by the sound of bells outside of his cab window. The herder at the far end of the yard had seen what the herder thought was a departing train and had lined it for the main track. The engineer then ran out onto the main track (without authority or flag protection), while the herder called the yardmaster and asked why the herder had not been notified of the departure. When the engineer awoke from ringing grade-crossing bells, he stopped his train and radioed the yardmaster and said, "I'm stopped; what should I do?" The unflappable yardmaster replied, speaking in railroaders' code, "The herder and I have you all lined up and will be protecting your shove; just backup." As customary, no one made a record and no trace remained of the incident. In accord with railroader culture (*27*) the wily yardmaster had deconstructed the incident as it unfolded.

The National Transportation Safety Board's (NTSB) broad interest in human performance and fatigue and the irregular hours of service on railroads dates to the early 1970s. The interest resulted from a collision in 1972 in which a freight train of the Pennsylvania Railroad hit a standing freight train. The NTSB considered it most probable that the engineer and head brakeman had both fallen asleep (NTSB-RAR-73-3, p. 1). Previously, in 1968, the FAA reviewed the effects of circadian rhythms on long-distance flights, effects similar to those of irregular shifts (*28*). By 1992 the NTSB found that "complicating the unpredictable work schedule, today's crews face increased demands as they are operating trains at higher speeds, over longer distances, and with shorter effective intervals between tours of duty. Smaller crews are operating longer trains on fewer miles of track than existed 20 years ago. . . . These increasingly stringent operating parameters have added stress to the work environment." Moreover the NTSB felt "workload issues that are prevalent now may become even more pronounced in the future." Finally, the NTSB welcomed the opportunity to assist Congress should it decide to visit the long-inadequate Hours of Service Act governing durations of certain railroad work (*29*).

Testifying at the Senate Subcommittee on Surface Transportation and Merchant Marine, then-FRA Administrator Jolene Molitoris said: "About one-third of train accidents and employee injuries and deaths are caused by human factors. We know fatigue underlies many of them" (September 16, 1998). John Lauber and Phyllis Kayten found that in two fatigue-related railroad accidents "the schedule was also unpredictable; employees had insufficient information to determine when they would next go on duty, regardless of whether they were waiting at home or at an away terminal for the next call. . . . management was responsible for scheduling policies that made it difficult for crewmembers to plan adequate rest periods" (*30*). Martin Moore-Ede found for operating railroaders "the hours of work are even worse than those driving a truck. Particularly problematic is the practice of keeping railroad engineers on a shift roster waiting at a terminal to be called in sequence for the next available train" (*31*).

Scheduled Work

The North American railroads have few scheduled shifts for freight train crews. But almost all of the rest of the world's railroads have them with rostered operators. In general, being rostered means paid duty for a fixed (therefore, totally predictable) period, a scheduled shift. More specifically, it means being listed for a regular assignment and period of duty—possibly while standing by, but not necessarily operating railroad equipment. Of the rostered schedules for operating employees that I have studied around the world, the Swedish one provides a typical example. The following information is from several Swedish operating railroaders.

A locomotive engineer ("lokförare" in Swedish) having 6 h or more of night service works a 36-h week. An engineer having 3 h or less of night service works a 38-h week. An engineer can perform night service only 1.4 times per week. Management can order engineers to take extra shifts, but this does not happen in practice. Given scheduled work, an engineer could say, "I am not fit for an ordered extra shift." ("Just before you telephoned, I drank a beer," a railroader gave me as an example.) An engineer must have an 11-h rest break after the previous shift. Overtime is limited to 200 h a year. Management cannot order emergency overtime because of a catastrophe for more than 2 consecutive days. Most engineers have a 6-week work schedule (some a 4-week schedule), which is repeated. After 12 weeks, management adjusts the schedule to see if the work time complies with the above-stipulated service hours per week. Engineers' schedules include work on a Sunday every second week, and on a Saturday every 3 or 4 weeks. Stand-ins fill all vacancies for engineer runs.

If a need arises for more engineers, for additional trains or switch engines beyond those scheduled, stand-ins protect the assignments. In large terminals like Stockholm, in addition to engineers with repeated 4- or 6-week schedules, there are engineers working "på skubben" (on the run). They are stand-ins employed under the standard time conditions, except they receive their run times for only 1 month at a time, before the 25th of the month prior to the month of work.

Finally, "rå-skubben" (raw–scurry/run), also called "vrål-skubben" (scream–scurry/run), exists. These engineers must call in at 4 p.m. the day before a workday to learn their run times and they receive extra pay for this pressured work schedule. Because all the "skubben" are on an annual "days-off schedule," they know their leisure days for a year in advance.

Studies of Fatigue and Sleepiness on Railroads

During 1977 Donald Devoe and C. N. Abernethy completed a report for the FRA defining the problem of assuring alertness for crews on locomotives. The report found that "the FRA statistical summaries do not provide enough details to identify accidents involving alertness." A special analysis of 30 train accidents found 43% had some amount of loss of alertness by crewmembers on the locomotive. Another analysis of 23 accidents found the same percentage (*32*). The House Subcommittee on Investigations and Oversight prepared a report, during 1983 and 1984, on circadian rhythms and rotating shift work. Only a brief mention was made about irregular shifts for airline pilots (*33*).

During 1985, locomotive engineer Michael Coplen was beginning his life-long study of circadian rhythms, fatigue, detriments to sleep, and railroad work. He outlined a number of circadian factors "that lead to poor health, lowered performance, and increased risk for accident." He concluded, "It is the unpredictable work hours and the ineffective coping strategies of the workers themselves when adjusting to the schedules that initiate and prolong the [sleep] disturbances" (*34*). In 1995, the NTSB and National Aeronautics and Space Administration sponsored a symposium to discuss countermeasures for fatigue, applicable to accident prevention in all modes of transportation. All the participating groups indicated that both operators and managers need education on the subject (*35*). From fiscal 1990 through 1998, the USDOT had spent over $30 million on fatigue research (*36*).

The NTSB found that in the FRA accident data from January 1990 to February 1999, the FRA coded 18 cases as "operator fell asleep" as a causal or contributing factor. The NTSB feels that these 18 cases, over 9 years, underestimate the actual number of fatigue cases. The NTSB finds that some accidents, coded by the FRA as resulting from "failure as to comply with signals," are fatigue related (*37*).

Worldwide, for over a century, our attention has focused on the sometimes-catastrophic consequences of railroaders "sleeping at the switch," as the saying has it (*38*). Back in 1974, the Canadian Institute of Guided Ground Transport, in a study of work–rest schedules and vigilance of railroaders, concluded "The work hours of railway crewmen are both too variable and lengthy to result in anything but sub-optimal vigilance under certain conditions, particularly in the case of returning freight runs" (*39*). A study by colleagues at the Ministry of Railways in China found that engineers' operating performance deteriorated after consecutive night shifts. Thus they suggested that engineers work no more than three successive night shifts (*40*).

In 1990 John Pollard reported on his comprehensive study of scheduling and management of locomotive crews, especially as contributing to fatigue and stress. He identified how various aspects of railroad practice contribute to fatigue and stress. As a follow-up in 1996, Pollard reported his locomotive engineer's activity diary, wherein subject engineers completed a 14-day diary. They recorded a variety of instructive information on amount and quality of sleep, fatigue, job-related stress, and related factors (*41*).

A Government Accounting Office (GAO) study represents an alternative view that found "the length of the work period allowed by the Hours of Service Act may have little impact on rail safety." Furthermore, "no researcher has yet found definitive proof that fatigue specifically causes accidents nor measured how fatigue affects the likelihood that accidents will occur" (*42*). This last statement is in contrast with my personal experience on the rails and that of operating railroaders with whom I have "old headed it" during the past 49 years. However, the GAO's conclusions must be leavened with the findings of Devoe and Abernethy, who stated, "the FRA statistical summaries do not provide enough details to identify accidents involving alertness." Research done by a highly focused and respected railroad–union management partnership, the Switching Operations Fatalities Analysis Working Group, investigating switching accidents, also found that they could not analyze fatigue as a contributing factor in fatalities because the required data were either lacking or inadequate. Accordingly, the group could reach no firm conclusions regarding fatigue-related switching fatalities (*43*).

In a follow-up report of 1993, the GAO held that "these findings do not indicate one way or another if accidents are more likely to happen later in the engineer's shift when engineers become more tired." Of course, often the last hour of a run is spent "yarding a train" at 10 mph or less and doing the final paper work in the register room. The GAO report allows that given the deadheading of crews out of a terminal and rescheduling of freight trains, "engineers may not plan for and receive adequate rest and may therefore be fatigued when reporting for work" (*44*). Essential in interpreting this last information is that it does not matter for maintaining operational safety, having 99% of crew rested when 1% can fall into uncontrollable microsleep. The potential for catastrophic accident is ever-present when just one crewman succumbs to microsleep. For example, in 1990 at Corona, California, the collision noted below realized this potential. Similarly, findings that on a particular line of a railroad, freight crews are on duty for an average of "only" 9 or 10 h does not provide an indicator on unfatigued safety. On average all of us are healthy. The GAO based the studies on assumptions of how matters should happen, not how they actually are in the rail world (*45*).

At the request of the FRA, the parties in the rail industry formed the North American Rail Alertness Partnership (NARAP) in 1997–1998. NARAP has a charter to "support industry-wide initiatives through the coordination, facilitation, and communication of efforts to reduce fatigue and promote safety in rail operations" and "to promote the safety of the industry's employees by developing effective countermeasures, based upon analytical and/or scientific data" (*46*). The NARAP membership includes key rail labor, rail management, and federal regulatory personnel meeting quarterly.

In 1997, under the sponsorship of FRA, and the direction of Garold Thomas and Thomas Raslear, the Illinois Institute of Technology, Research Institute conducted laboratory research on fatigue using the FRA Research and Locomotive Evaluator/Simulator high-fidelity locomotive simulator. They used 55 certified locomotive engineers and a computer-controlled locomotive simulator with a standard locomotive cab and six-axis motion base, plus a wrist-mounted actigraph to record subject activity. Other experiments with certified engineers in such a realistic environment of a locomotive simulator should yield other useful data for all manner of human-factors questions.

The study found degradations in train handling performance given work–rest cycles of less than 24 h. It succinctly states, "Current federal regulations governing hours of service for locomotive engineers allow work schedules that have backwards-rotating, shift start-times and do not allow sufficient sleep." Such engineers must arise hours earlier each day and try to go to sleep hours earlier that day. They characteristically have "sleep durations which are considerably less than those obtained by the general population." The study also reported that these performance degradations increased when the work–rest cycle was about 20 h in length, as opposed to 22 h in length. J. Pilcher and Michael Coplen researched the frequency and circumstances of engineers' cycles of less than 24 h of work–rest. They evaluated the effects of the work–rest cycles on sleep quantity, quality, and a self-rated alertness (*47*). Dawson et al. conducted an Australian study developing and validating field-based measures regarding impacts of particular rostering systems and related workloads on engine engineer health and safety. The study included an informational program for improving organizational knowledge of shift work issues regarding all matters of railway safety. As in North America, engineers did not physiologically adapt to their irregular work schedules. Significant in the findings are the following summations: "The ability of engineers to obtain an adequate amount of sleep (5 to 6 h) during a minimum-length break (11 h) was examined. Engineers only obtained an adequate amount of sleep-in breaks beginning between 1800–0400 h. For breaks beginning at other times of the day, more time off was needed. Current minimum-length break regulations are too simplistic. These [proposed] regulations should incorporate time-of-day effects" (*48*).

Patrick Sherry researched the development of fatigue countermeasures on North American railroads. After a discussion of salient conceptual backgrounds, his comprehensive report reviewed to year 2000 the various pilot and test programs for dealing with railroader fatigue. Sherry ended with a candid, perceptive discussion of the overarching issues for programs to reduce railroader fatigue. These include the structuring of work by the labor agreements and the interrelations of fatigue countermeasures with earnings and leisure time. Sherry insightfully concluded the railroad issue of fatigue is more than just a safety matter; it also concerns personal finances and quality of life. As Sherry demonstrated, the circumstances of trips paid about a dollar per mile, vary greatly across North America: on line X, a 300-mi run can take less than 10 h and on line Y, 116 mi can take 9 h (*49*).

The concern of the NTSB regarding fatigue has been continuous since 1972. It is also the most comprehensive in the number and scale of its studies on the subject. The NTSB has rendered a good number of probable causes for collisions between trains in which it implicated the "effect of work and rest cycles." On January 14, 1988, at Thompson, Pennsylvania, two Conrail freight trains collided, with resulting property damage of about $6 million, and two injuries and four deaths among the crewmembers. Contributing to the accident "was the sleep-deprived condition of the engineer and other crewmembers of train UTB-506, which resulted in their inability to stay awake and alert. . . . Contributing to the failure of the crewmembers were their unpredictable rest–work cycles [and] their voluntary lack of proper rest before going on duty" (NTSB/RAR-89/02, p. v). On November 7, 1990, at Corona, California, two Santa Fe freight trains collided head on, resulting in property damage of about $4,400,000, and two injuries and four deaths among the crewmembers. Central to the collision "was the failure of the engineer of train 818 to stop the train at the stop signal because the engineer was asleep. Contributing to the accident was the failure of the conductor and brakeman to take action, probably because they too were asleep to stop the train." Contributing also was the irregular work schedule of the engineer, the company's lack of policy for removing unrested personnel from service, and "the inadequacy of the federal rules and regulations that govern hours-of-service" (NTSB/RAR/91-03, p. v).

On August 9, 1990, at Davis, Georgia, two Norfolk Southern freight trains collided, with resulting property damage of $1,269,000, and four injuries and three deaths among the crewmembers. Regarding train No. 188, operated in rule violation: "The engineer's failure to bring the train to a stop at the signal was probably caused by a microsleep or inattention due to distraction." Additionally, "the conductor of train 188 was either distracted or fell asleep sometime after verifying the signal status at CP Davis" (NTSB/RAR-91/02, p. 30).

Rail transit is not immune. On August 28, 1991, at the Union Square station of the New York City Transit Authority, a subway train derailed at a crossover and struck steel columns, with resulting property damage of $5 million, 145 injuries, and 5 deaths. Concluded was "the operator failed to comply with the signal system and the general order because [the operator] was impaired by alcohol and was sleep deprived" (NTSB/RAR-92/03/SUM, p. 23). The probable cause of another New York subway collision on the Williamsburg Bridge in 1995 was, in part, "the failure of the J train operator to comply with the stop indication because the operator was asleep" (NTSB/RAR 96/03, p. 39). Concerning the collision of Union Pacific train NP-01 with another at Delia, Kansas, on July 2, 1997, the NTSB concluded, "The NP-01 engineer probably fell asleep…. at the time of the accident; the NP-01 engineer had been continuously awake for 18 hours" (NTSB/RAR-99/04, p. 25). Regarding a Norfolk Southern collision at Butler, Indiana, on March 25, 1998, the NTSB noted: "Statements made by the Norfolk Southern engineer and the student engineer after the accident suggest that the engineer and the conductor were probably asleep before the train was placed into emergency braking" (NTSB/RAR-99/02, p. 26).

In Canada, the Foisy Commission inquired into the February 8, 1986, catastrophic head-on collision near Hinton, Alberta, of Canadian National freight train No. 413 and VIA Rail passenger train No. 4. Property destroyed was in excess of Can$30 million; 71 persons required hospitalization and 23 others were killed. The commission found the crew of No. 413 "had little rest" and "were certainly fatigued." Furthermore, "the long and irregular shifts . . . and the working conditions . . . contributed to the risk of crew fatigue." Finally, these were not "isolated circumstances." "Well-motivated and responsible people throughout the company" acted improperly regarding fatigue from sleeplessness because of "the style of operations and the culture of the 'railroader'." The Canadian National took exception to the findings of the Foisy Inquiry (*50*). The Canadian Foisy and U.S. NTSB reports indicate that all of North American railroading, at its very core, is erratic and irregularly scheduled in its broad cultural patterns. This was reported about Hinton almost two decades ago.

Canalert was a 1995 program developed for the Canadian National, Canadian Pacific, and Via Rail conducted by Circadian Technologies, Inc. In part, the three railroads intended the program as a response to the problems associated with the Hinton crash. When the railroads implemented specially designed countermeasures, the project reported a reduction of nodding-off incidents, absenteeism, and health problems, plus over a million accident-free miles (*51*).

The NTSB has repeatedly noted that better industrywide fatigue countermeasures are long overdue on the railroads. Established for decades are both scientific principles for countering fatigue and the knowledge that effects of lost sleep accumulate over time and do not dissipate (*52*). One must conclude, as does the FRA, “Fatigue . . . which significantly reduces the alertness of employees, causes railroad incidents and is one of the most pervasive safety issues in the railroad industry” (*53*). “Burke Jefferson,” a pseudonym for a railroad manager, summarizes the crux of the rail fatigue issues: “Fatigue control starts with putting a rested engineer behind the throttle on every trip. But it is also the company’s responsibility to minimize the engineer’s opportunity to succumb to sleep, especially during critical circadian low points” (*54*).

4.5 IMPACT OF ADVANCED TECHNOLOGIES ON RAILROAD OPERATIONAL SAFETY

> Only a coupling pin broken in twain, . .
> Youthful the form that goes back through the rain. . .
> Only the bloody form there on the rail,
> Over whose horrors the strongest grow pale.

On “decorating the tops”
“Only a Brakeman”
Locomotive Engineers Journal, Vol. 19, 1885, p. 726

Railroad Technological Development

This section reviews the development of the technologies and their impacts on safety through the present. In this review some of the problems with technologies are noted.

The railroads’ industrial developments have been legion. Advances have been systematic and based upon interrelated technologies developing over time. Designers of this technology, however, often gave little attention to creating what railroaders call “traps” in a device and the procedure for using it. Such traps for an operator were the focus of Victor Riley’s conference presentation on technology. He explained in his two subthemes “that the design of systems can facilitate human error, and that the design of automation and human behavior can combine to affect human and system performance.” This has been true ever since brakemen fell to their deaths between moving cars while hand braking and switchmen lost fingers and worse while coupling cars by link and pin. It continued into recent times when regulators did not mandate two-way, end-of-train devices on caboose-less trains and catastrophic runaways resulted.

Some consultants and in-organization “technologists” posit what amount to technological fixes as the route to a safer workplace. Often not fully appreciated is the fact that new technologies, although perhaps fixing particular, previous risks, can engender new risks. Businesses introduce most new technologies to enhance productivity with the assumption that they are “safety neutral.”

Ever since the Industrial Revolution—a massive change in the production of nonagricultural goods, especially by using fossil fuels to greatly multiply human effort—the railroads have been both a transforming technology and a have been transformed by one advanced technology after another. The first large British railway, the Liverpool and Manchester of 1830, and the first large U.S. railroad, the Western of 1839, planned use of the familiar horse motive power with haulage at some locations by rope from stationary steam engines. In 1829 the great mechanical efficiencies demonstrated by Stephenson’s locomotive steam engines, notably his *Rocket*, changed haulage to steam almost overnight. The Morse electric telegraph freed North American trains from the slowing restrictions of movements solely by timetable schedule and supplementing flag protection. The telegraph also expedited the handling of a railroad's general communications (*55*). In 1851, the New York and Erie's use of flexible, electronic train-order dispatching, via telegraph to wayside operators, made rail lines much more fluid, thereby adding capacity (*56*).

Early Fixed Signals and Communications

Ever-advancing signal and communications technologies made rail traffic control safer and more efficient. In 1871 a New York Central predecessor installed the first signals in a system of automatic block signal (*57*). In 1874 another New York Central predecessor installed the first Saxby and Farmer interlocking plant. The Pennsylvania railroad in 1880 installed the first automatic train stop system on a busy district. In a revolutionary innovation during 1882, the Pennsylvania Railroad, on a stretch of hyperbusy double track at the Louisville Bridge, Kentucky, used wayside signals to authorize train movements with the current of traffic by signal indication alone, without timetable superiority or train orders. During 1884 the Chicago Burlington and Quincy placed into service some 68 mi of three and four main tracks, using bidirection manual block signaling. In 1907 the first automatic interlockings came into use. And in 1909 the Erie installed a system for operation by signal indication, directing trains to take siding, hold the main, or proceed, regardless of timetable superiorities on 140 mi of two main tracks (*58*).

Early Safety Appliances

By the turn of the 19th century the number of casualties from railroad accidents had grown to enormous economic and human proportions (*59*). Accordingly, from 1893 through 1920 Congress passed a number of rail safety statutes, amending the ICA, thereby addressing a pressing concern of public safety and an apparent need for railroad efficiency. The Safety Appliance Act of 1893, as amended, empowered, the then ICC (today the FRA), to require new safety technologies in the rail workplace. The act requires use of power brakes on locomotives and trains to replace speed control by brakemen using car hand brakes and mandates the use of automatic couplers to end the necessity of groundmen going between cars to make couplings. It contains standards for power brakes, automatic couplers, and other safety appliances required by law. The act also specifies the manner of application regarding cars, for secure grab irons, sill steps, ladders, running boards, and roof handles. Subsequently the great frequency of deaths and injuries from link-and-pin couplings by workers going between moving cars and the hand braking of trains by brakemen "decorating the tops" of cars gradually became a thing of the past (*60*).

Air Brakes

Air brakes on an entire train almost eliminated runaways. No longer did the engineer have to whistle "down brakes" in all kinds of weather, to the head, swing, and rear brakemen "decorating the tops" and having to jump from moving car to moving car to manually twist the control wheels of hand brakes. The so-called Tehachapi Horror occurred on a typical passenger train of the 1880s, not equipped with air brakes. One night in 1883, this occupied, transcontinental, "crack" passenger train silently rolled away from the Tehachapi, California, summit while its engines were detached. Downgrade survivors had to be rescued into a freezing night from splintered, burning passenger cars (*61*). The advent of the all-steel passenger car eliminated splintered cars, and the replacement of car stoves for heating by steam heaters supplied from the locomotive boiler further reduced passenger deaths and injuries from fires (*62*).

Slowly improved and implemented from 1869 on, the Westinghouse air brake system permitted greater control of trains at higher speeds and tonnages (*63*). Through about 1910, manual hand braking of cars often had to supplement air brakes, especially because the rear part of a freight train was often without air brakes. By 1900, freight trains of 6,000 tons, some 5,000 ft long, had become possible because of the supporting steel technology in car frames, draft gear, and couplers. At this time freight and passenger air brakes developed differentially. With conventional freight air brakes, the engineer can make graduated applications (after a 6 psi or so initial application) but can make only a full release, an act that is sometimes hazardous. It was impossible to design a graduated brake release because of the great length of many freight trains. Passenger service required air brakes having a graduated release and a high-pressure emergency application. In 1933 to operate freight trains of 100 to 150 (even heavier) cars, the vastly improved air brake system began its appearance. It replaced the previous system of K triple valves on freight cars. After 1950 the advent of the improved acoustic bearing detector (ABD) and wayside ABD (ABDW) control valves enhanced brake performance, but the advent of distributed power (see below) allowed the enormous train tonnages and lengths possible today.

Augmenting air brake systems since the advent of the No. 24 locomotive brake equipment in the 1950s is the pressure-maintaining feature. The feature compensates for the normal brake pipe leakage on a train. In service applications of train brakes, it thus makes it possible to hold any desired pressure in the brake pipe for long durations. By compensating for leakage, the feature prevents a reduction of brake pipe pressure greater than intended and thus, a similar greater brake application (*64*).

Electronically Controlled Pneumatic (ECP) braking systems show considerable promise for safety in North America. Australian iron-ore lines use ECP with great success, including on trains of 330 cars with three pairs of locomotives operated from the head end pair by distributed power (DP). ECP allows longer, heavier trains to have shorter stopping distances than lighter, shorter trains with conventional air brakes (*65*).

ECP has two versions, with braking signal propagation communicated electronically either by wire with intercar connectors or by radio signal. In either version the engineer uses a Head-End Unit, which additionally displays brake statuses and faults (*66*). ECP promises to increase greatly the safety in braking for freight trains and increase it for passenger trains, given its rapid response times for brakes and conservation of car reservoir air, always at full charge.

We should not confuse ECP with a precursor technology for high-speed passenger trains, dating to the 1930s and developed from multiple-unit control circuits from rapid transit, ca. 1907. The 100-mph Streamliners of the 1930s had to stop within the same block limits as ordinary passenger trains. This precursor is electropneumatic brakes using a self-lapping brake valve and having by-wire propagation, but not having microprocessor controls (*67*).

Dynamic Brakes

The dynamic brake system supplements a train's air brakes and allows greater control of the train by the engineer. In dynamic braking the traction motors become generators. They transform the train's kinetic energy into electrical energy dissipated as heat, or in some cases, recycled into the power grid for use by other locomotives. In either case the dynamic brake provides a useful method of retarding the motion of the locomotives and any attached train. Modern dynamic brakes originated in regenerative electrical technology from about 1900 (*68*). In the 1950s the railroads began keeping helper locomotives cut into a train after helping upgrade, so that the dynamic brakes of the helpers could assist in retarding and controlling a freight train down the other side of the mountain grade.

Later Signaling and Communications

Automatic train control system (ATC) and automatic cab signal system (ACS): The Signal Inspection Law of 1920 amended a 1910 act. With this amendment, on June 13, 1922, the ICC issued an order requiring 49 railroads to install by January 1, 1925, over one full passenger division, systems for a form of automatic train control. In 1923, the Pennsylvania Railroad placed in service for 47 mi, the first continuous inductive cab signal and train control system.

This was the first use of cab signals instead of wayside signals for movement of trains by signal indication. That year the Chicago and North Western installed a system of intermittent inductive train stop between West Chicago and Elgin, Illinois. During 1926–1927 on two and three main tracks between Chicago and Council Bluffs, Iowa, the Chicago and North Western completed a monumental 511-mi installation of two-indication cab signal system with no wayside signals, except at interlockings (*69*). On June 17, 1947, the ICC issued an order that required lines with speeds of 80 mph or greater to use an automatic train stop (ATS), or a so-called ATC, or an ACS (*70*).

The use of ATS and ACS did not necessarily prevent train collisions because they did not provide positive train separation (PTS). An engineer could simply acknowledge an ATS or ACS warning and then run into a train ahead. The systems, however, were precursors of advanced system implemented in recent years.

A great improvement in rail traffic control and its safety was the introduction, at several locations in 1927 and 1928, of systems of centralized traffic control (CTC), based on earlier interlocking and remote automatic manual block systems. CTC is a method of operation with movement of trains over routes and through blocks authorized by block signal indications controlled from a control office. CTC provides full interlocking protection at switches. A coded communication system allows the CTC operator to control the desired switches and signals in the field, often hundreds or thousands of miles away. Today a train dispatcher usually operates CTC through a computer assisted dispatching system, programmed to make many train dispatching decisions, including train routing and priorities, and to prevent conflicts in authorities for train movements.

The first extensive installation of CTC was for 20 mi on the Pere Marquette with 10 automatic OS reporting stations. The system used coded transmission over a two-line code circuit of signal indications and controls to and from the field. The year 1939 saw an installation of a super-safe continuous train control system with four indications and four speed controls, over the Oakland Bay Bridge and approaches, for suburban trains of the Key System, Southern Pacific, and Sacramento Northern. Thus, a precursor to positive train control became practicable. In 1943 CTC operated across 171 mi between Las Vegas, Nevada, and Yermo, California, on the Los Angeles and Salt Lake. A particular safety feature here was that, with a wartime labor shortage, the railroad could not get experienced telegrapher–operators to crew the train-order stations at isolated desert points. CTC eliminated the positions and their pressing need for safety-critically skilled personnel. In 1946 the Pennsylvania successfully tested the operation via radio of CTC circuits across 90 mi. Thus another precursor to positive train control, a communications-based train control, became feasible (*71*).

The locomotive event recorder is not directly a part of a train or traffic control system, but it is a safety-related technology. It is an on-locomotive, stand-alone, solid-state, digital device for electronically collecting, storing, sorting, and replaying a designated number of hours of data from a locomotive. Because this data is downloadable, law enforcement personnel can take it and lawyers can "discover" the information in lawsuits. With some event recorders, by transmitting the data by radio, railroad officers can monitor the data in real time. The newest locomotive event recorders are computers, which store data on up to 72 kinds of operational events. In the event of an accident, recorded data can be downloaded and used in analyzing what happened and thus assessing how to prevent such accidents.

Retarder Yards

Technology also advanced in railroad yards. In 1924 in its Gibson Yard, the Indiana Harbor Belt completed the first installation of car retarders. A retarder system eliminates the need for car riders (switchmen) who mount moving cars, climb a ladder to a platform, and hand brake to a coupling with standing cars in a classification track—work that is hazardous. In 1928 the New York Central installed cab signals on hump locomotives in three yards including Selkirk, New York. In shoving long cuts of cars, a distant, perhaps out-of-sight, switchman could thus signal the engineer to go ahead, stop, and back up. Signaling to the engineer on an engine at the far end of an extremely long cut would not be obscured. In 1941 the Norfolk and Western installed the first speed control for retarder operations, thereby reducing the chance of a car entering a track at too great a speed. In 1952, building upon these earlier technologies, the Milwaukee Road installed at its Milwaukee yard a complete automatic switch-control system and speed-control retarder system. Humping cars into classification tracks was now fully automated (*72*).

Wayside Detectors

A number of wayside detector safeguards afford additional protection against hazards on railroads. Detector fences guard against landslides and rock falls in steep cuts and canyons. Pressure against the wires of the fences activates block signals to a stop or stop-and-proceed indication before entrance into the affected track (*73*). Wayside hotbox detectors warn of any hot journals on car axles before they become dangerously hot and deform the axle or cause other damage. Wayside high-wide load detectors warn of loads oversize for a clearance ahead. Dragging equipment detectors warn of lading or car components pulled along the ground by a train, and shifting load detectors warn of a load, such as stacked lumber on a flat car that has moved off center. High water detectors warn of dangerously high water, usually under bridges. Other detectors include those for bridge integrity and flat spots on wheels. Most such detectors today "talk" to a passing train crew via voice-radio, informing of a defect present or not present. Some such detectors automatically "drop" the next block signal to a red aspect, thereby stopping the train for a needed inspection (*74*).

Journal Bearings

During the 1950s the railroads began to phase out the plain brass/bronze bearing, supporting the weight of the journal or end of a railcar axle, in favor of hardened steel roller bearings. Roller bearings are sealed components that greatly reduce rotational friction; thus nearly all bearing failures causing hot boxes to lead to fires and journal failures, possibly leading to derailments (*75*), were eliminated.

Rail

Engineering construction and maintenance-of-way (MOW) have made great strides in contributing to railroad safety. After the Civil War the Bessemer process for making steel allowed the rolling of cheap, tough rails and, in the 1890s, permitted the use of steel in construction of freight cars. This steel technology facilitated the explosion of rail lines across North America and physically supported the steady increase in size and weight of rolling equipment. The advent of continuous welded rail in the 1930s, welded in lengths of 400 ft or more, meant longer rail life and better track circuit conductivity.

Electronic Computation and Communications

Railroad clerical tasks, computation, and electronic communications support operations including its safety functions. In 1874 the Pennsylvania purchased mechanical, lever-activated calculators to accelerate numbers crunching. By 1901 the railroads had become early large-scale users of telephones for all manner of tasks, including telephonic transmission train orders and other operating information. Railroads developed their own telephone exchanges and local and long-distance lines for handling of company business. Officers, yardmasters, train dispatchers, roundhouse foremen, and towermen could now instantly communicate with one another in plain English from their usual, or another workplace (*76*).

During the 1950s the railroads became one of the largest users of computers and electronic exchange of data for conducting business. This use ranged from storing and retrieving data, to monitoring and controlling business procedures, to assisting in rail traffic control, to monitoring and controlling locomotive functions. The first computer interface between two railroads (the Union Pacific and Southern Pacific) was in 1976, via microwave transmission. It allowed automatic sharing of information on train and car movements (*77*).

Although well developed by the early 1940s, very high frequency (VHF) voice-radio communications among trains, engines, and fixed facilities such as yardmasters' and train dispatchers' offices became widespread in the 1950s and 1960s and provided another communications link for safe, efficient operations. Caboose to head-end communications and, when hand radios were issued, to flagmen allowed the head end to know what the rear end was doing and vice versa. Train dispatchers could keep a more precise location of trains and MOW and bridge and building gangs. Yardmasters could issue updated pull and spot orders to industrial switch engines (*78*). Today the North American railroads have 97 VHF frequencies, ranging from 160.110 to 161.565 megahertz, in 15-kilohertz increments.

By 1995 the railroads had implemented automatic equipment identification, whereby the locations of a particular piece of rolling equipment could be located. A trackside interrogator electronically receives from a piece of rolling equipment, and sends to a central computer, identifying information originating in data-transmitting tags on the equipment (*79*).

Locomotives

In an essay of this length it would be difficult even to discuss developments generally in motive power technology and the related human factors (*80*). A considerable history of federal regulation of locomotive safety exists, which also cannot be covered here (*81*).

Earlier we noted the change from horsepower to steam locomotive power. From just after 1800 through the 1940s, steam locomotives grew in size, weight, and tractive effort. In an effort primarily for efficiency, but also for aspects of safety during World War I, the USRA created designs for U.S. Government Standard Locomotives. These were of eight types (wheel arrangements) and in heavy and light versions. The railroads constructed these successful, long-lived locomotives during the period of federal control but, in 1920, railroad management began its customary practice of each road's motive power department purchasing or erecting custom-built locomotives (*82*). General Motors in the 1930s and, later, General Electric, in conjunction at first with Alco, produced standard, off-the shelf, diesel-electric locomotives for the various classes of service. Harking back to much earlier electric motive power and a Southern Pacific diesel-electric prototype of 1905, the diesel-electric introduced great efficiencies in operations and maintenance of motive power and right of way. The BLE, in 1927, thought the "oil-electric" locomotive had a future on railroads (*83*). Lack of boiler explosions, steam leaks and better control of trains with increased tractive effort and the dynamic brake also meant increases in safety. The adoption of the diesel-electric locomotive by the U.S. railroads resulted in other profound operational changes. Steam engines had limited operational ranges due to "watering" and servicing requirements. Dieselization allowed greater distances between stops and reductions in the engine crew size.

Today, on computer-equipped locomotives, the engineer uses the throttle and dynamic brake lever, AB-valve handles, and pushes buttons to communicate with a number of on-locomotive computers, which regulate the electrical propulsion, and the air and dynamic braking systems. Mechanical personnel use on-locomotive diagnostic computer displays for accurate troubleshooting and periodic maintenance checks. Since 1986 most newly constructed North American locomotives have had a computer-enhanced control system. Across the 1990s computerized locomotives have allowed a revolution in rail motive power unparalleled since the change from the external-combustion steam engines to the early diesel-electrics (*84*).

The newest diesel-electric locomotives, having AC-traction motors geared to the driving axles, use some 20 state-of-the-art microprocessors for onboard functions. These functions include a precise regulating of AC-tractive outputs, necessary for the replacement of the traditional DC- by AC-traction. Four microprocessors receive electronic signals from the locomotive engineer, changing them into commands to the prime-mover diesel engine, the traction alternator, and the traction motors. Another computer controls the in-cab, climate control, and ventilating system. The radio for voice communication has its own microprocessor. The distributed power (DP) system by which the engineer on the head end controls via coded radio signal any rear-end or swing helper units in the train, requires on-locomotive computer operation. Any use of ECP air brakes requires both on-locomotive and on-freight-car microprocessors.

Newer diesel engines have microprocessor control of the volume and pressure of the fuel injected into the cylinders for efficient fuel consumption and emissions control. Instead of the traditional gauges for air brake pressures and traction motor amperage, and the warning-light bulbs in the engineer's workspace, recent locomotives have console displays using cathode-ray tubes to provide information on system status and other information.

By 1991, integrated cab electronics were available to display the real-time operating statuses of the locomotive. On one railroad an on-locomotive terminal for the conductor now provides information regarding en route switching setouts and pick-ups of cars, given to or received from the conductor in seconds. Terminals are beginning to transmit instantly to the train crews operating documents formerly solely on paper and transmitted or received by human hand, such as track warrants, speed restrictions, and other operating directives.

Distributed Power

DP allows control from the lead locomotive of the power and braking of locomotives placed at separate locations in a train consist. With DP the engineer can handle long, heavy trains more safely than by non-DP methods. The engineer sends control signals via coded radio telemetry data to each remote locomotive the engineer operates. Thus the road engineer no longer has to rely on transmitting voice-radio signals to the helper engineer. This distribution of power and braking throughout a train results in quicker and smoother starting and stopping of a train, reduces train transit time, and allows trains of great tonnages, otherwise not feasible. DP reduces in-train forces, preventing the lifting off the rails of a light car and the buckling of a train, and reducing damage to lading, thus enhancing safety.

Older DP required that the engineer manipulate multiple sets of controls for the lead and remote locomotives operated. Newer DP equipment allows the engineer to use one set of controls for synchronous or independent operation of the lead and remote locomotives. Older and newer DP can both be operated in a synchronous mode or in "independent control" mode. Newer DP is operated independently from the head end consist using the function keys of the "summary screen" throttle and dynamic brake controls of the DP. Thus when enabled in independent mode by the settings on the head end, the remote DP units can be operated, as commanded, separately from the head-end units. Coded digital radio communication exists between a head-end DP radio and its electronically mated counterparts on each remote locomotive. Each locomotive in a DP train operates on a unique digital address.

DP practice for controlling remote road locomotives began in the 1960s on the Southern. The early label for DP was remote control locomotive, not to be confused with the same label for locomotives used in switching (*85*).

Remote Control Locomotives

The remote control locomotive system (RCLS), used in yard and industrial switcher and other locomotive operations, provides a method of operating a remote control locomotive (RCL) from a remote location, from in the RCL cab, or both by means of an onboard control computer (OCC) and a remote control device (RCD) mounted on the body of a remote control operator (RCO). The system, stemming in large part from older technologies, including that used in DP (*86*), uses a radio link, with coded digital ultra high frequency (UHF) signals between an RCO's RCD and an RCL's OCC. The RCD is a body-mounted, battery-powered console having controls and visual and audio indicators for radio communication with the OCC for the purpose of controlling and monitoring the RCL.

The RCD transmits three messages per second to the OCC. If the OCC does not receive a valid coded radio message from the RCD within the prescribed timeout duration (5 s, or 3.5 s for some equipment), then a full-service brake application occurs and any power throttle use is killed. RCOs even sit in the engineer's seat near the conventional locomotive controls when operating an RCL via an RCD. When used by an RCL crew, RCDs operate as single or multiple units. The RCD is body mounted by a vest or belt. The RCO must fasten the RCD at all four of its corners to the vest or belt to insure the functioning of a tilt protection feature.

Tilt protection functions as follows. If an RCO falls down (tilting the RCD more than about 45 degrees from the vertical) after an audible warning, the RCLS automatically executes an emergency air brake application. Such application occurs also if radio communication between the RCD and the OCC is interrupted or if the RCO fails to manipulate the controls (or activate a reset safety button) during a period of 60 s. Mounted on top of each side of an RCD is a vigilance button. Either button must be pressed for 1 to 2 s, in response to an alert tone from the vigilance-timer. This button also functions to acknowledge warnings from the RCD and, when continuously depressed for over 2 s, to apply sand in the direction of RCL travel.

Positive Train Control

Operations by positive train control (PTC) constitute a large-scale change in train operations, stemming in significant part from older technologies. The FRA's interest in PTC systems grows in part out of its mandates from Congress in the Rail Safety Enforcement and Review Act of 1992 regarding reduction of collisions of rail rolling equipment. Offsetting the significant costs of implementing PTC, and beyond safety considerations is a potential for increasing line capacity by operating more trains at greater average speeds on shorter headways. This implementation could save the capital otherwise required for building and maintaining additional right-of-way, locomotives, and cars.

PTC can be a component of an advanced train control system (ATCS) of the kind beginning development two decades ago for improving safety, productivity, and energy savings. In 1983 a consortium of U.S. and Canadian railroads embarked on ATCS. PTC systems are communications-based train control (CBTC) systems. The system has two basic functions: train monitoring and train control. The usual subsystems of PTC include a central dispatch system, comprising a train dispatcher's console and a central dispatch computer; an onboard locomotive system, comprising a display, and an onboard computer; for roadway workers, an onboard work vehicle system, consisting of a display and track force terminal for PTC-related inputs; an in-the-field system having components controlling and monitoring field devices; and a data communications system, having a UHF digital radio network, based on various components of communications hardware (*87*).

PTC has been defined to have the following three core functions in the Railroad Safety Advisory Committee's report to the FRA "Implementation of Positive Train Control Systems:" (1) prevent train-to-train collisions (positive train separation); (2) enforce speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders; and (3) provide protection for roadway workers and their equipment operating under specific authorities. PTS is included in the core-feature definition of PTC. The 1999 FRA report on implementation of PTC systems outlines some of the developing systems (*88*).

"With regard to future automation of railway systems, and in particular with regard to the implementation of PTC, questions have been raised about the possible propensity for a locomotive engineer or conductor to become over-reliant on automation and/or to become distracted by the additional monitoring burdens required by the automation, and for these effects to compromise the performance of their duties regarding safe and efficient train operation." These concepts are closely related to reliance are complacency and overtrust (*89*).

Configurations vary but PTC can comprise a satellite-based Global Positioning System automatically locating each specially equipped locomotive. The computers on the locomotive are provided with information on its train consist profile and tonnage, and about the physical characteristics of the territory to be traversed. An on-locomotive computer uses all these data in a special braking algorithm appropriate to a particular operating situation. The computers constantly monitor the locomotive's speed and location, thereby insuring that the engineer does not exceed either authority for occupying the main track or speed restrictions for track, train-type, bulletin-directive, and signal-indication. One plan for PTC eventually includes floating or moving (dynamically alterable) blocks, permitting closer headways for trains than with blocks fixed by the location of wayside signals. PTC allows precision train planning, replanning, and control in real time.

In this introduction it is useful to focus on the central train-separation function of PTC. Development of PTS systems in the 1980s and 1990s gradually included many of the functions of PTC systems; the two, therefore, are not discrete technologies. When PTS stands alone, apart from PTC, it is a reactive safety system. It enforces track authority and speed limits. This enforcing of authority protects the safety of persons and equipment working on a main track and of such track being disturbed during maintenance. PTS informs operating crews of the location of opposing and overtaken movements, with reference to their train's algorithms for location and profile- and territory-matched braking. The main difference in PTS, compared with the range of PTC, is that an on-locomotive computer warns operating crewmembers of pending violations of track or speed authority and, thus, to take proper action. Here proper action or performance means successful compliance with the governing rules.

PTS uses penalty applications of brakes to ensure proper compliance. Before any penalty application occurs, the crew members first have an opportunity to use their customary job-reinforced abilities for proper action. Thus PTS maintains the experience-based judgment and skills for operating crews and reinforces their experiential assessment and proper action for a potentially dangerous operating event. Ultimate operational safety in PTS however does not depend on human action.

A thorough safety discussion about PTC should include the monitoring of operator behavior and consequent modification of this behavior. Many computer workstations in ordinary offices monitor and record the nature of an employee's work tasks, and—for managerial supervision—employee performance evaluations and compliances (regarding speed, accuracy, and rules). A PTC with enhanced event recorders, similarly, will monitor, record, and report electronically an engineer's compliance with the rules. The on-locomotive computers will be highly effective in this kind of efficiency testing, because of their direct interface with the other on-board systems. Thus the modern, field, efficiency testing of operating employees begun by roads (such as the Southern Pacific around 1900) may become continuous and comprehensive for anyone running a locomotive under PTC. In short, not only will PTC eventually monitor and control the engineer in a way heretofore unprecedented, but also the engineer, accordingly, will have to behave in a strict conformity to the rules.

Following is a brief consideration of fully automated PTC operations of trains on main tracks. This is a method of operation provided for by the FRA in its presentations on PTC. According to the FRA's notice of proposed rulemaking for PTC, the agency would have to regulate any fully automatic operation of railroad trains in a future, new round of rulemaking. Ed Ripley foresees completely automated trains for which "locomotives would no longer have to be built with cabs. Un-crewed trains enhance safety," he says. "No crewmembers could be injured or killed, and control would be from control center personnel." "Central in importance," he concludes, "The savings from crewless line-haul operations would be great" (*90*). This increase in safety assumes no increase in the number of persons other than crew members being threatened, injured, or killed. Such operations would likely shift the discussion for accidents, and monetary savings associated with crewless operations to the case law developed for such totally automated operations.

End-of-Train Devices

There is one last advanced technology to cover: end-of-train devices (EOTs). In 1973 the Florida East Coast pioneered EOTs (also abbreviated ETDs), and these devices developed further after that date (*91*). Since December 17, 1987, in Canada, railroads must use a two-way EOT, called a train information and braking system, containing an emergency, rear-end, braking feature. Since the time of this requirement, no runaway freight trains have occurred in Canada. At that time the FRA did not require U.S. railroads to have two-way EOTs. They were thus not required when a freight train with a restricted or blocked brake pipe ran away down the Cajon Pass on December 1994, resulting in a collision with another train, two crew member injuries, and $4 million in damage to physical property (NTSB/RAR-95/04). In 1989 the NTSB, an advisory agency with no regulatory power, reasoned that a two-way EOT might have prevented a derailment of another runaway freight train (NTSB/RAR-89/05:28-29). Therefore, in 1989, the NTSB sent to the FRA Safety Recommendation R-89-82: "Require the use of two-way EOT telemetry devices on all caboose-less trains for the safety of railroad operations" (NTSB/RAR-96/05). The increased cost, in 1989, of a two-way over a one-way EOT was about $2000 (NTSB/RAR-89/05:29). The Cajon Pass, in Southern California, has 25.6 mi of mountain grade on its west slope, including 6.9 mi of 3% grade on its No. 2 main track.

EOTs are of two basic kinds, "smart" and "dumb." The "smart" EOTs, in turn, are of two kinds, one-way and two-way, each with different software. Most EOTs have two units, a rear unit on the rear of a train, and a head unit in the cab of the locomotive controlling a train. Every rear EOT mounts on the rear coupler of the rearmost car and connects at that location through its pressure-sensitive hose to the brake pipe by a standard glad hand. In the lead locomotive cab is a head EOT display and control console. It has various status indicators and controls such as brake pipe pressure, message window, distance counter, EOT code identification setter, and, if part of a two-way EOT, an emergency brake switch. A one-way rear EOT communicates via UHF radio telemetry through a receiver for the head EOT console, at least. Data are received on brake pipe pressure at the rear end, movement and its direction, EOT battery charge, and accurate measurement of the position of end of train. A two-way rear EOT additionally has a radio receiver, pilot valve, and emergency "dump" valve. Accordingly, the two-way EOT provides, at least, an emergency-brake application initiated telemetrically from the head end console and "dumped" at the rear end of a train. This rear EOT additionally transmits the statuses of the EOT communications and dump valve (*92*). Battery recharges last about 6 days.

The EOT replaces almost every caboose (crew car) formerly at the rear of every freight train (*93*) and carrying the train's marker(s). All EOTs have a marker train signal (signaling that a movement is designated as a train and marking its rear end) built into it. The marker is usually a highly visible marker (HVM) energized by the EOT battery and activated by a photoelectric cell. When the marker is a flashing light, the EOT is also designated a flashing rear-end device. The head EOT display also indicates the status (light illuminated, replace battery) of any HVM. "Dumb" EOTs serve only as markers and provide no other functions. The FRA originally required only that a "dumb" HVM replace the caboose, although some railroad officers thought trains needed more than this (*94*). By 1986, suppliers had developed the technology for a two-way EOT, and by 1987 some railroads had them successfully in operation (*95*).

The enormous safety advantage for the low-cost, two-way addition to the one-way EOT is that if the brake pipe is blocked or an angle cock has been turned to a closed position, the entire train can still be braked from the rear-end EOT. Accordingly, given an alignment of a particular chain of events causing a blocked brake pipe, railroads could virtually prevent accidents having fatalities, injuries, or loss of property. The two-way EOT is a great and necessary safeguard in caboose-less operations because a trainman with a brake valve is no longer at the rear of a freight train. Recently some railroads have equipped their emergency brake valves, when activated on the head end, to simultaneously send a radio signal to the EOT, automatically initiating an emergency application at the rear of the train.

4.6 SAFETY CULTURE

> But they overlooked this order, at the station called Ingleside;
> For they failed to take a siding, side by side in the cab they both died.

"The Wreck of the Virginian No. 3"
Roy Harvey
1927 song in Norm Cohen
Long Steel Rail, University of Illinois Press, Urbana, 2000, p. 252

Safety culture and human error analysis each constitute a broad, contested, and interrelated domain of research and application. Neville Moray reflected this relationship in his conference presentation on the implications of organizational style and culture on human errors, incidents, and accidents.

The Question of Safety Culture

> And if you said it wasn't safe/ You surely would get cursed,
> But things have changed since by-gone days, / And we have "Safety First.". . .
> And "pencil peddlers" will be less,/ with thanks to "Safety First."

W. H. Stober, yardmaster, Camas Prairie RR, 1919,
referring to the railroads "Safety First" movement

Conceiving of Safety Culture

As Neville Moray informed us in the introduction to his conference paper, “current texts on safety science and systems reliability include little discussion of social factors.” Moreover, as Moray explained, the concept of safety culture (SC) has little uniformity. Questions and skepticism regarding the utility of the concept exist (*96*). As Moray noted “Even when engineers consider human-machine systems rather than ‘technological fixes’, they seldom acknowledge that cultural factors are fundamental to safety.” And yet unsafe operations are generally a function of the perception or misperception of risk. Risk has no external existence outside of our collectively carried, learned culture in which it is relativistically constructed. Even though hazards physically abound, no risk is objective. Moreover, the subjectiveness in a risk assessment does not occur at just one or two critical junctures but, instead, occurs continuously in multiplying effects throughout its contemplation and analyses. A society, not an individual enculturated in it, both creates and maintains, with changes over time, its networks for determination of risk. Because risk is a sociocultural creation, it is subject to sociocultural limitations regarding its application to things in the real world.

The “new” concept of SC is an outgrowth of the thinking on organizational culture (OC) and climate. The culture of a large organization possesses heterogeneity, differentiation, and dissonances. On close investigation it is only rarely unitary, if ever. For each of its members, different sets of only some of multiple elements influence behavior in an organization (*97*). Subcultures must crisscross any sizable organization (*98*). Indeed most writings on SC, as with OC, assume a single, uniform, monolithic variety of culture covering an entire corporation and contained entirely within its organizational boundaries.

For instance, the “wreck” of the Penn Central can be ascribed to the failure of the “red” and the “green” teams (respectively, Pennsylvania and New York Central managements) to become one in the new railroad. In a subsection titled “Corporate Character,” the U.S. Senate’s report on the collapse into bankruptcy of the then recently merged pair of railroads, explained that “the corporate characters of the merged partners also had some bearing on the collapse” (*99*). Each of the red and green teams, in turn, consisted of an array of subcultures.

In all, not only does a multiplicity of cultural strands exist in corporate culture, but also there usually exists a multiplicity of sometimes conflicting goals and tactics to reach these. Conflict is not always dysfunctional to the organizational maintenance. Organizational members may successfully pursue conflicting goals sequentially or at the same time (*100*). Railroads have had some classic conflicts among their transportation, engineering, and mechanical departments, for example. (“You say you want *more* track time?” “These units should be sent to a hospital and not put on a train!”) Locomotive mechanical engineer Jack Wheelihan reported that the greatest problem he had was with the mechanical departments: “Nothing is ever their fault. They aren’t willing to help themselves”(*101*).

Some conflicting goals might be destructive toward particular organizational units or to the organization itself. Many goals might remain dormant or be recognized as an unobtainable ideal, and then be pulled out of limbo when pressures on the entire organization or one of its components dictate. Organizations might implement thus activated goals, for example regarding safety, in a haphazard fashion, apart from a formal strategy. Culture is patterned and not haphazard or a thing of shreds and patches. Multiple goals stem partly from multiple organizational subcultures.

Using the Phrase "Safety Culture"

Analysts seem to have first used safety culture in describing the startling accident of the nuclear reactor at Chernobyl. For example, the International Atomic Energy Agency found regarding Chernobyl that "the accident can be said to have flowed from deficient safety culture, not only at the Chernobyl plant, but throughout the Soviet design, operating, and regulatory organizations for nuclear power plants that existed at that time" (*102*). How this particular plant SC differentiated, if any, from the background societal culture, the agency did not explore, but, at least, it noted the close relation of the two. Since then analysts have used the term to label other large-scale accidents, such as the 1987 fire with 31 fatalities at Kings Cross station in London, although "climate" and "style" as well as "culture" were explanatory labels. The concept was not yet fully in vogue. Labels were not fixed and certainly not attached to clear-cut, universally usable definitions.

The NTSB reported after its investigation of the in-flight break up in 1991 of an airliner a probable cause was "the failure of Continental Express management to establish a corporate culture which encouraged and enforced adherence to approved maintenance and quality assurance procedures" (NTSB/AAR-92/04:54). The FRA now uses the term safety culture in official announcements, statements (*103*), and presentations to various audiences: "The bill also seeks to reduce human-factor causation of injuries, wrecks, and deaths by improving the safety culture in the railroad industry by expanding and strengthening existing statutory protections for employee whistleblowers" (*104*).

If the concept of SC has any utility, a common set of concepts and methodological assumptions for it would enable analysts, managers, and regulators to read from the same page and more effectively communicate about the subject. Without a pragmatic middle range of a conceptual and methodological framework, presentations about SC can be faddish and cannot build toward an understanding of safety and risk. If various persons use concepts and subconcepts for a subject with little or no relation between them, research and its analyses will be sterile. Common concepts and methods provide an orientation narrowing the range of phenomena studied.

We can understand culture through the concept of enculturation, the lifelong process of learning one's culture. As a lifelong process, enculturation includes one's formal and informal learning such as in the family, community, schools, interest groups, and in one's vocations and avocations. Accordingly, espousing any of one's conceptions of "accident," "hazard," "risk," "safety," "culture," or of anything else is necessarily a product of one's enculturation. Humans, then, are not passive receivers of worldly sensations. In accord with their particular enculturation, humans first screen and select stimuli, then organize a representation of stimuli, and, finally, classify and rank the culturally developed sensations.

As opposed to a purported natural scientific objectivism, cultural relativism holds that all of us interpret the so-called hard scientific facts (for example, concerning safety and hazards) "softly," that is, normatively and politically. Particular individuals and groups thereby interpret for their needs, in their cultural contexts. Relativism holds that an idea or theory is relativistic if it cannot demonstrate evidence of truth independent of itself. Thus values, norms, sentiments, beliefs, and concepts are relative to a society, subsociety, or sub-subsociety of a particular time and are not necessarily valid outside of such a social milieu. What a railroad's general officers think, is not necessarily what their division transportation officers think, and the conventions of these two do not necessarily reflect what the various crafts and classes of contract and exempt rank-and-file employees think. But then, this is a railroad truism and I did not have to make that observation. The vice president of operations (VPO) of the "Transcon RR" went into the field on a division and talked extensively to rank-and-file employees. The division officers told me they were "petrified with fear" that an employee "would say the wrong thing" to the VPO. The officers were doubly relieved when the VPO left "our property" and no one had "spilled any beans." Rank-and-filers said "We don't 'turn in' our local officials to the big brass." This might be an example of the "team" activities held in esteem by management theorists.

What can we conclude thus far? A concept of a SC should accord with the general conceptions of culture (or else some other superior body of conceptualization), including its dynamic flux of component conventions: norms, values, sentiments, and etiquette. Specifically, the concept should concern patterned behaviors relating at least to safety, hazard, and risk within an organization and among organizations. Every organization exists in an environment of interacting organizations. Thus, one should define the concept to include component cultural patterns from particular supra-organizational entities, for example, certain regulatory and umbrella organizational sentiments, practices, rules, policies, and political pressures.

Finally, no matter what school of leadership or communication an analyst espouses, managerial leadership and communication are not an approximation of all the cultural patterns regarding safety in an organization (*105*). One cannot say that senior management determines the SC of an organization. Nor can one posit that "the same management values that define and guide a company's corporate culture underlie all its subcultures, including safety" (*106*). Above all, "safety culture" must not become a vacuous mantra, used to indicate concern or activity regarding railroad safety but with no conceptualization or methodology to address concerns or conduct activity.

Military Roots of U.S. Railroad Culture

People in the industry often speak of and occasionally discuss in print the military nature of American railroads (*107*). These railroads have experienced three strong additive transfers of military management and its cultural patterns (including for business organization and social relations, rules and regulations for conducting work, employee discipline, and so forth). The third transfer many people generally recognize, the second may be almost unrecognized, and the first recognized only by some researchers.

After the American Civil War both federal and Confederate army officers and ordinary soldiers went to work for the railroads that were greatly expanding in the economically developing United States. The officers, especially, added a third transfer of and solidified militarisms in North American railroading. The earlier first wave was by military engineers of the U.S. Army. Beginning in the 1820s an act of Congress encouraged the use of commissioned army engineers and associated army personnel to survey routes, provide engineering management of construction, and furnish organizational management for a railroad. These officers, employed through 1839, still held an army commission and after this date resigned the commission to manage the engineering and transportation concerns of railroad operations (*108*). Then only military officers had the experience to oversee the large-scale, far-flung engineering and management of railroads. A second transfer came with elements of pioneering railroading from the British mother culture to its daughter cultures in the United States and Canada. The third transfer of militarisms in railroading reinforced this second transfer and built enduringly upon its formative foundation, parts of which have changed little to this day.

From the second transfer, terms, concepts, and managerial styles from the British military of the period of 1810–1850 still have a defining role in contemporary American railroading. For example, American railroads remain managed in a style of military order and brusqueness, with "morning reports" and written "general and special orders" (all having the parental British formats and symbols). Rail management is by "officers" (in formal parlance, but called "brass hats" by the "men") in "general" and "division" levels of hierarchy. Railroads label work as "the service" and "duty," and bind it by aged military rules and ideas. The "general notice"—long beginning books of rules (itself an ancient military label)—informs, "The service demands the faithful, intelligent and courteous discharge of duty."

To delve into but one military concept governing operations in railroading: a railroad "station" is a named place in the timetable, and the building for housing persons or goods is a "depot." Even General Rules A and B, the first two of the standard code of operating rules come from the first two rules of the rule book of the British army, effective 1811: "It is incumbent on every Officer in His Majesty's Service to [have] a copy of these regulations and to [be] acquainted with them" (*109*) The format and uses of train orders, utilized until recently for rail traffic control, come from army special orders. Finally, regulating individual aspirations on railroads, as in the army, "seniority" and its perquisites were and are a central pattern of behavior and underlying organizational culture. In U.S. railroading seniority was originally a militarism and unilateral managerial grant originating in the Civil War and predating the first 1875 bilateral agreement on the New York Central and Hudson River Railroad, between management and union for conditions of employment (*110*).

The strict employee discipline of American railroading, only now beginning to fade, originates in the military discipline constituting the counterpart, for enforcement, to militarized rules. Books of rules on American railroads have not only included the work and deportment directives of early British army manuals (prohibiting "employees" from being "insubordinate, dishonest, immoral, quarrelsome, or otherwise vicious" and unable to "handle their personal obligations") but also contained some of their basic rules. Thus American railroads adapted many of the militarized rules for deportment on British railroads of the mid-19th century, often word for word, in their rulebooks (*111*). In organization and regulation then, the North American railroads have long comprised an army for transportation (*112*). Of significance in my own service on U.S. railroads and in railroad field research here and abroad, railroaders repeatedly tell me, "The railroad is like the army." The reality is that the railroad is derived from the army (*113*). The British books of rules governing the range of operations regarding a dispersed and, in part, mobile workforce are paramount among the militarisms of railroading and are of a genre begun by Captain Mark Huish of the London and North Western Railway (*114*). Central to railroading are what railroaders have called for over a century and a half, the rules.

The Rules: The Basis of Railroad Safety

> You can get by with breaking the rules every time.
> Until the time you don't.

"Bozo Texino"
(the ubiquitous, collective alter ego of railroaders)

We now turn to the sometimes maligned railroad operating rules, found in the "book of rules" governing operating work on every railroad. At the heart of each culture and subculture are its conventions. For a railroad the conventions are grounded in "the rules." In considering safety culture, Moray explained, rules and procedures are a reaction to past incidents and accidents. Furthermore, he notes, the rules should not only ensure correct action when a past event reoccurs but also ensure an appropriate adaptive response to unforeseen events. Today the North American rules essentially have such a dual characteristic. The *ur*-root of safety on railroads is the rules. The railroad industry is defined by potentially catastrophic operations for which safety measures are essential and this has long been without question. Since at least the 1790s, the overarching safety measure for railroad operations has been an ever-evolving, written code of operating and related rules (*115*).

Use of the rules involves more than assessing a single safety-critical principle for a particular operating event. The late "dean" of operating rules and practices and successor–author of the authoritative *Rights of Trains*, Peter Josserand, explained that a railroader cannot understand or apply rules in isolation or out of context from other rules in the code of operating rules. For every railroad "each set of rules has one thing in common: they dovetail so as to provide for a safe operation." Since Harry Forman's first edition of the *Rights of Trains*, such dovetailing of the rules in their use has been explained (*116*). Thus operating rules are, in a word, systemic. Accordingly, "choices involving virtually any of the operating rules and regulations in differing combinations are the basis for safety-critical action and reaction by employees" (*117*). Railroaders make choices about which of the several rules should or should not be used and in which sequence they should be initiated (*118*).

What about more recent considerations, beyond Forman and Josserand? The supplier, General Motors, and the carrier, Burlington Northern, published an operating manual for engineers running the SD70MAC locomotive. The manual gives the ultimate instruction in rail safety and thereby echoes the theme of this and the above views on the rules: "No amount of training, however, can prepare you for every possible situation that you may encounter. There will be instances in which you must use your judgment and experience to determine the safest and most effective action" (*119*). Operating personnel achieve such safe and effective action, based on the rules, only by maintaining their customary range of safety–critical judgment and skills. Pivotal for this maintaining, the judgment and skills are job-experience based. As the foremost rule informs, obedience to the rules is essential to safety. Full, informed obedience, however, can only come from well-maintained abilities to make knowledgeable, experience-based judgments with situationally selected rule sets. Such capacity for judgments is essential for safe railroading. As a rules-examiner recently e-mailed me, he expects people to ask questions about the rules and discuss them intelligently rather than "just recite them like memorized poetry." Related to capacity for judgments, an expected (by the rules) and an accepted (bending the rules) way of railroading exists (*120*). Just as there can be no effective railroad rules without testing and discipline, so too there can be no safety actions without firm regulatory oversight.

To Err Is Also Organizational and Regulatory

> The engineer, poor chap he is killed/ That makes the explanation clear
> A trusted servant tried and skilled/ We'll blame it on the engineer.

Recorded, in 1955, from a chalked message on the side of a boxcar
and signed "Bozo Texino"

In his conference presentation, Moray probed deeply into common popular and frequent managerial misconceptions on accidents. He noted, “All those who have conducted research on safety are agreed that the tendency of accident enquiries to explain accidents, in terms of the ‘human error’ of some person or persons who can be blamed for the accident, is highly undesirable as well as being logically incorrect.”

It is much less arduous, time-consuming, mentally taxing (and less costly to a business organization) to blame an “accident” on a single person. This focus has historically been the long and the short of investigating human errors on railroads. [“Blame it on the hoghead (engineer).”] That single employee’s railroad thereby self-absolves against any part of the culpability. Members of the public, by individualistic ideology, want to find the lone culprit, the red-handed person “asleep at the switch.” After all, we affirm, every individual is fully responsible for the consequences of his or her behavior: each is captain of his or her own ship, or so the western tradition brainwashes (enculturates) our contemplation.

As observers of others then, we usually focus on necessarily quite visible individuals and not the abstractly intricate, seemingly unfathomable organizational contexts of error. We use causes, thought to be internal to a person, to explain the actions of an individual. What we can observe directly is the other person and his or her acts. (“I saw him do it.”)

Accordingly, we westerners feel that all the causes of behavior reside within an individual. Hence, we like to say that the person used poor judgment, broke the rules, was heedless, was “accident-prone,” or was a “foul up.” As Marvin Harris reminded us: “The road to . . . knowledge of mental life is full of pitfalls and impasses. Extreme caution is called for in making inferences about what is going on inside people’s heads even when the thoughts are those of our closest friends and relatives” (*121*). The pitfalls increase when we truly believe we understand the thinkers.

In considering human error we should note a hierarchy of error (*122*). Logically, and for results, an analyst needs to ascend the levels of error causation to chart any hierarchical chain of error resulting in an initiating event. Only in the upper levels of organizations and higher do we come to grips with basic kinds of error. At the highest overarching level are human errors generated by a state society and its culture(s), including the component institutions. Below this level are the human errors engendered in government, by legislation and judicial interpretation—a fleshing out of the legislative skeleton—and by executive enforcement, often through regulatory agencies.

Next, we descend to the level of error from modern organizations. An organization’s errors stem from the actions and inactions of managers on all levels, from the board of directors down to the first-line supervisors. At the bottom of this hierarchy of error causation is the individual actor, sometimes working in a team, or crew, of co-actors. His or her error is ordinarily not in isolation but shaped by errors on the higher levels.

Blaming an accident on one railroader, often a victim of the accident, is a practice from invalidated research and managerial programs. As Howe instructs: “These programs blame workers (the victims of occupational health and safety exposures to hazards) by focusing on worker behavior, rather than problems in the system, such as hazards inherent to the work process. By focusing on workers’ ‘unsafe acts’ as the causes of injuries and illnesses, companies do little to address the root causes of safety and health risks” (*123*). Fred Manuele highlights the underlying flaw in the practice of blaming an accident on an individual, in which allegedly, “man-failure is the heart of the problem.” “For years many safety practitioners based their work on Heinrich’s theorems, working very hard to overcome ‘man failure,’ believing with great certainty that 88% of accidents were primarily caused by unsafe acts of employees. How sad that we were so much in error" (*124*). Frequently blaming an individual railroader or team of railroaders addresses the symptoms but ignores the underlying causes, upon which scientific, valid accident prevention can be undertaken.

Notes

1. Cf. By the 1920s, the railroads "stood stolidly in the shackles of tradition, clinging to the old ways." Klein, M., *Union Pacific: The Rebirth, 1894–1969*, Doubleday and Company, Garden City, N.Y., 1990, p. xviii.
2. For further information on the genesis of railroading, see Gamst, F. C., and F. A. R. von Gerstner, Student of America's Pioneering Railroads, *Railroad History,* No. 163, 1990, pp. 13–27; The Context and Significance of America's First Railroad, on Boston's Beacon Hill, *Technology and Culture,* Vol. 33, 1992, pp. 66–100**;** *Early American Railroads*, F. A. R. von Gerstner, *Die innern Communicationen* (1842–1843), 2 vols., Stanford University Press, California, 1997; The Transfer of Pioneering British Railroad Technology to North America, *Early Railways* (Andrew Guy and James Rees, eds.), the Newcomen Society, London, 2001, pp. 251–265.
3. For federal action on many fronts, see Cothen, G., Jr., Partnerships for Safety, American Association of Railroad Superintendents, *Proceedings*, Vol. 207, 2003, pp. 31–37; Railroads and Federal Power, *Railroad Gazette,* Vol. 26, 1894, p. 507.
4. McAlpine, W. C., and H. E. Bartlett, Accidents on Railroads [in New York State], *American Railroad Journal,* Vol. 26, 1853, pp. 81–84, 117–118, 186–187, 309–310, 386–387; Board of Rail-Road Commissioners, *Codification of the Rules and Regulations for Running Trains of the Rail-Roads of the State of New York,* Albany, 1856; Railroad Commissioners of Massachusetts, *Rules and Regulations for Operating Railroads,* Boston, 1872; "State Railroad Control in Texas," *Railroad Gazette,* Vol. 26, 1894, pp. 790–791.
5. Prout, H. G., Safety in Railroad Travel, *The American Railway* (T. M. Cooley, ed.), Scribner's, N.Y., 1890, pp. 187–227; MCB Couplers Now in Use, *Railroad Gazette,* Vol. 27, 1895, p. 357; The State of the Law Regarding Safety Appliances, *Railroad Gazette,* Vol. 27, 1895, p. 367; Clark, C. H., The Development of the Semi-Automatic Freight Car Coupler, 1863–1893, *Technology and Culture,* Vol. 13, 1972, pp. 170–208; Usselman, S. W., The Lure of Technology and the Appeal of Order: Railroad Safety Regulation in Nineteenth Century America, *Business and Economic History,* Vol. 21, 1992, pp. 290–299.
6. The information on railroad economic, labor, and safety regulation is adapted from an instructional resource: Gamst, F. C., Railroad Industrial and Labor Relations and Craft Seniority: Characteristics and Bibliographic Sources, 7th ed. FCG-Z-99-1, 1999, 325 pp., copy available from fcgamst@aol.com.
7. Kolko, G., *Railroads and Regulation, 1977–1916,* W. W. Norton, New York, 1970 (1965); Hilton, G., The Consistency of the Interstate Commerce Act, *Journal of Law and Economics,* Vol. 9, 1966, pp. 87–113; Fellmeth, R. C., *The Interstate Commerce Omission: The Public Interest and the ICC,* Grossman, N. Y., 1970; Rosenthal, H., The Enduring Nineteenth Century Battle for Regulation: The Interstate Commerce Act Revisited, *Journal of Law and Economics,* Vol. 36, 1993, pp. 837–860.
8. Named after Glenn Plumb, an attorney who devised the plan. The Plumb Plan to the Front, *The Nation,* Vol. 16, Aug. 19, 1919; Plumb Plan Campaign Ineffective in Election, *Railway Age,* Vol. 69, 1920, p. 848; Plumb, G. E., Should Labor Participate in Management? American Academy of Political and Social Science, *Annals,* Vol. 86, November 1919, pp. 222–226.
9. Public Law 91-458, 91st Congress, S. 1933.
10. The basis of the Act is Railroad Safety and Hazardous Materials Control, Committee on Interstate and Foreign Commerce, House Report No. 91-1194, 91st Congress, 2nd Session.

11. National Transportation Safety Board, Evaluation of U.S. Department of Transportation Efforts in the 1990s to Address Operator Fatigue, Report No. NTSB/SR-99/01, 1999, pp. 5–6.
12. Maier, N. R. F., *Psychology in Industry,* Houghton Mifflin, Boston, 1946, p. 271.
13. Åkerstedt, T., Work Schedules and Sleep, *Experientia,* Vol. 40, 1984, pp. 417–422.
14. Folkard, S., and R. Condon, Night Shift Paralysis in Air Traffic Control Officers, *Ergonomics*, Vol. 30, 1987, pp. 1353–1363
15. For a comprehensive study of sleepiness, with 1000 Swedish locomotive engineers as subjects, see Kerstedt, T, L. Torsvall, and M. Gillbet, Sleepiness and Shift Work: Fields Studies, *Sleep,* Vol. 5, 1982, pp. 96–106
16. This and the other statements on fatigue and sleep in this essay are adapted from the meeting theme presentation at the 100th Anniversary Meeting of the American Association of Railroad Superintendents, Chicago, August 5, 1996, Gamst, F. C., Sleep Deprivation and the Railroads, What Is It, How Does It Affect Our Employees, and How Might We Combat It, Association of Railroad Superintendents, *Proc.*, Vol. 100, 1997, pp. 45–55. See also Gamst, F. C., "Workshop Summary—Sleep Deprivation," Association of Railroad Superintendents, *Proc.*, Vol. 100, 1997, pp. 66–67.
17. When I "hired out" on the railroad in 1955, the men who hired out before 1907 would recount being 20 h or more on duty and having their union "grievers" write to Congress about the problem and its dangers. There ought to be a law, they had said, and, then, there was one, sufficient for 1907. Engineer John M. Reilley recounts two continuous trips in 1889 when, despite his protest, he was kept 25 h on duty, fell asleep at the throttle, and almost hit a freight train ahead of him: Training 60 Years Ago, *Locomotive Engineers Journal,* June 1937, p. 483.
18. Currently, USC Chapter 211, Hours of Service.
19. Vantuono, W. C., NJ Transit Wreck: Was It Engineer Fatigue? *Railway Age,* March 1996, p. 18.
20. An Engineer's Nap, *Locomotive Engineers Monthly Journal,* Vol. 12, 1878, pp. 466–468.
21. A Bill to Regulate the Hours of Railway Duty, *Railroad Trainmen's Journal,* Vol. 24, 1907, p. 151.
22. Northwest, and Overworked, *Locomotive Engineers Monthly Journal,* Vol. 33, 1899, pp. 250–251.
23. Kelley, J., Railroad Men's Rest Periods between Trips, *Locomotive Engineers Journal,* Vol. 52, 1918, pp. 854–855.
24. Hours of Service Extension Opposed, *Railway Age,* June 1998, p. 14.
25. Coplen, M., and D. Sussman, Fatigue and Alertness in the United States Railroad Industry Part II: Fatigue Research in the Office of Research and Development at the Federal Railroad Administration, 4th International Conference on Managing Fatigue in Transportation, Fremantle Australia, March 2000. http://www.volpe.dot.gov/opsad/pap2fi-2.html. Volpe Center, Operator Performance and Safety Analysis Division (OPSAD), DTS-79.
26. Sussman, D., and M. Coplen, Fatigue and Alertness in the United States Railroad Industry. Part I: The Nature of the Problem. 4th International Conference on Managing Fatigue in Transportation, Fremantle, Australia, March 2000, Volpe Center, Operator Performance and Safety Analysis Division (OPSAD), DTS-79.
27. Discussions of culture and related matters in this essay stem from *Ideas of Culture: Sources and Uses* (F. C. Gamst and E. Norbeck, eds.), Holt, Rinehart and Winston, New York, 1976.
28. Mohler, S. R., et al., Circadian Rhythms and the Effects of Long-Distance Flights. Report AM 68-8. Office of Aviation Medicine, FAA, 1968.
29. Coughlin, S. M., Testimony . . . before the Committee on Energy and Commerce, Subcommittee on Transportation and Hazardous Materials, House of Representatives, Regarding the Hours of Service Act, June 10, 1992, pp. 2–3.
30. Lauber, J. K., and P. J. Kayten, Sleepiness, Circadian Dysrhythmia, and Fatigue in Transportation Systems, *Sleep,* Vol. 11, 1988, pp. 503–512.
31. Moore-Ede, M., *The Twenty-Four Hour Society,* Addison-Wesley, Reading, Mass., 1993, p. 125.
32. Devoe, D. B. and C. N. Abernethy, Maintaining Alertness in Railroad Locomotive Crews, Report No. FRA/ORD-77/22, 1977, p. 2.

33. Biological Clocks and Shift Work Scheduling, U.S. House of Representatives, 98th Congress, 1st Session; House Subcommittee on Investigations and Oversight, 1983; 2nd Session, 1984, p. 17.
34. Coplen, M., Circadian Rhythms and Railroaders, Gillette, Wyo., 1985. See also Coplen, M., Sleepiness in Railroad Operations—A Review, *Proc., International Association of Railway Operating Officers*, 1989, Vol. 53, 1990, pp. 157–161.
35. NTSB and NASA, *Fatigue Symposium Proceedings, November 1–2, 1995,* Washington, D.C., 1996, pp. 8–14.
36. NTSB, Evaluation of U.S. Department of Transportation Efforts in the 1990s to Address Operator Fatigue, Report NTSB/SR-99/01, Washington, D.C., 1999, p. 14.
37. NTSB, 1999, ibid., p. 8.
38. Studies of engineers go back at least to 1931 but not including fatigue; Pickl, R., and R. Schager, "Ein Beitrag zur Berufstypologie der Lokomtiveführer," *Industriele Psychotechnik*, Vol. 8, 1931, pp. 353–364.
39. McGaughey, T. P., et al., Work Rest Schedules and Vigilance Problems of Railway Operating Personnel, Canadian Institute of Guided Ground Transport, Queen's University, Kingston, Ontario, June 1974, p. 18.
40. Xia, W. S., Z. Z. Song, and N. Y. Li, Physiological Limits of Locomotive Engineers on Successive Night Shifts in the People's Republic of China, *Journal of Human Ergology*. Vol. 11 (supplement), 1982, pp. 393–398.
41. Pollard, J. K., Issues in Locomotive Crew Management and Scheduling, DOT/FRA/RRP-91-01, 1991; Locomotive Engineer's Activity Diary, DOT/FAR/RRP-96/02, 1996.
42. GAO, Engineer Work Shift Length and Schedule Variability, GAO/RCED-92-133, 1992, pp. 10–11.
43. SOFA Working Group, Findings and Recommendations of the SOFA Working Group, Report Nos. DOT-VNTSC-FRA-00-08, DOT/FRA/ORD-00/04, 1999; Volume II: Appendix. Findings and Recommendations of the SOFA Working Group, 2000.
44. GAO, Human Factors Accidents and Issues Affecting Engineer Work Schedules, GAO/RCED-93-160BR, 1993, pp. 15, 22.
45. For the same comment see Klein, M., Employee Rest—How Critical It Is to Safety and Morale, American Association of Railroad Superintendents, Vol. 98, 1995, pp. 33–44, 37.
46. North American Rail Alertness Partnership, Charter, April 1998.
47. Thomas, G., R. Thomas, G. Raslear, and G. I. Kuehn, The Effects of Work Schedule on Train Handling Performance and Sleep of Locomotive Engineers: A Simulator Study, Report No. DOT/FRA/ORD-97-09, July 1997, FRA, USDOT; Pilcher, J. J., and M. K. Coplen, Work/Rest Cycles in Railroad Operations: Effects of Shorter Than 24-Hour Shift Work Schedules and on-Call Schedules on Sleep, *Ergonomics,* Vol. 43, 2000, pp. 573–588.
48. Dawson, D., G. Roach, K. Reid, and A. Baker, Australian Railways Shiftwork and Workload Study: Final Report, Centre for Sleep Research, University of South Australia, Woodville, 1997.
49. Sherry, P., Fatigue Counter Measures in the Railroad Industry: Past and Current Developments, Counseling Psychology Program, University of Denver, Colo., June 2000.
50. Foisy, R., Commission of Inquiry: Hinton Train Collision. Report of the Commissioner the Honourable Mr. Justice René P. Foisy, December 1986; Region Responds to Foisy Concerns, *CN RailNews*, March 1987, pp. 1, 3; Thomson, G., Train of Errors, *Edmonton Sunday Journal,* February 4, 1996, pp. E1–E3; Finding Clues in Ashes: Disaster at Mile 173, *Edmonton Journal,* February 5, 1996, pp. A1, A12.
51. Moore-Ede, M., et al., Alertness Assurance in the Canadian Railways. Phase II, Circadian Technologies, Cambridge, Mass., 1996.
52. Czeisler, C. A., M. C. Moore-Ede, and R. M. Coleman, Rotating Shift Work Schedules That Disrupt Sleep Are Improved by Applying Circadian Principles, *Science,* Vol. 217, July 30, 1982, pp. 460–462; Dement, W. C., The Perils of Drowsy Driving, *New England Journal of Medicine,* Vol. 337,

1997, pp. 783–784; NTSB, Factors That Affect Fatigue in Heavy Truck Accidents, Vol. I Analysis, Report NTSB/SS-95/01, 1995.

53. FRA, U.S. Secretary of Transportation Slater Submits Railroad Safety Bill, August 2, 1999, http://www.dot.gov/affairs/1999/fra1899.htm.
54. "Jefferson, B.," Crew Fatigue: The Challenge to Rail Management, *Trains,* March 1993, pp. 43–45.
55. Professor Morse's Electric Telegraph, *American Railroad Journal,* Vol. 16, 1843, pp. 297–299; Early, A. W., *The Train Dispatcher: A Manual of Railway Telegraphy,* Henneberry, Chicago, 1903; Displacement of Morse Operators in Commercial Telegraph Offices, *Monthly Labor Review,* Vol. 34, 1932, pp. 501–515.
56. New York and Erie Railroad, *Instructions for the Running of Trains, etc*., effective August 1, 1857. These rules were far more developed than the first North American rules, on a broadside, of the Baltimore and Ohio for the drivers of its horse-powered trains of cars, ca. 1829–1830, *Rules to Be Observed by All Drivers on the Baltimore and Ohio Rail Road*. In 1840 the first book of rules appeared: Western Rail Road, *Regulations for the Government of the Transportation Department*.
57. Thomas S. Hall in 1871 developed the Hall "banjo" ABS. It was the first ABS operated by an electrical circuit. At the top of a wayside signal mast was a head having the appearance of a banjo. This head had an aspect from either of two disks. Red meant stop, block occupied, and white meant proceed, block not occupied. No intermediate approach signal was used, which would have been a green-caution, given the railroad color code of the period before about 1904.
58. Patterson, W. J., Developments in Railroad Signaling, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 122, 1947, pp. 91–94, AAR, op. cit., 1953. For the changing color codes of railroad signals, see Gamst, F. C., Rethinking Leach's Structural Analysis of Color and Instructional Categories in Traffic Control Signals, *American Ethnologist*, Vol. 2, 1975, pp. 271–296.
59. Dixon, F. H., Railroad Accidents, *Atlantic Monthly,* Vol. 99, 1907, pp. 577–590. Clark, C., The Railroad Safety Problem in the United States, 1900–1930, *Transport History,* Vol. 7, No. 2, 1974, pp. 97–123. Wetzel, K., Railroad Management's Response to Operating Employee Accidents, 1890–1913, *Labor History,* Vol. 21, 1980, pp. 351–368. Aldrich, M., *Safety First: Technology, Labor, and Business in Building the American Work Safety, 1870–1939,* Johns Hopkins University Press, Baltimore, Md., 1997, pp. 168–210, 283–297.
60. The development of railroad safety appliances of every kind for rolling equipment is covered comprehensively in ASME Rail Transport Division, *Railway Mechanical Engineering: A Century of Progress: Car and Locomotive Design,* American Society of Mechanical Engineers, New York, 1979; See also The Proposed MCB Coupler Tests, *Railroad Gazette,* Vol. 26, 1894, pp. 839–840; The Coupler Law, *Railroad Trainmen's Journal,* Vol. 20, 1903, pp. 287–289; Handling Air-Braked Freight Trains, *Railroad Gazette,* Vol. 26, 1894, p. 839; and Men Must Not Brake by Hand, *Railroad Trainmen's Journal,* Vol. 34, 1917, pp. 764–768.
61. Commemorate the 75th Anniversary of the Invention of Railroad Air Brakes, *Locomotive Engineers Journal,* Vol. 78, 1944, pp. 726–729, 790. Blackall, R. H., Runaways with Freight Trains, *Locomotive Engineers Journal,* Vol. 39, 1905, pp. 1078–1081. Safety Appliances, *Railroad Trainman,* Vol. 41, 1924, pp. 405–406. Oakes, F. O., The Tehachapi Horror, *Locomotive Engineers Journal,* Vol. 61, 1927, p. 694.
62. The Steel Car, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 66, No. 2, 1919, p. 7. Stoves and Lamps in Railway Cars, *Locomotive Engineers Journal,* Vol. 16, 1882, p. 221. The Car Stoves Again, *Locomotive Engineers Journal,* Vol. 23, 1889, p. 148. The Manhattan Arc Lamp, *Railroad Gazette,* Vol. 26, 1894, p. 492.
63. Sillcox, L. K., History of Air Brake Development, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 135, 1953, pp. 8–11; *Mastering Momentum,* Simmons–Boardman, N.Y., 1955. Blaine, D. G., The Westinghouse Air Brake Story—1, 2, 3, *Trains,* October 1975, pp. 44–53, December 1975, pp. 48–53, and January 1976, pp. 40–46. *Modern Freight Car Air Brakes,* Simmons-Boardman, Omaha, Neb., 1979. Usselman, S W., Air Brakes for Freight Trains:

Technological Innovation in the American Railroad Industry, 1869–1900, *Business History Review,* Vol. 58, 1984, pp. 30–50. Krug, A., Air Brakes Simplified, *RailNews,* August 1997, pp. 48–57.

64. Westinghouse Air Brake Company, *Operating Instructions 24-RL Locomotive Brake Equipment,* Wilmerding, Pa., 1955, pp. 71–76.
65. From field research in Australia and from Australian correspondents.
66. Carlson, F. G., Putting E-P Brakes to the Test, *Railway Age,* February 1995, pp. 31–39. Carlson, F. G., and B. Smith, ECP Braking Gets Results, *Railway Age,* October 2000, pp. 50–52. Gilfillan, J. W., Amtrak and the Development of Electronically Controlled Pneumatic Air Brake System for Passenger Trains, *Proc,,* International Association of Railroad Operating Officers, 2000, Vol. 63, 2001, pp. 64–67. Carlson, F., et al., Electronic Braking, *Proc.,* American Association of Railroad Superintendents, 2000, Vol. 104, 2001, pp. 313–334.
67. Harding, J. W. *Brake Equipment for High-Speed Trains,* International Correspondence Schools, Scranton, Pa., 1945. An EP system was available by 1897; The Chapsal Electro-Pneumatic Brake, *Railroad Gazette,* Vol. 29, 1997, pp. 902–903 and 910–911.
68. Eckels, A. E., Dynamic Braking, *McGraw–Hill Encyclopedia of Science and Technology*, Vol. 4, 1977, pp. 351–352.
69. AAR, op. cit., 1953.
70. Crying Need for Automatic Train Control, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 65, No. 5, 1918, pp. 19–21. Automatic Train Control, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 65, No. 6, 1918, pp. 1, 7. Two More Horrors Cry Aloud for Automatic Train Control, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 65, No. 7, 1918, pp. 19–20. Automatic Train Control Device Ordered, *Railroad Trainman,* Vol. 41, 1924, pp. 174–175.
71. CTC for Modern Train Schedules, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 123, 1947, pp. 165–171; AAR, op. cit., 1953.
72. AAR, op. cit., 1953.
73. Detector Fences, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 133, 1952, pp. 332–333.
74. From field observations and experiences.
75. Marsh, H. S., Hot Boxes, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 133, No. 3, 1952, pp. 191–193.
76. The Telephone in Railway Service, *Locomotive Firemen and Engineman's Magazine,* Vol. 31, 1901, pp. 859–861.
77. Welty, G., Railroads and Their Computers, *Railway Age,* Vol. 8, April 1974, pp. 20–21, 23, and 26. Gotschall, M., Load 'Em Up and Move 'Em Out, *Info Magazine,* May–April 1987, pp. 17–19. Welty, G., Customer Service Goes High-Tech, *Railway Age,* August 1993, pp. 29–32.
78. Bendix Radio, Bendix VHF Radio for Fast Communications, *Locomotive Engineers Journal*, Vol. 8, 1944, p. 793. Overbey, C. O., Application of Radio to Railroad Operations, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 130, 1951, pp. 8–12.
79. Lustig, D., [AEI], *Trains,* June 1992, p. 9. Walsh, A., AEI Surpasses Expectations, *Info Magazine,* May–June 1997, pp. 18–19.
80. For human factors of the diesel-electric locomotive cab and locomotive, see Gamst, F. C., Human Factors Analysis of the Diesel-Electric Locomotive Cab, *Human Factors,* Vol. 17, 1975, pp. 149–156. The Diesel-Electric Locomotive as a Work Environment: A Study in Applied Anthropology, *Studies in Cultural Anthropology,* Rice University Studies, Vol. 61, No. 2, 1975, pp. 37–78. Multer, J., R. Rudich, and K. Yearwood, Human Factors Guidelines for Locomotive Cabs, Volpe National Transportation Systems Center, 1998, Report No. DOT-VNTSC-FRA-98-08.
81. For a good review by the then-Director of the Bureau of Locomotive Inspection, see Davidson, E. H., Locomotive Inspection History, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 131, 1951, pp. 401–408.

82. United States Government Standard Locomotives, *Brotherhood of Locomotive Firemen and Enginemen's Magazine,* Vol. 64, 6, 1918, pp. 3–5.
83. Electric Motor on New York Elevated Railroad, *Locomotive Engineers Monthly Journal,* Vol. 20, 1886, pp. 12–13. Electricity for Railways, *Locomotive Engineers Monthly Journal,* Vol. 26, 1892, pp. 358–359. Wyatt, K., The First Diesel Electric Locomotive [1905], *RL&HS Newsletter,* Vol. 16, No. 4, 1996, pp. 8–9. Lipetz, A. I., Diesel Engines, *Locomotive Engineers Journal,* Vol. 61, 1927, pp. 704–718, 789. Smith, V. L., The Diesel from D to L–1, 2, 3, 4, *Trains,* April 1979, pp. 22–29; May 1979, pp. 44–51; June 1979, pp. 46–51; and July 1979, pp. 44–49.
84. For modern electronic standards on all rail equipment see Moody, H., and D. Meeks, Searching for Electronic Standards, *Railway Age,* August 2001, pp. 54–55.
85. Cavanaugh, H. F., Why and Wherefore of Remotely Controlled Diesels: Masters and Slaves, *Trains,* February 1983, pp. 34–38. Wheelihan, J., Helpers: How They Work, *Trains,* August 2001, pp. 42–51.
86. The information for this and the following paragraphs on RCLs comes from my research in an ongoing study of task analysis and risk assessment of convention compared to RCL operations in yards and from other RCL studies since 1994. For a recent report on RCL operations, see Kautzman, K., Remote Control Operations on Montana Rail Link, *Proc.,* American Association of Railroad Superintendents, Vol. 105, 2002, pp. 196–198.
87. Advanced Train Control, *Railway Age C&S Guide*, 1996, pp. 10–13. Gallamore, R., and H. Moody, The Curtain Rises on the Next Generation, *Railway Age,* July 1999, pp. 40–42. Vantuono, W. C., CBTC: A Maturing Technology, *Railway Age,* June 1999, pp. 37–43. Sullivan, T., PTC: Is the FRA Pushing Too Hard? *Railway Age,* August 1999, pp. 49–57. Wilner, F. N., Can the Cost of PTC Be Justified? *Railway Age,* January 2000, p. 16. Moore-Ede, W. J., How CBTC Can Increase Capacity, *Railway Age,* April 2001, pp. 49–50. Schwalbach, J., North American Joint Positive Train Control, *Proc.,* American Association of Railroad Superintendents, 2002, Vol. 106, 2003, pp. 33–45.
88. Railroad Safety Advisory Committee, Report to the Federal Railroad Administrator, Implementation of Positive Train Control Systems, July 1999.
89. Sheridan, T. B., F. C. Gamst, and R. A. Harvey, White Paper: 'Reliance' and 'Distraction' Effects in PTC Automation, FRA Paper No. STD-SCD-DEC-02-00, November 28, 1999, p. 1.
90. Ripley, E., Untouched by Human Hands, *RailNews,* April 1999, pp. 78–80. The issues of no-person operations are beyond the scope of this essay, but see A Railroader's Bad Day at Black Rock, *Business Week,* August 4, 1975, pp. 69–70. Does Lone Engineer = Trouble? *Trains,* February 2002, pp. 22–23. Reh, V., Muskingum Electric Railroad Just About Done, *Trains,* February 2002, pp. 22–23.
91. Howard, P., The Role of Telemetry in Cabooseless Train Operations, *Proc.*, American Association of Railroad Superintendents, 1985, Vol. 89, 1986, pp. 138–146.
92. Roberts, R., Hi-Tech Replacement for the Caboose, *Modern Railroads,* August 1984, pp. 20–22. Pomeroy, R. J., Operational Application of Rear-of-Train Telemetry, 1985. Borzo, G., End-of-Train Devices Move Ahead, *Modern Railroads,* September 1985, pp. 48–52. McElroy, J., Two-Way (End of Train) Telemetry Devices, *Proc.*, International Association of Railroad Operating Officers, 1993, Vol. 5, 1994, pp. 121–128.
93. Gelder, R., The Case against the Caboose, *Trains,* March 1987, p. 74. The Caboose as an Influence on the Safety of Train Operations in Through Freight Service in the United States, National Railway Labor Conference, October 3, 1986, Washington, D.C.
94. Stewart, W. A., F. C. Gamst, R. H. Nelson, V. Hand, D. N. McFarlane, and W. B. Vander Veer, Committee Report No. 1: Cabooseless Operations—Effects of End-of-Train Devices, *Proc.*, American Association of Railroad Superintendents, 1987, Vol. 91, 1988, pp. 33–45.
95. R. J. Pomeroy, Dynamic Sciences, Ltd., to F. C. Gamst, personal communication, March 2, 1987.
96. Cox, S., and R. Flin, Safety Culture: Philosopher's Stone or Man of Straw? *Work and Stress,* Vol. 12, 1998, pp. 189–201; Pidgeon, N., Safety Culture; Key Theoretical Issues, *Work and Stress,* Vol. 12, 1998, pp. 202–216; Harvey, J., G. Erdos, H. Bolam, and D. Gregory, An Examination of

Different Safety Cultures in an Organization where Safety Is Paramount, Eidgenössische Technische Hochschule Zürich, Hochschulverlag 22 (n.d.), www.psyc.adbn.ac.uk/newspage23.htm. Clarke, S., Perceptions of Organizational Safety: Implications for the Development of Safety Culture, *Journal of Organizational Behavior,* Vol. 20, 1999, pp. 185–198. Zhang, H., D. A. Wiegmann, T. L. von Thaden, G. Sharma, and A. A. Mitchell, Safety Culture: A Concept in Chaos? Paper presented at the 46th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, Calif., 2002.

97. Gamst, F. C., The Concept of Organizational and Corporate Culture: An Ethnological View, *Anthropology of Work Review,* Vol. 10, No. 3, 1989, pp. 12–19. Industrial Ethnological Perspectives on the Development and Characteristics of the Study of Organizational Culture, *Cross-Cultural Management and Organizational Culture* (T. Hamada and A. Smith, eds.), College of William and Mary, Studies in Third World Societies, No. 42, 1990, pp. 13–47.
98. Mearns, K., R. Flin, R. Gordon, and M. Fleming, Measuring Safety Climate on Offshore Installations, *Work and Stress,* Vol. 12, 1998, pp. 238–254.
99. Senate Committee on Commerce, The Penn Central and Other Railroads, 92nd Congress, 2nd Session, 1973, p. 342.
100. Perrow, C., *Organizational Analysis: A Sociological View,* Brooks/Cole, Monterey, Calif., 1970, pp. 156–158.
101. Schneider, P. D., Growing Pains for the Biggest Locomotives, *Trains,* August 2001, pp. 20–12, 21.
102. International Atomic Energy Agency, The Chernobyl Accident: Updating of INSAG-1, INSAG-7, 1992, p. 24. See also International Atomic Energy Agency, Safety Culture, Safety Series No. 75-INSAG-4, 1991, p. 4, for a pioneering definition of safety culture.
103. Streeter, K., Railroad Told to Get Back on Track, *Los Angeles Times,* Sept. 17, 2003.
104. FRA, U.S. Secretary of Transportation Slater Submits Railroad Safety Bill, August 2, 1999, www.dot.gov/affairs/1999/fra1899.htm.
105. Of course, policies of leadership and communication can have positive results including for safety Bell, R. J., F. C. Gamst, A. M. Henson, and J. G. Wilson, How Can Management Improve Employee Communications to Improve Employee Performance? *Proc.*, American Association of Railroad Superintendents, 1990, Vol. 94, 1991, pp. 11–13 and 70–74. Gamst, F. C., The Superintendent and Human Communication, *AARS News,* No. 3, 1996, pp. 3–4.
106. Cullen, L. Elements Influencing a Workplace Safety Culture (G. Swartz, ed.), *Safety Culture and Effective Safety Management,* National Safety Council, Chicago, 2000, pp. 41–72, 42.
107. “The traditional form of organization of the New York Central followed the lines of the English railroads and of the departmentalized army organization,” Morris, R., and W. E. Hooper, *Railroad Administration*, 2nd ed., Appleton, New York, 1930, pp. 69–70.
108. Hill, F. G., Roads, Rails, and Waterways: The Army Engineers and Early Transportation, University of Oklahoma Press, Norman, 1957. Wood, R. D., Stephen Harriman Long, 1784–1864: Army Engineer, Explorer, Inventor, Arthur H. Clark, Glendale, Calif.,: 1966. O’Connell, C. F., Jr., The Corps of Engineers and the Rise of Modern Management, 1827–1860, (M. R. Smith, ed.) Military Enterprise and Technological Change, MIT Press, Cambridge, Mass., 1985, pp. 87–116.
109. Army, Great Britain, *General Orders and Regulations for the Army* (Adjutant General’s Office, 1816 [1811]) 455 pp., p. iii.
110. Gould, Jay, [Erie Ry. Co. order establishing craft seniority by division, dated March 15, 1870]; New York Central & Hudson River-Brotherhood of Locomotive Engineers, [untitled labor agreement of seven articles, dated January 26, 1875].
111. Gamst, F. C., “The Development of Railroad Discipline,” Proceedings of the Railway Fuel and Operating Officers Association, 1985 49(1986):85–98, “The Development of Operating Rules,” Proceedings of the Railway Fuel and Operating Officers Association, 1982 46(1983):155–171.
112. “The railway army in America [is] about 600,000 men, commanded by some 5,000 general and division officers”: *Biographical Directory of the Railway Officials of America* (Chicago, 1885), p. iii.

113. Gamst, F. C. *The Hoghead: An Industrial Ethnology of the Locomotive Engineer*, Holt, Rinehart and Winston, New York, 1980.
114. Gourvish, T. R. Mark Huish and the London & North Western Railway: *A Study of Management*. Leicester University Press, Leicester, 1972; London and North-Western Railway, *Rules and Regulations for the Conduct of the Traffic and the Guidance of the Officers and Men in the Service*, London, 1847; Gamst, F. C., 1997, op. cit., pp. 820–825.
115. Gamst, F. C., 1983, op. cit., 1986 op. cit., "The Railroad Apprentice and the 'Rules': Historic Roots and Contemporary Practices," in *Apprenticeship: From Theory to Method and Back Again* Michael W. Coy, ed., pp. 65–86, 258–259, 274–277; State University of New York Press, Albany, New York, 1989; *Highballing with Flimsies: Working Under Train Orders on the Espee's Coast Line,* The Railway History Monograph: Research Journal of American Railways, Vol. 19, 1990, pp. 1–2; whole issue, "Over the Tehachapi on an SP Beet Train," *The Dispatcher's Office,* Vol. 10, No. 1, 2003, pp. 30–36.
116. Josserand, P., *The Rights of Trains*, 5th ed., Simmons–Boardman, New York, 1957, p. 81; Forman, H. W., *Rights of Trains on Single Track*, 1st ed., Railroad Gazette, New York, 1904.
117. Gamst, F. C., 1990, op. cit., p. 15.
118. In most instances, these operational choices of crewmembers cannot be significantly reduced by rewording of rules in a manner much more exacting than in the now quite refined *General Code of Operating Rules*.
119. General Motors Locomotive Group, *Introduction to the SD70MAC*, La Grange, Ill., 1993, p. ii.
120. Gamst, F. C., 1989 op. cit.
121. Marvin H. *Cultural Materialism: The Struggle for a Science of Culture*. Random House, New York, 1979, p. 39.
122. The theme of this and the next paragraph on error is developed in a paper presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C.: Gamst, F. C., "On the Hierarchy of Error in Railroad Operations: Beyond 'Blame It on the Pin Puller.'"
123. Howe, J. A Union Perspective on Behavior-Based Safety (G. Swartz, ed.). *Safety Culture and Effective Safety Management,* National Safety Council, Chicago, 2000, p. 226.
124. Manuele, F. A. *On the Practice of Safety.* Van Nostrand Reinhold, New York, 1997, pp. 62–63.

5. Fatigue and Safety in the Railroad Industry

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5.1. BIOGRAPHY

Göran Kecklund has worked in the field of fatigue, shift work, and safety since the late 1980s. He worked as a doctoral student at the Karolinska Institute, Sweden's foremost medical research institute, and received his doctorate at the Department of Psychology, University of Stockholm. He has continued to work at Karolinska and has a permanent position at the National Institute for Psychosocial Factors and Health (IPM). Kecklund has been responsible for many research projects related to sleep, fatigue, and safety among truck drivers, control room workers (within the power plant industry), construction workers, and train drivers.

Recently, he was responsible for the part of the Swedish TRAIN-project (TRAffic safety and INformation environment for train drivers) that was related to working hours, work situation, and work environment. In the TRAIN project the highly irregular working hours of drivers constituted their single most serious work environment problem, which results in greatly diminished sleep and high fatigue levels. Yet it is possible to minimize the amount of really serious fatigue by adopting ergonomic criterion (related to length of work shift, number of work days in a row, and length of rest between work shifts) when work schedules are planned, and by training drivers in how to handle their schedules.

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5.2 PRESENTATION

In Kecklund's presentation, the main results and recommendations from the TRAIN project were presented, as well as the results from two other recent train driver studies carried out in Finland and in Australia.

Introduction: Why Fatigue Is Important for the Railroad Industry

- Many mega-accidents like the nuclear power plant disasters [Three Mile Island (TMI) and Chernobyl] occurred during the night shift. Sleepiness was an important contributing factor.
- Poor work schedules that caused sleep deprivation and sleepiness were responsible for the *Challenger* accident and the Exxon *Valdez* accident.

Fatigue has been recognized as a major risk factor for accidents in the transportation industry (NTSB, 1999). In aviation, highway, and marine transportation fatigue has been estimated to be responsible for approximately 20% of the accidents (NTSB, 1999). It is likely that fatigue is a common contributing factor in railroad accidents and human errors, although currently it is not possible to determine the incidence of fatigue-related incidents. However, several reports of serious railroad accidents have identified fatigue as an important contributing factor (Lauber and Kayten, 1988).

The major contributing factor to fatigue in the railroad industry is the irregular work hours. The work involves 24-h on-call operations. Unpredictable work hours make planning preparatory rest periods difficult. Fatigue-inducing factors like short rest times between shifts and long work shifts (less than 8 h) frequently occur. However, there are also many fatigue-inducing factors inherent in the work task: boredom, monotony, solitary work, and a high level of automation.

The paper focuses on train drivers. The aim is to present a short summary of previous studies on fatigue and sleep, explain the underlying mechanism, and present the main findings from a recent Swedish study on safety and train driving. The paper ends with a discussion of strategies to combat work-related fatigue and how work scheduling can be improved.

Work Hours, Fatigue, and Accidents

It is well known that night work causes severe fatigue and even dozing off (Åkerstedt, 1995). A classic study on train drivers (Torsvall and Åkerstedt, 1987) showed that physiological sleepiness, as indicated by electrophysiologically recorded microsleep, increased during night driving and reached a peak toward the end of the work period. In some drivers, microsleep was associated with driving errors, like passing a danger signal or missing a speed reduction. Cabon and coworkers (1993) also observed severe electrophysiological sleepiness in a field study of train drivers, particularly during monotonous work periods. Heitmann et al. (1997), made a similar observation during night driving by North American train drivers.

Dawson et al. (1997) showed that subjective sleepiness peaked during the night. In that study performance on a neurobehavioral test (3-min tracking task) was also lower during the night, with the lowest scores between 2 and 3 a.m. A Finnish study (Härmä et al., 2002) showed that night driving was associated with severe sleepiness as indicated by the drivers themselves. However, severe sleepiness also occurred during early morning shifts, but to a lesser extent. The Finnish study showed that an increased length of a shift and short sleep lengths were important determinants of severe sleepiness. Their study also included traffic controllers, who showed more or less the same results as the drivers.

Few studies have focused on the relationship between accidents, near-accidents and errors, and fatigue. In another classic study, Hildebrandt et al. (1974) demonstrated a peak in errors (automatically induced emergency breaking) during the late night hours. In addition, they also observed a peak in the afternoon at around 1400 h. A Japanese study (Kogi and Ohta, 1975) analyzed accidents and near-accidents and their relation to sleepiness. They found that approximately 17% of the incidents were sleepiness-related. These frequently occurred during the night (79%) and when driving along monotonous stretches of the track.

Toward the end of the 1980s, a Dutch study was published on driver error (mainly missed signals) and working hours (van der Flier and Schoonman, 1988). They did not find more errors during the night when the analysis was adjusted for the number of drivers at each shift. However, they observed a small peak during the start of the shifts, and in particular for the morning shift between 0600 and 0800.

Recently, signals passed at danger errors have been analyzed in association with work hours in Great Britain (Gibson, 1999). They did not find a time-of-day pattern, although there are some indications of an increase during the morning (between 8 and 11 a.m.). However, they observed a significant increase in errors 2 to 4 h into a driver's shift and for the first workday after a period with free days. Accident data from the United States, adjusted for hours on duty, also showed a pronounced 2- to 4-h peak (McFadden et al., 1997).

Both the Dutch and the British studies discuss possible reasons for the increase in risk associated with the start of the shift but no clear explanation is offered. The available data does not include any information about the drivers' state in connection with the error. Thus, it is not known whether a driver involved in an accident felt fatigue, stress, or suffered from sleep loss.

It should be pointed out that the peak in connection with the start of the shift does not rule out fatigue as a contributing factor. Studies on car crashes show that a majority of the fatigue or sleep-related accidents occur after only one hour of driving (Stutts et al., 1999).

Considering the difficult work schedules that train drivers are exposed to, severe fatigue may occur not only during the night, but at all times of the day. The work task may also be different during the daytime when traffic intensity is much higher. Thus, the frequency of stop signals and speed reductions can be higher in the daytime, for example. Nonetheless, the question of error, fatigue and "time into shift" needs more studies, preferably experiments where confounding factors, such as workload, prior sleep length, etc., can be controlled.

The effects of work schedules on sleep have also been studied. The main results are that sleep is disrupted and shortened prior to early morning shifts and after night shifts (Foret and Lantin, 1972; Hak and Kampman, 1981; Torsvall, Åkerstedt, and Gillberg, 1981). In particular, older train drivers suffer from disturbed sleep during the daytime as indicated by less deep sleep and more awakenings (Torsvall et al., 1981). Dawson et al. (1997) reported that it was not uncommon for train drivers to skip sleep during the day, or just take a short nap, after a night shift. They also showed that short rest time between shifts was associated with shorter sleep length and disturbed sleep, which resulted in increased sleepiness at work. Similar results have also been shown in other studies (Cabon et al., 1993; Pilcher and Coplen, 2000; Sallinen et al., 2002).

As far as we know, there is only one study that has investigated train handling performance, fatigue and work schedules (Thomas, Raslear, and Kuehn, 1997). This study was carried out in a highly realistic locomotive simulator and compared two work schedules. The work schedules were backward rotating (the start times of the shifts advanced each day), but differed in the amount of off-duty time. The schedule that had a faster backward rotation (4 h earlier compared to 2 h earlier) resulted in less sleep. There was no difference in performance between groups, but both schedules showed accumulating fatigue across work shifts. Also errors, e.g., failure to sound the train horn at grade crossings and other indicators of poor performance (longer response times to audible warning of the alerter and increased fuel use) increased across work shifts.

Sleep Cycle Mechanism

The reason for severe fatigue and disturbed sleep in shift work is that displaced work hours are in conflict with the basic biological principles regulating the timing of rest and activity (Åkerstedt, 1995). The main cause of fatigue in shift work is the circadian rhythm (cyclical changes in physiological processes and functions related to the 24-h cycle.). Alertness and performance shows a distinct time-of-day pattern. It is at its highest in the late afternoon and lowest in the late night, at around 5 a.m. (Folkard, 1990; Monk, 1989). The diurnal (active during the day) variation in fatigue, and most other physiological and biochemical processes, is controlled by a self-sustained circadian rhythm driven by a biological master clock located in the hypothalamus.

Among day workers sleep is normally initiated at the declining phase of the circadian rhythm. Attempts to sleep at a rising phase of the circadian rhythm result in shorter sleep and more awakenings. Thus, the reason for the short sleep after a night shift is that the rising circadian rhythm truncates sleep after 4 or 5 h (Åkerstedt and Gillberg, 1981). The mechanism behind the short sleep before the early morning shift is the need to terminate sleep very early in the morning, however, without being able to advance bedtime (Kecklund et al., 1997). The failure to advance bedtime may be partly social, but the circadian rhythms also make it very difficult to initiate sleep early in the evening.

Another reason for the peak in sleepiness during night shift is the effect of the prior time waking. The night shift usually starts 10 to 16 h after awakening and is therefore preceded by an extended period of waking. This should be compared to the morning shift, which is preceded by only 1 to 2 h of awake time. Many laboratory studies have shown that sleepiness increases as a function of time awake, which is superimposed on the circadian variation (Fröberg et al., 1975; Åkerstedt et al., 1982).

Another determinant of fatigue is sleep deprivation. The impact of sleep loss is well documented. The consequences for performance are increased errors and variability (Dinges, 1992). Thus, attention is reduced and reaction times increase. In real life, sleep loss (more than 5 h) has been shown to increase the risk for car crashes (Connor et al., 2002).

In shift work it is common to have several short sleeps in a row. Sleepiness accumulates each day if sleep length is only 5 h or shorter (Balkin et al., 2000; Dinges et al., 1997). Thus, an accumulating sleep deficit may be an important cause of severe fatigue in train drivers.

The characteristics of the work schedule also play an important role for the level of fatigue in shift work. One of the most important factors is the rest time between shifts. A rest time as short as 8 h causes short sleep (~ 4 h) and severe fatigue (Lowden et al., 1998). Also the timing of the shifts is important. An early start time of the morning shift is associated with short sleep and high levels of fatigue. Furthermore, many studies show that fatigue or sleepiness and accident risk increase with extended duration of the work shift (Hänecke et al., 1998; Rosa, 1995).

The characteristics of the work task may also influence work related fatigue, although the empirical evidence is scarce. However, tasks that are physically inactive demand sustained attention and take place in a monotonous environment are probably more sensitive to sleep loss and night work.

Results from the Swedish TRAIN Project

The purpose of the TRAIN project was to investigate the train driver work situation and use of information, and how this affects driver behavior and railway safety. The project also focused on safety enhancing measures of the train driver system and intended to increase the awareness and understanding of how work related factors such as fatigue, stress and work hours contribute to safety. Preliminary results have been summarized in English in a report from the National Rail Administration (Kecklund and TRAIN project group, 2001).

The project included a number of substudies. The present paper will summarize those studies that were related to fatigue and work hours among train drivers. The first substudy described the work hours. Early morning shifts (start time before 6 a.m.) and night shifts were common and constituted 42% of the shifts. Short rest times (less than 16 hours) between shifts were common and most schedules were backward rotating.

A common pattern was an evening shift preceding an early morning shift. Consequently the rest time was not longer than 8 or 9 h (and sometimes even less). The on-call group had the most difficult schedules since they did not know their work hours in advance (except for their days off). This group also had very compressed work hours, and on some occasions the drivers worked for 12 days in a row.

An attempt was also made to analyze accident reports with respect to the incidence of fatigue. Seventy-nine accidents or near-accidents reports were studied in order to discern whether working hours, fatigue and stress were contributing factors. Since most of the reports contained no, or very limited, information about fatigue and stress it was difficult to draw any conclusions of the latter factors. However, in 4% of the accidents the driver had admitted that fatigue was a contributing factor. If one considers the time of the accident, the work schedule, and the self-reported sleep times, it can be suspected that another 13% of the accidents were fatigue related. Thus, it is estimated that fatigue was involved in 17% of the incidents, although the lack of information on fatigue suggests great caution. Furthermore, the fatigue related incidents were more common in the 1980s, before the automatic train control (ATC) system was fully introduced.

The train drivers' work situation was also analyzed in a survey and a diary study. The response frequency for the survey was 72% and the study involved 46 drivers whose sleep, alertness and fatigue, stress, and workload were reported in a diary and through the use of an actigraph (which measures wrist activity and provides an objective measure of sleep time).

The survey showed that sleep problems were most acute before an early morning shift and after a night shift. Stopovers also reduced the quality of sleep and resulted in more non-refreshing sleep. There was also a tendency that sleep efficiency (as measured with the actigraph) was lower during a stopover than for sleep at home. Nineteen percent of the drivers fulfilled the criteria of suffering from chronic sleep disturbance (e.g., insomnia), which has a high prevalence. Chronic fatigue was also frequently reported and 30% suffered from either chronic insomnia or fatigue. This group constitutes a risk group for work-related errors and accidents, but may also develop stress-related conditions, such as depression or burnout (Ford and Kamerow, 1989).

The sleep length (as measured with the actigraph) was 4.5 h prior to early morning shifts. Thus, they obtained about 65% of their self-reported sleep need in connection with the early morning shift. The drivers rated the sleep prior to the early morning shift as insufficient and non-refreshing.

Severe fatigue while driving occurred mostly on night and morning shifts. The diary study showed that mental fatigue and sleepiness were higher during early morning shifts than during day and evening shifts. The drivers also rated that they had to exert a greater effort in order to do their job during early morning shifts. In general, the level of sleepiness during early morning shifts was as high as during night shifts. This was somewhat unexpected and is probably related to the severe sleep loss associated with the early morning shift.

Another diary study was conducted with the purpose of getting a deeper understanding of the problems associated with an early morning shift (starting before 6 a.m.). Again, the latter study demonstrates that the early morning shift was associated with high subjective sleepiness, in particular during the first half of the work shift. Approximately 90% of the drivers had at least one episode of severe sleepiness during the early morning shift.

Severe sleepiness occurred most frequently for those stretches of track that had the longest interstop segments. These segments probably resulted in more monotony. However, during work shifts that started later in the day (between 6 and 10 a.m.) long interstop segments did not produce severe sleepiness. This suggests that early morning shifts are more vulnerable to monotony. In connection with the early morning shift, about half of the drivers took a nap during the rest break in the middle of the work shift. The nap group showed higher alertness during the second half of the early work shift, although the alertness-enhancing effect disappeared toward the end of the shift.

The survey included a number of questions about the frequency of errors, particularly related to the ATC system and signals passed at danger. Although the number of self-reported mistakes was low, it was possible to divide the drivers' into three groups. One group (87 drivers) reported no errors, and this group was compared with groups that reported 1 to 2 errors (133 drivers) and 3 errors or more (70 drivers). These groups were compared with respect to stress symptoms, sleep disturbances, and fatigue or sleepiness. The high error group showed more sleep disturbances and 28% in this group fulfilled the criteria of chronic insomnia (the number of insomniacs in the no error group was 11%). The high error group also reported more sleepiness, anxiety or depressive symptoms, and stress symptoms during work. Lack of motivation for the job was also more common among the group that made most errors.

Recommendations: Fatigue Countermeasures

The TRAIN study, as well as many other studies on train drivers, identified the highly irregular work hours as the single most serious work environment problem for the train drivers. It should be pointed out that it is virtually impossible to get regular work schedules since the demand for rail transport varies across the 24-h day. It therefore has to be accepted that working hours will always be irregular and somewhat difficult for the train industry. Thus, a total absence of fatigue is perhaps not a realistic goal. However, severe sleepiness (dozing off) and accumulating sleep loss should be minimized.

Another problem with the work schedules is that there is no "one-size-fits-all" solution. Thus, specific conditions within the organization, such as age of the work force, type of work and the drivers' individual preferences, must be considered. However, some general recommendations about work hours are appropriate. These focus mainly on avoiding short rest times between shift, the handling of early morning and night shifts, and avoiding compressed work schedules (too many work shifts in a row). If these factors are neglected severe sleep loss, disturbed sleep and serious fatigue can occur and the risk of fatigue-related accidents increases.

1. Introduce at least 12 h rest between shifts to avoid serious lack of sleep and critical fatigue.
    - If the period of rest between shifts is less than 12 h, the driver will not get sufficient recovery and a risk of accumulating fatigue is obvious. This is particularly true in the case of early morning shifts. The combination of an evening shift followed by an early morning shift the next day should be avoided. If not, many drivers will get a maximum of 4 h of sleep, which naturally gives rise to serious fatigue. For the same

reason the night shift should not be followed by an afternoon or evening shift the same day.

2. Sleep loss and fatigue should be compensated with rest and recuperation and not with economical compensation.
   - Irregularity of work hours is not compatible with the biological need for sleep and rest. From a biological point of view it is not possible to adapt to constantly changing work hours and, as a consequence of this, the need for sleep and fatigue will accumulate across the work period. Thus, it takes about 2 to 3 days to recover after a taxing work period and some vulnerable individuals may not be fully recovered during free days. However, if the working week is being reduced by 3 to 5 h, from today's 38- to 40-h week, it will be easier to create work schedules that do not cause the accumulation of sleep loss and fatigue.
   - The need to reduce working hours is, of course, greatest for the schedules that have the highest number of early morning shifts and night shifts. Thus, in order to keep the salary constant, lighter schedules (involving less taxing shifts) could have more work hours per week. A more tolerable work schedule, with less taxing shifts but more work hours per week, should also suit drivers that have difficulties tolerating night and early mornings shifts and help them to manage their work situation.
3. Avoid compressed work hours.
   - When lack of sleep frequently occurs, it is important that the number of workdays in a row is not too many. If the schedule includes many taxing work shifts (e.g., early morning shifts and night shifts), the limit should be 4 days in a row. Less taxing schedules could include 5 days in a row. Although compressed work schedules (many workdays in succession) provide social advantages, they often cause fatigue, insufficient recovery and accident and error risk.
4. Work more toward forward rotation of schedules.
   - Many studies show that backward rotating schedules are frequent. Many drivers appreciated the social advantages with such schedules. However, such schedules include more periods with short rest time between shifts and will therefore create more problems with fatigue and insufficient sleep.
   - Forward rotating schedules usually avoid the really short rest times between shifts and are easier to tolerate. In fact, results from the TRAIN survey demonstrated that forward rotating schedules were judged as better than the backward rotating schedules, despite some social disadvantages. It should be possible to work out schedules based on a fair compromise between safety, long-term health, and social needs.
5. Educate the drivers in sleep and fatigue management.
   - Even with good schedules, one cannot avoid the fact that the drivers also have a personal responsibility for organizing their sleep and leisure activity. This means that the driver has to give priority to sleep and recuperation for a certain period of their free time, often at the expense of social needs. Education can raise the drivers' understanding of the connection between sleep, fatigue and safety.
   - Another important aspect of the education is to focus on how irregular work hours may cause negative long-term effects on health. The education should also give concrete advice on how to handle irregular work hours and involve key areas such as sleep and fatigue management and stress management.
6. Rehabilitate risk groups.

- The high prevalence of drivers' (30%) that suffered from chronic sleep disturbance (insomnia) or chronic persistent fatigue in the Swedish TRAIN study should be taken seriously from a safety point of view. There is a great risk that many of these drivers will develop stress-related problems, such as burnout syndrome, which is likely to lead to prolonged sick leave. In addition, drivers suffering from other sleep disorders, such as snoring and sleep apnea syndrome, are also at risk and need treatment. The chronic sleep and fatigue problems are naturally also associated with impaired performance and increased risk of making errors.
- The high average age of the train drivers in Sweden suggests that the problems with chronic sleep and fatigue disturbance may increase in the near future. This could constitute a serious problem for the Swedish rail industry and in other countries with an aging work force, since there is already a shortage of drivers. It is important to take preventive measures for the risk groups to ensure that these drivers are able to continue working. The suggested schedule improvements may not however be sufficient for the most seriously affected individuals; they probably need a special rehabilitation program.

7. Use fatigue modeling—a tool for better shift work management.

- The large and unpredictable variability in the demand for rail transport makes construction of work schedules a complex and difficult task. However, recently computer software for fatigue modeling has been developed. This can be a very useful and important tool that could improve work scheduling. The models are based on basic (biological) determinants for fatigue, i.e., the circadian rhythm, time awake and prior sleep length (Åkerstedt and Folkard, 1997).
- In real life conditions, timing and length of shifts, and prior work history may be added to the factors related to the biological limits (Dawson and Fletcher, 2001). The input of a fatigue model is normally the start times and finishing times of the work shifts. The output is fatigue scores, but the three-process model developed by Åkerstedt and Folkard (1997) also predicts sleep length, performance and accident risk.
- Fatigue modeling will probably be an important tool for fatigue and shift work management within a near future. Target groups for fatigue models could be those that construct and plan schedules, such as supervisors, managers and safety inspectors. In the construction of work hours, a fatigue model could evaluate the rosters and sort out those schedules that show too much critical fatigue.
- Other areas where fatigue modeling can be useful are to identify groups that are at high risk for work related fatigue, or to evaluate whether fatigue was a contributing factor to an accident.

Acknowledgment

The Swedish TRAIN study was initiated and financed by the National Rail Administration (Banverket). A final, full length, report in English on the TRAIN project is available as a PDF file. The PDF file ("Final Report on the TRAIN Project: Risks and Proposals for Safety-Enhancing Measures in the Train Driver System) can be ordered from the following e-mail address: lena.kecklund@mtop.nu.

References

Åkerstedt, T. Work Hours, Sleepiness and the Underlying Mechanism. *Journal of Sleep Research*, Vol. 4 (Supplement 2), 1995, pp. 15–22.

Åkerstedt, T., and S. Folkard. The Three-Process Model of Alertness and Its Extension to Performance, Sleep Latency, and Sleep Length. *Chronobiology International*, Vol. 14, No. 2, 1997, pp. 115–123.

Åkerstedt, T., and M. Gillberg. The Circadian Variation of Experimentally Displaced Sleep. *Sleep*, Vol. 4, 1981, pp. 159–169.

Åkerstedt, T., M. Gillberg, and L. Wetterberg. The Circadian Co-Variation of Fatigue and Urinary Melatonin. *Biological Psychiatry*, Vol. 17, 1982, pp. 547–554

Balkin, T., D. Thome, H. Sing, M. Thomas, D. Redmond, N. Wesensten, J. Williams, S. Hall, and G. Belenky. *Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance.* DOT-MC-00-133. Federal Motor Carrier Safety Administration, U.S. Department of Transportation, 2000

Cabon, P., A. Coblentz, R. Mollard, and J. P. Fouillot. Human Vigilance in Railway and Long-Haul Flight Operation. *Ergonomics*, Vol. 36, 1993, pp. 1019–1033.

Connor, J., R. Norton, S. Ameratunga, E. Robinson, I. Civil, R. Dunn, J. Bailey, and R. Jackson. Driver Sleepiness and Risk of Serious Injury to Car Occupants: Population-Based Case Control Study. *British Medical Journal*, Vol. 324, 2002, pp. 1125–1128.

Dawson, D., and A. Fletcher. A Quantitative Model of Work-Related Fatigue: Background and Definitions. *Ergonomics*, Vol. 44, 2001, pp. 144–163.

Dawson, D., G. Roach, K. Reid, and A. Baker. *Australian Railways Shiftwork and Workload Study, Final Report*. Centre for Sleep Research, University of South Australia, Queen Elisabeth Hospital, Woodville, 1997.

Dinges, D. F. Probing the Limits of Functional Capability: The Effects of Sleep Loss on Short-Duration Tasks. In *Sleep, Arousal, and Performance* (R. J. Broughton and R. D. Ogilvie, eds.), Birkhauser, Boston, Mass., pp. 176–188.

Dinges, D. F., F. Pack, K. Williams, K. A. Gillen, J. W. Powell, G. E. Ott, C. Aptowicz, and A. I. Pack. Cumulative Sleepiness, Mood Disturbance, and Psychomotor Vigilance Performance Decrements During a Week of Sleep Restricted to 4-5 Hours Per Night. *Sleep*, Vol. 20, 1997, pp. 267–277.

Ford, D. E., and D. B. Kamerow. Epidemiological Study of Sleep Disturbances and Psychiatric Disorders: an Opportunity for Prevention. *Journal of the American Medical Association*, Vol. 262, 1989, pp. 1479–1484.

Folkard, S. Circadian Performance Rhythms: Some Practical and Theoretical Implications. *Philosophical Transactions of the Royal Society*, London, Vol. 327, 1990, pp. 543–553.

Foret, J., and G. Lantin. The Sleep of Train Drivers: An Example of the Effects of Irregular Work Schedules on Sleep. In *Aspects of Human Efficiency*, *Diurnal Rhythm and Loss of Sleep* (W. P. Colquhoun, ed.), The English Universities Press Ltd., London, 1972, pp. 273–281.

Fröberg, J., C. G. Karlsson, L. Levi, and L. Lidberg. Circadian Variations of Catecholamine Excretion, Shooting Range Performance and Self-Ratings of Fatigue During Sleep Deprivation. *Biological Psychology*, Vol. 2, 1975, pp. 175–188.

Gibson, W. H. *Human Factors Review of Category A SPADs*. Special Topic Report. Safety and Standards Directorate, Railtrack PLC, London, U.K., 1999.

Hak, A., and R. Kampman. Working Irregular Hours: Complaints and State of Fitness of Railway Personnel. In *Night and Shift Work: Biological and Social Aspects* (A. Reinberg, N. Vieux, and P. Andlauer, eds.), Pergamon Press, Oxford, 1981, pp. 229–236.

Heitmann, A., A. Aguirre, U. Trutschel, and M. Moore-Ed. Can Freight Train Drivers Adapt Their Sleep Pattern to a 24-Hour Operation? *Shiftwork International Newsletter*, Vol. 14, 1997, p. 80.

Hildebrandt, G., W. Rohmert, and J. Rutenfranz. 12 and 24 Hour Rhythms in Error Frequency of Locomotive Drivers and the Influence of Tiredness. *International Journal of Chronobiology*, Vol. 2, 1974, pp. 175–180.

Hänecke, K., S. Tiedemann, F. Nachreiner, and H. Grzech-Sukalo. Accident Risk as a Function of Hour at Work and Time of Day as Determined from Accident Data and Exposure Models for the German Working Population. *Scandinavian Journal of Work Environment and Health*, Vol. 24 (Supplement 3), 1998, pp. 43–48.

Härmä, M., M. Sallinen, R. Ranta, P. Mutanen, and K. Müller. The Effect of an Irregular Shift System on Sleepiness at Work in Train Drivers and Railway Traffic Controllers. *Journal of Sleep Research*, Vol. 11, 2002, pp. 141–151.

Kecklund, G., T. Åkerstedt, and A. Lowden. Morning Work: Effects of Early Rising on Sleep and Alertness. *Sleep*, Vol. 20, 1997, pp. 215–223.

Kecklund, L., and The TRAIN Project Group. Risks and Proposals for Safety Enhancing Measures in the Train Driver System. Banverket/National Rail Administration, 2001.

Kogi, K., and T. Ohta. Incidence of Near Accidental Drowsing in Locomotive Driving During a Period of Rotation. *Journal of Human Ergolology*, Vol. 4, 1975, pp. 65–76.

Lauber, J. K., and P. J. Kayten. Sleepiness, Circadian Dysrhythmia, and Fatigue in Transportation System Accidents. *Sleep*, Vol. 11, 1988, pp. 503–512.

Lowden, A., G. Kecklund, J. Axelsson, and T. Åkerstedt. Change from an 8-Hour Shift to a 12-Hour Shift, Attitudes, Sleep, Sleepiness and Performance. *Scandinavian Journal of Work Environment and Health*, Vol. 24 (Supplement 3), 1998, pp. 69–75.

McFadden, E., S. Popkin, D. Tepas, and S. Folkard. Time-of-Day and Hours-on-Duty Effects of Railroad Accidents in the United States. *Shiftwork International Newsletter*, Vol. 14, 1997, p. 47.

Monk, T. H. Circadian Rhythms in Subjective Activation, Mood, and Performance Efficiency. In *Principles and Practice of Sleep Medicine* (T. R. M. H. Kryger and W. C. Dement, eds.), W. B. Saunders Company, 1989, pp. 163–172.

NTSB. *Evaluation of U.S. Department of Transportation: Efforts in the 1990s to Address Operation Fatigue*. Safety Report NTSB/SR-99/01. NTSB, Washington, D.C., 1999.

Pilcher, J. J., and M. K. Coplen. Work/Rest Cycles in Railroad Operations: Effects of Shorter Than 24-H Shift Work Schedules and On-Call Schedules on Sleep. *Ergonomics*, Vol. 43, 2000, pp. 573–588.

Rosa, R. Extended Workshifts and Excessive Fatigue. *Journal of Sleep Research*, Vol. 4 (Supplement 2), 1995, pp. 51–56.

Sallinen, M., M. Härmä, P. Mutanen, S. Pihl, R. Ranta, J. Virkkala, and K. Müller. Sleep in an Irregular Shift System. *Journal of Sleep Research*, Vol. 11, 2002, p. 200.

Stutts, J. C., J. W. Wilkins, and B. V. Vaughn. Why Do People Have Drowsy Driving Crashes? Input from Drivers Who Just Did (202/638-5944). AAA Foundation for Traffic Safety, Washington, D.C., 1999.

Thomas, G. R., T. G. Raslear, and G. I. Kuehn. *The Effects of Work Schedule on Train Handling Performance and Sleep of Locomotive Engineers: A Simulator Study*. Final Report DOT/FRA/ORD-97-09. U.S. Department of Transportation, 1997.

Torsvall, L., and T. Åkerstedt. Sleepiness on the Job: Continuously Measured EEG Changes in Train Drivers. *Electroencephalography and Clinical Neurophysiology,* Vol. 66, 1987, pp. 502–511.

Torsvall, L., T. Åkerstedt, and M. Gillberg. Age, Sleep, and Irregular Work Hours: A Field Study with EEG Recording, Catecholamine Excretion, and Self-Ratings. *Scandinavian Journal of Work Environment and Health*, Vol. 7, 1981, pp. 196–203.

van der Flier, H., and W. Schoonman. Railway Signals Passed at Danger. *Applied Ergonomics*, Vol. 19, 1988, pp. 135–141.

5.3 BREAKOUT GROUP DISCUSSION

Panelists

- Scott Kaye, Office of Safety, Federal Railroad Administration;
- Göran Kecklund, invited speaker from the Karolinska Institute in Stockholm, Sweden;
- Alan Lindsey, Burlington Northern Santa Fe Railway;
- Steve Popkin, Office of Research and Development, FRA; and
- Mark Ricci, Brotherhood of Locomotive Engineers.

Summary

Technical Issues

- Need to know which fatigue countermeasures are valid and effective and under what circumstances.
- Develop a policy regarding hours of work that recognizes individual and operational differences.

Research and Development Issues

- Need measures to assess
  (a) Fatigue and its related performance decrements and
  (b) Validity of existing fatigue monitoring and management tools.
- Need a valid and accepted process for evaluating a fatigue management business case put forward by a railroad to determine when a fatigue countermeasure program supersedes the Hours of Service legislation.

Emerging Issues

- Workforce is aging.
- Introduction of new technologies and automation may lead to increased worker stress and boredom. Therefore, there is a need to explore new methods of mitigating fatigue.
- There are fatigue issues for nonoperating crafts that go beyond those of operating crafts (e.g., interrupted sleep).
- Currently no method or methodology that links or compares physical fatigue and cognitive performance decrement.

How Concerns Arise

- Some participants had no clear answer.
- For train, yard, and engine crews, the nature of their work schedules was intuitively a problem.

- Senior management needs to/must recognize the concerns (from junior staff, employees, labor, bottom line figures, etc.).
- Labor polls its members.
- FRA gets letters from Congress.

Perspectives of Stakeholders

Labor Perspective

- Create a safety net that goes beyond hours of service by empowering of employees.
- Need to examine fatigue issues for nonoperating crafts.

Railroad Management Perspective

- Getting information to employees to help them make better lifestyle choices with regard to sleep.
- T&E scheduling alternatives—get employees to expand use of overlay schedules and take more time off.
- Non-T&E schedules—develop options for shift workers (e.g., dispatchers, mechanical).

Government Perspective

- Help supervisors and managers understand sleep patterns and identify need to improve sleep hygiene.
- Continue SAIC work to validate predictions of fatigue models.
- Develop guidelines for evaluating the efficacy of fatigue management programs and scheduling regimes for minimizing fatigue-related impairment.
- Foster development of better safety net through the exploration of the sensitivity of laws, policy, and equipment design on inducing fatigue and fatigue-related errors.

Opportunities for Collaboration

- Pilot projects.
- Collection of data to validate models.
- Determination of a way to validate measures for use in evaluating fatigue management programs and equipment.

6. Culturing Safety for Railroads

NEVILLE MORAY
University of Surrey

6.1 BIOGRAPHY

Neville Moray received his undergraduate and graduate degrees in psychology from the University of Oxford, where he also completed a pre–clinical medical degree, and is a fellow of the Human Factors and Ergonomics Society and of the Ergonomics Society. He is a certified professional ergonomist. He has taught in universities in the United Kingdom, Canada, the United States, France, and the People's Republic of China. He is Emeritus Professor of Psychology in the Department of Psychology, University of Surrey.

He has served as the U.K. representative on the human factors committee of the NATO Science Committee, and on the National Research Council. He has consulted in areas including nuclear safety, chemical weapons destruction, ship design, transportation ergonomics, and control room enhancement. He is a member of the U.K. Nuclear Safety Advisory Committee. His research interests are in human–machine interaction in complex industrial systems, process control, mental workload, human error and safety, and the human factors of environmental problems. He acted as an expert witness at the public inquiries into the Southall and the Ladbroke Grove train accidents.

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6.2 PRESENTATION

"In a safe culture, people are thinking about safety" (Kirwan and Rea, 2001).

Introduction

This paper focuses on "safety culture" and its role in reducing the probability of accidents. After defining safety culture we shall examine

- What is known about the nature and advantages of strong safety cultures,
- How safety culture can be developed in an organization,
- Problems in maintaining effective safety cultures and in assessing their presence and effectiveness, and
- Whether there are particular problems in building and maintaining safety cultures in the railroad industry.

I shall be using British terminology in most of the paper, so that when I speak of "engineers" I mean people who practice engineering. I shall use the term "drivers" or "train drivers" to refer to those who drive trains.

Current texts on safety science and systems reliability include little discussion of social factors. Even when engineers consider human–machine systems rather than "technological fixes," they seldom acknowledge that cultural factors are fundamental to safety. As social scientists say, the notion of safety is not objective but is "socially constructed;" as Rochlin (1999) points out, a purely engineering approach does not ask whether a risk that exists is accepted or acceptable. All it can do is estimate it.

In contrast, the idea of a "safety case" is now accepted when regulating hazardous industries, and this necessarily includes subjective judgment. The human factors profession increasingly considers social and cultural factors as well as physical and cognitive ergonomics, as can be seen both in the rise of "macroergonomics" and in the increasing discussion of cultural factors, for example, in the quadrennial meetings of the International Ergonomics Association (Moray, 1999, 2000).

When discussing safety cultures, we are concerned with the properties of sociotechnical systems, which can be described at many levels and in complementary languages, as in Figure 6-1.

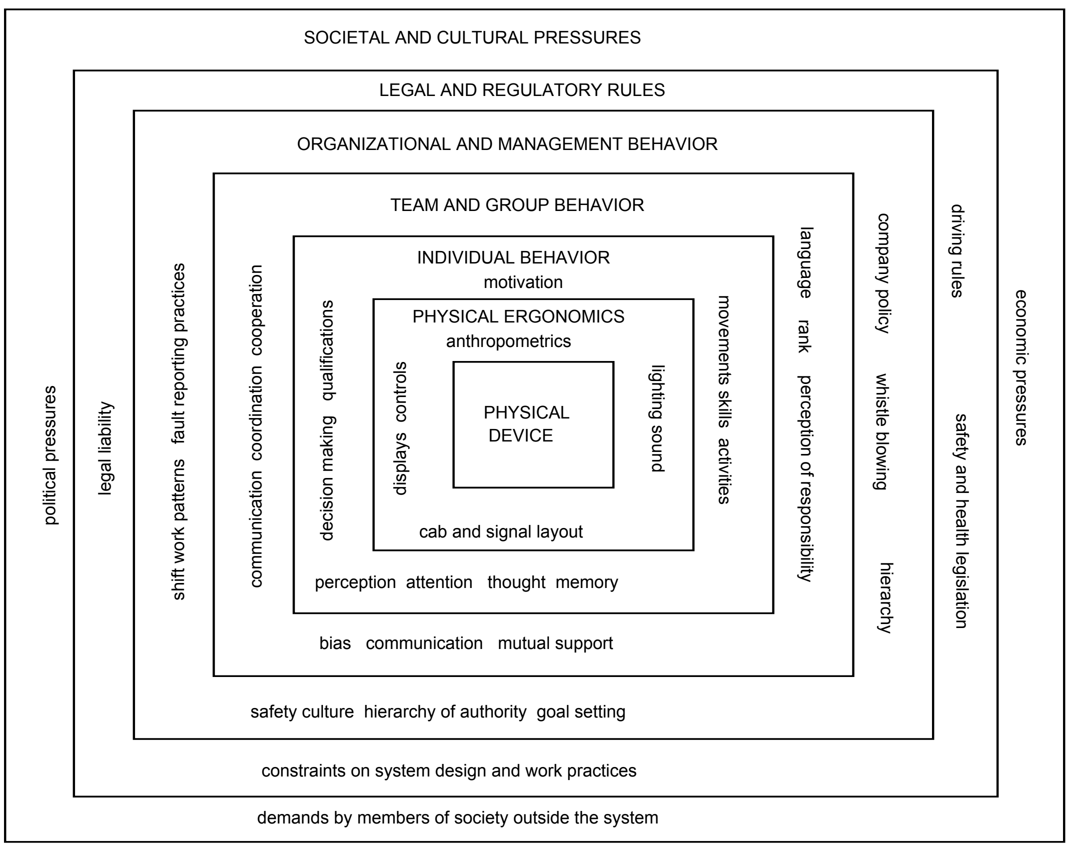

FIGURE 6-1 The general organization of human factors and ergonomics. The terms in upper case define levels of application. The terms in lower case describe typical variables relevant to each level of description.

Definitions

Throughout this paper

- Risk means the probability of an undesirable event;
- Hazard means the magnitude of the (undesirable) consequences of the occurrence of that event;
- An incident is an event that brought a system close to an accident, but from which recovery occurred;
- Error is an undesired human action or judgment performed in trying to reach a well-specified goal, while fault is a failure in a nonhuman part of the system;
- A violation is a deliberate decision by a human not to obey a rule or procedure; and
- A sociotechnical system is defined as any combination of humans and nonhuman equipment having a common goal, together with the properties of all the components and their interrelations.

The notion of safety itself is ambiguous (Cox and Flin, 1998a, 1998b; Pidgeon, 1998). What we think of as appropriate for safety under one circumstance may not look as safe to somebody else or in other contexts.

Many papers offer definitions of safety culture, and despite some variation, there is broad agreement on what is meant. The following are typical definitions:

> The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management. (ACSNI, 1993)

> Shared values (what is important) and beliefs (how things work) that interact with an organization's structures and control systems to produce behavioral norms (the way we do things around here). (Reason, 1998)

Some social scientists distinguish between safety culture and safety climate.

> Climate … reflects perceptions of organizational structures and how it feels to be a member of the organization. Culture involves beliefs about how to behave within an Organizational unit." (Mearns et al., 1998)

Mearns et al. quote others as saying that climate is the "visible practices, procedures and rewarded behaviors that characterize an organization," but that culture is the collection of assumptions, values, etc., that give meaning to what happens." Hofstede (1994), one of the leading researchers into psychological differences due to culture, suggests that culture is a strategic concern of top management, and climate the tactical concern of those lower down. Lee (1998) argues that the term culture is better because it emphasizes that the social dynamics are independent of the people who make up the organization.

For our purposes these distinctions do not seem important and will not be pursued. In this paper, the phrase safety culture will be used to cover everything and taken more or less in the sense suggested by ACSNI. Perhaps not the least important characteristic of a safety culture is that it should outlast changes in top management and the biases of the current chief executive officer (CEO) (Reason, 1998).

Organizational climate or culture includes the way the members of an organization perceive and understand the contingencies between acts and outcomes. This in turn includes how the risk of an action is perceived and felt, the characteristics of an organization that encourage people to obey or violate rules and procedures, and how people relate such behavior to their need for safety, in a very broad context (e.g., job security).

If the notion of safety is seen in a social context, then a given physical situation embodying risk may be perceived as more or less risky at different times even if nothing in the physical situation changes. Risk is both subjective and objective (Kasperson, 1992) while safety is perhaps only subjective. A safe state is one where the current risk is perceived to be acceptably low (Redmill, 1997). Since what is acceptable is socially and politically determined, it cannot be objective, even if a quantitative criterion (such as 1 accident per 10,000 hours operation) is adopted. Indeed Reason (1997) suggests that an organization's goal should not be absolute safety (whatever that may mean). Instead it should be a level of protection that matches the hazards of productive operation and that is acceptable to stakeholders.

Cultural Factors in the Definition of Risk

Cox and Flin (1998b) suggest that the idea of safety culture has been over-sold and "a naïve belief in the concept has far outstripped the evidence for its utility."

That is a fairly radical attack on the notion. What can be said against such a view? If we disagree, what are we claiming? How can safety culture be shown to be an important way to increase safety?

It may be difficult to prove that any factor increases safety significantly (Amalberti, 2000). Given that many modern sociotechnical systems have accident rates with probabilities of the order of one or two per year, a reduction of one or two accidents over a 3- or 5-year period may be chance. Even if a statistical model such as a Poisson distribution can be applied, the uncertainty of any estimate may be large.

Moreover, systems are not stationary, and a change in accident rate may be due to some unknown change in the system, or a change in the demands on it by the environment, rather than the actual manipulation performed by those in control. All the problems of analyzing sequential "quasi-experiments" apply to assessment and evaluation (Cook and Campbell, 1979). There are however, some data that are more than merely suggestive.

Consider Reason's remarks about "organizational accidents." Talking about "defense in depth" in the design of high technology systems, he states:

> All defenses are designed to serve one or more of the following functions:
>
> 1. To create understanding and awareness of the local hazards.
> 2. To give clear guidance on how to operate safely.
> 3. To provide alarms and warnings when danger is imminent.
> 4. To restore the system to a safe state in off-normal situations.
> 5. To interpose safety barriers between hazards and the potential losses.
> 6. To contain and eliminate the hazards should they escape this barrier.

7. To provide the means of escape and rescue should hazard containment fail. (Reason, 1997)

Safety culture is a particular kind of defense against risk and hazard, one that predisposes people to act so as to diminish or compensate for the perceived threats. How would a safety culture have an effect through Reason's functions? Presumably it would act directly on Items 1 and 2, and in so doing predispose operators to use Item 3 to perform Items 4 through 7.

There is no doubt that cultural differences can affect the way in which people respond to the demands of technical systems. Even simple factors like stimulus-response stereotypes, which are by definition cultural, can have an impact. The most obvious example is the direction in which switches are expected to operate. In North America "up" is "on", and down is "off": in European countries the opposite is true: in Japan a switch is "on" when it is to the right and "off" when it is to the left. Obviously if an operator has a piece of "foreign" equipment embedded in an otherwise "native" control panel, there will be a greatly increased probability of error (Moray, 1999).

Cultural effects have also been reported at much higher levels of sociotechnical systems (the outer levels of Figure 6-1). Cultures influence what people learn, and different cultures would, for example, change the emphasis on various norms such as those described by Mitsumi et al. (1999) in Table 6-1. Hofstede (1984, 1994) showed that different cultures seem to generate different "personalities." I have shown that we can expect these to limit the ability of different cultures to implement the suggestions of Rochlin and his co-workers for the construction of highly reliable systems (Moray, 2000; Rochlin, 1999; Rochlin, LaPorte and Roberts, 1987).

Hofstede's work suggests that different (national) cultures will change the extent to which their members stick rigidly to rules, question authority, show initiative and creativity in responding to "beyond design base" events, and so on. In the systems studied by Rochlin, Roberts and LaPorte, "operators' perceptions of potential risk were an essential element in their construction of an environment of safe operations." Consider how differences in Hofstede's three main personality characteristics—perceived distance from authority, individualism versus collectivity, and tolerance of uncertainty—would affect how people respond to the group norms for process control listed in Table 6-1, Norms in Process Control Operation. Hofstede's work suggests there will be large cultural differences in the willingness of people to query instructions or information and to take initiative. See also Moray (2000).

TABLE 6-1 Norms in Process Control Operation

A list of norms that operators may be bearing in mind.
Efficiency norms (good operators know how to maximize efficiency and minimize risk)
Norms about sharing responsibility
Norms about correctness of displayed (electronic) information
Norms about tolerance of departure from rules
Norms about passing information to superiors
Norms of self-presentation (give an outward appearance of competence and self-confidence)
Gender-specific norms (macho) about sharing personal emotional experience

A study by Mason (1997) showed how experience of a work situation changes the perceived riskiness of work. The results are summarized in Table 6-2, Risk Ratings for "All Activities" Performed in Bunkers and Silos. How would such changes influence safety? Kasperson (1992) speaks to the point in a delightful metaphor:

> The experience of risk is … both an experience of physical harm and the result of culture and social processes by which individuals or groups acquire or create interpretations of hazards. These interpretations provide rules of how to select, order, and explain signals from the physical world. Additionally each cultural or social group selects certain risks and adds them to its strand of worry-beads to rub and burnish even as it selects out other risks as not meriting immediate concern.

Risks in this framework are

- The direct threat of harm to people and their environments (that is, the "direct" risk that is dealt with by technical approaches), and
- The indirect risk arising from such things as peer groups, social stigmatization, etc.

Kasperson suggests that attenuation of risk can increase objective risk by eroding risk management resolve or diverting effort to other domains. This may be either at the level of the individual operator, or at the higher levels of management (where people may be unwilling to spend money on safety if an activity is not perceived to be risky).

Does the existence of a safety culture cause significant differences in the probability of accidents when other factors are held constant? If we believe that people's behavior depends on the perceived riskiness of the job being performed, then if the safety culture of an organization (or the subculture of a team, or group) identified a task as low risk when objectively it has really a high risk, we might expect accidents to increase. However, things may not be quite so straightforward. In Mason's study, perhaps the most experienced workers are objectively much more skilled than the neophytes, and hence, when they believe the work situation to be low risk, they are quite right for themselves.

TABLE 6-2 Risk Ratings for "All Activities" Performed in Bunkers and Silos

Job Category	Risk Rating
Inexperienced bunker workers—newcomers to such work	240
Trainers—instructors in methods of working in bunkers	112
Skilled men—welders, blacksmiths, etc., who occasionally apply their trade in bunkers	3.0
Shaftsmen—experienced workers who normally work in shafts but less in bunkers	2.1
Supervisory staff—charged with planning and monitoring work in bunkers	2.0
Experienced bunker workers experienced at conducting a variety of jobs in bunkers	1.9
Area shaft teams—very experienced, regularly work in shafts and bunkers	1.3

After all, experienced mountaineers are probably correct in judging a particular climb as being of lower risk *for them* than it would be for beginners, who would rate it as more risky. The question then becomes not so much whether skilled workers are taking more risks, but whether they are well calibrated with respect to the effect of their expertise on objective risk. Adapting what Carroll (1998) says concerning worries about mistakes, when too many people are worried about risks, does it mean that there is a risky culture, or a worrying culture, or that there are in fact too many risks? Or as Hollnagel has suggested, it may be that people do not take risks, but unintentionally run risks as their skill increases and leads to lower perception of risk.

There is fairly convincing evidence that when equipment, environment, and similar variables are held constant, culture can have a strong influence on safety. Two examples come from civil aviation and medicine. There are about 20 major accidents worldwide every year in civil aviation, and 75% or so are attributed to human factors. But QANTAS (the Australian national carrier) had no fatal accidents between 1951 and 2000 with the same aircraft and the same operating manuals that are used by other national carriers. Again, a study in the United States found that hospitals when matched for types of patients, characteristics of staff, range of illnesses and accidents treated, etc., still show differences in morbidity rates.

The work of Rochlin, LaPorte, Roberts, and their co-workers on high reliability organizations (HROs) is also very suggestive. Whereas Perrow (1984, 1999) argued that complex technological systems were inherently prone to accidents, Rochlin and his colleagues point to systems where a good safety culture resulted in far fewer accidents than one might expect (Rochlin, 1999; Rochlin, LaPorte, and Roberts, 1987). They suggest that the difference is largely due to culture: in some cultures accidents are *not* "normal" in Perrow's sense.

Overall the evidence supports the claim that safety culture makes a substantial difference in reducing accidents. We turn now to consider what the characteristics of a strong safety culture are.

Characteristics of Successful Safety Culture

Several themes recur constantly in the literature on safety culture. They are

1. The need for a strong management commitment to safety,
2. Good communications, and
3. A constant preoccupation with safety (or fear of something bad occurring).

In the research literature there is no exception to the emphasis on the need for the highest levels of management to show unequivocal commitment to safety, and on the need for this to be apparent and believed throughout the organization, if a safety culture is to be created. Management and workers must both inform and trust one another in the search for safety, and there must be belief in both directions about the seriousness of this commitment.

> Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perspectives of the importance of safety, and by confidence in the efficiency of preventative measure. (ACSNI, 1993)

> It is essential to create a corporate atmosphere or culture in which safety is understood to be and accepted as the number one priority. (Cullen, 1990, reported in Mearns et al., 1998)

> Two of the main tenets of safety culture are that (1) the responsibility for safety is devolved to every employee in the organization and (2) the pattern of interaction between employees is critical. (Lee, 1998)

The need for continuous commitment to safety even when things seem to be going well is constantly emphasized.

> The best chance of achieving safety occurs not simply when a special effort is made but when a pervasive safety culture exists in an organization. (Redmill, 1997)

> As indicated earlier, the only attainable goal for safety management is not zero accidents, but to reach that region of the safety space associated with maximum resistance—and then staying there. Simply moving in the direction of greater safety is not difficult. But sustaining the improvements is very hard. (Reason, 1998)

> In a safe culture, people are thinking about safety. (Kirwan and Rea, 1998)

Many case studies and accident investigations bear unequivocal witness to what happens when top management does not give such a lead. For examples see Reason (1990, 1997).

Here are three summaries of safety cultures by authorities from different countries, and based on different industries. They show strong similarities.

According to Reason (1998), a good safety culture has the following characteristics:

1. It is so solid that it can survive changes in leadership.
2. Power is derived from not forgetting to be afraid.
3. Is an informed culture, which means collecting the right kind of information.
4. Is a reporting culture allowing reporting of faults, errors and near misses.
5. Is a just culture—not exactly no blame, but response that promotes trust.
6. Has flexible responses involving shifts from hierarchical to flat forms of organization and back again.
7. Is a learning culture that evolves from past experience.
8. It reduces the gap between the variety in the system and the variety in the human controllers.
9. It favors face-to-face communication.
10. Work groups are made up of divergent people with diverse skills.

First-line supervisors must be site-wise and experienced in the domain, and must gain the respect both of work force and of management—they may need to have a storing hierarchical management initially in order to develop the flexibility (Reason, 1998).

Lee (1998) describes a strong safety culture as having

1. High level of communication between and within levels of the organization, and informal exchanges—managers do walkabouts to observe and apply positive reinforcement; safety is discussed;
2. Good organizational learning, good response to respond to change;
3. A strong focus on safety by the whole organization in all activities;
4. Senior management strongly committed to safety and providing resources and giving a high priority to safety and promoting it personally;
5. Management leadership style that is democratic, cooperative, participative, and humanistic;
6. More and better quality training, not just on safety, but on the safety aspects of all skills;
7. Clean and comfortable working conditions as far as possible, good housekeeping;
8. High job satisfaction, favorable perception of possibilities of promotion, layoff and employee benefits as well as task satisfaction; and
9. Workforce that includes people retained because they work safely and have lower turnover and absenteeism, as distinct from yielding higher productivity.

And a summary of the findings of Rochlin and his group on High Reliability Organizations (HROs) includes the following:

1. HROs consciously try to give service and reliability leading to acceptance by society equal "safety culture."
2. HROs have strong technology and social relationships.
3. HROs have good training and expertise and understand the system state at all times (good communication).
4. HROs emphasize activities that enhance reliability, with easy access by lower grades of personnel to senior levels of management to report problems.
5. HROs learn from detailed records of past accidents and errors.
6. HROs have an organizational style with flexibility and redundancy, and can self-organize to meet new demands.
7. HROs show a sense of collegiality and shared responsibility.
8. HROs permit decision making without a need to refer to a central authority.
9. HROs constantly seek to improve safety and reliability. There are people whose job is to seek and report problems and signs of weakness. Good performance is regarded with suspicion: have standards been lowered?
10. HROs self-reported errors and faults are rewarded, not punished, and used for "lessons learned," which are transmitted to upper levels of management.

Communication is emphasized and is important in two senses. It permits management to make clear its attitude and commitment. It is required so that all people in the work force at all times have at their fingertips the knowledge about the state of the system they are operating, because it is such knowledge that allows them to take appropriate action. We should regard the role of humans in a sociotechnical system not as blindly obeying rules and procedures. If that attitude is adopted, only rule-based behavior is available (Rasmussen, 1986), and rules and procedures are inherently backward looking: they are designed to cope with past incidents in the system's history or foreseen design-based incidents. They are necessary as a basis for operation and training, but they are inherently limited.

Rasmussen (2001) and Rochlin (1999) emphasize the importance of flexible self-organizing adaptive behavior, which provides a means for the system to cope with unforeseen future challenges. To allow, indeed encourage such behavior requires trust in the workforce, and absolutely requires a free flow of information, both straightforward status information and also information about the history of near misses. That in turn requires trust and commitment from management to develop an atmosphere in which people will report their own near misses, and tell stories to one another, which in turn brings us to the need for management commitment. Values arise from trust, which in turn derives from information and communication. As Takano, et al. (2001) observe, companies with good safety records have good safety communications between field workers and management.

Perhaps the single most important attitude on a day-to-day basis is that of constantly questioning and testing the system. Requiring the workforce at all levels in the organization constantly to look for what is wrong and report it, rather than to look for what is right increases safety. Whistle-blowers should be rewarded, not muzzled: indeed in a strong safety culture there will be no such thing as a whistle-blower, but rather an active search for faults and people who are praised for drawing attention to danger. The only way to increase the probability of finding "latent faults" that are lurking in the system (Reason, 1997) and are the precursors of catastrophe is to assume that if things are going well, it is probably because the standards of inspection have fallen - and that implies just as much to auditing the financial state of the company at managerial level as to the monitoring of the state of rails over which trains are running. (Wilpert, 2001; Rasmussen, 2001; Reason, 1997, 1998).

To emphasize these factors, even Cox (Cox and Flin, 1998b) (whose skepticism about safety culture began this section) reported that critical features preceding an accident were

1. Rigid perceptions,
2. "Decoy problems,"
3. Organizational exclusivity,
4. Information difficulties,
5. Violations, and
6. Failure to recognize emergent danger.

Together they produce an unsatisfactory attitude to safety.

It seems appropriate to end this section by reproducing an example of what management is like when it wholeheartedly adopts the attitudes that are required for strong safety culture. Carroll (1998) describes a case where a new manager was appointed to a nuclear utility following a period of disastrous underperformance and intervention by regulators on safety grounds. The vice president implemented a survey of what was wrong in the plant, and sent the following documents to all members of the workforce:

> It is crucial that we are completely honest with ourselves, if we hope to deal with the issues that hinder, or demotivate us from achieving the level of engineering work we all want. My personal commitment to you is to communicate to you the collective results of your input, and my intentions for acting upon them.

A second letter gave the definition of safety culture as it was to be constructed for the future of the plant:

> Safety culture refers to a high value (priority) placed on worker safety and public (nuclear) safety by everyone in every group and at every level of the plant. It also refers to expectations that people will act to preserve and enhance safety, take personal responsibility for safety, and be rewarded consistent with these values. Safety refers to worker safety or industrial safety on the job, and to public or nuclear safety in regard to releases into the environment that pose a risk to the public.

Rules, Procedures, Design, and Accidents

A strong safety culture is one of the defenses that guard a system against the risks and hazards that challenge it. But how is this brought about? What exactly does a strong safety culture *do*?

An obvious way in which we might expect a safety culture to affect personnel is to ensure that they do not violate rules and procedures. [A violation, following Reason (1990) is a deliberate failure to follow a rule or specified procedure.] But there is a strong feeling among all those who have studied error, accidents, and safety culture in recent years that that is incorrect.

Rules and procedures are formulated either on the basis of an analysis of past incidents and accidents, or on the basis of deductions from design specifications. They deal with known or foreseeable challenges to a socio-technical system, and often represent the slamming of the stable door after the horse escapes. The problem is that, particularly in sociotechnical systems with very low fault rates, many, if not most, accidents are unique, and would not recur even if nothing were done.

A safety culture is intended not only to ensure that the correct action will be taken when any such challenge recurs, but even more importantly, it tries to ensure that an appropriate adaptive response will be made to *unforeseen* events and challenges. Such a goal requires creativity, and adaptive and flexible behavior, which may require workers to go beyond given rules and procedures, and may indeed mean that the latter must be violated. I have myself seen a case where to pass a licensing examination a procedure that was seriously faulty had to be performed, and to run the plant correctly from an engineering and physics point of view the procedures would have had to be violated. (I might add that the procedure had been signed off by at least four levels of quality control!)

The accounts given by Rochlin and his group both show examples of how violations arise and how they can be effective in a strong safety culture, and Woods, et al. (1994, p. 188 et seq.) provide a detailed account of several further cases. Moreover there are recurring claims by those who study work in hazardous systems that it is almost *commonplace* that rules and procedures are inadequate. Bourrier (1999), for example, states:

> One of the least controversial results in social science appears to be that prescribed work never matches real work….
>
> [In] conditions under which both compliance and violations develop….the independent variable is the degree to which staff are allowed to participate in the design of a prescribed set of procedures (whether planning or maintenance).

Mearns, Flin, Gordon, and Fleming (1998) in a study of the offshore oil industry, report that

- 57% of workers said they sometimes took short cuts that did not involve significant risk;
- 49% said the conditions of workplace seldom or sometimes stopped them obeying rules;
- 46% seldom or sometimes bent rules to achieve targets,
- 46% said they got jobs done better by ignoring rules, and
- 44% said that rules did not always describe the safest way of working.

It seems that design generates procedures that are insufficient to cope with the reality of the workplace: rules and procedures *cannot* be sufficient for all events, since they are limited by the imaginations of designers.

System design problems are "situated" (as sociologists say); that is, systems are designed with a particular set of assumptions. These include assumptions about the quality and training of the workforce, the environment in which the work will be performed, etc., that is, assumptions about the context of operations. These assumptions may be explicit or implicit, but they are often violated in practice.

One example is where a chemical plant was designed with the intention of building several copies in different locations. It went unnoticed that one location was on a site exposed to sea, wind, and tropical high humidity. The result was a series of corrosion problems that would not have occurred had the plant been constructed in a "normal" setting. Needless to say, no explicit operating procedures were written to cope with corrosion. Other problems arise when a technology is exported to a foreign country, with different education, social and cultural norms of the workforce from those in the country of origin (Hofstede, 1984, 1994; Moray, 2000). Is the United States big enough for there to be significant cultural differences in different geographical areas of recruitment?

Systems in the real world, as distinct from on designers' computers or drawing boards, are "open." They change their properties with time, and evolve into new and unforeseen configurations. This is a normal process. Over the years new equipment is introduced, spare parts become unavailable for old equipment, and "work arounds" have to be introduced, and management policies change and result in unforeseen pressures on equipment and the working environment. Even climatic changes may influence the physics and chemistry of processes in unforeseen ways, and in some cases the processes may include state-of-the-art processes and equipment that are not fully understood by anyone. (For example the rate of embrittlement of components in nuclear power reactors exposed to intense neutron fluxes turned out to be much greater than expected.)

Bearing such problems in mind, what is the role of a safety culture, what should be its aims, and what can reasonably be expected of it?

A Model of Safety Culture

Rasmussen (1986, 2001; Rasmussen, Pederesen, and Goodstein, 1995) has suggested a generic model for work in hazardous settings that is useful to consider. See Figure 6-2, Generic model for working in hazardous settings.

Any system can be described in principle by its state space, that is, the list of variables it contains and their values from moment to moment. This kind of representation is most natural when considering physical engineering systems such as process control plants, but it can be extended in principle to all systems, and to all levels of description of the system including those in the outer layers of Figure 6-2 (Ashby, 1956). Thus at any moment the temperature of a process variable has some value measurable in degrees Celsius, the amount of product being processed has a mass measurable in kilograms, and the bank balance of the company's current account has a value measurable in dollars, and so on. Together these values are a vector that describes a multidimensional space defining the state of the system at the time the measurements were made.

Safe and productive operation requires the system to be held in certain regions of state space (Rasmussen, 1986; Rasmussen et al., 1995). There are certain temperatures that must not be exceeded, certain costs that must not be incurred, and so on. Equally, some regions that could be productive impose too great a workload, or too dangerous work conditions on the workforce.

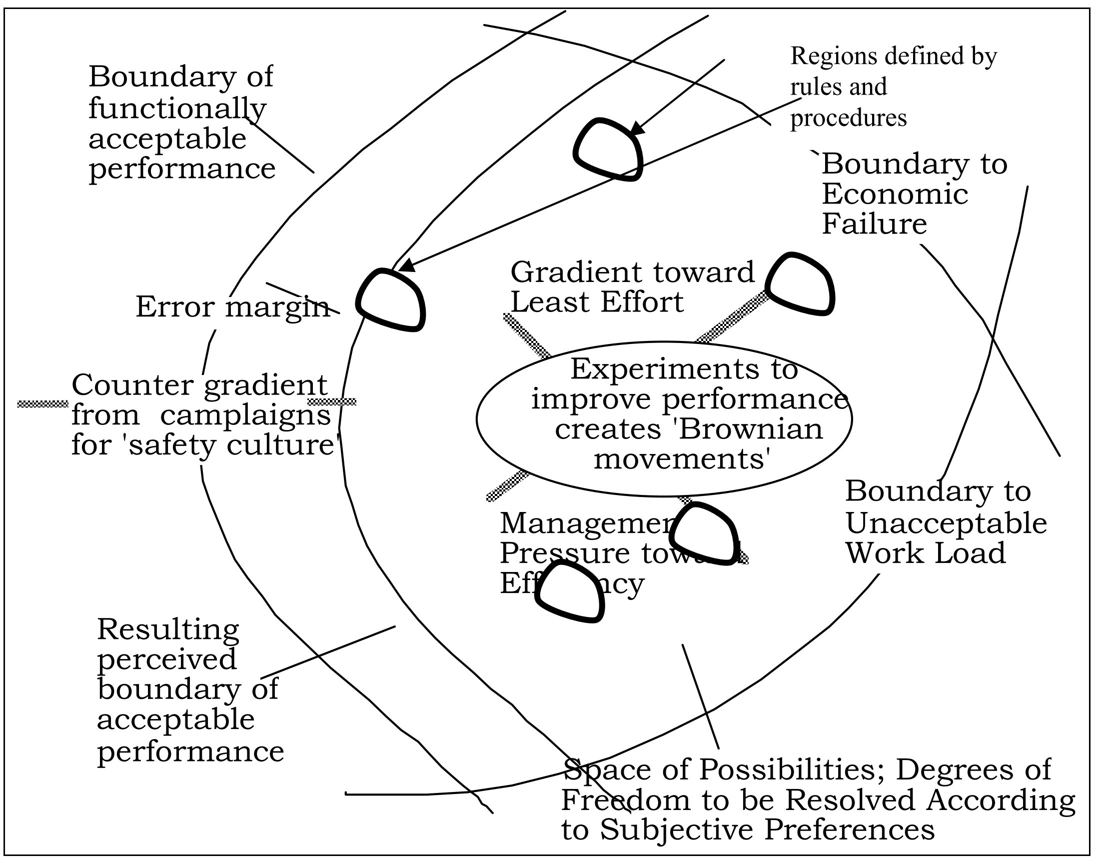

FIGURE 6-2 Generic model for working in hazardous settings.

An analogy between migration toward boundaries to loss of control of human activities under pressure to optimize effectiveness and the Brownian movements of particles in a field subject to strong gradients (after Rasmussen).

The aim of manning levels, training, rules and procedures, managerial policy, etc., is to constrain the system so that undesirable regions of the state space are always avoided. Usually there are substantial regions of state space that have not been considered when designing rules and procedures, but that are nonetheless far from the boundaries that must not be crossed if accidents are to be avoided. Such regions are often not known in detail, or at least not taught to workers. (I am using the word “worker” here to mean anyone who is a member of the system, management, operators, supervisors, maintenance people, support staff—even shareholders or regulators.)

Migration toward accidents is caused by the side effects of decisions by people at all levels. Usually people remain in the work context of their own level, a rather small region of the total state space, and are unaware of the effects of their actions on people at other levels. Those effects are normal but change the value of the state space vector, and the fluctuations caused in other people’s work areas perturb them, and so *their* normal work practices are now pushed into unexpected regions. If someone is close to an undesirable boundary in their state space, the action of someone far distant, working quite normally, may push them over the boundary into accident areas.

The effect of rules and procedures is normally to constrain the state space to certain well-defined values, because it is known that those regions are safe and productive. But the rest of the state space offers many opportunities for workers. Some regions are safer even than those defined by rules and procedures. Equally some are more productive or safer: hence the results reported by Mearns et al. (1998).

It is characteristic of good operators that they tend to explore the state space outside the regions defined by rules and procedures and in so doing build up “unofficial” or “folk” knowledge about how to operate the system. This may be particularly important if the system unexpectedly enters undesirable regions of state space (“a fault develops”), which has potentially catastrophic effects of the system (“an accident is about to occur”). In such a case it may only be possible for workers to construct a path back to a safe region if they have knowledge of regions of the state space other than those prescribed by the rules and procedures.

The “unknown” regions may have many unexpected properties. For example, it may be that in some cases it requires cooperation between several workers to navigate that region of state space. It may be that following a fault, some of the usual equipment is not available for the execution of known rules and procedures, and a new route must be discovered through state space. Violations may be desirable to protect the system. It may be that navigating such a route requires information to be integrated in ways for which no provision has been made in the control room. And so on. A famous case is that where the pilot of a DC-10 lost all hydraulic power when a baggage door came off and cut the lines to the tail, so that ailerons, rudder, flaps, etc., were all inoperative. By using differential thrust on the engines, the crew nonetheless managed almost to land the aircraft safely, and the loss of life was greatly reduced over what could have occurred.

Rasmussen notes that in general there is no harm in workers operating the system in unconventional ways (that is, visiting unknown parts of the state space), provided at all times they know where they are in relation to the boundaries beyond which lie undesirable states. They may even test the boundaries, and provided that there is good feedback, they can recover from short excursions into "forbidden " regions, depending on the time constants of the system in comparison with their actions. Note again that this in principle applies equally to the outer layers of Figure 6-1, The general organization of human factors and ergonomics. The board of directors may wish to explore unconventional financing methods—but they had better have adequate feedback about the effects that this has on the state space of the company as a whole. (An example of where this was not present is the collapse of Baring's bank a few years ago.)

Using Rasmussen's model, we can now see what the adaptable and flexible HRO of Rochlin's group achieves. The permissive social dynamics of the safety culture allow, indeed encourage, the exploration of a much larger region of state space than is defined by the rules and procedures. The system, although based on a knowledge of rules and procedures and on formal training about limits, constraints, and boundaries, becomes self-organizing in a way that provides a much richer and more powerful range of behaviors to cope with a much greater range of problems than that foreseen by designers, trainers, management, etc. Sources of information are sought out and passed between workers. Skills belonging to different people are shared and integrated. The significance of changes in a variable that is measured by one person may become obvious only to someone in a different part of the state space. Information, diagnosis, decision and tactical action can be integrated, and strategic decisions supported. Less and less of the state space is unknown. More and more routes through it are explored. And the system becomes more and more rugged and resistant to challenges, even those that have not been foreseen.

An effective safety culture builds itself into, evolves into, a system that can deal with almost anything. Moreover, being aware of the structure of state space, it knows when dangerous boundaries are being approached and will automatically take extra care to measure, observe, diagnose, and initiate ways to return to more desirable regions. How can we design systems so that they will evolve a safety culture, so that they will learn from small errors, faults, and incidents and become more error tolerant and fault absorbing? What are some of the problems in building and maintaining such a safety culture?

Threats to Good Safety Culture

The Importance of Systems Design

A badly designed system will be vulnerable to challenges even if there is a good safety culture. We have seen that it is vital that workers can identify the state of the system, and that in turn requires adequate sensors and means of collecting and collating information. During systems design, decisions are made about displays, sensors, communication systems, etc. Those decisions will place hard limits on what can be achieved even by the best safety culture.

All systems evolve over time, and this is known to be a potent source of hazards and accidents. See for example Flixboro, King's Cross in Reason (1990) and Woods et al. (1994).

- How can operators, maintenance crews, supervisors, and management become aware and keep aware of slow changes that accrue to the system?
- How can their different viewpoints be integrated?
- Are objectives, intentions, and performance criteria known and communicated effectively among the decision makers and formulated at a level and in a language appropriate to their task?

The notion of "the language of the client" applies: here the client is whomever you are addressing at another level. Messages from management to blue collar workers must be couched in the language of day-to-day operations of the latter and related to their needs and practices. A proposal from the lower levels of the workforce to management needs to be related to the latter's needs and goals, not just to those of the workers.

People in organizations have a limited view of what goes on elsewhere in their organization. Shop floor workers have little understanding of the constraints on management and supervisors; management (unless they have "risen through the ranks") have little real understanding of how operators and maintenance people are actually forced to behave by the system, and seldom if ever see them working. The different languages used at different levels of an organization to discuss problems may have little relevance to one another's views, and the time scales on which they operate may be very different. ("Urgent" to a manager may mean "before the end of the financial year:" to an operator it may mean "within the next 30 s.")

The provision of system state information is essential to good safety culture, and hence efficient communication is fundamental. Decisions taken at the time of systems design, including not just hardware and software design, but manning levels, schedules of work, communications and control hierarchies, etc., can make the development of a safety culture either easy or prohibitively difficult. A very important issue is the support of "corporate learning" and the preservation of corporate knowledge based on past experience.

It is useful to think in terms of "requisite variety" (Ashby, 1956). In dangerous situations people are faced not only with risk but also with uncertainty. In order to control a system there must be as much potential variation in the way that people work as there is uncertainty in the environment and system to be controlled, and rules and procedures effectively limit variety. Operator training must introduce the requisite variety to match the dynamics and complexity of the system. Requisite variety again emphasizes the need for good information about system states.

- Can workers obtain reliable information on the actual state of affairs in a form that is directly comparable to their goals?
- Can the state of affairs be verified with reference to target states without detailed analysis?
- Is the correspondence directly visible?
- Are the boundaries of safe operation visible in a way that will catch their attention during their normal work?
- Is the influence on the boundaries of other members of the system visible (represented) so that people can see what the effects of their actions will be on others? (It is not uncommon for a worker to perform an action that is correct for his or her goal, but which puts the system into a state that is hazardous for others: this will happen if there is not good communication.)

Reason has used the phrase "requisite imagination," which while not as rigorously defined as requisite variety, is a striking notion in how safety culture may feed into accident management: when rules and procedures fail, the workers must have as many new ways to think about the system as there are degrees of freedom in the system being challenged.

Maintaining Vigilance

One of the major problems with good safety culture is, paradoxically, that it can be too successful. Workers in a system that has manifest failings will be on their guard. The more successful a safety culture is, the fewer are the signs that there is any risk or danger, and the greater the tendency for vigilance to decline. It is difficult to know whether the more skilled workers in Mason's research (see Figure 6-2, Generic model for working in hazardous settings) would be less or more likely to detect faults than the less skilled. Certainly the more experienced will know better where faults are likely to develop and what they look like, but will they, after a prolonged period of safe operation, look for them? Reason (1997) emphasizes this problem as an underlying cause of several well-known disasters.

Rochlin and his co-workers have noted that the HROs that they have investigated often have a group of people whose job is specifically to look for developing problems, and that the successful cultures are those whose attitude to a long period of safe operation is to think that their standards may be slipping rather than that they have been successful in maintaining safety (Rochlin, 1999; Rochlin, LaPorte, and Roberts, 1987).

Pidgeon (1998), using the concept of the "normalization of deviance," discusses some mechanisms that may result in a decline in vigilance. Signs that there may be a problem appear, and system behaviors deviating from the norm are treated as a serious sign of danger. The evidence is investigated, but after discussion the deviant behavior of the item is "normalized," accepted as tolerable, so setting a revised working norm. The risk is then judged acceptable according to the new norm.

Such behavior can be related to the account that Reason (1997) gives of the way in which latent faults enter a system. A specific example is the PORV valve at Three Mile Island that had developed a small leak, so that the temperature at its output read somewhat high. The operators, intending to have it fixed at the next planned outage, had adjusted to this fact. The result was that when a high temperature appeared at the output of the valve due to the fact that it had stuck open, it was accepted as "normal:" a decision that helped to cause the accident. Other examples, specifically to do with railways, will be found in Rolt (1998).

It is important to recognize that such normalizing of deviations, or attenuation of risk due to past experience (Kasperson, 1992), is seldom deliberate. As Hollnagel has put it, people often do not *take* risks even when they *run* risks. The problem is how to maintain awareness of risks, and to understand their implication. (There is some evidence from research at Eindhoven to suggest that when people are told that the risk of an event is very low, they interpret that to mean that it will be a long time before it happens: what it really means is that it could happen immediately but will not, over a long period, happen often.)

Normally operators see nothing, and seeing nothing presume that nothing is happening. If nothing is happening and they continue to act the way they have been, nothing will continue to happen. This diagnosis is deceptive and misleading because dynamic inputs can create unstable outcomes (Reason, 1997). Also a series of small challenges can successively erode defense in depth until even a small additional challenge will lead to catastrophic collapse—the straw that breaks the camel's back. Until the final straw it may be extremely difficult to tell that the system is in any way threatened, and the better the technological defenses in depth, the more true this will be. Past success can lead to complacency within the organization, which may produce a widening gap between perceived and actual safety performance (Wahlstom, 2001). It is interesting that Carroll (1998) found in the nuclear industry that some workers said that it was easier to get recognition for fixing problems than for preventing their occurrence: an unpromising reinforcement contingency for safety!

Reason suggests that it is not the repetition of a successful action or policy that that produces stability, but rather constant change. (Indeed in general this is the nature of any successful evolutionary system with enough variety to match the demands of a dynamic environment.) The success of technology and of safety training and safety culture means that there is a very real problem in manning very safe systems. As has been often pointed out, modern sociotechnical systems, whether trains, planes, or nuclear power plants (but not automobiles!) are remarkably safe. Given that there are long periods when there are no signs of danger or abnormalities, can vigilance be maintained?

A lengthy period without a serious accident can lead to the steady erosion of protection as productive demands gain the upper hand. It is easy to forget to fear things that rarely happen. What is required is, to quote the IAEA definition of a safety culture, "a questioning attitude" (Monta, 2001).

Amalberti (2000) has recently published a very thought-provoking paper on the "paradox of almost completely safe systems." He discusses systems with a failure rate of something of the order of 1 in 10^5 or 1 in 10^6 operations. If as a result of an accident a change is made in the system, it may take several years to tell whether the change has been for the better or the worse. Even the occurrence of another accident shortly afterward is not really evidence for anything other than the naturally occurring event of a Poisson process. Unless standards are internalized, the probability of an organization keeping high standards is probably in the end dependent on the number of inspectors visiting the plant. If audits, record keeping, regulatory inspections, etc., are required, the organization will become defensive about the records being exposed to the media and the public, and the organization will become secretive, thus defeating the safety culture.

Problems of Management

Culture evolves from group communication and interaction, not by being imposed, although as we have seen there is an absolute necessity for managerial commitment to safety, which must be visible, communicated, and sustained. In these days of intense commercial competition, can this happen? Pidgeon (1998) summarizes the requirements as follows:

- Senior management must show commitment to safety in both actions and words.
- Management must demonstrate attitudes of shared care and concern for hazards, and solicitude over their impacts upon people distributed through all levels of the organization.
- Management must demonstrate that they support norms and rules that permit flexible working practices to deal with both well and ill defined hazardous conditions, and must put in place ways to reflect on practice (organizational learning) through monitoring, incident analysis and feedback systems (reporting systems).
- Higher levels of management must be extremely careful not to convey a mixed message implying the need to cut costs and pursue profits, thereby shifting emphasis away from safety issues. It goes without saying that unless a company makes sufficient profit, there will be less safety—and probably in the end no profit: but again and again it has been shown that a safe organization is a profitable organization, so there should be no conflict.

Given the political pressures, shareholder expectations, multiple goals, etc., in an organization, it will be hard for managers to commit money to safety, because, given the rarity of accidents and the logical problems identified by Amalberti (2000), shareholders will see little reason to "waste" money on already "safe" systems. Moreover, as we have already seen, there is always a problem of communication: the language of management is not that of shareholders, regulators, or different levels of the workforce. Reason (2002, personal communication) has told me that a successful system that he had helped to implement in British Rail (Reason, 1997), and which provided a dynamic way to assess the safety culture and its effect on the level of safe operation, has been dropped following privatization.

To promote a safety culture, the workforce must trust management. In this respect the notion of the "professional manager," independent of the domain expertise, is deeply flawed and prevents the kind of management interaction with workers that is needed to promote safety. How can a manager whose past experience has been in retailing or the military understand the properties of rails, the mental demands of controlling an engine hauling a mile long freight train, or how fatigue affects driving a train?

There has sprung up in the last 30 years or so what many of us (including Rasmussen, Reason, Moray, Hollnagel, and Woods) believe to be a highly undesirable practice, namely, the appointment of people to top management who have no domain knowledge. Universities teach "management" as a subject largely independent of domain knowledge and skills. Thus because someone has been a good military commander, or has managed a financial organization or retailing operation successfully, he or she is identified as "a good manager" and put in charge of a railway or a nuclear power utility.

Such managers cannot fully understand information coming up from the workforce, nor are they credible as being technologically competent to set rules for the workforce.

- Given a lack of domain expertise, how can they even communicate in language that is meaningful to the workforce or understand what is said to them?
- How can such a person know what is reasonable to expect of a worker?
- How can they understand the pressures or the purposes that lead to violations?
- How can they really understand whether the equipment provided and the working conditions are such that the vigilant monitoring for latent conditions leading to accidents can be performed?
- How can they understand the suggestions that arise from technically expert people low down at the blue-collar level of the organization?

Rasmussen reports that Scandinavian marine safety officials predict more accidents because shipping is now managed by banks, not by shipping experts. They report that the shipping industry tries to influence legislators, ship owners try to influence classification societies, owners and classifiers cooperate and do not inform legislators adequately of current practice, communication from classifiers to designers is inadequate, and communication between designers, ship yards and operators has been inadequate in a time of technological change (Rasmussen, 2001). I believe that another clear case is the recent history of the management of Railtrack plc in the United Kingdom, where various statements by the CEO showed little understanding of the day-to-day life of railways. Similarly in a recently studied nuclear utility workers thought that management were concerned with safety but did not always have the knowledge required to act appropriately (Carroll, 1998).

Management style largely determines whether a successful safety culture can be implemented and maintained. In the very interesting analysis of safety culture on a nuclear powered aircraft carrier (Rochlin, 1999; Rochlin, LaPorte, and Roberts, 1987) one of the most surprising findings is that the moment-to-moment operational demands of tasks such as landing aircraft in bad weather could almost completely subvert the official power hierarchy of the ship. Although nominally the officers on the bridge have absolute authority at all times, in practice the NCOs on deck took control for periods when their expertise was paramount for safety. This could happen because of the particular social dynamics of a warship. As Bourrier puts it in her study of nuclear power plant maintenance, "assessing organizational reliability cannot be separated from the assessment of power relations and group interests" (Bourrier, 1999).

That view is supported strongly by Hofstede's cross-cultural studies, which found that there were three major dimensions on which people within a single organization differed in different countries, namely how distant they felt management was, whether they worked mainly for themselves as an individual or for the collective good, and how much uncertainty they would tolerate. I have pointed out how we may expect attitudes about work, creativity, and management authority in different cultures to be strongly affected by such variables (Moray, 2000). Even within a single country, and within a single industry, we may expect such cultural differences, since apart from differences in the social background and education of different personnel, different groups in an organization (management, supervisors, operators, maintenance) themselves comprise different subcultures.

When studying research literature one should be very clear that results from one country, or from one industry or organization, do *not* necessarily apply to all others. It is *not* true that "psychological laws" are independent of the culture for which they are formulated. Psychological characteristics of individuals and teams are probably at least as determined by their context (what sociologists call "situated") as by what is inside the individual's head. Indeed Pidgeon (1998) questions whether a single safety culture can serve all the different subcultures within a large sociotechnical organization, and Mearns et al. (1998) also emphasize the importance of subcultures.

A classical problem of management of safety culture is that of the attitude to human error and how to avoid a "blaming" culture (Reason, 1997; Woods, et al. 1994; Rochlin, 1999). All those who have conducted research on safety are agreed that the tendency of accident enquiries to explain accidents in terms of the "human error" of some person or persons who can be blamed for the accident is highly undesirable as well as being logically incorrect.

Vigilance can only be maintained if people keep a constant lookout for signs of deterioration in the system, and that must include any errors they themselves make. But if they are blamed for errors, most of which arise because of systemic pressures on individuals rather than deliberate risk taking, they will not report their errors. The alternative is not a completely blame-free system. Where really egregious errors or risk taking behavior occurs it imperils fellow members of the workforce, and that is not tolerated at any level in the organization, including those in the appropriate peer group. Systems such as the Aviation Safety Reporting System (ASRS]) operated by the Federal Aviation Administration for self-reporting of errors are probably needed, although often such systems are resisted by management, because "openness" exposes the organization to media interest and the possibility of litigation. The blaming and litigious nature of society, especially U.S. society, is one of the greatest barriers to good safety culture.

Finally, there is a problem of scale in complex organizations. The time scale of events is very different at the level of management and at the "sharp end" of operations. If it takes months or even years for the management of the organization to respond to warnings from the workforce, the latter will learn that it is not worth making suggestions or reporting hazards. Unless there is response and reward for safe behavior, people will assume that any verbal assent to a safety program is simply window-dressing and will ignore it if it causes any extra effort or pressure on them. Rapid response is needed to make feedback perceived as realistic and rewarding, and attention must also be paid to the way to reward whole groups or teams rather than individuals for their input to safety. (There seems to be little work done on this issue in social psychology.)

Downsizing, Outsourcing, and Subcontracting

Although I know of no research specifically on the topic, I believe that a very real threat to the development and maintenance of an effective safety culture comes from the increasing tendency to use outsourcing and subcontracting for work that used to be done "in house." After a recent rail crash in the United Kingdom, someone in the organization was quoted as saying that they had partly lost the ability to monitor the state of the track because the parent organization was in effect a holding company that contracted out work, and the contractors hired subcontractors, who hired casual labor as their workforce, "and all for profit, not safety."

Every time that another level of subcontracting is put in place, the link between the basic safety culture of the parent organization and that of the workforce is weakened. How can communication, the learning of good practice, tradition stemming from a feeling of pride in the organization, the knowledge that work for safety *matters* to management—how can this be instantaneously passed to an organization that has no real history of relations with the parent organization, and whose loyalty will last only as long as the contract lasts, and is based simply on profit? How can such people know, or care, what is important? How can they understand the state space of the sociotechnical system? If, as Pidgeon (1998) suggests, organizations are defined by what they choose to ignore, subcontracting will lead to a spreading sense of "this is not really our work, so we need pay no attention to it," and the conditions for effective vigilance will be lost.

In the U.K. nuclear industry, the notion of the "intelligent customer" has been developed. Even if subcontracting is allowed, it is the responsibility of the parent company to retain enough expertise to be able to understand the technical (and one hopes the safety cultural) efficiency of the contractor. If there is no one in the parent company who retains enough technical knowledge to understand and monitor the work being performed by subcontractors, then the organization is not permitted to operate. (This, it should be added, arose because of the massive downsizing of the workforce that followed privatization.) But this is a poor substitute for a coherent in-house expertise supported by safety culture.

Related to this is the tendency as organizational learning proceeds to adopt "feed-forward control." It is cheaper and easier to use rules and procedures and to hire a low quality workforce to follow them (Reason, 1997). But the continuing proliferation of rules and regulations, in an attempt to prescribe all work patterns can result in so many rules that they become incomprehensible and have to be degraded in practice, assuming the role of mere "back protectors." "It's not my fault—I followed the procedure" (Lee, 1998; Zubov, 1988). Amalberti (2000) notes that

> For example, the rate of production of new guidance materials and rules in the European Joint Aviation Regulations is significantly increasing while the global aviation safety remains for years on a plateau at 10^{-6} (over 200 new policies/guidance/rules per year). Since nobody knows really what rules/materials are really linked to the final safety level, the system is purely additive, and old rules and guidance material is never cleaned up. No surprise, regulations become inapplicable sometimes, and aviation field players exhibit more and more violations in reaction to this increasing legal pressure.

Moreover, rules and procedures only apply at certain levels of the organization. As Reason (1997) put it,

> The task of a train driver, for example, is to start, run and stop the train according to dictates of the track signaling and time table. How this should be done is clearly prescribed by the company's procedures. But there are no procedures setting out how the senior management team should achieve the company's strategic goals.

Assessment of Safety Cultures

If we insist on the importance of a good safety culture, we must also offer ways to assess the quality of such a culture. This is difficult. Assuming that we are starting from a modern, well-designed sociotechnical system, the fault and accident rate will be low, perhaps very low, in the region of 1 in 10^5 opportunities or lower. If so, how can we be sure that our safety culture will detect the precursors of such events? As already mentioned, Amalberti (2000) has recently published a very provocative paper on this topic, based on his experience of civil aviation.

He noted that currently there are about 20 serious accidents a year worldwide in civil aviation, which is about 1 in 10^6 per flight, and that almost all of them are nowadays due to "human error." He then asked how long it would take, following the implementation of a change in procedures to reduce this accident rate, to be able to tell, statistically, that it had had a beneficial effect. He used a statistical model related to the Theory of Signal Detection that is based on modeling Type 1 and Type 2 errors. Using plausible values for these parameters, he proved that an improvement of 50% in safety would take about 2.25 years to be revealed, while a (much more plausible) improvement of 15% (reduction of 3 accidents a year) would take 32 years! If the improvement only reduces accidents by 1 per year, and note that we are talking of a single improvement in procedures in an industry where accidents are very rare, it will take more than 3 centuries to accumulate the evidence that it has had an effect.

Amalberti further reviews evidence from experiments and field studies on human error, and concludes that

> 1. Subjects produce a more or less constant rate of error, whatever their expertise, except for absolute beginners. The average rate of error observed in various situations hardly ever varies, and stands at one to three errors per hour, according to the situation and the challenges at hand. The number of errors tends to decrease in more demanding situations (increased cognitive control), but at the

> same time the recovery rate also tends to collapse (lack of sufficient resources for on-line control and recovery).
>
> 2. The nature of errors changes with expertise. Routine-based errors increase with expertise, whereas knowledge-based errors decrease.
> 3. This error flow stays under control. Seventy-five to 85% of errors are detected, with a higher detection rate for routine-based errors than knowledge-based ones. Notably, expert subjects tend to disregard an increasing number of errors having no consequences on the work under way (28% of non-recovered errors are considered as inconsequential by expert subjects, whereas this percentage is only 8% in the case of beginners).

Relating his data to Rasmussen's notion of a field of safe activity with dangerous boundaries that we reviewed earlier, he shows that beyond a certain fault probability that he places at about 1 in 10^7, the absence of incidents (small abnormalities or near misses) does not decrease the occurrence of accidents, and may even increase it because of its effect on cognitive control of the system. Speaking of current systems that are about to be replaced by new generation, more automated, safety systems, he concludes,

> 1. It is essential…to fully understand that in this area of operation, system behavior becomes special.
> 2. Such a system must be treated with methods allowing it to remain simultaneously at the edge of safety and at a sufficient performance and competitiveness level to resist market constraints.
> 3. It is also important to recognize that these systems are nearing the end of their life, and should not be placed off-balance by requiring operations to take place within unreachable performance and safety objectives. (Amalberti, 2000)

Amalberti's paper is extremely important. It requires close analysis to determine whether it is correct, and whether it applies to all modern sociotechnical systems. But at least it points to the extreme difficulty in telling whether changes in a system have made any difference once the system is already as safe as, say, modern railroads. As Reason (1997) says, successful protection is indicated by the absence of negative outcomes. But we need to have measures of safety that are continuous, and do not depend on particular incidents, otherwise we fall into the problem of having to rely on failures or near misses to tell us how we are doing—we will be able to tell when things are not good enough, but unable to tell that they are going well. Amalberti's calculations seem to show that the latter may be impossible.

Reason (1997) reviews several proposed methods for assessing the safety "state of health" of a sociotechnical system. He points to several signs that seem to correlate with the "health" of a sociotechnical system.

- Systems with good safety culture, for example, will have a line item in the budget for pursuing safety.
- Generally the workplaces will be clean.
- The workforce will show many of the characteristics of HROs described by Rochlin, such as active hunting for problems, self-reporting of errors, easy and fluent communications up and down the organization, and so on.

But, and this will be a constant problem for management in justifying the safety budget, there may be no reduction in accidents. Even when a plausible system for tracking the state of the safety culture has been put in place, a change in management or a change in the position of the organization in the market place can be enough for the program to be dropped, because it apparently makes no difference.

The problem is not simple.

Are There Particular Problems for Railways?

Are Railways Different?

The above discussion about the nature of safety culture is based on evidence from many different investigations and different organizations. The vast majority of work on safety cultures has been in process control, with some on aviation and a little on medicine. Systems that have been studied are characterized by close coupling (changing one variable rapidly causally influences others due to system kinetics), high dimensionality (many degrees of freedom), obvious hazard (chemical and nuclear processing, flight), social coupling in a local setting (the work is performed by teams at a single site in a geographically circumscribed building or vessel), a diversity of jobs and tasks, and ready access to other people. This is very different from railways, so let us finally consider railways in particular.

As Reason (1997) says, “The task of a train driver, . . . is to start, run and stop the train according to dictates of the track, signaling and time table.”

Gamst, in the papers circulated for this meeting, provides vivid pictures of the tasks of a train driver. But there are, in railways, very different types of technical cores apart from trains—track, track maintenance, train maintenance, signaling, driving, loading and shunting, vandalism control, etc.. All have very different dynamics and social interaction. Do they form a single “culture” and can their social dynamics be integrated in the interests of safety?

An operator in a process control plant has on the control room display panel access to measurements of almost all the relevant state variables. That is not in general true of train drivers. At best their control panel shows them relevant variable to the state of the *train*, but many of the state variables of the railway *system* are not accessible. The state of the track (cracks, obstacles, subsidence) are not shown. The position of other trains is not displayed. There is no indication whether barriers are down at level crossings (grade crossings) or whether ice has blocked points at junctions. Even at the speed of a slow freight train cracks in rails are not visible, and even subsidence in the rail bed may not be visible in time to stop the train, certainly not at night. As the speed of trains rises, we reach a point where the driver can neither take in relevant information from the environment nor, even if the driver does, use it to avoid an accident. At speeds of nearly 200 mph and with trains weighing hundreds of tons, the driver of a TGV is effectively uncoupled from the immediate control of the train.

In the most general sense of safety culture there is no doubt that the concept is applicable to railways. Clarke (1998) describes the effect of poor safety culture in the U.K. railway system in the years following privatization. (Note in what follows that references to the “Hidden Inquiry” meant not an inquiry that was concealed, but one that was conducted by someone called “Hidden.”) Because the relevance to railway safety culture is so direct, I quote it at length.

> Following the Clapham Junction crash the Hidden report noted that the internal labor market had led to a workforce and management that was understaffed and lacking in requisite skills. The Hidden enquiry noted that sloppy work practices were thought by the worker to be not unsafe, and this supervisor agreed. Understaffing was resulting in excessive overtime and staff shortages, and failure to circulate information. Inter-group perceptions were unrealistic and revealed biased views of other groups.

There was form filling, proliferation of minor incidents, and poor management response. Common perceptions of BR permanent way workers included

- Staff perception that their section was "doing well" on safety indicating that local information and feedback on performance was limited.
- Greater emphasis on the physical dangers of track work (e.g. being hit by train) than on careless behavior and unsafe acts.
- Lack of open and honest discussion of safety due to fear of recrimination.
- Safety is managed and controlled by management: safety representatives have a low status and profile.
- Completion of work to deadlines takes priority over safety.
- Safety is largely someone else's problem; do not accept personal responsibility for safety.
- There is a macho attitude about safety.

Recent incidents (since privatization) highlight the difficulties involved in maintaining a 'good safety culture' across the railway network, because of the numerous different companies that operate on it. For example, the derailing of a freight train at Bexley in February 1997 illustrates how responsibility for track conditions falls across three different bodies: Railtrack, the infrastructure controller, and two contractors, South East Maintenance Company Ltd. And Southern Track Renewals."

It is quite astonishing that the opposite of almost every quality that is quoted by Rochlin as needed for a HRO appears in this list.

Clarke's comments refer to permanent way workers, not drivers, station staff, or other members of the railway. As several researchers have noted, there may be subcultures in a complex organization, and these may become at least partly uncoupled from the point of view of safety. This is very likely in the current state of the U.K. railways, because the way in which privatization was carried out could almost have been designed to minimize cooperation for safety. The permanent way and associated infrastructure was sold to one company, at that time called Railtrack. The construction of trains is the responsibility of another company from which trains are leased or purchased by train operators. And there are several dozen train operating companies who actually run trains, more or less in competition, over the Railtrack tracks and signaling system, paying for the right to do so. In most cases the companies that bid for the franchises to operate trains were run by people with no prior experience of railways. (After all, you don't need to understand the details, do you? Management is management is management. One is reminded of the various people, both in the United States and Russia, who were quoted in the nuclear power industry as saying that there was nothing special about nuclear power plants—they are just another way of boiling water.)

U.K. privatization was planned by civil servants and explicitly modeled on the (rather successful) privatization of electricity, again as if there were no difference between industries, so that all the subcultures (the different companies) were put into competition with one another. This provokes a desire to shuffle blame and responsibility onto another company for anything that is costly. The "blame culture" now operates at the outer levels of Figure 6-1 in addition to the traditional inner levels. At public enquiries into accidents the lawyers for Railtrack make much effort, train operators, and labor to prove that whatever happened was the fault of one of the others, and it is greatly to the credit of the chairmen of such enquiries that the truth almost always emerges clearly in the end. In recent cases there has been increasing demands by the chairmen that the human factors of safety be taken seriously by all concerned. (See, for example, the Cullen report on the Ladbroke Grove accident, HMSO, 2001.)

An example of the kind of problem that arises and that militates against safety was quoted to me by a rail operator 3 years ago. One of the staff of a station observed that a fire had broken out in the grass beside the track a few meters beyond the end of the platform near a station, and the person went off to try to extinguish it with a fire extinguisher. He was called back by the stationmaster who said that the location of the fire meant that it was not his responsibility, but that of a different company, and he was therefore not to do anything about it!

Such examples show a clear need for the development of an integrated safety culture. But I would like to raise the question as to whether even in a railway company where the infrastructure, trains, support staff, etc., are all operated as a single system safety culture will function as we have seen it described in the classical research. The problem is that the way in which railways work may make the social dynamics of a safety culture difficult to implement.

On a warship, in a process control plant, or in the cockpit of an aircraft, operators (in the widest sense) are close, physically and psychologically, to others who can provide support and pressure to behave safely. In the case of the aircraft they are coupled to others through the air traffic control system. But in railways interaction is often very loosely coupled. In Europe a train driver is probably never more than 20 miles from a station, and the intervals between signals is on the average not more than a few minutes, and on many routes only a few seconds. In the United States with its vast distances and much single track line, a driver may have little or no contact or support except by radio for very long periods. It is not easy to see how a really intense and lively feeling of mutual support can be made to exist between drivers and track-laying gangs spread over hundreds of miles and on journeys of many hours, often at comparatively low speeds, when there is little or no anticipation of threatening incidents. After all, *railways are safe.*

Furthermore, because of the nature of train driving, there is a problem in thinking in the terms of "innovative adaptive behavior" that characterizes the HROs studied by Rochlin, Woods and others. One of the things that strikes one most forcibly on one's first ride in the cab of an engine is how little there is that the driver can do. The driver can start, accelerate, slow, and stop. But unlike car driving or even aviation, the driver cannot steer, there is no alternate route the driver can take, and there is a striking impression of being at the mercy of other people's decisions. Are the points switched correctly? Is that train coming in the opposite direction actually on the adjacent track rather than on his? Have the signals been set correctly? One has a striking feeling of how dependent the driver is on the behavior of other people, in particular those responsible for signaling, switching the points, and scheduling other trains.

But at the same time the driver cannot immediately consult others about the state of the system, it takes many seconds to halt a train, and the driver's actions do not affect the other members of the organization in a tightly coupled way. Interaction is rather unidirectional, compared with the close interplay among members of a warship's crew or people in a process control room.

This may be felt to be a rather naive response, rather like the surprise one has when first seeing air traffic control radar and noticing two echoes intersect, which the controller knows to be at different altitudes. But nonetheless, it does seem that the opportunities for inventive adaptation are much less in train driving than in process control, or in the operations on an aircraft carrier. The same goes for permanent way maintenance gangs. Indeed one is struck by how very different railways are from most systems that have been studied in the context of safety culture, despite Clarke's (1998) findings. It is at least possible that the reason that safety culture was so weak in the system he investigated is that it was particularly difficult to implement it in railways.

Reading Gamst's description of the tasks of a long-haul freight train engineer in the United States, one is struck by how very different his or her world is from those in which safety culture has traditionally been studied. In process control or even on an aircraft carrier there are long periods when there is no obvious threat to the worker. The traditional description is "long hours of boredom interrupted by moments of panic."

But driving a train is very different. There is clearly a sense of constant demand and even imminent peril from the dynamics of the train and its interaction with the challenges of the environment, grades, curves, etc. And the driver is effectively alone, with no backup group for support, since even the conductor cannot provide the kind of support found in the other industries that have been studied. On the one hand, the real-time demands on the driver are likely to provoke a high level of alertness, until that is eroded by long hours of uneventful operation. But on the other hand, the coupling of the driver to the rest of the organization is not like other industries, where the development of an esprit de corps can by supported by social interaction in real time. The safety culture needs to ensure that the entire organization, however loosely coupled and remote in time and space, see itself as united in a single pursuit of excellence. I have to say that the reports provided by Gamst of the railroad system, from federal authorities all the way down to subcontractors' casual labor, do not leave me feeling this will be easy on the railroads.

There will be more problems with the introduction of high-speed trains. The TGV (*Train à Grande Vitesse)* between Paris and London runs at just under 200 mph between Lille and the French coast, even faster than the Shinkansen trains in Japan. The Japanese have experimented with magnetic levitation and are considering (or at least were on my last visit to Japan) building maglev trains to run at 300 mph. Even at the speed of the TGV there is really nothing that one can expect of the driver. Achieving such speeds is an admission that technological solutions have been accepted for the transportation system. At that point the role of the safety culture clearly has little to do with driving. It must concentrate on the systems design, and maintenance of train and track, protection from incursion by vandals, and so on. Both the French and the Japanese run their fast trains on dedicated track, so that some of the accidents such as that at Southall which I will describe below cannot happen, nor can the actions of automobile drivers produce grade-crossing accidents.

What is the Aim of the NTSB?

Let me raise the question another way: what does NTSB think is important? Table 6-3 shows a list of the "most wanted improvements" from the NTSB 1999 report (the last one available on the web at the time I started to prepare this paper.) The bold entries are those most directly aimed at railway safety.

If these are the most wanted improvements, will the development of a safety culture for the railways in the United States deliver them? No, obviously not. The only one that is not a "technological fix" is the item about fatigue, and even there the aim is to add more regulation and procedures. Why is the development of strong safety culture not on the list? Because the program is aimed at technological fixes rather than to the development of HROs. It is an engineer's document, not a safety systems' document.

Some More Accidents

I would like to give a few more examples of accidents with a view to stimulating discussion of how a safety culture or the development of an HRO for railways (to give it another name) should be developed. Bear in mind that Rasmussen and Reason both emphasize that one should not concentrate on past accidents in trying to redesign systems but look for ways in which an improved safety culture can develop generic error avoidance strategies through a safety culture.

The Southall Crash This accident occurred about 4 years ago in the United Kingdom and is a classical "human factors" accident in the broadest sense. On the day before the accident a train was driven down from London. At that time the driver reported that the automatic warning system (AWS) that sounds a horn 200 m from a red light was not working. The train was put into maintenance overnight, but no fault could be found in the system, and on the next morning the train was given to a driver to drive back to London, with the AWS still inoperative and the ATP system disabled because the driver was not familiar with its function. The train was an express that ran at up to 125 mph. A second driver was put into the cab to assist on the first part of the route (which the driver knew well). However, as the driver approached London at high speed, and alone

TABLE 6-3 Most Desired Improvements: NTSB 1999

Automatic information recording devices: Require adequate recording devices on all types of vehicles, such as flight data recorders on aircraft and voyage event recorders on ships.
Positive train separation: Mandate the installation of automated systems to stop trains when crewmembers make signal or speed mistakes or are incapacitated.
Human fatigue in transportation operations: Translate the latest human fatigue research into meaningful time and duty hour regulations for workers in all modes of transportation.
Child and youth safety in transportation
Airport runway incursions
Excavation damage prevention to underground facilities
Recreational boating safety
Airframe structural icing
Explosive mixtures in fuel tanks on transport-category aircraft

Bold emphasizes those most directly aimed at railway safety.

in the cab, the driver ran a red light while putting papers away in a briefcase and hit a freight train.

Several people were killed. The light in question was only visible for about 6 s and was slightly misaligned. The driver should not have taken his eyes off the track to put away papers, but consider. Never before had the driver driven a train in which the AWS was not operational, so the driver expected there to be an audible warning if there were a red light ahead. It was asserted by the Railtrack representative at the enquiry that drivers did not depend on the AWS to attract their attention to signals, that they knew where they were at all times on the route, and that therefore the driver was at fault. (Note that the fact that a freight train was crossing the track was due to the control of the signals by Railtrack, since signaling is regarded as part of the infrastructure. Normally no freight train was scheduled to cross the track of the express at that time.)

Subsequent work by my colleague, John Groeger, has shown using eye movement recording that in fact up to 30% of occasions drivers hear the horn before looking in the direction of the signal light, at least on some routes. The absence of the horn meant that the deep-rooted expectations of the driver, acquired as part of his expertise, were violated. A Markov model showed that it was highly likely that at least on a small proportion of occasions drivers, in carrying out their duties correctly, will not look at the signals for more than 6 s, so that the AWS is essential to attract their attention. It was inevitable that sooner or later the driver would run a red light even if fully alert. Note also that the assertion that drivers do not relay on the AWS to attract their attention was made, strongly, on the basis of no evidence whatsoever.

Now, apart from the obvious questions about integration between the signaling system, scheduling of exceptional freight trains, and the express train schedules, there are four other points of interest:

- First, the driver apparently did not feel that the driver could refuse to drive a defective train.
- Second, the train operating company did not feel able to take the time to replace the engine. (There was tremendous pressure to run to time, because there had been widespread publicity about the appalling record of failure to keep to time in the U.K. railways.)
- Third, the people in the signaling control room did not notice the express run the red signal in time to communicate with the driver of either train.
- Fourth, I was asked, when cross-examined as an expert witness, whether I thought that either stopping the train when a fault developed, or running it more slowly to ensure a safe journey, would not in itself generate risk, because a train behaving abnormally would cause problems for other trains, time-tabling conflicts, extra workload on the signalers, etc. This last point brings up the question of the subjective perception of risk and the problems of integration over a widely dispersed, and in this case fragmented, system.

As we have seen, the notion of safety is ambiguous (Pidgeon, 1998). What one person thinks appropriate for safety under one circumstance may not look safe to somebody else viewed from their different context. Safety culture by enhancing mutual communication and support should reduce these kinds of conflicts.

The history of the railways is a history of steady evolution of safety, driven often by astonishingly subtle and sophisticated accident investigation. A wonderful source of reports about historical accidents in the United Kingdom is the classic book by T.V. Rolt (1998) *Red For Danger*. While we may feel that in many cases the modernization of railways, with increasingly sophisticated electronic signaling, communication, and automatic protection devices may mean that many of the accidents could no longer happen, it is still very thought-provoking to look through the accounts of accidents from an earlier age and to try to map the findings to more modern systems.

I strongly recommend the book to anyone who does not know it. Again and again it makes one question whether failures of attention and memory, slips and mistakes in the interpretation of information and choices of action could have been reduced even if there were a strong safety culture, because personnel are so *dispersed* in the railways. There is so little opportunity for mutual support and intercommunication in real time. The personnel in railways are very diverse, dispersed, and loosely coupled compared with other industries.

Rochlin and his co-workers have described how at times of heavy workload or critical incidents, HROs self-organize themselves to cope. People who are present but not directly on shift may move about the room so as to provide extra help if needed. In warships the chain of command may reorganize itself so that even noncommissioned officers become the critical decision takers because of their immediately applicable skills, while more senior officers take back command once the crisis has passed. But all this seems very unlike the distribution of personnel and authority in railroads.

Level (Grade) Crossings There is a long history of accidents where vehicles crossing a rail line are struck by trains, and the NTSB report notes that this is one of the major remaining sources of accidents on the railways. Can this class of problem be addressed by the railway safety culture? Probably not. In the end, whether a vehicle is on the track at the time that a train arrives is due to the road vehicle driver, not the train. In countries where barriers cover only half the road, rather than blocking the full road, drivers not infrequently drive around the end of the half barriers rather than wait for the train to pass. Where trains are very long, there is clearly pressure on a driver to cut across rather than wait.

Although grade crossing accidents seem to remain as a major source of accidents in the United States, this seems to be a case where the safety culture must involve the population of road users rather than train crew. (We may note that safety culture can sweep rapidly through the general public at times. A few years ago there was an extraordinarily rapid change in the propensity for drinking and driving in Toronto. Suddenly, over Christmas and the New Year, everyone decided that one member of each party should be the driver and should not drink alcohol, and restaurants gave people badges on arrival so the waiters and waitresses would not serve alcohol to the designated person wearing the badge. The reason for this sudden switch in behavior was quite unclear but was very striking. We need to understand how to bring about such changes in those outside the sociotechnical system, who interact with it on occasion.) Despite the cost, probably the only way to reduce such accidents is by the physical structure of the crossings.

So Where Should We Intervene? The place where a safety culture seems to me to be most likely to have a strong effect is at the interface between infrastructure, management, and train operation and between maintenance and operations. Consider two more examples of where this recently failed in the United Kingdom. The Hatfield crash was caused by rails cracking on tight curves due to heavier and faster trains running more frequently on them than had been foreseen ("gauge cracking"). It became evident that the scheduling of inspection and the quality of inspection were both gravely defective.

Even given the disastrous fragmentation of authority due to the style of privatization, would not a better overall safety culture have meant that the train operators would have notified the track maintenance company of the characteristics of the trains, and would not this have lead to more inspection? Well, probably not, given the outsourcing of maintenance by Railtrack through subcontractors and the fact that its most senior executive was not a railway person and so would not have understood the urgency of any information passed to his company. Certainly the subcontracting seems to have been a very serious issue, and also very defective inspection resulting from downsizing.

One cannot help feeling that there was no feeling of responsibility for what happened to the trains, only for fulfilling a paper commitment to what inspection and maintenance work had to be done under contract. The two parts of the system, on the one hand inspection and maintenance and on the other train operation, were simply not seen or felt to be part of a single mutual endeavor.

In a more recent case, someone who was either a rail inspector or an engine driver was traveling as a passenger, noticed that the line on which the passenger was traveling to London was unusually rough, and actually notified the railway maintenance people of the fact that in his opinion there might be a broken rail. Unfortunately, although someone was sent to inspect the track, they inspected the down line, not the up line, and a few days later a train was derailed. Again one feels that there simply was not a sense of urgency and dedicated responsibility in the organization. There was not a system of mutual support that allowed the combination of the intelligence and expertise of people in different branches of the system to unite in solving the safety problem.

Conclusion

Perhaps the overall message I want to leave with you is that there is no doubt whatsoever that it should be possible to improve safety *and* performance by developing strong safety culture in the railways: the two go together. But it is not be any means clear exactly where to tackle the problem.

Let me close with a quotation from Monta (2001):

> Safety culture makes it possible for the intelligence of each person to be used for the achievement of the competing goals of safety and economic competitiveness while ensuring that the people concerned understand the observance of orders coming from the top of the organization. At the same time, safety management that contains monitoring functions in all of the organizational levels will become increasingly important as the level of responsibility transferred increases.

References

ACSNI , 1993. Advisory Committee on the Safety of Nuclear Installations, Study Group on Human Factors. Third Report: Organizing for Safety. HMSO, London.

Amalberti, R. The Paradoxes of Almost Totally Safe Transportation Systems. *Safety Science*, 2000, pp. 1–18 (volume number unavailable).

Ashby, W. R., *An Introduction to Cybernetics*. Chapman and Hall, London, 1956.

Bourrier, M. Constructing Organizational Reliability: The Problem of Embeddedness and Duality. In *Nuclear Safety: A Human Factors Perspective* (J. Misumi, B. Wilpert, and R. Miller, eds.), 1999, pp. 25–48.

Carroll, J. S. Safety Culture as an Ongoing Process: Culture Surveys as Opportunities for Enquiry and Change. *Work and Stress,* Vol. 12, No. 3, 1998, pp. 272–284.

Cheyne, A., et al. Modeling the Safety Climate of a Manufacturing Company. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 254–271.

Clarke, S. Safety Culture on the U.K. Railway Network. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 285–292.

Cooke, T. D., and D. J. Campbell. *Quasi-Experimentation: Design and Analysis Issues for Field Settings*. Houghton Mifflin, Boston, Massachusetts, 1979.

Cox, S., and R. Flin. Editorial. *Work and Stress*, Vol. 12, No. 3, 1998a, pp. 187–188.

Cox, S., and R. Flin. Safety Culture: Philosopher's Stone or Man of Straw? *Work and Stress*, Vol. 12, No. 3, 1998b, pp. 189–201.

Redmill, F., and J. Rajan (eds.) *Human Factors in Safety-Critical Systems*. Butterworth-Heinemann, Oxford, 1997.

Helmreich, R. L. Anatomy of a System Accident: Avianca Flight 052. *International Journal of Aviation Psychology*, Vol. 4, 1994, pp. 265–284.

Hofstede, G. *Culture's Consequences*. Sage Publications, Newbury Park, Calif., 1984.

Hofstede, G. *Cultures and Organizations*. HarperCollins, London, 1994.

Ignatov, M. Implicit Social Norms in Reactor Control Rooms. In *Nuclear Safety: A Human Factors Perspective* (J. Misumi, B. Wilpert, and R. Miller, eds.), 1999, pp. 77–83.

Kasperson, R. E. The Social Amplification of Risk. In *Social Theories of Risk* (S. Krinsky and D. Golding, eds.), Praeger, Westport, Conn., 1992, pp. 153–178.

Kirwan, B., and K. Rea. A Review of Six Human Reliability Assessment Issues for the U.K. Nuclear Power and Reprocessing Industries In *Safety Culture in Nuclear Power Operations*, (B. Wilpert and N. Itoigawa, eds.), Taylor and Francis, London, 2001, pp. 61–73.

Lee, T. Assessment of Safety Culture at a Nuclear Reprocessing Plant. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 217–237.

Mason, S. 1997. Procedural Violations—Causes, Costs and Cures. In *Human Factors in Safety-Critical Systems* (F. Redmill, and J. Rajan, eds.), Butterworth-Heinemann, Oxford, 1997.

Mearns, K., R. Flin, R. Gordon, and M. Fleming. Measuring Safety Climate on Offshore Installations. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 238–254.

Monta, K. The Significance of Safety Culture for Nuclear Power Operations. In *Safety Culture in Nuclear Power Operations* (B. Wilpert and N. Itoigawa, eds.), Taylor and Francis, London, 2001, pp. 79–92.

Moray, N. Advanced Displays, Cultural Stereotypes and Organizational Characteristics of a Control Room. In *Nuclear Safety: A Human Factors Perspective* (J. Misumi, B. Wilpert, and R. Miller, eds.), 1999, pp. 97–112.

Moray, N. Culture, Politics and Ergonomics. *Ergonomics*, Vol. 43, No. 7, 2000, pp. 858–868.

Perrow, C. *Normal Accidents*. Basic Books, New York, 1984.

Pidgeon, N. Safety Culture: Key Theoretical Issues. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 203–216.

Rasmussen, J. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*, North-Holland, Amsterdam, 1986.

Rasmussen, J. Nuclear Power and Societal Problems in Risk Management. In *Safety Culture in Nuclear Power Operations* (B. Wilpert and N. Itoigawa, eds.) Taylor and Francis, London, 2001, pp. 19–35.

Rasmussen, J., A.-M. Pederesen, and L. Goodstein. *Cognitive Engineering: Concepts and Applications*, Wiley, New York, 1995.

Reason, J. *Human Error*. Cambridge University Press, 1990.

Reason, J. *Managing the Risks of Organizational Accidents*. Ashgate, Aldershot, 1997.

Reason, J. Achieving a Safe Culture: Theory and Practice. *Work and Stress*, Vol. 12, No. 3, 1998, pp. 293–305.

Redmill, F. Introducing Safety-Critical Systems. In *Human Factors in Safety-Critical Systems* (F. Redmill and J. Rajan, eds.), Butterworth-Heinemann, Oxford, 1997, pp. 3–36.
Rochlin, E., T. LaPorte, and K. Roberts. The Self-Designing High Reliability Organization: Aircraft Flight Operation at Sea. *Naval War College Review*, Autumn 1987, pp. 76–91.
Rochlin, G. I. The Social Construction of Safety. In *Nuclear Safety: A Human Factors Perspective* (J. Misumi, B. Wilpert, and R. Miller, eds.), 1999, pp. 5–23.
Rolt, T. C. *Red for Danger*. Sutton Publishing Ltd., Stroud, U.K., 1998.
Takano, K., M. Kojima, N. Hasegawa, and A. Hirose. Interrelationships Between Organizational Factors and Major Safety Indicators: A Preliminary Field Study. In *Safety Culture in Nuclear Power Operations* (B. Wilpert and N. Itoigawa, eds.), Taylor and Francis, London, 2001, pp. 189–205.
Wahlstrom, B. Assessing the Influence of Organizational Factors on Nuclear Safety. In *Safety Culture in Nuclear Power Operations* (B. Wilpert and N. Itoigawa, eds.), Taylor and Francis, London, 2001, pp. 177–188.
Weick, K. *Reframing Organizational Cultures*, Sage, London, 1991.
Westrum, R. Social Factors in safety-Critical Systems. In *Human Factors in Safety-Critical Systems* (F. Redmill and J. Rajan, eds.), Butterworth–Heinemann, Oxford, 1997, pp. 233–256.
Wilpert, B. The Relevance of Safety Culture for Nuclear Power Operations. In *Safety Culture in Nuclear Power Operations* (B. Wilpert and N. Itoigawa, eds.), Taylor and Francis, London, 2001, pp. 5–18.
Woods, D. W., L. J. Johannsen, R. I. Cook, and N. D. Sarter. *Behind Human Error: Cognitive Systems, Computers, and Hindsight*. CSERIAC, Wright-Patterson AFB, Ohio, 1994.
Special Edition on Safety Culture. *Work and Stress,* Vol. 12, No. 3, 1998.
Zuboff, S. *In the Age of the Smart Machine*, Basic Books, New York, 1988.

6.3 BREAKOUT GROUP DISCUSSION

Panelists

- Neville Moray, invited speaker;
- Tim DePaepe, Brotherhood of Railroad Signalmen;
- Pete Hall, Amtrak; and
- Michael Coplen, Office of Research and Development, FRA.

Summary

Safety Culture Has Not Yet Been Defined by the Railroad Enterprise

In this breakout discussion, group participants talked about the barriers to improving safety culture. Safety culture is still perceived by all stakeholders as somewhat abstract and nebulous, with no clear definition.

The following are some related comments that were reported on but were not part of the breakout group discussion.

- "Safety culture in the U.S. rail industry is like … Swiss cheese. It has a lot of holes and smells, but some people like it."
- "Improving safety culture is like … changing an intractable, yet motivated, family."

The group agreed that one thing that was needed was to get a better understanding about what safety culture is in the railroad enterprise and how to measure it. That was an important outcome from this session.

Understanding organizational culture generally, and safety culture in particular, is also difficult in part because it is "hidden."

A participant added the following comments later for clarity.

> The visible indicators of shared organizational values (culture) are less important than the ones that are assumed but unarticulated. If the organization really values something it doesn't find it necessary to state it outright; rather it becomes an unstated assumption. Understanding an organization's culture therefore consists of learning what the unstated assumptions of the organization are. In order to understand an organization's culture it is necessary to "dig down" and uncover unstated assumptions. Examples of unstated assumptions sometimes found are things like: production takes priority over safety; avoid reporting injuries whenever possible; give lip service to safety but don't really take it seriously.

Lots of rules can become a substitute for culture. In the discussion, participants began to clarify some of the unstated assumptions about safety culture in the railroad enterprise. Participants noted that this was also an important activity to continue. This sets the stage and is a prerequisite for some of the railroad enterprise's ongoing work in defining and measuring safety culture (organizational safety performance).

Other Potential Barriers to a Positive Safety Culture

Labor representatives provided numerous examples of how the typical ways of responding to incidents and complaints (both FRA and rail management) contribute to a reluctance to report incidents. One of the most important issues that can be addressed is improving safety reporting. This is one of the more salient points of the entire session.

A participant added the following comments after the session for clarity.

> In this reactive environment, where most communications occur around incidents or accidents, interactions with workers usually take place after the incident. Since most feedback is negative, interactions tend to be negative and punishing. The appeal of looking at close calls is that the process circumvents these barriers.
>
> If a "close call" system is a proactive one, it fosters active communications before. Such a system establishes a framework that is superimposed on the existing framework, without challenging it. It does not change FELA [Federal Employers Liability Act] or replace the framework. Consequently, focusing attention on safety reporting systems in addition to pragmatically defining safety culture will provide fruitful research activity.

Some thought that productivity is often valued more than safety. The existing system is focused on a negative safety reporting culture. The safety reporting culture barriers have evolved to create systems and reinforce those that undermine safety. In this rule-driven industry, there are three critical structural barriers that create a punitive atmosphere. They are legislation and regulations, operating and safety rules, and the discipline system. Each barrier has rewards for not sharing information and punishments for reporting safety. Specific barriers suggested include

- Problems with the regulatory requirements and process;
- Unclear, duplicative, and conflicting rules;
- Lack of clarity of rules, and duplication and often conflicting rules;
- Lack of positive recognition (management to employee) for sharing accurate safety information;
- "False rewards" for perceived safety. Symbols or rewards encourage underreporting incidents (e.g., some incentive awards, management and employee incentives);
- Changes in management and other influences can undo an existing safety program / countermeasure; and
- Lack of employee trust of management.

Perspectives of Stakeholders

The Labor Perspective

- The "blaming culture" keeps management from acknowledging their responsibility.
- FELA has negative side effects, but without it management would not address safety risks.
- Government punishes workers for sharing safety information. The way the regulation procedure works, if an employee makes a complaint to FRA about a violation of a regulation, FRA reports it to the company. The company will get a minor penalty, but the employee can be severely punished by the company. As a result, accurate, honest safety hazard information becomes less and less available since employees are unwilling to share information.
- Workforce safety rules are written to protect management from liability by reducing their share of the blame. Labor believes that management typically writes rules to protect itself from blame. Violating a rule triggers an investigative process. Each party strives to reduce their own responsibility by assigning blame to others.
- Need to address FRA's selective enforcement of regulations, which is perceived by labor as soft on railroads and hard on employees.
- Lack of equal representation between labor and management stakeholders affects subcommittee outcomes (e.g., selection of research problem statements).

The Railroad Management Perspective

- Concern about how to sustain positive culture change when it starts to get under way and there is a change in senior management.
- Need a collaborative effort between labor and management in the selection of new employees.

The Government Perspective

- Legislation, primarily FELA, makes it difficult to negotiate on issues between labor and management to come to an agreement.
- Lack of employee involvement in developing railroad safety rules hampers compliance.

Opportunities for Collaboration

- Change reporting atmosphere or culture to allow more open and accurate reporting and sharing of information. Need to address at all levels: legislation, regulatory, management, and labor.
- Hire new employees: There should be a joint effort between management and labor to select employees. This provides an opportunity to instill safety culture from the beginning.
- Determine how to define and measure culture for the railroad enterprise. We need a way to measure the level of effectiveness of safety culture and how to evaluate improvements against a baseline. Look at relationship between safety culture metrics and downstream indicators (e.g., cost benefits, reduced injury ratio), and develop a business case to sell safety to others.
- Reduce other barriers to collaboration:
  - Encourage employee involvement in rules revisions to get ownership by employee.
  - If FELA stays, reduce impact.
  - Develop close call reporting system.
  - Reestablish trust between employees and front-line supervisors.

The group overall went away with an increased understanding of the importance of safety culture and some overall general directions for the future. The goal of this session was not to have clear outcome goals. Rather, it was to increase buy-in to the research process and use the input provided in the meeting to help shape the direction of the research agenda in this area.

7. Technology

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7.1 BIOGRAPHY

Victor Riley has a bachelor's degree in architecture from the University of Arizona and a doctorate in experimental psychology from the University of Minnesota. He worked in human factors research at the Honeywell Technology Center for 19 years and recently left to start a consulting practice in user-centered research and design. He has worked mostly in commercial aviation but also in military aviation, space, nuclear power, and residential technologies. His work is primarily devoted to developing and applying systematic analysis methodologies to anticipate sources and consequences of human error, and making systems and products easy to use by defining the product's functions and functional logic to match existing user mental models. One new technology he invented using this approach reduced pilot training time to use a flight management system from several weeks to about 10 min.

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7.2 PRESENTATION

Abstract

In this paper, we explore two major themes: the design of systems can facilitate human error and the design of automation and human behavior can combine to affect human and system performance. One factor that ties these two themes together is cognition: system designers often ignore the cognitive aspects of the design and consequently fail to understand how the design will affect user actions, decisions, and responses. We examine these issues in the context of automated systems and follow the evolution of human-centered automation issues from the rarified atmosphere of aerospace to their emergence in society at large through the 2000 Florida presidential election and the 2001 terrorist attacks in New York.

Introduction

In January of 1992, an Airbus A320 operated by the French carrier Air Inter was approaching Strasbourg on a flight from Paris in a snowstorm. As the flight approached the mountains near the airport, the Strasbourg approach controller gave the crew a clearance for a different runway than they expected, requiring them to start down sooner than they planned. They used the airplane's autopilot controls to dial in what they intended to be a 3.3-degree flight path angle descent, which would intercept the approach path at the appropriate speed and altitude for landing. But instead of a 3.3 angle, they mistakenly selected a 3,300-ft-per-minute rate of descent. This caused the plane to descend much faster than they intended, and they crashed into a mountainside.

The control device the crew used was a knob that could control either flight path angle or vertical speed, depending on the mode of the control. The mode was selected by a pushbutton at the center of the panel. This button toggled back and forth between the heading lateral mode and "vertical speed" vertical mode, on one hand, and the track lateral mode and "flight path angle" vertical mode, on the other.

There are several possible ways the wrong mode could have been selected: the pilot could have thought the airplane was in "flight path angle," but it was actually in "vertical speed" when the knob was adjusted; the pilot could have pressed the button to select "flight path angle" but hit it twice inadvertently to reselect "vertical speed;" or the vertical mode could have reverted from "flight path angle" to "vertical speed" when the lateral mode changed from track to heading.

The indicators that should have informed the crew that they were in the wrong mode were not compelling enough to draw their attention to the error. Furthermore, the crew was using a head-up display, on which there were no mode indications, so it was possible that they never looked at the primary flight display where the selected mode was indicated.

This is one example of an accident where aspects of the user interface design and mode logic apparently facilitated pilot error. Until the early 1980s, accident investigators didn't look beyond the finding of pilot error to identify the underlying design causes of error. Starting with a commuter airline accident in 1979 (Nance, 1986), however, the National Transportation Safety Board (NTSB) began to consider how corporate culture and equipment design contributed to the pilot errors that were responsible for a majority of aviation accidents (U.S. Department of Transportation, 1990).

Design-Related Human Error

Human factors have been a topic of interest in aviation since World War II. For the most part, it has stayed primarily in the laboratory and in academic circles. However, as technology became more widespread and society became more dependent on it, accidents involving human performance began to receive public attention as well, starting, perhaps, with the Three Mile Island nuclear power plant accident.

The 2000 presidential election in Florida was probably the major coming-out party for human factors into society at large. Never before had the failure of a designer to anticipate and accommodate human behavior had such drastic consequences or gained so much attention. Furthermore, it was not just the designer who failed to recognize the problem; many observers, including politicians, pundits, and members of the general public couldn't understand how anyone could be confused by the "butterfly ballot" that had apparently led to so much confusion in Palm Beach County.

It is possible that this failure to understand the problem with the design is symptomatic of a broader failure to recognize the role of cognition in design. To see how cognition played a role in the confusion over the ballot, look at the ballot layout, shown in Figure 7-1. Reproduced on a flat sheet of paper or displayed on a flat computer screen, the layout looks perfectly clear. But consider how it would appear to the user in person: the ballot has several pages and is laid out like a book, with a cover and a central spine. In western culture, a person using a book begins by reading from the top of the left-hand page and typically doesn't look at the right-hand page until

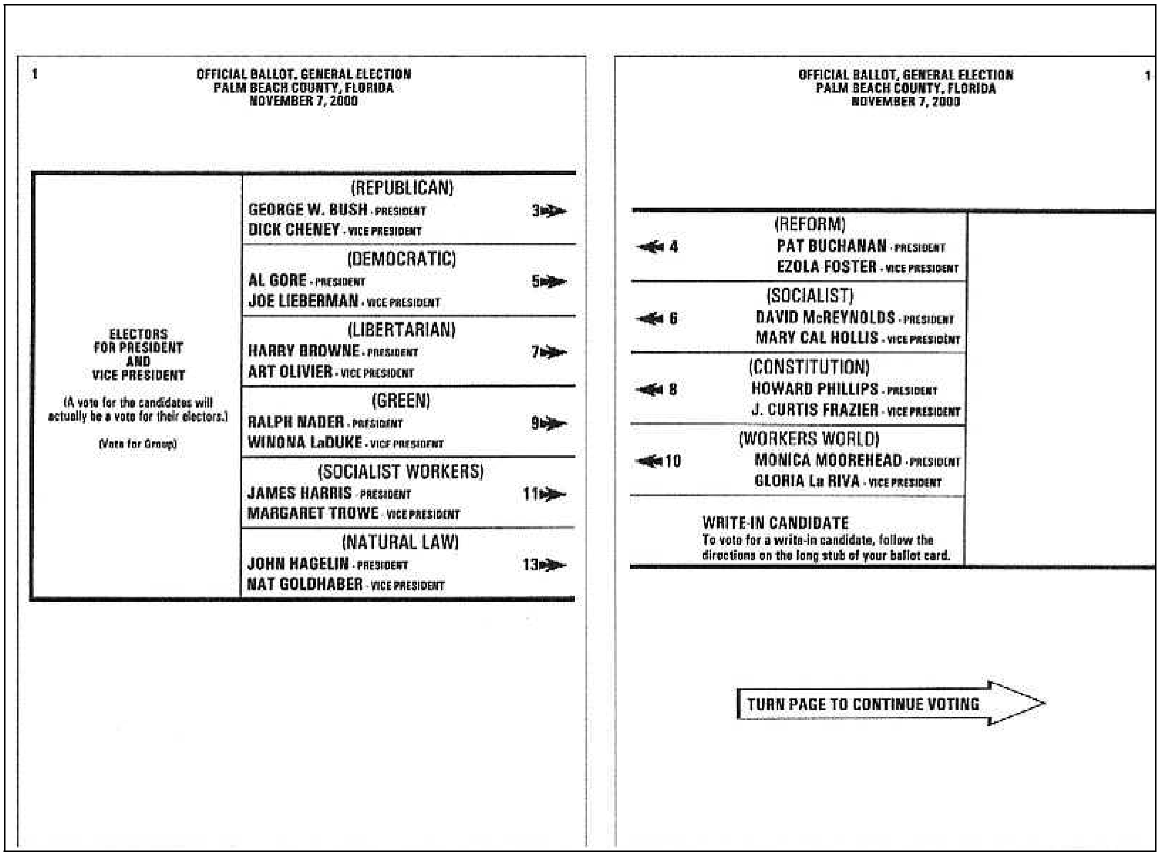

FIGURE 7-1 Palm Beach County ballot layouts.

finished with the left. Now, notice that the two major party candidates' names both appear on the top of the left-hand page. Unless a voter intended to vote for someone other than those two, it would be unlikely that the voter or she would even look at the right-hand page. Someone voting for Al Gore would likely find his name below George W. Bush's on the top of the left page and look to the center of the ballot to punch the hole. However, the act of punching the hole may cause the voter to realize that there were more holes than candidates and thus to become confused. Some voters probably then looked at the right-hand page and understood how the ballot was laid out. But others may have looked to the instructions for guidance, saw that the instructions stated "vote for group," and decided that they had to punch a second hole for the vice presidential candidate as well.

What was ironic about the design was that the designer had paid particular attention to the special needs of the elderly people in the precinct. Recognizing that many of them had vision problems, the ballot designer had the candidates' names printed in larger-than-normal type so they would be easy to read. Because of the number of candidates on the ballot, the larger type required that the names be spread over two pages. With the punch holes in the center, the names had to alternate from side to side as one went down the ballot.

The essential problem with this design is that the graphic layout was inconsistent with the cultural associations conveyed by the physical form. The physical form suggested that the ballot be read like a book, starting at the top of the left page, reading down to the end, then starting again at the top of the right page. But the ballot was intended to be used in alternating fashion, jumping between the left and right pages as one read down. It is likely that voters' experiences with books and their associated cultural conventions overwhelmed all the graphic cues that were intended to indicate how the ballot was supposed to be used. The physical, book-like form of the ballot operated like an unintended metaphor, conveying a compelling but misleading message about its intended use.

In trying to accommodate the physical limitations of the user, the designer ran headlong into an unforeseen cognitive limitation. This conflict between design and cultural convention was much like reversing the "on" and "off" positions of a light switch, or the hot and cold handles of a faucet; due to cultural conditioning, user error was inevitable.

The consequences of this oversight were well documented. Palm Beach County voters were 100 times more likely to double-vote than anywhere else in the state. Twenty percent of the votes cast were thrown out for double voting, compared with 4% across the rest of the state; 5,264 votes were cast for Gore and Pat Buchanan; there were only 184 ballots with that combination out of 1.2 million votes cast in Miami–Dade and Brower Counties. And, in a county made up largely of elderly Jewish residents, Buchanan, whom many considered to be anti-Semitic, received 3,704 votes, accounting for 20% of his total vote count in the state (Merzer, 2001; *New York Times*, 2001).

The case of the butterfly ballot is interesting for a number of reasons. First, it demonstrates, on a large scale, how design can lead to human error. Second, it typifies the tendency of designers to attend to the physical and perceptual needs of users while overlooking the cognitive needs. This tendency to overlook the cognitive aspects of design is the reason that so many technology products, from videocassette recorders to transportation systems, are hard to use: designers pay a lot of attention to the user interface but fail to recognize that the barriers to ease of use really lie at a deeper level than the interface. It's often not how the product looks and feels to the user that determines ease of use, but rather how hard it is to learn and remember how the product works underneath: the "functional logic" of the product, which defines the sequence of steps the user has to follow to access and use product functions.

The third reason the butterfly ballot is interesting is the response it generated from observers and decision makers. In testimony before the U.S. Congress by the United States Civil Rights Commission, the Republican member of the commission, relying on a statistical analysis by an economist at Yale Law School, said that "voter error was the central problem in Florida" (*New York Times*, 2001). Note the similarity of this position to the attributions of accidents to "pilot error" by the NTSB before 1980.

When the time came to carry out a limited recount, a new debate erupted regarding whether the recount should be carried out by humans or by machines. Academics who had been studying human-centered automation issues in the rarified atmosphere of high technology were perhaps astonished to discover that automation was a partisan issue, with the Democrats holding that only human counters could bring the degree of flexibility required to interpret voter intent correctly from ambiguous data (such as "hanging chads") and Republicans holding that machines were unbiased, more consistent, and didn't make errors. Even the Florida Supreme Court (made up primarily of Democrats) offered the far-reaching observation that "although error cannot be completely eliminated in any tabulation of the ballots, our society has not yet gone so far as to place blind faith in machines. In almost all endeavors, including elections, humans routinely correct the errors of machines."

As technology has matured, this has become a more common, and critical, question. Who should be in charge: the human, with his or her greater flexibility, judgment, creativity, and discretion or the automation, with its greater consistency, precision, and predictability? When humans and automation perform tasks together, which one should be able to override the other? Should the human be able to intervene in automated processes whenever he or she thinks the automation isn't behaving correctly, or should the automation provide protections that guard against human error?

Automation and Human Performance

An early instance of this question came up in the first days of the U.S. space program. The designers of the Mercury capsule—that was to take the first humans into space—wanted to make vehicle control completely automatic. The astronauts objected, stating that they were in the program in the first place because of their skills as test pilots and if a life-threatening event occurred, they wanted to be able to take control. The designers eventually gave in, providing flight controls and a window.

The Soviet space program faced the same question but arrived at a somewhat different solution. When Yuri Gagarin was sent into orbit on the first manned space flight, he had flight controls available. But the controls were locked out by a combination lock. If Gagarin wanted to take control, he would have had to open an envelope that was taped to the cabin wall and contained the combination code and enter the code into the system before it would recognize his inputs (Oberg, 1981).

Since then, automation has filtered down from the realm of high technology into everyday products, and product designers are facing the question of who's in control all over again. And, without the benefit of a human-centered automation philosophy, they are arriving at many different answers.

For example, the Porsche Boxster sports car has a safety feature in which a computer shuts off fuel flow to the fuel filters to prevent fire if the car has been in an accident. The computer knows the car has been in an accident when an accelerometer measures a high level of acceleration. However, the Boxster is a very high performance and highly agile sports car. So agile, in fact, that it can corner with enough acceleration to trigger the safety feature. Thinking it's been in a crash, the computer shuts down the fuel injectors in midmaneuver (Cooper, 1999).

In the early 1990s, the crew of a Fokker 100 regional jet, landing at Chicago O'Hare airport, Illinois, was surprised to discover that they could not stop the aircraft on the ground. The brakes, thrust reversers, and ground spoilers all refused to work. If they shut down the engines to eliminate thrust, they'd lose control over nose wheel steering. So, keeping the engine thrust at idle, they made a grand tour of the airport, up and down taxiways and runways, while the air traffic controllers told all the landing aircraft to go around. Finally, the aircraft lost enough speed that the crew could guide it into the infield, where it came to a stop in the grass. When they looked at the displays, they realized that the stall warning was being shown; apparently, the aircraft still thought it was in the air, and the automatic protections that locked the crew out of in-flight deployment of these systems were in effect. The logic governing access to these functions was based on a wheel sensor that detected when the aircraft was on the ground. Apparently, the sensor didn't register that the aircraft had landed and the protections had not been lifted.

While no one was injured in this incident, a similar incident in Warsaw, Poland, involving an Airbus A320 did result in fatalities. The airplane landed on a wet runway, and the pilots made such a smooth landing that one of the weight-on-wheels sensors didn't trigger. At that time, the protection logic required that both sensors register the landing before the protections were lifted (demonstrating a bias in favor of the automation—a high burden of proof before manual control was permitted). The aircraft couldn't slow down enough to turn off the runway and crashed into a retaining wall at the end. After this accident, Airbus modified the sensor logic so that only one sensor had to detect weight in order to lift the protections.

These incidents illustrate the balance that designers must strike between protecting the operator and the vehicle from error and allowing the operator adequate control over the vehicle. But the balance of power between operator and automation is not limited to protections. It can also be affected by mode logic.

In 1994, a China Airlines Airbus A300 was on approach into Nagoya, Japan, when the crew inadvertently selected the "go-around" mode. This mode selects full thrust and brings the nose up to abort landing and begins to track the go-around procedure, which takes the airplane along a predefined trajectory over the airfield to a safe position. In this case, however, the crew didn't intend to select that mode; they still wanted to land. The first officer, who was flying the plane at the time, tried to stay on the glide slope for landing by pressing the control column forward to keep the nose down and pulling the thrust levers back to maintain idle thrust. However, the autopilot, still intending to go around, tried to bring the nose and thrust up.

Normally, when the pilot deflects the control column, the autopilot disconnects and allows the pilot to take control. This happens in every other aircraft in every mode, and in this particular aircraft in every mode except for the "go-around" mode. In this one, unique case, the crew must explicitly turn off the autopilot once they have selected "go-around" mode. The crew of this flight apparently didn't understand this unique case and persisted in their belief that the autopilot should disconnect when they moved the control column. Consequently, a power struggle developed between the pilot and the autopilot, with the former attempting to keep the nose down and thrust low, and the latter trying to bring the nose up and thrust high. The pilot had control over the elevators, but the autopilot countered with trim (which biases the pitch for fine control to minimize drag). Eventually, the pilot gave up and let the autopilot have control. But by this time, the aircraft was so far out of trim that it was uncontrollable; it pitched up onto its tail over the runway threshold and crashed.

In order to gain a more structured understanding of human-centered automation issues, we can look at them in four general categories: automation use, misuse, disuse, and abuse (Parasuraman and Riley, 1997). The first has to do with how people decide whether or not to rely on automation. The second has to do with over-reliance on automation. The third has to do with underreliance, and the fourth with inappropriate use.

Automation Use

Despite the ubiquity of automation in industry, transportation systems, medical devices, consumer products, and so forth, we know very little about how people choose to either rely or not rely on automation in a given situation. This is unfortunate, because most accidents can be traced, at some point in the chain of causes, to such a decision. This fundamental lack of understanding about how automation is used has led some system designers and many operators to make bad decisions about how automation should be implemented and what policies should govern its use.

This decision is a potentially complex one. It may be affected by a large number of factors:

- How reliable the automation has been over time;
- How much the operator trusts the automation;
- How much experience the operator has with it;
- How much self-confidence the operator has in his or her own ability to perform the task manually;
- How much fatigue the operator is experiencing;
- How much workload the operator is experiencing;
- How difficult the task is;
- How much risk is involved; and
- Company policies and procedures on automation use.

Experiments

In 1994, we carried out a series of studies to examine the influence of these factors on automation use decisions (Riley, 1994). The first set of studies used a simple laboratory experiment to provide independent control over each factor. This is difficult to do in simulators and in the real world because multiple factors usually vary together; for example, workload typically rises in high-risk situations.

The experiment used a simple categorization task combined with a pseudo-tracking task. In the categorization task, subjects were asked to indicate, by pressing a key on the keyboard, whether a character that appeared in a certain position on the screen every 1.75 s was a letter or a number. The user could turn this task over to automation and take it back at any time by pressing the space bar. There was always feedback at the top of the screen showing whether the automation was right or wrong for each trial; this was shown all the time, even when the automation was turned off, to allow the subject to monitor automation performance and develop trust in it.

On the right side of the screen was the pseudo-tracking task, which was intended to impose workload. A vertical line appeared over a target (a carat symbol); in any given trial (each trial lasting 1.75 s), there was a certain likelihood that the line would move off of the target. The subject had to ensure that the line was back over the target when the trial ended in order to get a point for a successful categorization. If the line was off the target and the categorization was right, the subject didn't win a point for the trial. If the line was off the target and the categorization was wrong, the subject lost a point.

The display used is shown in Figure 7-2. Workload was manipulated by the probability that the line would move off the target in a given trial. Task difficulty was manipulated by introducing characters that were neither letter nor number, but would be randomly scored as one or the other. These characters included #, ?, %, and so forth. The difficulty, or uncertainty, of the task was set by the probability of getting an unclassifiable character. Automation reliability was manipulated by the probability that the automation would be correct or incorrect in a given trial.

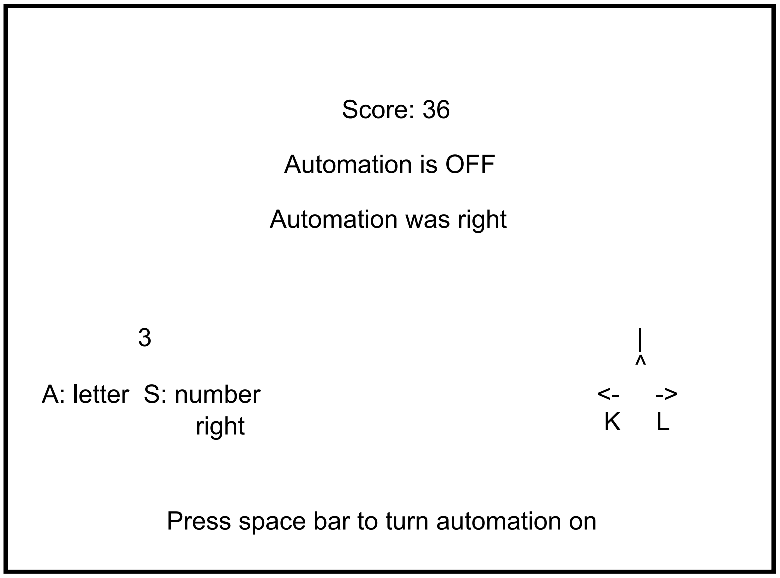

FIGURE 7-2 The automation experiment task screen.

The first experiment tested the influences of task uncertainty, workload, and automation reliability on subject decisions to rely on automation. Figure 7-3 shows the profiles of these values over the 1-h time period of the experiment. In the “normal” condition, which the experiment returned to after each manipulation, automation reliability was at 90% (the automation was 90% likely to make the correct classification in any given trial), workload was at 40% (there was a 40% likelihood that the line would move off the target in any given trial), and task uncertainty was at 10% (the character was 10% likely to be unclassifiable in any given trial). After about 7 min, workload increased to 80% for a period of time, then returned to normal. After about 200 trials, uncertainty would increase to 40% for a period of time, then return to normal. After about 23 min, automation would fail for about 50 trials. In the failure condition, automation would get 50% of the classifications correct, which was chance performance on the binary task. After the failure period, it would recover for 200 trials, then fail again for 50 more, then recover again.

The purpose of the second failure was to test a theory in the literature at that time, derived from human trust experiments, that it would be harder to recover trust in a system that had proved itself unreliable than it would be to develop trust initially (Muir, 1987). Finally, a combined failure, high workload, and high uncertainty manipulation was imposed toward the end, with the last 200 trials in the normal condition.

In the first experiment, 30 university students served as the subjects, with a cash award given to whichever student posted the highest score. This was to ensure that the subjects took the task seriously and used the automation rationally. Figure 7-4 shows the profile of automation use (the proportion of subjects who used the automation during each trial). The overall level of automation use is relatively low, with fewer than half the students using it during most of the experiment. The workload manipulation did not have a significant effect, but the uncertainty manipulation did. When the automation failed, most of the students turned it off, but they were quick to turn it on again when it recovered, and the level of automation use returned to its prior level.

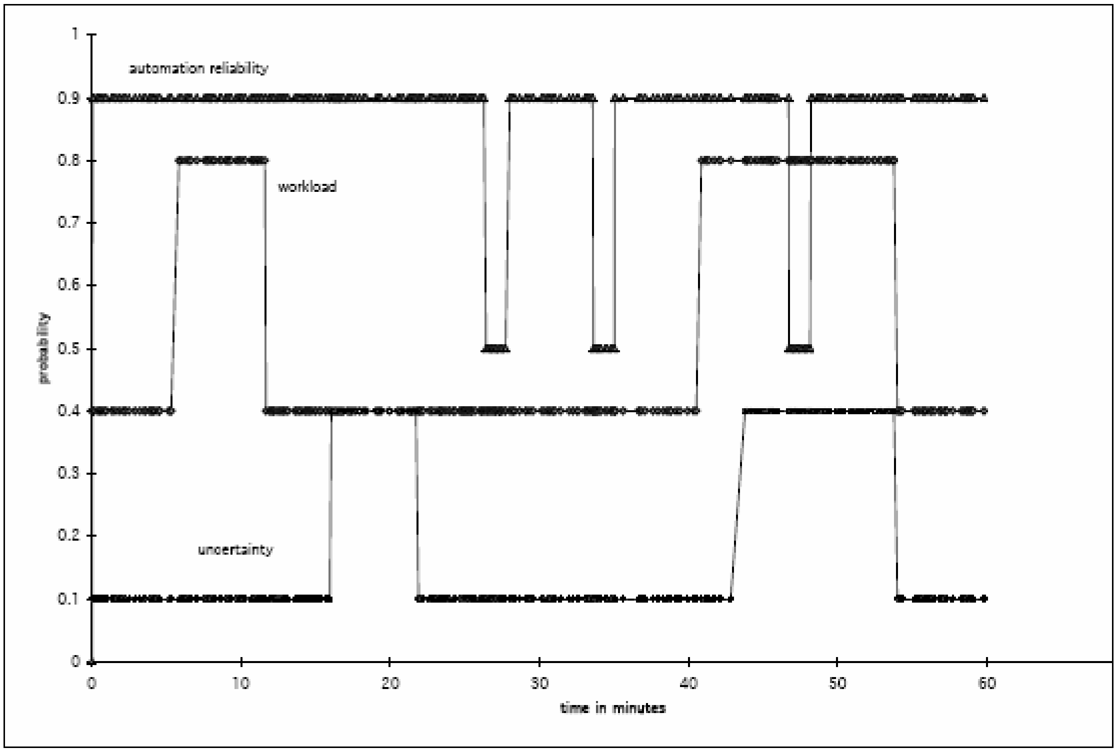

FIGURE 7-3 The experiment sequence.

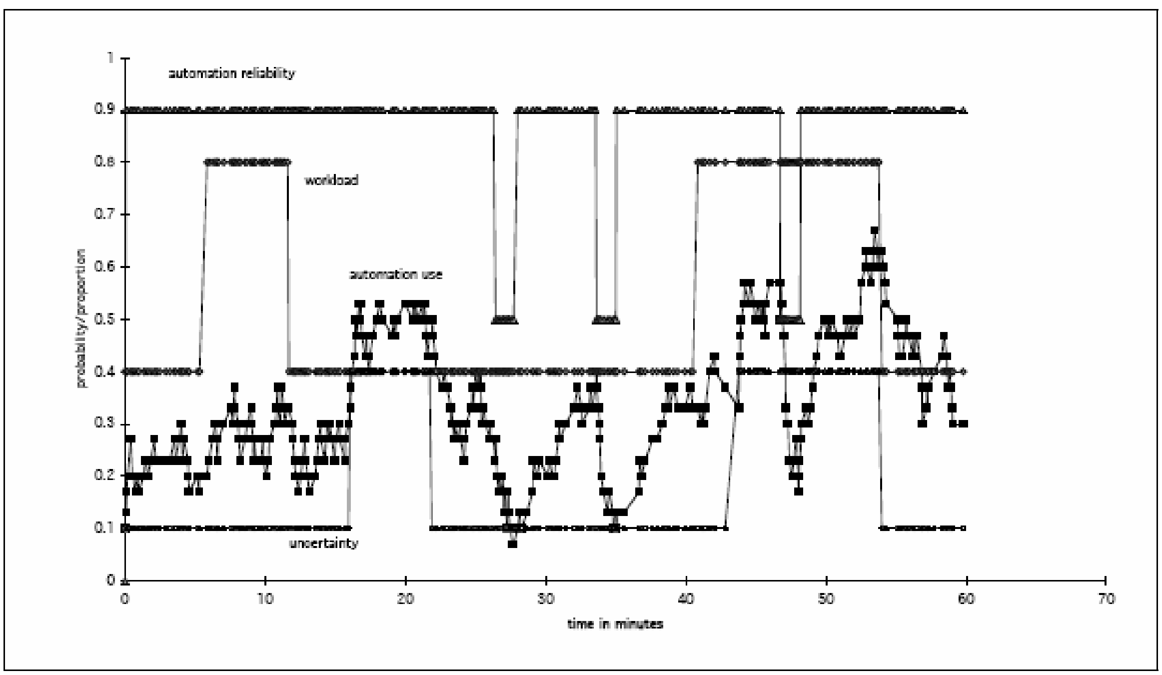

FIGURE 7-4 Automation use by students.

When it failed a second time, the subjects turned it off faster than for the first failure, but turned it on again faster when it recovered. This argues against the theory that trust was harder to regain after failures than before. A full multiple regression analysis revealed a gradually rising trend over the timeline, which, based on subject responses to postsession questions, was due to fatigue. Some students didn't use the automation at any time, preferring to exert continuous manual control. When asked about this, they stated that they were doing so well at the task that they didn't need help. Ironically, however, these students were the worst manual performers of the task.

One of the interesting results of this experiment was the finding that there was no reluctance to use the automation following failures. It appeared that subjects were learning to recognize automation states, and using that knowledge to make their use of automation more rational—relying on it when it worked and turning it off when it broke.

In experiment two, we tried to determine whether the subjects' trust in the automation was based on global attitudes toward automation or specific knowledge of that particular system, and also whether subject knowledge of automation states played a significant role in addition to "trust," which we defined as the subject's future projection of the automation's reliability.

We ran three groups of 17 students each, using the same task but removing the workload and uncertainty manipulations. We also made the automation either 100% reliable when it was working and 100% unreliable when it failed. One group was giving prior information about possible automation states (100% reliable or 100% unreliable), so when the automation failed, they would know right away that it was a true failure and not a transient anomaly. A second group was given the same information but was also told about future behaviors: that when the automation failed, it would stay failed for 50 trials and then recover. The third group was given no prior information about automation states or behaviors. Thus, the first group's decisions were influenced only by trust, since they had no prior knowledge of future behaviors. The second group's decision was not influenced by either trust or state knowledge. Both influenced the third group.

The results demonstrated that both knowledge of the state and trust significantly contributed to automation use decisions. Subjects who knew of future behaviors turned the automation on significantly faster at the start of the experiment than the other two groups, suggesting that it takes time for subjects to develop enough trust in a system's automation to start using it. Subjects who knew about possible automation states turned the automation off when it failed faster than those who didn't, suggesting that operators do leave failed automation on for a period of time to determine whether it's really failed or not. And subjects who knew about future behaviors turned it off significantly faster than those who knew only about possible states, suggesting that operators also wait to see if it will recover before turning it off. This demonstration of two factors that contribute to delays in turning off failed automation was a particularly interesting result.

However, lack of trust did not cause subjects to turn the automation on more slowly following failures. In fact, subjects who knew only about possible states turned it on significantly faster following the first failure than they did initially, again suggesting that they had learned to recognize automation behaviors and respond to them quickly. This suggests that good information about automation reliability (system health, automation intentions and actions, feedback) promotes more rational use of automation.

Since university students were not thought to have had much experience with advanced automation, we thought that it would be interesting to compare student use of automation with that by professional airline pilots. In the third experiment, we repeated the first experiment with 34 commercial airline pilots from a major carrier. All of them had experience in high-technology "glass cockpit" aircraft with advanced automation. Figure 7-5 shows the profile of pilot use of the automation along with the student use of automation from the first experiment. The dynamic characteristics of the two curves are remarkably similar. Regression analysis again showed a significant effect from the uncertainty manipulation but not from the workload manipulation. However, overall, pilot use of automation was about 34% higher over the course of the experiment than student use. Perhaps of greatest interest, almost half the pilots never turned the automation off when it failed. There were no correlations found between automation use tendencies and risk taking, age, experience, or other demographic factors.

The contrast between experiments one and three, and indeed the sharp split seen within the pilots (with half of them turning the automation off faster than the students when it failed and the other half leaving it on through the failure periods), demonstrates what has become a common theme of automation use experiments: the presence of marked individual differences. This, and responses to the postsession questionnaires, suggests that different people are influenced by different factors: some by self confidence in their own performance, some by fatigue, some by trust in automation, some by a rational comparison of automation and own performance, and some likely by other factors, such as the need for control.

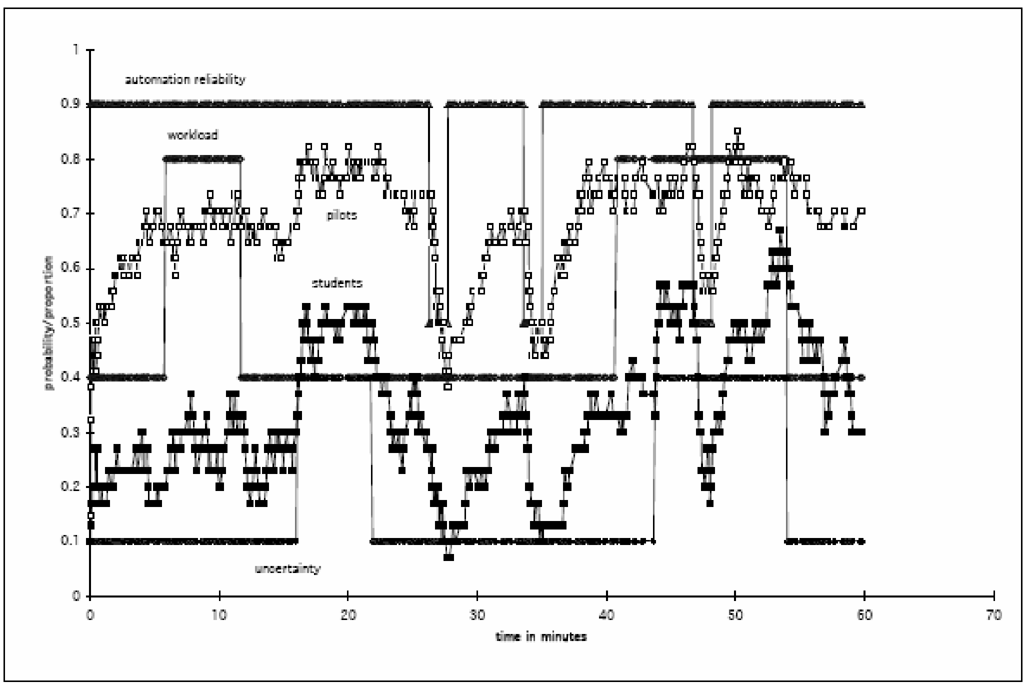

FIGURE 7-5 Automation use by pilots (top profile) compared with students (bottom profile).

However, the consequences of making an error in this experiment are far from the risks encountered in the flight deck, so we can't conclude from these results that pilots will necessarily overrely on automation in practice. While we couldn't impose a similar penalty for error (such as death) in our laboratory experiment, we could raise the stakes by making the consequences of errors more severe. In experiment four, we repeated experiment three, with 31 pilots from the same airline, again all with high technology aircraft experience. But this time, there was a 5% probability that they would lose 20% of their accumulated points whenever they made a character classification error.

Figure 7-6 shows the profile of automation use for pilots in experiments three and four. Again, the dynamic characteristics of the two curves are remarkably similar, in fact almost identical up to the second failure recovery. However, after the second failure, the pilots began to demonstrate some reluctance to use the automation, taking longer to turn it back on when it recovered than those in experiment three. When the experiment returned to the "normal" condition after the combined manipulation toward the end, the pilots in the higher risk group used the automation about 19% less than those in the lower risk group.

These results offer support for automation reliability, trust in automation, knowledge of automation states, self-confidence, risk, and fatigue as factors that can influence decisions to either rely or not rely on automation. Furthermore, they demonstrate that operators may continue to rely on faulty automation when they are uncertain about the nature of an apparent failure, both in terms of what state the automation is in and how it will perform in the near future. They also

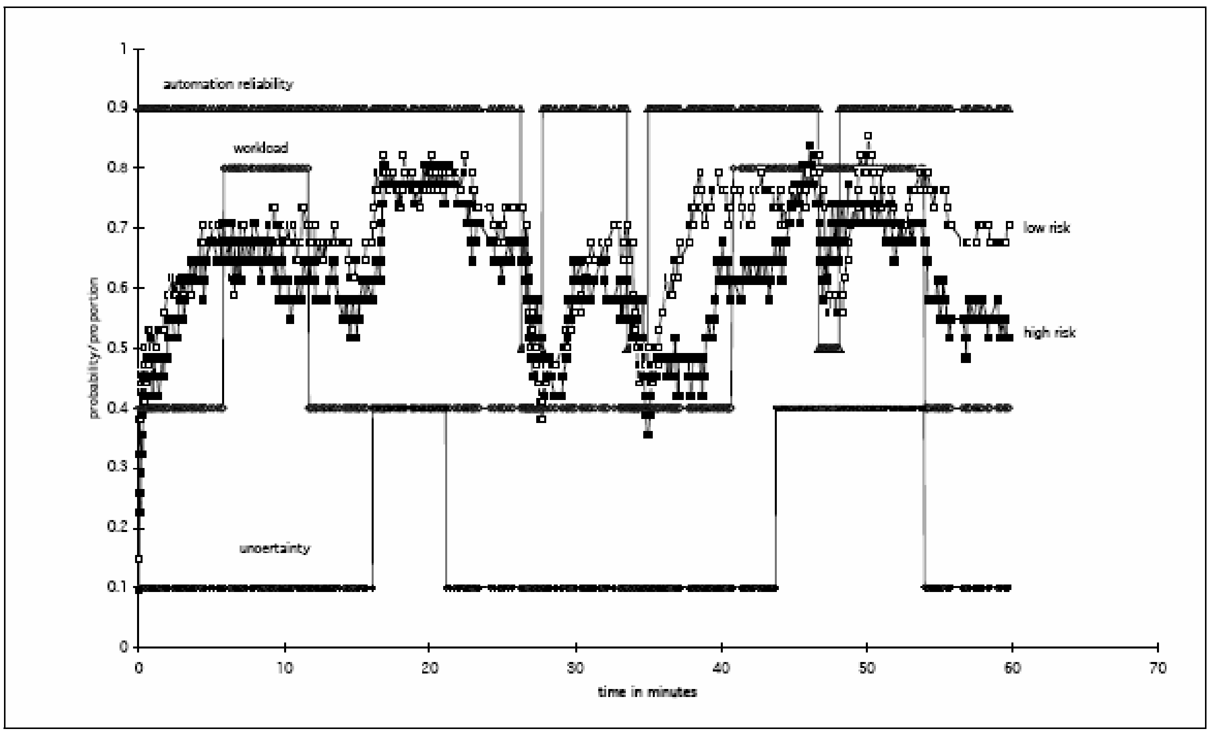

FIGURE 7-6 Automation use by pilots in low-risk (upper profile) versus high-risk (lower profile) conditions.

demonstrate that operators can learn to recognize automation states and use the automation rationally on the basis of that knowledge. However, operators also exhibit very large individual differences, with different people perhaps being susceptible to different automation use biases in different situations and conditions.

Summary of Results

For system designers and operators, the implications of this research are that

- Automated systems should provide very good feedback about automation states, intentions, and actions, so operators can accurately diagnose failures and intervene appropriately;
- Companies may want to consider training operators to understand their own potential automation biases (such as continuing to use unreliable automation) so they can be consciously countered;
- Safety-critical automation may be relied on less in high-risk situations, precisely when it may be most needed, perhaps because people prefer errors of commission to errors of omission;
- Operators who have low self-confidence in their own performance may tend to over-rely on automation; and
- Operators who have high self-confidence in their own performance may tend to under-rely on automation, and it's possible that their high self-confidence may not be justified.

Now that we've dissected some of the factors that can contribute to automation use decisions and over-reliance and under-reliance, let's look at the phenomena of overreliance (misuse) and under-reliance (disuse) in actual practice.

Automation Misuse

Here are some examples of over-reliance on automation:

- From the Associated Press: A German couple out for a Christmas drive ended up in a river—apparently because their luxury car's computer navigation system forgot to mention that they had to wait for a ferry. The driver kept going straight in the dark, expecting a bridge, and ended up in the water.
- In 1972, an Eastern Airlines Lockheed L1011 crashed into the Florida Everglades while the crew was preoccupied trying to determine why the landing gear indicator had not lit when the gear was dropped for landing. The crew set the autopilot to hold at an altitude of 2,000 ft above the ground while all the crewmembers tried to troubleshoot the light, but the captain inadvertently disconnected the autopilot by nudging the control column. (The autopilot system had been designed to disengage whenever one of the pilots moved the control column to provide an instantaneous transfer of control to the pilot.) The crew did not realize that the autopilot was no longer controlling the airplane until, prompted by a message from the air traffic controller, they reported their altitude at 30 ft above ground level (NTSB, 1973).
- A commuter plane stalled and crashed short of the runway in Columbus, Ohio, in 1994. The flight approached the airport at night and in a snowstorm. Normally, these conditions would not have caused a problem, but the captain of the flight, who was also the flying pilot on that trip, had previously demonstrated a low level of self-confidence in his own stick-and-rudder skills

during low-visibility approaches and tended to rely exclusively on the autopilot and autothrottle in such conditions. In this particular case, the captain failed to monitor the airspeed during the approach (NTSB, 1994). It's possible that the captain relied on the auto throttle system to maintain airspeed above stall speed, but this particular aircraft didn't have an auto throttle, so the captain was in fact relying on nonexistent automation.

Automation Disuse

Underreliance on automation typically comes in the form of ignoring warnings and alerts or disabling safety systems. One of the most egregious examples of the latter occurred in 1986, when one of the generator buildings at the Chernobyl nuclear power station in the Soviet Union exploded as operators were conducting low power tests. The plant was unstable at low power levels and required constant fine corrections at a frequency that was too high for humans to effectively control. However, the plant managers wanted to perform a test that required disabling the primary control system. They intended to run the plant manually and assumed that backup safety systems would take over control of the plant at the first sign of instability. However, when the backup system failed to control the plant effectively, there was nothing to prevent an accident (Stein, 1990).

Automation Abuse

Abuse of automation is when potentially inappropriate use of automation is dictated by company policies or procedures or by design. For example, a heavy snowstorm in Washington, D.C., confused the speed sensors on a Metro transit train. The operator of the train asked for permission to control the train manually, but the request was refused because Metro system policy required automatic control. In Gaithersburg, Maryland, the train failed to stop and collided with a standing train (NTSB, 1997).

A good example of automation abuse by design is automation that intrudes into the user's task when the user prefers to perform the task manually. Microsoft's Office Assistant, the paperclip icon that appears to offer assistance with tasks, is a good example of this: it appears when it recognizes a task the user is doing, interrupting the task and requiring the user to dismiss it actively.

Trends, Challenges, and Recommendations

If the Florida election ballot was the first major infusion of human-centered automation issues into society at large, the September 11, 2001, terrorist attacks on New York City prompted the second. Shortly after the attacks, letters appeared in many publications from people who suggested that if airplanes already had the technology required to land automatically, why couldn't the airplane take control away from the pilot in case of hijack and land itself?

Why indeed shouldn't automation be able to take control away from the operator?

This has been a topic of debate between Boeing and Airbus, in the most recent generation of aircraft. Both manufacturers have adopted fly-by-wire technology, in which pilot control commands go to a computer instead of directly to the flight control surfaces and engines; the computer determines the desired amount of surface deflection and thrust on the basis of pilot inputs and the current state of the aircraft. Fly-by-wire saves weight, allows for greater flight efficiency and fuel economy, and makes it possible to build in sophisticated protections. Airbus has used this last feature extensively; every aircraft from the A320 on provides stall protection and maneuver protection (which prevents the pilot from overloading the airframe with a high acceleration maneuver).

Boeing maintains that pilots should be able to exceed design limits if necessary for the safety of the flight, and asserts that Airbus's maneuver protections would prevent pilots from taking necessary action in some cases. An incident involving a China Airlines Boeing 747 off the coast of San Francisco seems to support this position. In this flight, an engine problem resulted in reduced thrust on one side of the aircraft. The autopilot gradually corrected for the thrust asymmetry, but as the asymmetry increased, the autopilot gradually reached the limits of its control authority. The pilots took over manual control but didn't correctly anticipate the dynamics of the aircraft, and the airplane rolled over and entered a nosedive. The pilots tried every strategy they could think of to slow the airplane down and regain control. Finally, after losing 20,000 ft of altitude, they lowered the landing gear, which lowered the centered of gravity enough and created enough drag that they were able to pull out of the dive. Analytic reconstruction of the incident estimates that the pilots put about 5 Gs on the airframe during the recovery maneuver. The airbus maneuver limits are set at 2.5 Gs.

Airbus counters that their automatic control system provides enough stability so that pilots will never enter into such an unusual attitude situation. Furthermore, they point to the large amount of accidents due to low airspeed and stalls, which their system protects against. Preliminary data suggest that this was the cause of the crash that killed U.S. Senator Paul Wellstone and seven others in northern Minnesota this last fall.

Nonetheless, the protections themselves may have some unintended consequences for human behavior. In the initial years after the introduction of the A320, the first civil transport aircraft with these protections, there were three A320 accidents and one A340 accident, all operated by experienced pilots (the chief pilot of Air France in one, the Airbus chief test pilot in another, a highly experienced captain and a check airman in a third). All involved loss of awareness of a basic, fundamental aspect of the flight path: altitude, airspeed, energy, and descent rate. These are aspects of flight control that are so basic and fundamental to aircraft safety that most pilots never lose track of them in a conventional aircraft, where there are no protections in place. Although I have no data to confirm this, I suspect that the presence of the protections may have allowed these pilots to become complacent about monitoring these parameters.

It is also known that human operators aren't always trustworthy themselves. Some pilots make errors that are not related to design. Some pilots are incompetent, despite the qualifications and testing required. And some accidents may be intentional. For example, the NTSB believes that a relief pilot at the controls of Egypt Air Flight 990 in 1999 brought the plane down intentionally, in an act of suicide (NTSB, 2002). Unfortunately, there is currently no way to protect against such an act.

Conclusion

So the question of whether the human operator or the automation should have ultimate authority is still unsettled. However, Billings (1992) has offered some guidance in the form of a human-centered automation philosophy. The first three principles of this philosophy are particularly important and far-reaching.

1. The human operator should be in charge. This is because the operator has the ultimate fiduciary responsibility for the safety of the system, and it doesn't make sense to impose such responsibility without granting the commensurate level of authority.
2. In order to be in charge, the operator has to be informed. This suggests that automation needs to be very informative about its state, intentions, and current actions.
3. In order to be informed, the operator has to be involved. To me, this is the most interesting of the three, because it is the least obvious and the one most rooted in experience. To date, we have commonly automated whatever we could, on the basis of the availability of technology, and left the human operator with whatever was left. Typically, this puts the operator in a monitoring role, rather than a position of active involvement. But we know from many studies and much evidence that people are not good passive monitors. Billings suggests that, although automation may perform a task more efficiently, we give up some measure of efficiency in order to gain the measure of safety that comes from having an operator who's awake, aware, and able to intervene.

This brings me to my final point. When we automate processes on the basis of technological availability, cost, efficiency, and the other factors we usually consider, we end up optimizing the role of automation and defining the role of the operator by default, rather than by design. This often leaves the operator with a random collection of tasks and responsibilities that he or she may or may not be well suited for. This may have been necessary when technology was less capable than it is now. But I believe that we have passed the point where the technology is the weaker partner, and in doing so, we have often exceeded the limitations of the human operator.

A safer and perhaps more rational approach now would be to define the operator's role first. Assign to the operator those tasks that he or she is best suited to and which keep the operator involved in the process and aware. Optimize the role of the operator to account for human strengths and limitations, and design the automation to support the operator, rather than training the operator to support the automation. Since most accidents are due to human error, and since human error often results from suboptimal operator roles, I believe the result will be safer systems, lower operating costs due to loss of property, and more saved lives.

References

Billings, C. *Human-Centered Automation: A Concept and Guidelines*. NASA Technical Memorandum 103885, Moffett Field, 1992.

Cooper, A. *The Inmates Are Running the Asylum*. Macmillan Computer Publishing, Indianapolis, 1999.

Federal Aviation Administration. *The National Plan for Aviation Human Factors*. U.S. Department of Transportation, 1990.

Merzer, M. *Democracy Held Hostage: The Miami Herald Report*, St. Martin's Press, New York, 2001.

Muir, B. Trust Between Humans and Machines, and the Design of Decision Aids. *International Journal of Man–Machine Studies*, Vol. 27, 1987, pp. 527–539.

Nance, J. *Blind Trust*. William Morrow and Company, New York, 1986.

National Transportation Safety Board. *Eastern Airlines L-1011, Miami, Florida, December 20, 1972*. Report No. NTSB-AAR-73-14. NTSB, Washington, D.C., 1973.

National Transportation Safety Board. *Aircraft Accident Report: Stall and Loss of Control on Final Approach*. Report No. NTSB/AAR-94/07. NTSB, Washington, D.C., 1994

National Transportation Safety Board. *Collision of Washington Metro Transit Authority Train T111 with Standing Train at Shady Grove Station, near Gaithersburg, Md., January 6, 1996*. Report NTSB-ATL-96-MR008. NTSB, Washington, D.C., 1997.

National Transportation Safety Board. Accident Brief, EgyptAir Flight 990, Accident Number DCA00MA006. NTSB, Washington, D.C., 2002. www.ntsb.gov.
New York Times. *36 Days*. Times Books, New York, 2001.
Oberg, J. *Red Star in Orbit*. Random House, New York, 1981.
Parasuraman, R., and V. Riley. Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors*, Vol. 39, No. 2, 1997, pp. 230–253.
Riley, V. Human Use of Automation. Unpublished Doctoral dissertation, University of Minnesota, 1994.
Stein, G. First Bode Award Address, 1990.

7.3 BREAKOUT GROUP DISCUSSION

Panelists

- Victor Riley, invited speaker;
- Bob Harvey, Brotherhood of Locomotive Engineers;
- John Grundmann, Burlington Northern Santa Fe Railway;
- Tom Raslear, Office of Research and Development, FRA; and
- Grady Cothen, Office of Safety, FRA.

Summary

Common themes emerged across stakeholders. In many cases, more than one stakeholder raised safety issues:

- Safety concerns related to human–machine interface (HMI) issues in technology revolve around technologies related to positive train control (PTC) and remote control of locomotives. The application of human factors was discussed by a number of panel members in another forum addressing the use of positive train control. Several members participate in meetings of the PTC Railroad Safety Advisory Committee (RSAC) to develop a rule for the use of signal-based processor train control systems. This forum has members from labor, management, government, and the vendors who will develop these systems for the railroads.
- Impact of technology change.
- Lack of knowledge about how new technology would impact human and system performance.
- Speed with which new technology was becoming available and pace of change.
- Challenges of having to operate multiple systems.
- Need for collaboration between railroad enterprise stakeholders.

The stakeholders feel the impact of these themes in different ways. The unique perspective of each stakeholder is discussed further below.

Perspectives of Stakeholders

The critical issues vary somewhat on the basis of the unique perspective of each stakeholder group.

Labor Perspective

1. User-centered designs are more effective than technology-centered designs.
    - Experience with PTC has given us opportunities to see what issues and potential problems will affect the HMI. As automation becomes more sophisticated, the HMI should be developed in a user-centered way and in a way that maintains the operator's skills. In a user-centered approach, the technology is designed around the needs of the operator rather than requiring the operator to adapt to the way the technology works.
    - To be responsible for safe train operations, the operator needs to understand how the technology works. The operator needs an accurate understanding and mental model of what the technology is doing. For example, if train control technology enables the use of dynamic block allocation, the operators need to understand how the system is allocating blocks. As another example, the train crew may see a (phantom) signal that makes no sense based upon his or her understanding of the situation. The mental model of system operation should match the operator's.
2. Technology change has an impact on the role of operator.
    - Other key concerns identified by labor organizations are the psychosocial implications of new technology change on the operators. The introduction of new technology may change the role of the operator. A function allocation may be needed to determine which tasks are best suited to the operator and which are best performed by the technology.
    - Depending upon how the technology is implemented, skill requirements may increase or decrease. Current job descriptions may evolve as the tasks performed by technology and people change. More complex tasks may reduce the ability of people to catch and recover from errors. Questions for labor are
        - How will the introduction of new technology affect the ability to attract the most qualified job candidates?
        - How does the introduction of new technology impact job satisfaction? Simpler tasks can increase the level of boredom and complacency contributing to a loss of situation awareness.
3. Pace of technological change makes it difficult to keep up skills.
    - Skill maintenance and training of train crews, dispatchers, and roadway workers are challenging issues. For labor organizations, the lack of knowledge and the speed of technological change are reflected in concerns about preparing to operate the new technology through phases of skill acquisition and maintenance.
    - Skill maintenance and training needs are two related issues that were identified as critical to safety and for which we need more information. Key questions are
        - How much training will be needed to learn how to operate the new technology? The need for training to understand how the technology works applies to maintenance, as well as train control. The employees who maintain the software and hardware will also need to understand how the technology operates and how to troubleshoot and fix problems to be able to maintain it properly and for it to work safely. This includes the roadway workers whose job it is to test, troubleshoot, and fix the systems.
        - If the system fails, will the operator know what to do?
        - Train crews worry about losing the necessary, highly practiced skills when the technology takes over performance of these tasks. How will the operator's situational

awareness be maintained when the operator supervises the train control system instead of controlling the train directly?

- How will operator's skills be maintained when technology can perform tasks previously performed by the operator? Will the operator become complacent or lose situational awareness?

4. Challenges of having to operate multiple systems.
   - New technologies will not simply replace old technology all at once. New technology will coexist with existing technology, particularly with respect to train control systems. The operators will need to work with multiple technologies. There is the potential for negative transfer of training, in which operators apply the knowledge they gained about one technology to another, where the knowledge is incorrect.
   - For example, in one airplane, pressing a toggle switch forward activates a control while in a different airplane pressing the toggle switch backward activates the control. These design conflicts can contribute to human errors.
   - The operation of remote control technology may require a different set of behaviors to operate safely than operating a locomotive directly. Developing a standardized interface could reduce the amount of training and the negative transfer of training. What human factors issues must be addressed (i.e., interface design, training) to foster safety?

Railroad Management Perspective

1. Pace of technological change makes it difficult to make decisions.
   - For industry management, the rapid pace of technology change affects their decisions. This begins with deciding what technology to adopt and continues through having concerns about technological obsolescence.
   - This includes the costs and benefits (cost trade-offs) in adopting a new technology. Adopting a new technology can be costly, particularly if it involves a high level of customization. Purchasing commercial off-the-shelf technology tends to be less expensive than customized technology, however, it is not always available and may not meet the railroad's operational requirements. Railroad management must show the benefits for railroad operations outweigh the costs.
   - For railroad management, safety concerns revolve around the rapid pace of technological change, which can quickly make an investment in technology obsolete. Making the business decision to adopt a new technology represents a significant challenge when the pace of new technology is advancing quickly. Speed of technology change also makes it difficult to develop consensus.
   - Railroad management is concerned as well with the risks associated with using new technology.
   - Will it work as intended? Is it reliable?
   - What are the unanticipated effects of using the new technology?
2. Challenges of having to operate multiple systems.
   - For a variety of reasons, the railroads tend to adopt new technology in incremental ways, rather than replacing an existing technology. However, the incremental approach presents challenges as well. Consider the use of an overlay train control system in which the new technology is proposed to operate without interfering with the existing technology. If the new technology fails, the safety should remain the same as it was with the existing

technology or method of operation. What are the safety implications of using multiple overlay systems? There is a concern that use of more than one new system could create new safety issues.

3. Technical challenges to meeting performance requirements.
   - Implementing new technology is associated with uncertainty. There are significant challenges to meeting performance requirements in a safety-critical environment. For example, a new braking algorithm may be developed as part of a train control system. Given the large variation in operating conditions, will the braking algorithm work as expected? Developing a braking algorithm that can handle the wide variety of railroad operating conditions is a significant challenge.

Government Perspective

1. Pace of technological change makes it difficult to keep up with human factors issues.
   - There is a lack of knowledge about how technology affects human performance. The government is concerned that the rapid pace of technology change makes it increasingly difficult to keep up with decisions about how people and technology interact.
   - Train control systems are becoming more complex. This complexity creates a larger number of interactions between people and technology about which we lack an understanding of real-world implications. For example, a variety of computer-assisted dispatch (CAD) systems currently assist dispatchers in managing track resources. Ongoing questions include
   - What does the system do?
   - How should the tasks be allocated between the operator and the technology?
   - Who makes the train-control decision, the computer or the dispatcher?
   - What is the role of the dispatcher?
   - When exceptions occur that the CAD system cannot handle, what happens?
2. Challenges in having to operate multiple systems.
   - New technology requires interoperability among different railroads so that train can move safely. The government needs to answer questions such as:
   - How well can these systems coexist?
   - What are the challenges that must be met for the interoperability of multiple technologies? How well can the dispatchers, train crews, and roadway workers manage the variety of technologies in use?
   - If interoperability is achieved, is there a way to permit scaled implementation while ensuring a good HMI in territories with multiple methods of operation and varying technologies?
3. Technical challenges to meeting performance requirements.
   - For PTC systems, there is a movement toward performance-based applications that enable railroads to develop systems that best meet their needs. Performance-based applications of train control require significant amounts of data to assist design and evaluation efforts. For new train control systems, there is a lack of information that directly addresses the safety implications of the interactions between the humans and technology.
   - Both system and human reliability will need to be determined. How will human and system reliability be determined when there is no experience with the technology? There is a need to identify the human and system failure modes.

- Human factors guidelines exist to guide the designers in the development of performance-based train control systems. An important question for the government is how to determine if the railroad enterprise is applying these guidelines appropriately. Practical guidance is needed to provide the railroad enterprise and the government with information to design and evaluate these new systems.

4. Identify best practices for user-centered design.
   - The government called for information in the form of best practices to guide the development and evaluation of new technology. For example, it was suggested that the users of the technology be involved early in the design process and developers use an iterative process for developing the system (rapid prototyping). Also, it was suggested that human-in-the-loop testing be done before the system goes into revenue service s to identify and correct unanticipated human factors issues.

Opportunities for Collaboration

Find New Ways to Work Collaboratively

The railroad enterprise recognizes the significant challenges in adopting new technology. Labor, management, government, vendors, and consultant organizations have met in a variety of forums to discuss how to address these issues. The FRA has worked with the industry through RSAC to discuss the development of rules and the use of technology. The PTC working group has explicitly addressed the use of signal-based train control systems.

Another example where different railroad enterprise groups collaborate is the Safety Assurance and Compliance Program. This program oversees the management and resolution of safety initiatives and performs special studies to improve safety on specific railroads.

Several other collaborative efforts are also under way. These projects include the North American Joint Positive Train Control to use PTC technology on a railroad corridor between St. Louis, Missouri, and Chicago, Illinois. This an effort headed by the University of Virginia to develop a method for assessing risk associated with new PTC systems. There is another effort to identify the requirements for integrating intelligent transportation systems technology at highway-railroad grade crossings.

Share Information Through Website and Paper Publications

In addition to these collaborative efforts, the railroad enterprise shares information through paper publications and web sites. The Association of American Railroads has published a variety of guidelines and recommended practices for the use of train control and other technologies. The FRA publishes its research in the paper form and electronic form at www.fra.dot.gov/.

It was noted that these collaborative efforts should continue and represent a positive environment in which to discuss the challenges posed by new and existing technology.

8. Overview of British Human Factors Research Program

ANN MILLS
Rail Safety and Standards Board

8.1 BIOGRAPHY

Ann Mills leads the human factors team at the Rail Safety and Standards Board (RSSB) in the United Kingdom. She is a chartered psychologist graduating from Cranfield University with both an MSc and Ph.D. in applied psychology. Before joining RSSB in 2001, she worked as research fellow at Cranfield University for 7 years, running internationally funded research investigating human behavior in emergencies. Ann is also a visiting professor in the Fire Safety Engineering Research and Technology Centre (FireSERT) at Ulster University.

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8.2 U.K. RAILWAY INDUSTRY STRUCTURE

Britain's railway system was restructured and privatized between 1994 and 1997. The industry now consists of separate companies, including infrastructure controllers, train and freight operating companies, rolling stock companies, and contractor companies to maintain and renew the infrastructure. Several government bodies have regulatory roles.

Network Rail, the principle infrastructure controller, owns the main national network and charges access fees to train operating companies. Network Rail is responsible for the maintenance, repair, and renewal of the track, stations, signaling and electrical control equipment, and for enhancing the network.

The RSSB's role is to provide leadership in the development of the long-term safety strategy and policy for the U.K. railway industry. The company was established April 1, 2003 (it was formally called Railway Safety), implementing one of the core sets of recommendations from the second part of Lord Cullen's public inquiry into the Ladbroke Grove train accident.

The company measures and reports on safety performance and provides safety intelligence, data, and risk information to inform safety decisions on the railways. It also manages the industry's new research and development program, and promotes safety within the rail industry and to the traveling public.

The RSSB is a not-for-profit company owned by the railway industry. The company is limited by guarantee and has a members' council, a board, and an advisory committee. It is independent of any single railway company and of their commercial interests.

As safety regulator, the Health and Safety Executive enforces statutory requirements and accepts Railway Safety Cases. It issues guidance for railway operators, undertakes inspections of new lines, monitors safety equipment and investigates accidents.

The Rail Regulator is responsible for economic regulation, while the Strategic Rail Authority has statutory functions set out in the Transport Act 2000 in relation to overall strategy and franchising of passenger train operators.

8.3 RSSB's HUMAN FACTORS TEAM

The RSSB's structure is based on two directorates: Policy and Standards and Safety Management Systems. Technical Services, within the Safety Management Systems directorate, comprises a pool of technical experts who provide high-quality advice to other departments on specialist engineering and operational matters. The department gives vital input to support decisions on safety strategy, writes the content of Railway Group Standards and other risk controls, and provides technical input to vehicle acceptance body management and to the audit function. It also supports the directorate by representing the United Kingdom in European standards development. The department is also responsible for delivering the industry's safety-related research and development program.

Disciplines include vehicles and plant engineering, electrification, track and structures, signaling and telecommunications, operations, and human factors.

Following privatization there was a lull in the numbers of human factors professionals working within the industry. As a result of an awareness of the importance of human factors issues, particularly following the Ladbroke Grove accident, the RSSB's Human Factors team has grown from one individual recruited in 2000 to a team of five professionals, all with degrees in psychology and (as a minimum) a master's degree in either human factors or ergonomics.

8.4 RSSB RAIL SAFETY RESEARCH PROGRAM

In 1996, the Davies report, *Review of Research and Development in the Railway Industry*, noted that several parts of the privatized railways found it hard to invest in research. It recommended that the government should provide research funding in the short term. The RSSB Research Programme (RSSBRP) was set up in 2001 for an initial period of 5 years, with funding from HM Government to fulfill the Davies report recommendations—at least as far as safety is concerned.

RSSB is managing the RSSBRP on behalf of the industry and its wider stakeholders; in carrying out this duty, our vision is to deliver research that identifies achievable ways of improving safety, as a contribution to meeting the expectations of society for a safe railway. There is universal agreement on the need for research. The challenge has been and continues to be to build a program that delivers achievable ways of improving safety in the most important areas.

The railways are in an era of substantial change, arising from investment in new trains, train control systems and infrastructure, new industry structures, and new regulatory approaches and directives from Europe. The RSSBRP offers the opportunity to ensure safety, built in as a fundamental element during these changes.

The research carried out in the RSSBRP will offer new insights and lead to a greater understanding of the risks and the controls needed to mitigate these risks. It plans to pull together and build on existing knowledge, including experience from across Europe and internationally. The development element of research and development will also feature strongly within the research program, for example creating and piloting new products or processes, or producing good practice guides. There will also be some elements of radical, blue skies research where it's needed.

The RSSBRP (Figure 8-1) is now fully under way, with research being conducted across seven broad topic areas divided into 24 themes, ranging from the engineering of the wheel–rail interface, through human factors and operations research, to policy issues such as the tolerability of risk. It should be acknowledged that while there is a separate human factors theme, there are many research projects across the broad spectrum of the research themes that have a significant human factors element that is being investigated.

Outputs from research will include prototype products, good practice guidance, new training materials, and recommended new risk controls to be mandated via Railway Group Standards. The research program should result in the development and application of new products and practices that will secure improved safety for passengers, customers, workers, and neighbors.

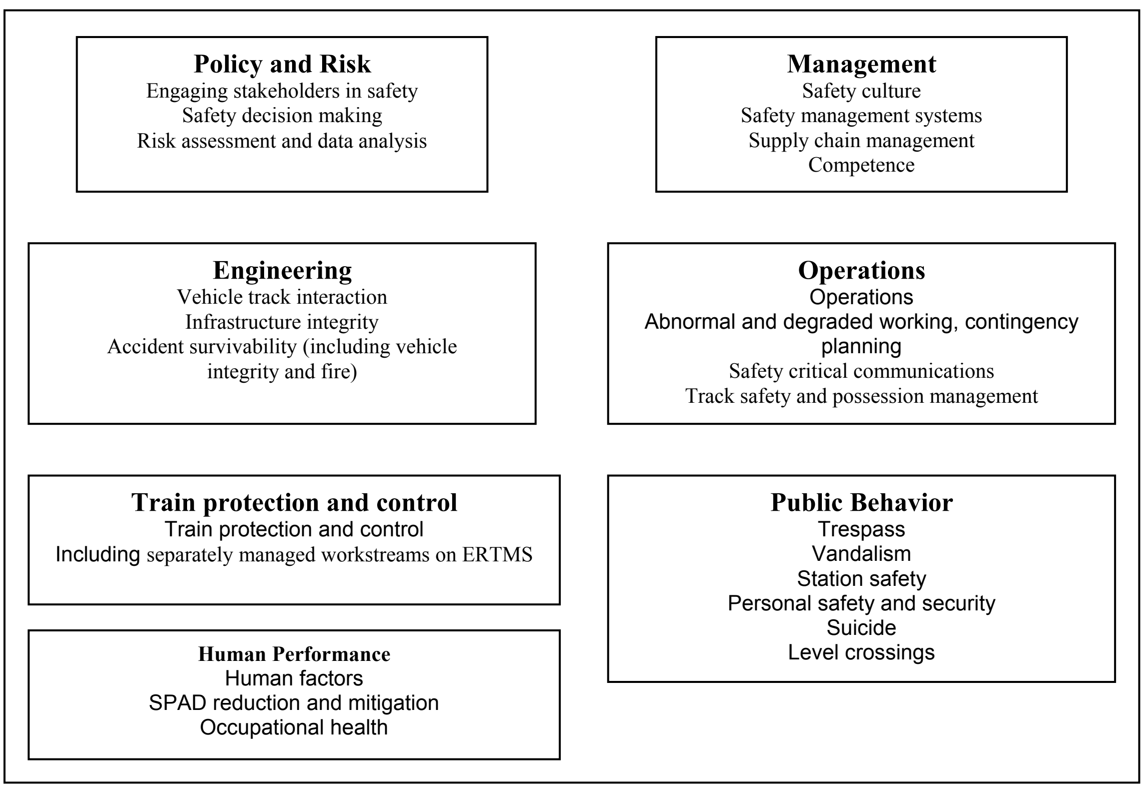

FIGURE 8-1 RSSBRP.

Consultation with stakeholders (Figure 8-2) is another key activity for the research program, both during the initial stages of defining the scope of the program and in ensuring that research continues to meet the needs of the rail industry. Industry involvement in the entire process is crucial to the research programmer's success. For each research theme there is a lead stakeholder group, whose role is to advise on the governing strategies, consider research proposals and help to integrate the results into the mainstream of industry activity.

Examples of Human Factors Research

The tables below, Tables 8-1 and 8-2, provide a summary of recently completed and current research projects respectively. Table 8-3 provides a list of proposed research to be initiated in the forthcoming research year (April 2004). It should be noted that these tables only contain work that the human factors team are leading; for a complete list of ongoing research please refer to the RSSB website at www.rssb.co.uk.

Work is currently under way to scope further work for the forthcoming years program of research (April 2004–2005), particularly in the areas of trackside safety and maintenance issues.

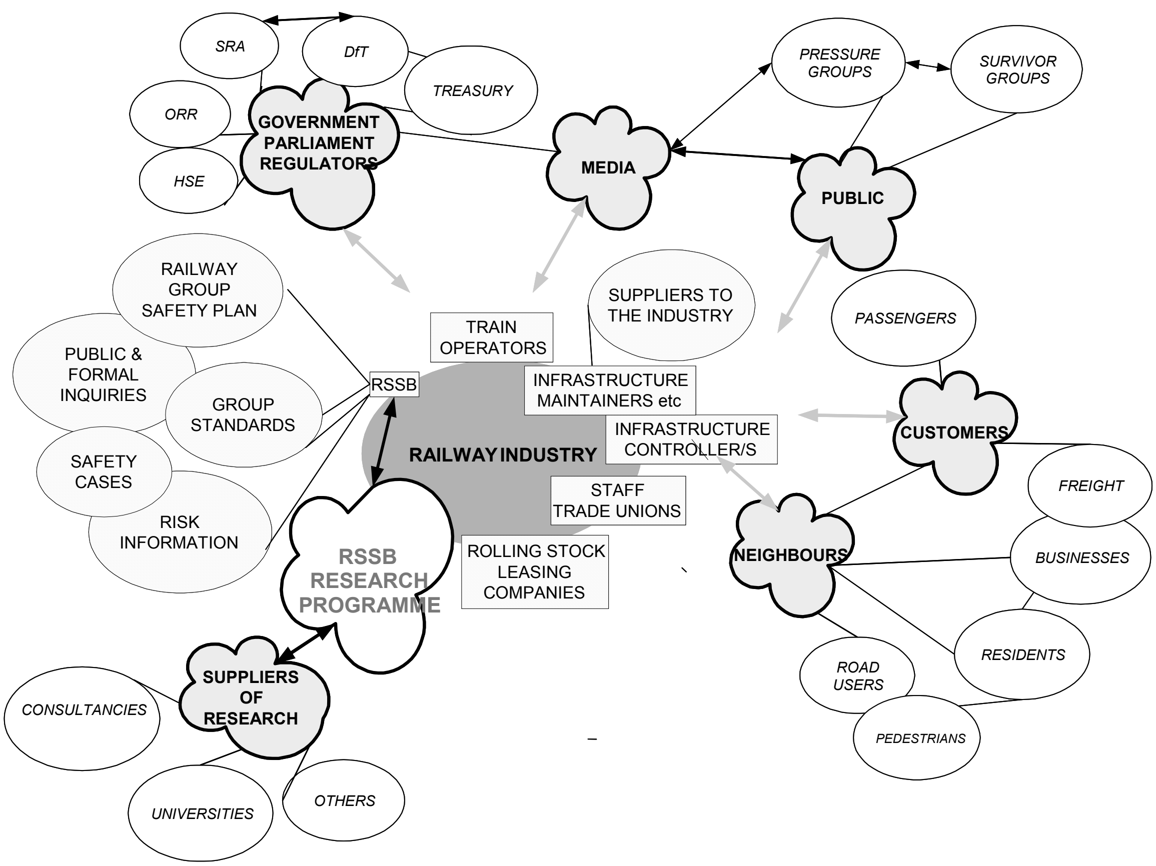

FIGURE 8-2 RSSBRP stakeholders.

TABLE 8-1 Completed Research

Project Title	Research Theme
Human Factors	
Illuminated signals background verification	To critically examine test results (based on simple computer simulation) that show a significant reduction in red aspect detection time when a white illuminated background is used in place of a conventional background.
Core data	To provide a whole industry database of human error incidents in standard categories. This will give greater knowledge of human error occurrence, leading to improvements in risk assessment capability and the associated control measures.
Lineside speed signage	To consider the human factors issues associated with train drivers being able to locate, read and obey lineside signs when there are several speeds displayed at the line side.
Signals Passed at Danger (SPAD) Reduction and Mitigation	
Drivers reminder appliance (DRA)	To improve understanding of the current usage of the passive and active DRA systems including human factors, reliability, and operational factors. The research will develop strategies that support the standardization of practices associated with the current driver-set DRA system, and to understand and evaluate the safety benefits of the automatic warning system- (AWS-) set DRA system.
Driver vigilance devices	To gain a fundamental understanding of the underlying physiological characteristics that could be used to monitor and evaluate driver vigilance. The project will provide an overview of vigilance devices being developed across industries. It will go on to consider their suitability for the rail environment and identify the most suitable devices for evaluation in the workplace.
Accident Survivability	
Emergency door release	To establish best practice in this area including the use and placement of relevant pictogram-based signs, and illumination of signs and release handles
Emergency hammers	To establish best practice on the numbers and locations of hammers, associated pictogram-based signage, illumination of signs and emergency hammers together with an assessment of the feasibility of linking the release of the hammers with activation of the passenger alarm system, as well as an assessment of alternatives to hammers.
Communications technology	To understand what safety benefits GSM-R will provide and by when, and what additional functionality would be needed to fully address the recommendations from Part 1 of the Cullen report into Ladbroke Grove, how this could be achieved, and when these could be provided.
New escape routes	To evaluate the feasibility of, and the risks and benefits from, the installations of escape hatches, and the replacement of fixed windows with removable windows.
Additional emergency lighting	To consider the use and effectiveness of "snap wands" and "way finding directional lighting systems" as supplementary means of providing lighting in an emergency.
Accident scenario development	To define accident scenarios starting from the initial event (e.g., SPAD) through to the end point. All relevant scenarios must be considered (e.g., need to consider speed, direction, location, loading, vehicles involved, nature of vehicles, external conditions) and modeled.
Track Safety and Possession Management	
Root cause analysis of red zone working	To undertake a position analysis to establish the amount of red zone working; to determine what is involved, who is involved and what the barriers are to safer working in the track environment.
Root Cause Phase 2	Phase 2 of the above project involves extending the research from the single zone investigated in Phase 1 (i.e., Midland Zone) to the whole of Railtrack Controlled Infrastructure.
Trackside safety research	To examine the behavior of trackside workers and determine why unsafe acts occur. It identifies some practical interventions that could help to minimize accidents and incidents. The report was commissioned jointly by Railway Safety and the Infrastructure Safety Liaison Group (ISLG), and was prepared by Cranfield University.

TABLE 8-2 Examples of Current Human Factors Research

Project Title	Research Theme	Completion Date
Human Factors		
Development of Human Error Assessment and Reduction Technique (HEART)	To assess the feasibility of adapting HEART or an equivalent methodology to the railway industry and to develop, test and validate, and deliver the selected methodology for use by the industry. The HEART methodology was developed mainly for use in the nuclear industry and therefore it is difficult to apply directly to railway environments.	Q1, 2004
Human Factors CD Edition 3	To disseminate railway-related human factors research/knowledge. This work updates the existing version of the CD-Rom.	Q3, 2003
Fatigue and shift work	To understand the risks of current shift patterns, and develop strategies for risk reduction and control. The project will measure baseline risk associated with current rostering/shiftwork patterns, propose and test risk-reduction strategies, design improved approaches, and improve monitoring systems.	Q1, 2005
Driver simulator for human factors research	To procure a driving cab simulator for the purpose of conducting research, particularly in the field of human factors (e.g., cab ergonomics, fatigue, concentration, visual acuity, communications, etc.). The simulator may also be used for research relating to driver training, performance monitoring and operating scenario development.	
Safety critical rule compliance	To improve the level of compliance with safety rules and practices (the most obvious being the rule book), while clarifying the concept of compliance. The scope of the work is focused on those railway personnel that use the rulebook in their day-to-day activities and the people who supervise and manage them. It covers compliance with the rulebook, standards and company specific procedures.	Q2, 2004
Teamwork in the rail industry	To define the different operational teams that there are on the railway and to develop best practices in team work to improve safety and performance for normal, abnormal, degraded and emergency operational scenarios.	Q2, 2004
Workload assessment	To define the requirements of a tool to assess workload, and to evaluate existing workload assessment methods to determine whether they meet those requirements.	Q2, 2004
Driver error data collection	To support the development and use of error-tolerant systems through an improved understanding of driver error factors. It will focus on where different performance levels occur in different populations despite similar environments and tasks. The project will focus on potential issues relating to reliance on protective devices and the issue of "cold starts."	Q3, 2004
User information requirements	To understand the information that is needed by different railway "user" populations (including train drivers, signalers and trackside workers) in order to complete their tasks. Conducting task analyses will provide a basis to determine when the information is needed and how it should be communicated. This will also support more effective ergonomics design, e.g., of train cab environments.	Q2, 2004

continued

TABLE 8-2 (*continued*) **Examples of Current Human Factors Research**

Project Title	Research Theme	Completion Date
Human Factors		
The future role of the train driver	To consider the future role of the train driver, and a description of the key attributes of and changes to drivers' roles, tasks and work organization in the next 5, 10, and 15 years. The project aims to produce an agreed model for the design and future specification and development of train systems where a driver forms part of that system.	Q2, 2005
Key factors influencing signal detection in drivers	To consider all driver visual strategies when driving routes. The work will build on a previous Railway Safety project, which piloted the collection of driver visual strategy data.	Q4, 2004
The impact of experience erosion on safety	To define what the baseline requirement is for maintaining experience and what the trends are (actual versus perceived).	Q1, 2004
Safety Culture		
Measurement and benchmarking of safety culture	To understand • The components of a good safety culture and develop a model to assist the industry in making improvements • How safety culture is measured in the industry and establish a benchmark for Railway Group members • How to communicate and implement safety culture initiatives within the UK rail industry	Q3, 2003
Train Protection and Control		
Driver task analysis and operational specification	To establish a method for assessing existing driver workload and workload under European Rail Train Management System (ERTMS) operation. Risks associated with driver overload or underload will be established, and control measures to reduce safety risk related to driver workload under ERTMS will be proposed.	Q4, 2003
SPAD Reduction and Mitigation		
Signal sighting: strategies for managing conflicting requirements	To provide a framework that can be used by signal sighting committees to resolve conflicting requirements. It will identify the principle requirements for a well-sighted signal and analyze the potential conflicts that can occur between these requirements.	Q4, 2003
Extending the use of AWS	To establish whether any extension of the use of (Automatic Warning System) AWS could lead to a change in the risk of human failures leading to a SPAD, the direction and nature of any change in risk, and any specific circumstances where human reliability would be adversely affected.	Q4, 2003
The roles of data recorders in improving railway safety	To determine to what extent train data recorders (sometimes referred to as On-Train Monitoring and Recording equipment or OTMRs) can assist the industry in further reducing and mitigating against SPADs, over-speeding, etc.	Q2, 2003
Common factors in SPAD-ed signals	To address a list of 20 common causes of SPADs, which has been accepted by Railtrack and HSE. The first task is to identify which of the known common SPAD causal factors can be addressed immediately without further research. The second is what research is required to be able to address any remaining known factors and to identify further new factors.	Q2, 2004

continued

TABLE 8-2 (*continued*) **Examples of Current HF Research**

Project Title	Research Theme	Completion Date
Accident Survivability/Vehicle Integrity/Fire		
Human factors evacuation and communications	This research builds on earlier work that investigated technologies to support staff-to-passenger and passenger-to-staff communications. The study will investigate human behavior in the full range of abnormal operations as well as in incidents and accidents. The study will identify the most appropriate procedures/communications/ equipment, etc., in order to manage passengers in each of the scenarios.	Q4, 2004
Passenger survey	To determine: • What, if any, safety concerns passengers have about traveling by train? • How significant are these safety concerns compared with non-safety concerns related to railway travel (e.g., reliability, punctuality, comfort)? • What measures do passengers recognize as already in place to address safety concerns? • Are passengers satisfied with the safety measures identified above? • What, if anything, would passengers like to see the industry do to address any remaining safety concerns?	Q4,2003
Communications		
Safety critical communications	To understand and model the impact that the quality of safety-critical communications between drivers and signalers has on railway safety, and identify measures to bring about an improvement. The research will also develop a process for the quantified assessment of driver/signaler safety-critical communications.	Q3, 2004
Stations		
Managing large events and perturbations	To look at better ways of planning for and managing major events such as sports and concerts, and other major deviations from normal levels of activity.	Q3,2004
Operations		
Safety critical staff error investigation	To develop a framework for the investigation of faults, errors and failures, and their underlying causes, which are made by safety critical staff.	Q4, 2003
Level Crossings		
User Worked Crossings	To understand the decision-making process of users related to when to cross, and their behavior at these types of crossings. The research will develop appropriate interventions on the basis of this data.	Q2, 2004

TABLE 8-3 Examples of Future Research Currently Scoped

Project Title	Research Theme
Human Factors	
Driver route knowledge	To undertake research on driver route knowledge in order to understand the fundamental role it plays in safe train operations and how this may change in the future. The research will answer the following key questions: • What constitutes route knowledge and what are its component parts? • How is route knowledge acquired? • How should route knowledge be trained and assessed? • How should route knowledge be maintained? • How will future change affect the acquisition and use of route knowledge? • What is the role of route knowledge in SPAD-related incidents? What strategies could the industry adopt to best support the needs for route knowledge (both now and in the future), to reduce associated incidents?
Sleep apnea	To investigate the prevalence of this disorder within the railway industry. The research will develop a screening tool to help identify those individuals who are potentially suffering from the disorder.
SPAD Reduction and Mitigation	
Role of the driver manager	To determine "best practices" in driver management including the competencies, approaches and frameworks for good driver management. This will be based on the current status of worldwide knowledge and practice in the area of driver management. This project will consider all aspects of driver management, e.g., selection, training, assessment, ongoing monitoring and management.
The impact of different roles in reducing SPADs	To determine the full impact on SPAD causation of all roles that have a stake in SPAD reduction and mitigation. This will be a holistic study encompassing a broad range of work design factors (e.g., organization structures, communication, etc.).
Monitoring people in key safety critical roles	To look at measures to proactively identify any developing potential for human error. The research is specifically not to focus exclusively on drivers and signalers, but must capture all safety-critical roles within the 'system' that have a stake in SPADs.
Signal alignment devices	To identify the potential for simulation technology to assist in the design of signal sighting To produce a prototype of a standardized tool & method for checking signal alignment during installation To produce a prototype of a standardized tool & method for checking signal alignment following an incident.
Trackside reminder devices	To identify the impact of trackside reminder devices on the potential for SPADs, to identify deficiencies and recommend improvements.
European Rail Train Management System (ERTMS)	
Driver–machine interface (DMI) selection	To define the process for DMI requirements selection, utilization of the planning area information on the in-cab DMI and risk-based criteria for managing heritage TPWS.
External driver information under ERTMS specification	To provide guidance on the design, layout and content of external driver information under UK ERTMS operation and determine solutions to any conflict between internal and external information sources.

continued

TABLE 8-3 (*continued*) **Examples of Future Research Currently Scoped**

Project Title	Research Theme
European Rail Train Management System (ERTMS)	
ERTMS training needs analysis	To research, define and propose a suitable process for generating individual training needs analyses for each safety-critical grade of employee involved.
Role of the Control Operator and ERTMS	To develop a full understanding of the impact that ERTMS, Levels 1, 2, 3, will have on control operator functions, determine potential failure points and identify any systems/equipment design features required to minimize risks of operator failure
Safety Culture	
Understanding influences on safety culture	To focus on the impact of leadership (from senior management through to front line supervision) on safety culture.
Understanding communications risks across the railway	To look at the causes and effects of communications errors made after the occurrence of an incident on the railway, and the development of proposals for remedial action.
Stations	
Flooring materials for stations	To consider flooring materials used at stations—including floors, stairs, ramps, escalators, etc.—and passenger behavior, which together lead to a high level of slips, trips and falls.
Use of tactile surfaces and footways at stations	To look at the type and location of tactile surfaces at stations and the possible use of new materials. It will consider the safety implications of using similar materials as guide paths to help people with certain disabilities to navigate their way around stations. It will also include a comparison with what is done on other railways and by other public building operators (such as airports and shopping malls).
Guidance systems for people with disabilities	To consider the further development of guides to large stations for people with sensory impairments and learning difficulties to improve their spatial awareness and to reduce accidents.
Accidents at stations affecting people with disabilities	To collect data on accidents at stations affecting people with various disabilities, to help in identifying where further action is needed.
Platform screen doors at stations	To look at the benefits which could accrue from the wider application of platform screen doors (or other equivalent technologies)?
Gaps between platforms and trains.	To consider what mitigation measures would be appropriate, and how they could be implemented, to reduce the risks from the train/ platform gap.
Occupational Health	
Occupational stress and Post Traumatic Stress Disorder (PTSD)	To examine the different roles, key stressors and likely levels of stress associated with each job type/work task and work setting investigated. It will consider whether the relationship between job types/work tasks, work setting and stressors change, depending on whether individuals received 'treatment' for PTSD.
Managing workplace trauma	To look at intervention, managing symptoms, monitoring arrangements, training and competence. It will consider what interventions have the best results in reducing trauma symptoms. Railway Safety is a part of a consortium funding the work, which is primarily being managed by the British Occupational Health Research Foundation.

9. Summary and Next Steps

9.1 ONE-YEAR UPDATE

Ten months after the meeting took place, attendees were asked to provide their input and views on what this meeting accomplished and describe the next steps that they plan to take in areas of safety. A summary of that information by content area is listed below. (The raw data, using the attendees' own words as much as possible, are in the tables, Table 9-1 and Table 9-2. In both tables, information is listed by the speaker's stakeholder group.)

Most comments were submitted in writing by vendors and suppliers and government representatives. Perhaps this was because these groups were the most able to commit to specific "next steps."

In general, although almost a year had passed since the meeting, there was a great deal of overlap between what was stated at this time and what was said in September 2002 on the meeting evaluation form (see Volume 2). At the meeting, the focus was on specific research areas. Comments made in the follow-up tended to be more high-level and process-oriented.

In retrospect, the greatest accomplishment was the synergy created by the broad scope of the membership of the subcommittee, and the quality and openness of the dialogue that took place. The international speakers provided an appreciated worldwide perspective.

For the railroad enterprise, this meeting was seen as a good first step at creating a dialogue among stakeholders. It was suggested in a variety of ways that a similar forum should continue the discussion of research needs and funding. Many comments began with "continue the dialogue." One participant said, "There is a need for a continuing discussion among government, labor, railroad management and researchers to improve safety in railroads." Another participant encouraged "participation by all industry segments; include and even expand labor's participation from the beginning." Others noted the overlapping research and the need to "share human factors presentations with railroad R&D [research and development] people" and internationally "leverage our knowledge." One person suggested, "Try to capitalize on the synergy at this meeting through NARAP [North American Rail Alertness Partnership] or other industry working group."

Among the comments received, it was noted that "there is still much to be done in the area of understanding railroad operational safety and the human in railroad operations." The complexity of most issues will require many different approaches. Since there are also "synergies between 'problems' … we need to move toward more joint approaches in raising these issues," through more dialogues. To this end, better outcome measures are also needed.

Current and future research projects, and research issues are listed below. These studies and issues may have been mentioned informally at the September 2002 midyear meeting, but were not generally captured and documented at that time.

- FRA-sponsored experiments are currently in progress to measure the relationships between fatigue and operator performance—they monitor alertness and operator performance simultaneously in a simulator.
- One union is participating in an experimental sleep and work cycle 2-week trial of selected members.

- Michael Coplen and Susan Labin are developing a generic instrument to determine if training results in behavior change.
- Michael Coplen and Joyce Ranney are doing research on leading indicators.
- The United Kingdom is forging links between different parties while forging a better understanding of the industry culture. A current project is to measure culture.

Other statements about research that is needed included the following.

Training

- There is a lack of standards and an industrywide variance in training. Make high-quality training of employees a top priority.
- Evaluate the effectiveness of training.

Fatigue

- Study the effects of cumulative fatigue on human performance. Find acceptable solutions and develop with a menu of pilot projects to find a regular dependable schedule.
- The connection between fatigue and economics is difficult. Explore the development of better tools with other organizations (i.e., the military).
- Gain a better understanding of issues relating to fatigue, modeling, and countermeasures.

Safety Culture

- Expand the safety culture programs at railroad.
- In order to improve the safety reporting culture, we need to make changes in all the stakeholder groups (government, industry, labor).
- Include positive culture change benefits in all negotiations.
- The term "safety culture" is used so many different ways it is useless. We need more useful terms to further the research area.

Other

- We need to study occupational stress and post-traumatic stress disorder (PTSD), how it affects engineers and signalmen after they have been involved in an accident.
- We need simulator studies on the effects of positive train control (PTC).

Table 9-1 breaks down the comments by the stakeholder group of the speaker.

TABLE 9-1 Meeting Accomplishments

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers /Academics
General				
		California is a really neat place for a meeting		
Synergy/Participation/Diversity				
	It was good to see what was happening at international level.	There was a lot of synergy.	The diversity of the subcommittee leads to a healthy debate over the more important research projects.	
I was impressed with the labor turnout.	Having the meeting in California allowed/enabled new people to attend.		I enjoyed/found value in seeing what others outside the industry are doing in areas of fatigue, safety culture, and technology. It supports my research and expands my ability to conduct effective, informal research	
			The industry as a whole—government, labor, railroads—are cooperating now more than ever; synergy	
Safety Culture				
		Safety culture is the most important factor in every accident.		

9.2 NEXT STEPS FOR RAILROAD ENTERPRISE

The purpose of the Railroad Operational Safety Subcommittee is to discuss, identify, and monitor key research areas. It will attempt to “shape” the research direction and move the railroad enterprise forward, but it is not a research or funding body. It hopes to provide food for thought and stimulate private-sector research. The committee will continue to offer opportunities for dialogue. In addition, it will track and collect research and develop a process to distribute research reports to members and other stakeholders.

There appears to be considerable support for continuing a forum for open dialogue across safety areas with all stakeholders at an international level.

Table 9-2 breaks down the comments by the stakeholder group of the speaker.

TABLE 9-2 Next Steps

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers/ Academics
		General		
		Many issues are highly multifaceted and require multiple approaches to completely understand and remediate.	Improve industry communications to ensure that research efforts are not replicated.	
	We are working on the development of a generic instrument to determine if training results in behavior change.	I am working on leading indicators in research I am conducting.	Based on the number of RPS (52) it is clear there is still much to be done in the area of understanding railroad operational safety and the human in railroad operations.	
			The utility and applicability of research projects should be given thoughtful consideration before money is invested in research. This forum makes that possible.	
			One consultant made this commitment, [I will]: • Continue to provide feedback when requested; • Participate in meetings; and • Continue to advocate for improved industry safety.	

continued

TABLE 9-2 (*continued*) **Next Steps**

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers/ Academics
Synergy/Participation/Diversity				
It is important to include and even expand labor's participation to get at problems at the beginning instead of after the fact.		There is a need for a continuing discussion among government, labor, railroad management, and researchers to improve safety in railroads.	It is important to encourage continued participation by all industry segments.	
		There is an amazing overlap in research needs between United States and the United Kingdom. I hope we can keep sharing findings.		
		Try to capitalize on the synergy at this meeting through NARAP or other industry working group.		
Training				
There is a lack of standards and an industry wide variance in training. Make training of employees a top priority.	Evaluate the effectiveness of training. Propose an industry conversation on this; the current BAA isn't going anywhere.			
Fatigue				
Need to study occupational stress (and PTSD), how it affects engineers and signalmen after they have been involved in an accident.	A discussion of a research project convinced us to go to Phase 2 of a study.	There are a number of international efforts in railroad fatigue. Become connected with these folks to leveraging more our knowledge.		

continued

TABLE 9-2 (*continued*) **Next Steps**

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers/ Academics
Fatigue				
• Study the effects of cumulative fatigue on human performance. • Continue a dialogue with industry to find acceptable solutions. • Develop a menu of pilot projects to find a regular dependable schedule.		The connection between fatigue and economics is difficult. Explore the development of better tools with others (i.e., the military).		
One union is participating in a sleep and work cycle 2-week trial of selected members		Measurements of relationships between fatigue and operator performance.		
		Experiments are currently in progress to measure the relationships between fatigue and operator performance—they monitor alertness and operator performance simultaneously in a simulator.		

continued

TABLE 9-2 (*continued*) **Next Steps**

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers/ Academics
Fatigue				
		Understanding of issues relating to fatigue, modeling, and countermeasures—despite differences in working practices, e.g., "on call," many tried interventions/approaches developed in United States are being fed into our existing work researching fatigue-related issues potentially leading to changes in standards. However any change will have to be shown to be of economic benefit.		
		Better outcome measures are important for fatigue factors.		
		We need simulator studies on the effects of PTC—initiated procurement and development of simulation capabilities to support such studies.		
Safety Culture				
		There are synergies between "problems" in balancing performance/ safety issues and the culture of industry and its different parts, particularly the "blame" culture. Therefore we need to move toward more joint approaches in raising these issues.		

continued

TABLE 9-2 (*continued*) **Next Steps**

Labor	Industry Management	Government	Vendors/ Suppliers	Researchers/ Academics
Safety Culture				
(We need) acceptance and expectations of all parties that there will be frequent safety failures.		The term "safety culture" is used so many different ways it is useless. We need more useful terms to further the research area.		
Expand safety culture programs at railroad.		In order to improve the safety reporting culture, we need to make changes in all the stakeholder groups (government, industry, labor).		
Include positive culture change benefits in all negotiations.		Better outcome measures are important for safety culture factors.		
		The United Kingdom is forging links between different parties while forging a better understanding of the industry culture. (Current project is to measure culture.)		
Technology				
	Share human factors presentations with railroad R&D people. We need a better understanding of how they impact each other.	There is concern over changes to technologies currently being developed in the United Kingdom (ERTHS, which is similar to PTC) and that we will not understand implications of these changes from a human factors performance before designs of new systems are frozen. We need to understand that changing technology changes the types of errors, but doesn't remove them.		

APPENDIX A

Detailed Meeting Agenda

	Times	Activities	Presenter
September 10	2:00 p.m.	Introduction to Meeting	Don Sussman
	2:20 p.m.	Research Problem Statements	Tom Rockwell
	5:30 p.m.	Adjourn	
September 11	7:30 a.m.	*Breakfast at the TRB Center*	
	8:00 a.m.	Welcome; Moment of Remembrance	Don Sussman
	8:05 a.m.	Meeting Agenda	Steve Popkin
	8:20 a.m.	Fatigue and Railroad Operations: A European Perspective	Göran Kecklund
	9:20 a.m.	Safety Culture in Modern Railroads	Neville Moray
	10:20 a.m.	*Break*	
	10:35 a.m.	Technical Advancements	Victor Riley
	11:35 a.m.	Audience Discussion	
	11:55 a.m.	Instructions for Breakout Discussion Sessions	Steve Popkin
	12:00 p.m.	Lunch and Speaker: Railway Safety in the United Kingdom	Ann Mills
	1:30 p.m.	Concurrent Panels on Fatigue, Safety Culture, and Technology	
	3:30 p.m.	*Break*	
	3:45 p.m.	Continuation of Concurrent Panels	
	5:30 p.m.	Adjourn; Reception at TRB Center	
September 12	8:00 a.m.	*Breakfast at the TRB Center*	
	8:30 a.m.	Review of Agenda	Steve Popkin
	8:40 a.m.	Fatigue Report	Judy Gertler
	9:30 a.m.	Technology Report	Jordan Multer
	10:20 a.m.	*Break*	
	10:35 a.m.	Safety Culture Report	Steve Reinach
	11:25 a.m.	Discussion of Next Steps and Concluding Remarks	Don Sussman
	11:45 a.m.	*Adjourn*	

APPENDIX B

Generated Research Problem Statements and Breakdown by Stakeholder

COMPLETE LIST OF BRAINSTORMED PROBLEM STATEMENTS

Brainstorming resulted in a list of 52 unedited and unmerged research problem statements (RPSs). Table B-1 lists these problem statements. For the submitter, the following categories indicate their stakeholder group affiliation:

- L = railroad labor
- M = railroad management
- G = government
- R = research/academic
- S = supplier

TABLE B-1 Research Problem Statements

Problem Statements	Submitter
A. Effects of FELA on safety culture and performance in railroad (RR) and other industries.	R
B. What are the organizational cultures affecting safety in the RR?	R
C. (Training) tools to help employees identify risks.	M
D. Risk identification and options to mitigate.	M
E. Can behavior-based safety improve safety outcomes and performance?	G
F. Use of wrist actigraphs and feedback to improve sleep hygiene and planning for countermeasures.	G
G. Effect of PTC on nature of dispatcher's job and workload.	S
H. Develop human performance measures to be validated with simulators and revenue-service.	G
I. Impact of workload on yardmasters, and how that affects yard crews and safety.	R
J. Effective metrics for evaluating human factors programs/interventions.	S
K. Effect of environment on human performance in RR.	L
L. Baseline on HOS and safety measures (accidents, incidents, rules violations)	L
M. How to tailor information about fatigue management for different audiences.	M
N. Relationships among lifestyle-related health risks, chronic health risks, and safety. (diet, diabetes, etc)	M
O. Effects of fatigue on family life and implications for work safety.	M
P. Crew resource management: Can checklists developed in aviation be used in RR?	M
Q. Explore ways to deliver information more effectively (technologies, information structure, etc.)	M
R. Cab design effects on lumbar injuries.	G
S. Simulator studies examining effects of PTC on crew performance.	S

continued

TABLE B-1 (*continued*) **Research Problem Statements**

Problem Statements	Submitter
T. Criteria for deciding the allocation of control functions between humans and computers.	G
U. Personal risk-taking behaviors and effects on RR safety.	S
V. Relationship between fatigue and individual behaviors (encompassing social and organizational factors) (e.g., you can't layoff).	R
W. What technology is available to enhance alertness?	M
X. What is the effect of safety committee leadership on employee safety?	M
Y. Impacts of safety culture on safety performance.	G
Z. Non-accident performance measures that can help predict incidence of safety problems.	G
AA. Fatigue in the nonoperating crafts.	S
BB. How to normalize accident and injury data. (train miles, hours, etc.)	G
CC. Relevant components of fatigue recovery (family time, social obligations, etc)	G
DD. What behavior based safety techniques can improve sleep hygiene?	R
EE. Impact of unpredicted (extended) work events on operator/technician performance and safety.	S
FF. Effects of phantom signals (mode awareness) (malfunctions of computerized control systems) on crew performance.	L
GG. How to measure workload on signalmen.	L
HH. Uses of wrist actigraph in promoting sleep hygiene. And comparisons with low-tech methods of improving sleep hygiene.	M
II. Measurements of effectiveness of safety interventions of any sort.	M
JJ. How can computer communication technologies be used to support cross-craft coordination?	S
KK. How to discover and model the antecedents and causal chains of operational errors.	G
LL. How to determine when information overload occurs? And impact on safety.	M
MM. Incidence of fatigue in train crews based on models of work schedule data.	G
NN. Human reliability estimates for various RR operations.	G
OO. Sensitivity of fatigue models to performance-related measures?	G
PP. Extent to which labor-management perception of safety culture affects safety practices and decision making.	R
QQ. Relationship, if any, between incentives, hours worked and safety.	S
RR. An individual RR employee can implement what approaches to fatigue management?	L
SS. Have the United States and Canada achieved different rail safety performance? Regulatory differences.	M
TT. What critical safety information is needed across crafts?	G
UU. Error taxonomy for RR, and compare with other modes.	G
VV. How do teamwork-related activities contribute to creation, recovery from, and prevention of errors?	G
WW. Effects of high-speed ops on all of the above.	R
XX. How can we predict human error resulting from new equipment, policies, and procedures?	S
YY. Relationship between fatigue and operator performance.	R
ZZ. Oxygen concentration and air temperature effects on operator alertness.	S

Tables B-2 through B-5 break down these 52 RPSs into four categories: fatigue, culture, technologies, and other and list the number of stakeholder votes for each problem statement.

TABLE B-2 Fatigue-Related RPSs

Fatigue	Votes
A. Use of wrist actigraphs and feedback to improve sleep hygiene and planning for countermeasures. Uses of wrist actigraph in promoting sleep hygiene. And comparisons with low-tech methods of improving sleep hygiene.	25
B. Effect of PTC on nature of dispatcher's job and workload.	7
C. Impact of workload on yardmasters, and how that affects yard crews and safety.	7
D. Effective metrics for evaluating human factors programs/interventions.	3
E. Effect of environment on human performance in RR, including air temperature and gas concentrations.	13
F. Baseline on HOS and safety measures (accidents, incidents, rules violations)	7
G. How to tailor information about fatigue management for different audiences.	
H. Effects of fatigue on family life and implications for work safety.	6
I. Relationship between fatigue and individual behaviors (encompassing social and organizational factors) (e.g., you can't layoff).	7
J. What technology is available to enhance alertness?	23
K. Fatigue in the non-operating crafts.	3
L. Relevant components of fatigue recovery (family time, social obligations, etc)	10
M. What behavior based safety techniques can improve sleep hygiene?	11
N. Impact of unpredicted (extended) work events on operator/technician performance and safety.	7
O. How to measure workload on signalmen.	6
P. Incidence of fatigue in train crews based on models of work schedule data.	23
Q. Sensitivity of fatigue models to performance-related measures? Relationship between fatigue and operator performance.	23
R. Relationship, if any, between incentives, hours worked and safety.	5
S. An individual RR employee can implement what approaches to fatigue management?	17

TABLE B-3 Culture- and Educated-Related RPSs

Culture and Education:	Votes
A. Effects of FELA on safety culture and performance in RR and other industries.	20
B. What are the organizational cultures affecting safety in the RR?	12
C. Training and tools to help employees identify risks.	19
D. Risk identification and options to mitigate.	14
E. Can behavior-based safety improve safety outcomes and performance?	10
F. Relationships among lifestyle-related health risks, chronic health risks and safety. (diet, diabetes, etc)	7
G. Crew resource management: Can checklists developed in aviation be used in RR?	13
H. Personal risk-taking behaviors and effects on RR safety.	5
I. What is the effect of safety committee leadership on employee safety?	7
J. Impacts of safety culture on safety performance. Extent to which labor-management perception of safety culture affects safety practices and decision making	34
K. Non-accident performance measures that can help predict incidence of safety problems.	0
L. How to discover and model the antecedents and causal chains of operational errors.	21
M. Extent to which labor-management perception of safety culture affects safety practices and decision making.	0
N. Have the United States and Canada achieved different rail safety performance? Regulatory differences.	14
O. What critical safety information is needed across crafts?	0
P. Error taxonomy for RR, and compare with other modes.	18
Q. How do teamwork-related activities contribute to creation, recovery from, and prevention of errors?	6

TABLE B-4 Technology-Related RPSs

Technologies	Votes
A. Explore ways to deliver information more effectively (technologies, information structure, etc.) How to tailor information about fatigue management for different audiences.	28
B. Simulator studies examining effects of PTC on crew performance.	24
C. Criteria for deciding the allocation of control functions between humans and computers.	23
D. Effects of phantom signals (mode awareness) (malfunctions of computerized control systems) on crew performance.	3
E. How can computer communications technologies be used to support cross-craft coordination?	6
F. How to determine when information overload occurs? And impact on safety.	10

TABLE B-5 Other RPSs

Other	Votes
A. Distribution of glance data for engineers.	14
B. Cab design effects on lumbar injuries.	0
C. How to normalize accident and injury data (train miles, hours, etc.).	9
D. Measurements of effectiveness of safety interventions of any sort. Relationship between fatigue and operator performance. Develop human performance measures to be validated with simulators and revenue-service.	46
E. Human reliability estimates for various RR operations.	0
F. Effects of high speed operations on all of the above.	7
G. How can we predict human error resulting from new equipment, policies, and procedures?	21

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APPENDIX C

Attendees

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General Manager, Safety and Regulatory Affairs
Canadian Pacific Railway

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Human Factors Program Manager
Federal Railroad Administration

Grady Cothen
Deputy Associate Administrator for Safety Standards and Program Development
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Drew Dawson
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Royal Gelder
Director, Risk Management and Planning
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