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Communication and Coordination Demands of Railroad Roadway Worker Activities and Implications for New Technology

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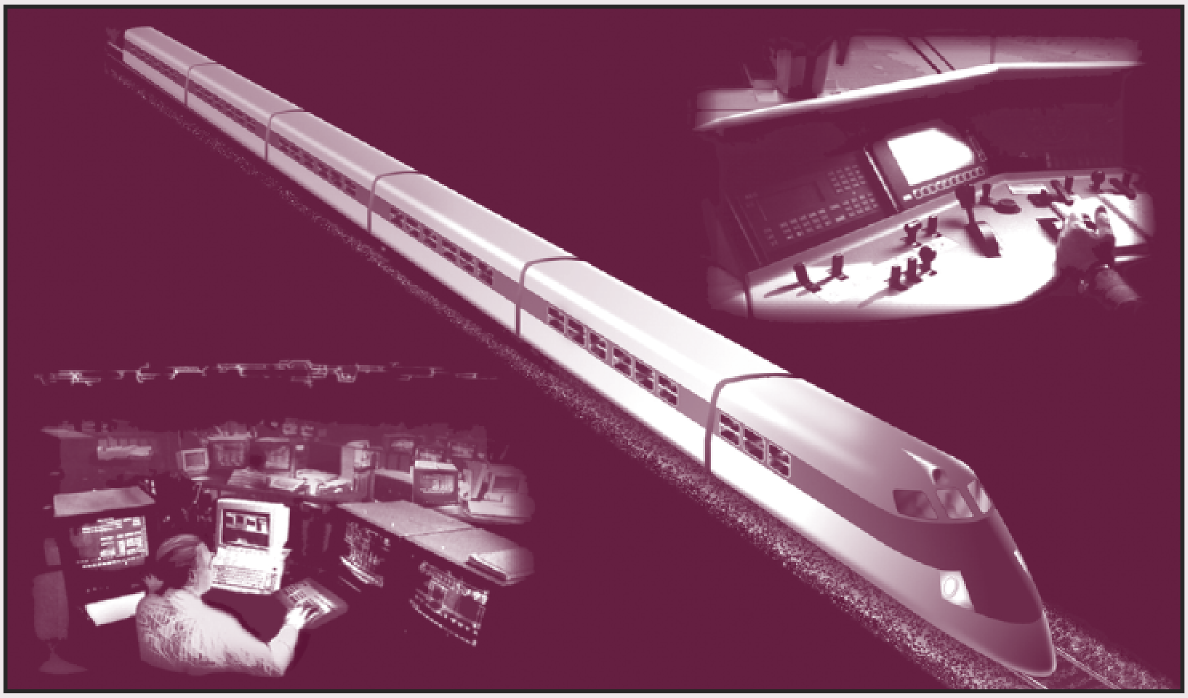

Human Factors in Railroad Operations

DOT/FRA/ORD-07/28

Final Report
November 2007

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13. ABSTRACT (Maximum 200 words)

This report documents the results of a cognitive task analysis (CTA) that examined the cognitive and collaborative demands and activities of railroad roadway workers. The purpose of the CTA of roadway workers was to understand the factors that complicate performance in today's environments, as well as the knowledge and skills that roadway workers have developed to cope with the cognitive and collaborative demands placed on them.

The results revealed numerous activities that railroad workers engage in that improve overall efficiency of railroad operations and enhance roadway worker safety on and around the track. These include cooperative activities within and across crafts, including dispatchers, train crews, and roadway workers. Some of these activities are codified in formal operating rules. Others have developed informally. The results point to the potential benefits of introducing portable digital communication systems with global positioning system capabilities and suggest specific design recommendations. The results also suggest potential benefits of implementing positive train control systems for enhancing roadway worker safety.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	= y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (km)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t)	= 1,000 kilograms (kg)
	= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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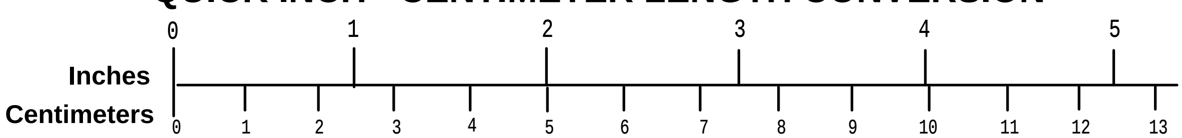
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Acknowledgments

This report describes an approach to evaluating the reliability of human actions that are modeled in a probabilistic risk assessment of train control operations. It describes an approach to human reliability analysis (HRA) and its application to a test case called Communications Based Train Management. The Federal Railroad Administration's (FRA) Office of Research and Development funded this research effort.

Many people and organizations made the completion of this task possible. We would like to thank the members of the Railroad Safety Advisory Committee (RSAC) Positive Train Control (PTC) Working Group Task Force for the guidance and support they provided us throughout the HRA quantification project. We would particularly like to thank Ms. Denise Lyle of CSXT for all her support. Denise facilitated our visits to the yard in Spartanburg, SC, to conduct interviews and observations of CSXT locomotive engineers and conductors, and the CSXT Dispatch Center in Jacksonville, FL, to interview and observe CSXT railroad dispatchers. She also responded kindly and promptly to our many requests for information. We would also like to thank Mr. Tim DePaepe, Brotherhood of Railway Signalmen, Mr. Bob Harvey, Brotherhood of Locomotive Engineers and Dr. Fred Gamst, University of Massachusetts, for their thoughtful inputs and their careful review and comment on early drafts of the results of the two site visits and quantification materials.

Finally, we would like to thank Dr. Thomas Raslear of FRA for his support in this effort.

Executive Summary

As part of its effort to investigate the safety implications of applying emerging technologies to railroad operations, the Federal Railroad Administration's (FRA) Office of Research and Development sponsored a series of Cognitive Task Analyses (CTA) to examine the cognitive and collaborative demands associated with different railroad operations' positions. The first CTA focused on railroad dispatchers (Roth, Malsch & Multer, 2001). This report documents the results of a follow-on CTA that was conducted to examine the cognitive and collaborative demands and activities of roadway workers.

The purpose of the CTA was to understand the factors that complicate performance in today's environment, as well as the knowledge and skills that roadway workers have developed to cope with the cognitive and collaborative demands placed on them. An important aim was to identify cognitive activities that could be supported more effectively through the introduction of advanced technologies, such as positive train control (PTC) technologies and portable digital communication devices that are currently being developed by the railroad industry and FRA research and development programs. A second, related aim was to anticipate the impact of new technologies such as PTC on roadway workers, both in terms of new demands for equipment troubleshooting and maintenance and impact on roadway worker safety.

Method

The research team performed interviews and observations in both passenger and freight territories. A total of 13 trackmen, who are responsible for inspection and maintenance of the track; 8 signalmen, who are responsible for inspection and maintenance of the signal systems; and 5 dispatchers, who control track usage, were interviewed individually or in groups of up to 5 people. Interview sites included:

- Amtrak, in Niles, MI, where the advanced Incremental Train Control System (ITCS) is being field tested
- New Jersey Transit, Hoboken, NJ, where the Advanced Speed Enforcement System (ASES) train technology is being tested
- Amtrak in Boston, MA
- Amtrak in Providence, RI
- CSX at the Montefiore Yard in Jacksonville, FL

Interview topics included the factors that impact roadway worker safety; the needs for communication and coordination with dispatchers, train crews, and other roadway workers; the challenges that arise in performing inspection and maintenance tasks; and how new technologies, such as PTC and portable digital-based communication devices, might impact their work and safety.

Findings

Cognitive and Collaborative Demands Associated with Working on and Around the Track

Roadway workers may work alone or as part of a team that must coordinate and cooperate in order to accomplish a common task. In some cases they may work at a particular location on the track to perform a specific maintenance task (changing a rail, troubleshooting a malfunctioning signal). They may also move across track (for example, to perform track inspection). This may be done on foot or riding a high-rail track car.

Communication is an element of the roadway worker's job and contributes to overall railroad system safety. Roadway workers communicate with dispatchers to obtain and release track occupancy authority, as well as to communicate track problems that may require speed restrictions to be put in place or track to be taken out of service. They also need to communicate and coordinate with other roadway workers or supervisors and with train crews.

Sources of communication challenges included:

1. Problems with radio transmission, including weak signals, poor radio quality, and high radio traffic
2. Problems related to monitoring and communicating on multiple radio channels, as well as other communication media (e.g., cell phones)
3. Problems in reaching the individuals in a timely manner
4. Problems with use of ambiguous language and similar sounding names that can lead to confusion and miscommunication

Cooperative Communication Strategies for Facilitating Work and Enhancing Safety

Communication plays a significant role in accomplishing work objectives, as well as in enabling roadway workers to establish and maintain safe working conditions. Many communications are prescribed by formal operating rules. Others are more informal. A general theme that emerged from the interviews and observations is the importance of these informal, proactive communications. Informal communications facilitate work across railroad crafts and contribute to the overall efficiency, safety, and resilience to error of railroad operations.

For example, dispatchers act proactively to facilitate the work of roadway workers and improve overall track usage efficiency. As one roadway worker put it, "a good dispatcher will call you and help to make your job easier." An example that the researchers observed was a dispatcher who proactively called a roadway worker to offer track time when a window of opportunity became unexpectedly available. Another example was a case where multiple dispatchers of adjacent territories communicated and coordinated among themselves to enable a roadway worker on a track car to obtain permission to enter a freight yard several dispatch territories away.

In addition, informal, cooperative practices have grown where others will routinely alert roadway workers to trains approaching them. Roadway workers and dispatchers mentioned that dispatchers routinely call roadway workers to let them know about a train coming by on an adjacent track, particularly if the train is unscheduled (e.g., a freight train or a work engine) and/or if it is coming on a different track than usual or in an unanticipated direction. Similarly, the research team observed cases of roadway workers traveling on track cars who called a roadway worker group that they passed earlier to alert them to a train that was heading their way. The researchers observed similar behavior on the part of train crews who called roadway workers they passed to alert them to other trains coming in their direction. Roadway workers refer to these practices as courtesies. Operating rules do not require them. However, these informal, cooperative practices play an important role in increasing the safety of railroad operation by enhancing the situation awareness of individuals distributed in time and space, enabling roadway workers to anticipate and prepare for trains heading their way.

Proactive Strategies for Maintaining Shared Situation Awareness and Enhancing On-Track Safety

Whether working at a fixed location or traveling across track, certain knowledge and skills emerged as important to establishing and maintaining on-track safety. These generally relate to the ability to maintain broad situation awareness and include:

- Territory knowledge and maintaining awareness of the physical location where they work to ensure that they work at the location for which they have authority.
- Maintain awareness of trains expected in the vicinity (in both time and space).
- Maintain awareness of time to ensure that they do not exceed track authority expiration times.
- Maintain awareness of the location and activities of other roadway workers in a work group to ensure mutual safety. This is particularly important in the case of the Employee in Charge (EIC), who is responsible for insuring that all roadway workers are clear of the track before allowing a train to enter a work zone or releasing a track authority back to the dispatcher.

Failure to detect an oncoming train on the track being worked on or on an adjacent track contributes to roadway worker accidents. Trains that are unexpected or come from an unexpected direction pose a particular challenge. Interviews with roadway workers and dispatchers indicate that roadway workers actively engage in building and maintaining awareness of trains in their vicinity to help them predict when trains are likely to approach and in what direction. Roadway workers are able to anticipate regularly scheduled trains based on review of train bulletins, timetables, and their own experiences on the territory.

Anticipating unscheduled trains can be more challenging. Roadway workers have developed strategies to help them anticipate unscheduled trains. For example, the EIC will routinely monitor the road channel for train communication. This allows him or her to hear communications among locomotive engineers and to hear locomotive engineers calling out signals as they are about to reach them. This allows the EIC to build an understanding of the locations and intentions of trains in the general vicinity. In addition, as described above, informal, cooperative practices have grown; for example, others (roadway workers, train crews, and dispatchers) will routinely alert roadway workers of trains that may be about to reach them.

Another important cognitive demand associated with establishing and maintaining track safety is the need to maintain awareness of the location and activities of everyone working under the same working limits track authority. Keeping track of the location and activities of other roadway workers can be challenging since the work can occur over a large geographic area and communication occurs primarily over the radio. One of the ways that roadway workers maintain shared situation awareness is by taking advantage of the party-line aspect of radio communication. For example, all the relevant parties can monitor the radio when a track authority is issued. This increases efficiency and reduces the potential for error due to lack of miscommunication.

Opportunities to Facilitate Communication, Support Performance, and Enhance Safety Through the Portable Digital Communication Device

The previous analysis of cognitive demands highlighted the importance of communication and coordination in both facilitating the work of roadway workers and enhancing on-track safety. It revealed the value of the party-line aspect of radio communication that allows individuals to monitor communications between other parties, fostering situation awareness of the location and activities of others that may impact their own work or safety. More generally, it revealed the importance for roadway workers to maintain broad situation awareness of their location and the location and activities of other roadway workers and trains in their vicinity, as well as the informal cooperative activities that roadway workers, dispatchers, and train crews engage in to build and maintain shared situation awareness of each other's location and activities.

New, emerging technologies have the potential to more effectively facilitate communication and support the cognitive and collaborative processes required for maintaining shared situation awareness among roadway workers, dispatchers, and train crews. Specifically, the potential exists to develop portable roadway worker devices that combine technologies for more accurate location information and more reliable communication, as well as data storage, retrieval, and computation functions to support maintenance and inspection tasks.

These new technologies can be used to:

- Facilitate communication among roadway workers, dispatchers, and train crews
- Enhance ability of roadway workers to be aware of approaching trains
- Enhance ability of dispatchers and train crews to be aware of location of roadway workers
- Enhance ability of roadway workers to be aware of location of other roadway workers

This report summarizes some of the concepts that have been proposed for a portable communication device and prototypes that have been developed within the railroad industry. For example, FRA has been funding a research and development effort through the Volpe National Transportation Systems Center (Volpe Center) to prototype and test a handheld digital communication device with integrated global positioning system (GPS) technology for roadway workers (Malsch, Sheridan & Multer, 2004; Masquelier, Sheridan & Multer, 2004; Oriol, Sheridan & Multer, 2004). Preliminary user feedback from roadway workers and dispatchers has been positive.

The report includes a list of specific functions that a portable digital communication device with integrated GPS could provide to facilitate roadway worker performance and enhance on-track safety. The list was derived from the analysis of the cognitive and collaborative demands of roadway worker activities, as well through direct suggestions made by roadway workers, dispatchers, and train crews. The recommendations are consistent with and amplify similar recommendations for support functions made by the Railroad Safety Advisory Committee (RSAC) PTC working group roadway worker protection task force as part of their recommendations for best practices for Portable Remote Terminals to be utilized with PTC systems (November, 2004).

Demands Associated with Inspection, Maintenance, and Troubleshooting of Systems

A second focus of the CTA relates to the cognitive and collaborative activities associated with inspection, maintenance, and troubleshooting of equipment and the impact of advanced digital technologies, such as PTC systems on roadway worker maintenance activities. Introduction of new systems can create new maintenance and troubleshooting challenges. If appropriate maintenance support systems are not put in place (e.g., quality manuals and training, organizational support), maintenance errors can impact the reliability and safety provided by the systems.

Many of the human factors problems related to equipment maintenance identified in other industries are also present in the railroad industry. This includes:

- Inadequate training and lack of sufficient refresher training
- Maintenance manuals that are incomplete, inaccurate, and not tailored to the requirements of maintenance personnel
- Shortage of test equipment
- Cryptic error codes and lack of adequate self-test diagnostics
- Inadequate support from vendors
- Communication problems across crafts
- Poor physical ergonomic design of equipment

The introduction of systems with new technology can exacerbate existing problems and introduce additional challenges. Testing and maintenance of new systems may require different knowledge than systems that use older technologies. Cryptic error codes and incomplete documentation can make it difficult to diagnose and repair system malfunctions. This can lead to delays in getting a system back online and can contribute to safety-related errors.

Discussion and Recommendations

The results of the CTA pointed to opportunities to enhance roadway worker performance and on-track safety through the use of digital communication technologies.

Use of Portable Digital Communication Systems to Facilitate Communication and Enhance Situation Awareness

Portable roadway worker devices that combine technologies for more accurate location information with digital communication technologies for more reliable communication have the potential to facilitate communication and coordination among roadway workers, dispatchers, and locomotive engineers. By incorporating broadcast capabilities that enable a given message to be sent to multiple individuals at the same time, it is possible to preserve some of the positive party-line aspects of analog radio communication that foster shared situation awareness of the locations and activities of others working in the same vicinity. The prototype handheld communication device developed and tested by the Volpe Center provides a promising model for leveraging the efficiency and reliability of digital communication while preserving the positive party-line aspects of analog radio (Malsch et al., 2004; Masquelier et al., 2004; Oriol et al., 2004).

Potential benefits of portable digital communication devices coupled with location finding technology include:

- Ability to obtain and release working limits more efficiently (e.g., through reduction in failed attempts to reach a party due to radio congestion, dead zones, etc.)
- More reliable communication and reduced potential for communication errors
- Opportunity to warn roadway workers when they are about to exceed their limits of authority (either going outside geographic limits, working on the wrong track, or approaching time expiration)

- Opportunity to warn roadway workers of approaching trains (both on the track they may be working on or near, and on adjacent tracks)
- Improved ability to keep track of and coordinate with other roadway workers in a work group
- Improved ability to maintain awareness of trains in the vicinity
- Improved ability for dispatchers to maintain situation awareness of the location and dispersion of roadway workers and equipment in their territories

Use of PTC Technology to Enhance Roadway Worker Safety

The results of the CTA reaffirmed the potential benefits of PTC technology for enhancing roadway worker safety. PTC systems have been explicitly designed to stop trains before they enter working limits. This protects roadway workers from trains exceeding their limits of authority due to train crew error or communication failures. PTC technology, coupled with digital communication technology, can also enhance roadway worker safety outside working limits by providing roadway workers with accurate information as to the location and movement of trains in their vicinity and alerts when trains are approaching their location. This includes cases where roadway workers are operating under a train approach warning or individual train detection forms of on-track protection and cases where they have been provided working limits on the track they are working on but not on the adjacent tracks where trains are allowed to run.

Design New Technology for Maintainability

The results of the CTA also revealed a need for more effective support for maintenance activities. This includes explicit consideration of system maintainability during the design phase, more training (including refresher training), better manuals, better self-diagnostics, and more technical support from vendors. The need for more effective support is particularly important as new, advanced digital systems are introduced, which require different knowledge and skills to troubleshoot and maintain.

As new systems are developed, it is important to consider issues of maintainability as part of the system design and evaluation process. This includes consideration of physical ergonomics (ability to reach, ability to see), as well as cognitive aspects of task performance.

Importance of Cross-Craft Cooperative Strategies for Facilitating Work and Enhancing Safety

The CTA revealed the importance of communication and coordination across multiple individuals, spanning multiple crafts, distributed in space and time for facilitating work and enhancing safety. Railroad personnel have developed informal cooperative strategies, across roadway workers, dispatchers, and train crews, that contribute to overall safety of railroad operations. These strategies are not codified in operating rules and are often described as courtesies. Nevertheless, they serve to foster shared situation awareness and create safety nets. The analysis identified a number of instances where these informal cooperative strategies enabled errors to be caught and recovered from before severe consequences resulted. It is important to recognize the existence and value of these informal cooperative strategies to guide the design of more effective support systems and ensure that the introduction of new technology does not inadvertently disrupt informal communication and coordination processes that contribute to overall system safety.

1. Introduction

As part of its efforts to investigate the safety implications of applying emerging technologies to railroad operations, FRA Office of Research and Development sponsored a series of CTAs to examine the cognitive and collaborative demands associated with different railroad operations' positions. The first CTA focused on railroad dispatchers (Roth, Malsch & Multer, 2001). This report documents the results of a follow-on CTA that examined the cognitive and collaborative demands and activities of roadway workers. A third CTA that focuses on train crews is in preparation. The purpose of the CTA of roadway workers is to understand the factors that complicate performance in today's environment, as well as the knowledge and skills that roadway workers have developed to cope with the cognitive and collaborative demands placed on them. An important aim of the CTA was to identify cognitive activities that could be supported more effectively through the introduction of advanced technologies, such as PTC technologies and portable digital communication devices that are currently being developed by the railroad industry and FRA research and development programs. A second, related aim was to anticipate the impact of new technologies, such as PTC on roadway workers, both in terms of new demands for equipment troubleshooting and maintenance and impact on roadway worker safety.

1.1 CTA Methodology

CTA methods have grown out of the need to explicitly identify and take into account the cognitive requirements inherent in performing complex work (Schraagen, Chipman & Shalin, 2000; Potter, Roth, Woods & Elm, 2000). This includes the knowledge, mental processes, and decisions that are required to perform a task. CTAs reveal (1) the factors that contribute to cognitive performance difficulty; (2) the knowledge and skills that expert practitioners have developed to cope with task demands; and (3) opportunities to improve individual and team cognitive performance in a domain through new forms of training, user interfaces, or decision-aids.

A broad overview of CTA methods and applications can be found in Schraagen, Chipman, and Shalin (2000). Traditional task analysis approaches break tasks down into a series of external, observable behaviors. For certain kinds of tasks that involve little decisionmaking requirements (e.g., assembly line jobs), traditional task analysis methods work well. As the routine aspects of jobs have become more automated, however, there has been a growing appreciation that many critical jobs (e.g., air traffic controller, aircraft pilot, power plant operator, electronics troubleshooter, operating room staff) involve complex knowledge and cognitive activities that cannot be observed. Examples of cognitive activities include monitoring, situation assessment, planning, deciding, anticipating, and prioritizing. A variety of specific analysis techniques drawing from basic principles and methods of cognitive psychology have been developed (Cooke, 1994; Klein, Calderwood & MacGregor, 1989; Militello & Hutton, 1998; Potter et al., 2000; Roth & Patterson, 2005). These include structured interview techniques, critical incident methods, field study methodologies, and simulation-based methods.

In performing CTA, two mutually reinforcing perspectives are considered. One perspective focuses on the characteristics of the domain and the cognitive and collaborative demands they impose. The focus is on understanding what factors contribute to making practitioner performance challenging. Understanding domain characteristics is important because it provides a framework for interpreting practitioner performance. For example:

- Why do experts utilize the strategies they do?
- What complexities in the domain are they responding to?
- Why do less experienced practitioners perform less well?
- What constraints in the domain are they less sensitive to?

Domain characteristics are also helpful in defining the requirements for effective support. For example:

- What aspects of performance could use support?
- What are the difficult cases where support could really be useful?
- What are the bounds of feasible support?
- What technologies can be brought to bear to deal with the complexities inherent in the domain?
- Which aspects of the domain tasks are amenable to support?
- Which aspects are beyond the capabilities of current technologies?

The second perspective focuses on how today's practitioners respond to the demands of the domain. Understanding the knowledge and strategies that expert practitioners have developed in response to domain demands provides a second window for uncovering the challenges of the current work environment, as well as effective strategies for dealing with those challenges. These strategies can be captured and transmitted directly to less experienced practitioners (e.g., through training systems), or they can provide ideas for more effective support systems that would eliminate the need for these compensating strategies.

CTA is fundamentally an opportunistic bootstrap process (Potter, Roth, Woods & Elm, 2000). The CTA process generally involves the use of multiple techniques, such as document reviews, interviews with domain practitioners, and field observations. In a typical CTA approach, the cognitive analyst might start by reading available documents that provide background on the field of practice (e.g., training manuals, procedure guides, and policy guides). The knowledge gained will raise new questions or hypotheses to pursue, which can then be addressed in interviews with domain experts. Examining the literature will also provide the background for interpreting what the experts say. In turn, the results of interviews may point to complicating factors in the domain that place heavy cognitive demands on the user and create opportunities for user error. This information can provide the necessary background to create scenarios or case studies to be used to observe practitioner performance under simulated conditions or to look for confirming example cases or interpret observations in naturalistic field studies. The particular set of techniques selected will be strongly determined by the pragmatics of the specific local conditions (e.g., time available with domain experts, demands of the operator's environment).

The researchers performed the roadway worker CTA based on a combination of structured interviews of individuals and groups of roadway workers and field observations that included accompanying track foremen on high-rail track car rides. The team performed interviews and observations in both passenger and freight territories. Section 2 provides more details on the particular sites visited and groups interviewed.

1.2 Purpose of Roadway Worker CTA

The primary purpose of the CTA was to identify and document cognitively challenging aspects of the current work to anticipate potential impacts of new technologies on roadway worker performance, as well as provide guidance for their design and introduction. The railroad industry is developing a number of new technologies that have the potential to impact roadway workers. This includes new forms of PTC and new portable digital communication devices that are envisioned to be used by roadway workers to support communication with dispatchers and train crews, as well as within and across roadway worker crafts.

Railroads in the United States and Canada are developing a variety of PTC systems that are intended to improve the safety of railroad operations. Their goal is to prevent train-to-train collisions, prevent exceeding speed limits, and protect roadway workers. This is accomplished by providing backup warnings to train crews and by stopping trains that are about to:

- Violate movement authorities
- Exceed speed restrictions (including civil engineering restrictions and temporary slow orders)
- Enter track segments protected for roadway workers and their equipment operating under specific authorities

While PTC technologies have the potential to improve roadway worker safety, they also have the potential to impose new demands on roadway workers with respect to inspection and maintenance of the new on-track and in-cab equipment. Part of the objective of the roadway worker CTA was to understand the cognitive and collaborative activities associated with inspection and maintenance of equipment and how that is impacted by the introduction of advanced in-cab and on-track equipment. The goal was to provide guidance for the design and introduction of new systems so as to facilitate inspection and maintenance and reduce the possibility of maintenance error.

A second, related technology that is emerging in parallel with PTC technology is the development of portable digital communication devices that allow roadway workers to communicate more reliably among themselves, as well as with dispatchers and train crews. The Railroad Safety Advisory Committee (RSAC) PTC Working Group Roadway Worker Protection Task Force, in a report on PTC technologies as they relate to roadway workers (November 2004), describes the characteristics of such a device and how it is envisioned to facilitate roadway worker performance. They envision that roadway workers would be equipped with portable terminals, which can request authority to occupy track and to release authorities. FRA has been funding a research and development effort through the Volpe Center to prototype and test a handheld communication device for roadway workers that provides this type of functionality (Malsch, Sheridan & Multer, 2004; Masquelier, Sheridan & Multer, 2004; Oriol, Sheridan & Multer, 2004). The device also incorporates GPS technology to provide an accurate means to identify and communicate roadway worker location information.

An objective of the CTA of roadway workers was to understand the communications and coordination demands among roadway workers, dispatchers, and train crews to provide guidance in the design of these types of portable digital communication devices for roadway workers. An important aim of the CTA was to identify (1) cognitive activities that could be supported more effectively through the introduction of digital data link communication systems. A second, related aim was to identify features of the existing environment that contribute to effective performance and therefore should be preserved when deploying these new technologies.

1.3 Scope and Focus of CTA

The CTA focused on two aspects of roadway worker activity: (1) the safety demands associated with working on and around the track and (2) the cognitive and collaborative demands associated with inspection, maintenance, and troubleshooting of systems and the impact of new technology on those demands.

A roadway worker is defined as

> Any employee of a railroad, or contractor to a railroad, whose duties include inspection, construction, maintenance or repair of railroad track, bridges, roadway, signal and communication systems, electric traction systems, roadway facilities or roadway maintenance machinery on or near track or with the potential of fouling a track, and flagmen and watchmen/lookouts (CFR Title 49 214.7, pg. 65976).

The CTA focused primarily on two groups:

- Employees, who are responsible for inspection and maintenance of the track
- Signalmen, who are responsible for inspection and maintenance of the signal systems

The research team selected these two groups because they work regularly on and around the track. They are most likely to be impacted by technological changes, such as PTC systems. Both groups depend on communication with dispatchers to obtain and release authority to occupy the track. In addition, they communicate with other roadway workers and train crews to coordinate work and maintain broad situation awareness of the location of trains and the ongoing activities on the track. As a consequence, they would be heavily impacted by new digital communication technologies. Section 3 presents the results of the CTA relating to the cognitive and collaborative demands associated with working on and around the track.

A second focus of the CTA related to the cognitive and collaborative activities associated with the inspection, maintenance, and troubleshooting of equipment and the impact of advanced technologies, such as PTC systems on roadway worker maintenance activities. This aspect of the CTA focused primarily on signalmen who test and maintain wayside equipment. The analysis also covered mechanical department personnel who maintain and troubleshoot in-cab digital equipment. While mechanical department personnel are not roadway workers, they were included in the analysis because they play a significant role in the maintenance of railroad systems and interact extensively with signalmen.

Introduction of new systems can create new maintenance and troubleshooting challenges. If appropriate maintenance support systems are missing (e.g., quality manuals and training, organizational support), maintenance errors can occur that can impact the system reliability and safety. Section 4 provides a summary of the human factors literature on system factors (e.g., equipment design factors, organizational factors, training factors) that impact inspection, maintenance, and troubleshooting. This is followed by the results of interviews with signalmen and mechanical maintenance personnel.

2. Methods

The CTA combined a number of converging methods:

- A review of the human factors literature on maintenance work and sources of performance problems and error (e.g., Patankar & Taylor, 2004; Reason & Hobbs, 2003).

A series of interviews with individuals and groups of signalmen, trackmen, and mechanical maintenance personnel focused on the cognitive and collaborative demands of their work and the potential impact of new technologies on their work. Table 1 lists the interviews that were conducted, the crafts that were interviewed, the locations where the interviews took place, and the topics that were covered. Appendix A contains the questions that guided the interviews.

A primary focus of those interviews was on the impact of the new train control technologies on roadway workers. Topics covered included maintenance demands associated with the new technologies and the adequacy of support available for performing maintenance (e.g., the adequacy of manuals, training, availability of tools). The interviews also covered factors that affected roadway worker safety and the perceived impact of the new train control systems on roadway worker safety. Finally, the interviews covered communication and coordination with dispatchers, train crews, and other roadway workers; the challenges that arise; and how portable digital-based communication devices might impact their work.

Interview sites included Amtrak, in Niles, MI, where the advanced ITCS was field-tested, as well as New Jersey Transit, Hoboken, NJ, where the advanced ASES train control technology was tested. Researchers also conducted interviews at Amtrak facilities in Boston, MA, and Providence, RI, and CSX at the Montefiore Yard in Jacksonville, FL. The Amtrak interviews occurred while accompanying track foremen on high-rail track car rides and included discussion of the demands associated with track inspection and related documentation tasks.

The research team conducted parallel interviews with railroad dispatchers to elicit their perspective on the challenges associated with communication with roadway workers and how portable digital-based communication devices might impact work.

- Preliminary examination of selected roadway worker fatalities based on an FRA roadway worker fatality data set covered the period from 1986 through 2003. The purpose of the analysis was to begin to understand some of the situational factors that appear to contribute to the roadway worker accidents.

Table 1. Site Visits and Interviews				
Date	**Crafts**	**Number Interviewed**	**Railroad/ Location**	**Topics Covered**
9/2000	Track foreman	1	Amtrak, Boston, MA	Job activities and challenges. Interaction/communication with dispatchers, train crews, and other roadway workers.
10/2000	Track foreman	1	Amtrak, Providence, RI	Job activities and challenges. Interaction/communication with dispatchers, train crews, and other roadway workers.
12/2000	Dispatchers	5	Amtrak, Boston, MA	Interaction/communication with roadway workers. Feedback on a prototype handheld communication device.
8/2001	Roadmasters, track inspectors, road foreman	5	CSX, Montefiore Yard, Jacksonville, FL	Interaction/communication with dispatchers, train crews, and other roadway workers. Feedback on a prototype handheld communication device.
8/2002	RSAC PTC subcommittee representatives from BRS, IBEW, and BMWE	3	Multiple	Impact of introduction of new train control technology on roadway workers. Potential of PTC systems to improve safety.
10/2003	Foremen with surfacing gangs and welders	6	Amtrak, Niles, MI	Job activities and challenges. Factors that can contribute to roadway worker accidents. Opportunities to improve roadway worker safety. Potential of PTC systems to improve safety.
10/2003	Signalmen, Mechanical Maintenance Department personnel	8	Amtrak, Niles, MI	Maintenance activities and challenges. Added maintenance challenges with the introduction of new train control technologies (ITCS). Factors that can contribute to roadway worker accidents. Potential of PTC systems to improve safety.
3/2004	Signalmen, Mechanical Maintenance Department personnel	4	New Jersey Transit, Hoboken, NJ	Maintenance activities and challenges. Added maintenance challenges with the introduction of new train control technologies (ASES).

3. Demands Associated with Track Work

Roadway workers are responsible for inspection; construction; maintenance; and repair of track, bridges, roadway, signal and communications systems, electric traction systems, and related facilities and equipment. As such, their work primarily occurs on and around track. This section focuses on some of the generic cognitive demands that relate to working on and around railroad track. These include cognitive demands associated with communication and cognitive demands associated with establishing and maintaining on-track safety.

Roadway workers may work alone or as part of a team that must coordinate and cooperate to accomplish a common task. In some cases, they may work at a particular location for an extended period to perform a specific task (e.g., replace or repair defective track, troubleshoot a malfunctioning signal). They may also work for short periods over large sections of track (e.g., when performing track inspections).

Communication is an important aspect of the roadway workers' jobs and contributes to overall railroad system safety. Roadway workers communicate with dispatchers to acquire and release authorization to occupy track, as well as to communicate track problems that may require speed restrictions to be put in place or track to be taken out of service. They also communicate and coordinate with other roadway workers or supervisors and with train crews. Some of these communications are prescribed by formal operating rules, and others are informal. Both types of communication facilitate work across railroad crafts and contribute to the overall efficiency and safety of railroad operations. Communications primarily occur over very high frequency radio channels and impose a number of challenges. Section 3.1 reviews the cognitive activities and challenges associated with roadway worker communication.

Because their work is primarily conducted on or near railroad tracks, roadway workers are at risk of being struck by a train or other on-track equipment. A review of FRA's accident and injury data for the period of 1989–1995 revealed that roadway workers accounted for 12 percent of employee on-duty fatalities (Horn, Raslear & Schulte, 2002). In 1996, FRA issued the Roadway Worker Protection regulation (49 CFR 214) in an effort to improve on-track safety for roadway workers. Section 3.2 summarizes some of the cognitive factors associated with establishing and maintaining on-track safety.

3.1 Communication Demands and Sources of Complexity

Roadway workers may work alone or in groups. In either case, communication plays a significant role in enabling them to accomplish their work objectives, as well as in enabling them to establish and maintain safe working conditions. Roadway workers primarily communicate over VHF radio channels, although cell phone use is increasing.

Roadway workers need to communicate with dispatchers to obtain and release track occupancy authority, as well as to communicate track problems that may require putting speed restrictions in place or taking track out of service. They also communicate and coordinate with their peers and supervisors. At times, they also communicate with train crews. Many of these communications are prescribed by formal operating rules, and others are informal, proactive communications. A general theme that emerged from the interviews and observations was the importance of these informal communications in contributing to the overall efficiency, safety, and resilience to error of railroad operations.

This section summarizes the types of communications that roadway workers engage in, followed by a discussion of factors that contribute to communication difficulty and potential for communication error.

3.1.1 Communication with Dispatchers

Roadway workers communicate regularly with railroad dispatchers or with block operators in the case of territory controlled by block operators.[1] In cases where roadway workers operate alone, they typically carry a radio and communicate directly with the dispatcher. When working as teams in close proximity to each other, the EIC takes responsibility for communicating with the dispatcher.

Roadway workers contact dispatchers for several reasons:

1. To obtain authority to work on the track and release it
2. To report conditions that may require taking track out of service or imposing speed restrictions
3. To alert dispatchers of other potential hazards on or near the track

Requesting and Releasing Track Authorities

The dispatcher may give permission to occupy the track by a paper copy received by the train crew before departure, by electronic transmission (e.g., fax), or by dictating the authority orally over the radio or phone. If the dispatcher gives the authority orally, the receiver must repeat back the contents of the authority to the dispatcher. The repetition by the receiver is required as a safety measure to guard against mishearing the contents of the track authorization and to provide a mechanism by which either party may detect and recover from an error.

Roadway workers may request authority to work at a particular location on the track delimited by specific working limits (identified by mileposts, stations, or other physical characteristics). If the work involves on-track equipment or will disturb the track or the catenary structure making it unsafe for trains to travel over the track, the roadway worker will request authority to remove a track from service (Form D line 4 in the Northeast Operating Rules Advisory Committee (NORAC) operating rules). If the work to be performed only requires a portion of in-service track to be obstructed for maintenance, the roadway worker will request protection by stop signs (Form D line 5 in NORAC operating rules). If the work will not disturb the track or catenary structure or place equipment on the track, the roadway worker may request foul time.[2] Once the work is completed, the roadway worker contacts the dispatcher to release the track authority.

Once the EIC has received authority to take track out of service, the EIC becomes the owner of that track. Any train or on-track vehicle that wishes to enter that portion of track must obtain permission from the EIC instead of the dispatcher. Similarly, any roadway worker who wishes to perform work on that portion of track needs to obtain permission from and coordinate with the

[1] The report refers to communication with dispatchers to cover situations where roadway workers communicate directly with dispatchers, as well as situations where roadway workers communicate with block operators who then communicate with a dispatcher.

[2] Foul time is a method of establishing working limits on controlled track in which a roadway worker is notified by the train dispatcher or control operator that no trains will operate within a specific segment of controlled track until the roadway worker reports clear of the track.

EIC. Before releasing track back to the dispatcher, the EIC must notify all affected roadway workers to make sure they have left the track.

Roadway workers will typically let the dispatcher know the kind of track work they plan to do at the time that they request track authority. It is important to give the dispatcher an idea about the nature of the work, whether it will disrupt the track, and the estimated amount of time the work will take to complete. Some types of work can be interwoven around train traffic. In those cases, the dispatcher can ask the roadway worker to stop and get off the track to let a train through. This is typically the case in requests for foul time. Work that disrupts the track requires roadway workers to complete their work before trains can pass through.

Roadway workers may also request movement authority to travel across a portion of track in a high-rail vehicle (e.g., Form D line 2 and 3 in NORAC operating rules). A dispatcher typically gives authority for one or more blocks at a time. Once the roadway worker reaches the end of the authorized block limit, he or she would call the dispatcher, typically over the radio, to release the track that he/she passed and ask permission to enter the next block (or blocks).

Reporting Track Conditions Necessitating Speed Restrictions or Track Out of Service

Track inspector foremen are responsible for inspecting track. If they detect a track defect, they consult a book of inspection rules and tolerance levels to determine the speed limit that corresponds to that track condition. Depending on the nature of the problem, the rules may necessitate imposing a train speed restriction (e.g., to 15 miles an hour) or taking the track out of service. The roadway worker would then call the dispatcher on the radio to inform him or her of the need to issue a speed restriction or to take the track out of service. The dispatcher would then communicate the information via a speed restriction bulletin or, if necessary, the dispatcher will call every train that will be passing that portion of track to alert them of the speed restriction. The track inspector foreman would also physically place speed restriction signs to designate the start and end of the speed restriction limits.

Reporting General Unsafe Conditions

Roadway workers will also call dispatchers to alert them to unsafe conditions on the track they may notice in the course of their work that trains need to be informed about. Examples might be potentially obstructing material on the side of the track.

A roadway worker may also receive information about an unsafe condition when he/she is away from the main line (e.g., a call may be received at the yard letting him/her know of a car stuck on the track). In those cases, the roadway worker would call the dispatcher to let him/her know.

Dispatchers will also contact roadway workers. Primary reasons that dispatchers call roadway workers include to:

1. Check on the status of their work to determine when track authorities may be released or to request release of track
2. Alert them to reports of track conditions that require inspection or repair
3. Alert them to unexpected conditions that may pose a safety hazard to the roadway workers (e.g., unscheduled trains on adjacent track)
4. Proactively provide track authority to facilitate work and improve efficiency of roadway operations
5. Relay communications between roadway workers who are not able to communicate directly (e.g., due to weak radio signals)

Check on the Status of Work

Dispatchers will periodically call roadway workers to check on the status of their work to anticipate when track is likely to be available for routing trains. For example, dispatchers might call a track car to find out their location or determine if they have passed a particular interlocking so that they can plan their next move.

Take Back Track

If a dispatcher gives foul time for maintenance-related work, an expectation exists that the roadway worker will release the track back to the dispatcher upon request. The dispatcher may call the roadway worker at any time and request the release of this track authority. The dispatcher may not take foul time back without contacting the roadway worker and getting explicit acknowledgement that he or she agrees to suspend work and get off the track.

If a dispatcher needs to route a train through a portion of track on which foul time has been given to a roadway worker, the dispatcher may call to request a release of foul time. After the train has passed, the dispatcher may call the roadway worker to provide foul time again.

Request Inspection or Maintenance

When dispatchers receive information about hazardous track or signal conditions (e.g., by a train crew), they may call roadway workers to request an inspection or maintenance work (e.g., to fix a broken rail or troubleshoot a malfunctioning signal).

Alert to Unexpected Conditions and Potential Hazards

Dispatchers may also call roadway workers to alert them to unusual or unexpected conditions that may pose a safety hazard. For example, if a roadway worker or roadway worker group has authority to work on a track and a train is about to be routed through on an adjacent track, the dispatcher may call to alert the roadway workers to the presence of the approaching train. Similarly, if a roadway worker group was working around a track without fouling it, the dispatcher would call to let them know to expect a train he/she was sending through. The dispatcher is particularly likely to call the roadway workers if the train is unscheduled, running at a different time, on a different track or direction than it normally does, or is otherwise unexpected. As one dispatcher stated, “I let them know what my plan is so that they are not startled.” Operating rules do not mandate this call. Dispatchers take this action as a courtesy; this represents part of the informal redundant safety net provided through voluntary cooperative activities among railroad workers.

Similar informal courtesies that provide an important safety function have been observed among train crews. For example, if a member of a train crew passes a roadway worker group working by the side of the track, he or she may call over the radio to alert other trains passing through the territory of the presence of the roadway workers. These informal courtesies enhance overall railroad safety and contribute to the resilience of the railroad system to errors that might occur.

Proactively Calling to Provide Track Authority

Dispatchers act proactively to facilitate the work of roadway workers and improve overall track usage efficiency. As one roadway worker put it, “a good dispatcher will call you and help to make your job easier.” For example, the researchers observed a dispatcher proactively calling a roadway worker to offer foul time when an unexpected window of opportunity to squeeze in track work became available. In another example, the team observed multiple dispatchers of adjacent territories communicating and coordinating among themselves to enable a roadway worker on a track car to obtain permission to enter a freight yard several subdivisions away.[3] In this example, the track car sought permission to enter the freight yard located two subdivisions away from its present position. The roadway worker contacted the dispatcher responsible for the subdivision he was currently in to inform him of his desire to travel to the freight yard. The dispatcher coordinated with the adjacent dispatcher who in turn contacted the freight yard dispatcher. This information enabled the yard dispatcher to plan ahead and accommodate the needs of the roadway worker on the track car. These examples illustrate the informal anticipation, cooperation, and coordination across crafts that contribute to improved safety and operating efficiency.

Relaying Communications Between Roadway Workers

In some cases, a roadway worker will contact a dispatcher to relay a message to other members of a road crew. Due to radio equipment limitations, reception between members of a road crew may be good for only a few miles. If crews work farther apart than the radio's capabilities, they will be unable to communicate directly by radio. In those situations, they may request that the dispatcher relay messages between them since the dispatchers' radios are more powerful.

3.1.2 Communication Among Roadway Workers

Communication is required within a work group to coordinate work and to ensure the safety of the workers in the group. While the EIC is in charge of the work zone, he or she must also ensure that everyone in the work group is alerted to potential hazards, such as a train coming through on an adjacent track. He or she is also responsible for making sure that all workers in the work group are clear of the track before giving permission to a train or track car to enter the work zone. The EIC must ensure that all roadway workers have completed their work and are clear of the track before releasing a track authority back to the dispatcher.

The EIC, who is responsible for communicating with the dispatcher and obtaining and releasing track authorities, may be located far from the actual work and must keep track of the location of workers in the work group and the status of their work via radio.

Communication and coordination can be particularly challenging in the case of large roadway projects that involve large numbers of workers (up to 100 workers), include multiple crafts, many pieces of equipment (up to 20 or 30 pieces) working in multiple subgroups, and spread out over a wide portion of track. The EIC keeps track of the different subgroups by communicating via radio with the secondary foreman in charge of each subgroup.

In large multi-craft work groups, some work occurs in parallel, and some work occurs in sequence. For example, trackmen may need to complete their work first, but other crafts, such as the communications and signal, may also have to complete their work before track can be released back to the dispatcher. Keeping track of who is in charge, where everyone is located, what work needs to go on in parallel, and what work needs to be completed by one craft before the work of another craft can start can be a challenge. The need to keep track of everyone's location and ensure that all roadway workers are clear of the track before it is released back to the dispatcher presents a significant challenge.

[3] A subdivision represents the geographic region managed by a dispatcher.

Similarly, it can be a challenge to ensure that everyone is clear of the track before giving permission for a train or on-track vehicle to enter a work zone. Consider the following example of a close call that illustrates the vulnerability of communication error and safety consequences. The case in question involved a work zone protected by stop signs (Form D line 5 in NORAC rules of operation). In that situation, the EIC is only supposed to allow a train to enter the work zone after making sure that everyone in the crew has cleared the track. However, because of a miscommunication, the EIC allowed an unscheduled freight train to enter the work zone while the roadway worker crew worked on the track. Because the train was unscheduled, the roadway workers were not expecting it. The roadway workers were all gathered around a spiking machine that was working improperly when the freight train went by them on an adjacent track. With the workers focusing their attention on the malfunctioning spike machine and the high level of background noise, they failed to notice the train until it came by. While no one was hurt, three fatalities could have easily occurred. The roadway worker explained that the incident occurred because of a miscommunication between the person in charge of the track and a secondary foreman in charge of the roadway workers on the track.

3.1.3 Communication with Train Crews

Roadway workers also communicate with train crews. Just as with dispatchers, some communication is prescribed by formal operating rules, and some communication is informal and intended to facilitate work and enhance safety.

One example of formal communication requirements between roadway workers and train crews occurs when trains require permission to pass through a designated work zone protected by stop signs (e.g., Form D line 5 operating rule). The train crew must contact the EIC via radio and obtain verbal approval to enter the work zone. The EIC is supposed to establish that:

- The track is clear and safe for the authorized speed.
- All affected switches are secured in normal position.
- All affected roadway workers are notified.

Provided those conditions are met, the EIC is authorized to issue permission to the train to enter the work zone verbally. The train crew must verbally repeat this permission to the EIC.

Roadway workers will also contact train crews informally to find out their location and plans in an effort to find additional opportunities to complete maintenance activities. The roadway worker calls trains scheduled to pass on the track around the time of interest to find out where they are and when they are anticipated to pass that portion of track.

This activity reduces the dispatcher's communication workload. If the roadway worker learns that a train will occupy the track at the time during the desired time window, he or she will know that track time is unavailable without having to contact the dispatcher. If the roadway worker finds out that the trains will not pass through during the desired time window, the roadway worker can call the dispatcher to share that information and request track time. This allows the dispatcher to know that time is available to give to the roadway worker. This example illustrates the kinds of cooperative strategies that level workload across work groups and improves overall operating efficiency.

3.1.4 Challenges to Effective Communication

The interviews and observations revealed that communication is central to the ability of roadway workers to accomplish their jobs, as well as to establish and maintain on-track safety. At the same time, the team's research revealed a number of factors that pose challenges to rapid and effective communication.

Sources of communication challenges included the following:

1. The presence of radio transmission problems including weak signals, resulting in poor radio quality and high radio traffic
2. The need to monitor and communicate on multiple radio channels, as well as other communication media (e.g., cell phones)
3. The inability to reach individuals in a timely manner
4. The use of ambiguous language and similar sounding names that can lead to confusion and miscommunication

As mentioned previously, the two-way voice radio serves as the primary communication device. Trackmen and signalmen normally carry handheld radios. The EIC will typically carry a more powerful scanning radio. Track cars contain built-in radios with greater transmission range than the handheld radios. Because of problems in radio reception and congested radio channels, many roadway workers also carry a cell phone that they use in situations where radio quality is poor.

Many of the communication challenges that roadway workers raised relate to properties of analog voice radio technology previously summarized by Roth et al. (2001). These include limitations in transmission range, as well as signals that are subject to disturbances caused by local terrain properties (e.g., tunnels) and weather phenomena. Signal strength problems range from dead spots where radio communication does not reach and the phenomenon of skip where signals may unexpectedly carry across long distances, resulting in unexpected communication traffic on a given channel and interference. Another related problem is high communication traffic over radio channels, resulting in communication being cut off and stepped on. These factors can make it difficult to reach the desired party, as well as to hear and understand the message. The problems are compounded in the case of roadway workers because their radios tend to generate weak signals with limited transmission range. If someone using a more powerful radio (i.e., a train) comes along, communications with the dispatcher can be lost or blocked. In addition, if roadway workers in a work group are spread out across a wide territory, they may be unable to reach each other by radio. In those cases, they often find themselves needing to rely on the dispatcher to relay messages between them.

Another problem mentioned is the need for roadway workers, particularly the EIC, to monitor and communicate on multiple radio channels, as well as other communication media such as cell phones. Road operations and dispatcher-train communications are supposed to occur on different channels.

Dispatchers and train crews communicate on a single channel called the road channel. Maintenance-of-way employees use alternative channels to communicate among themselves. When roadway workers listen to one radio channel, they cannot hear communication directed at them or of relevance to them broadcast on a different channel. For example, if a roadway worker is communicating with a dispatcher on a road channel, he might miss roadway worker communications being broadcast on a maintenance-of-way channel.

Because there are multiple channels to monitor, roadway workers scan multiple channels. The foreman in charge may use a scanning radio to support this task. The EIC may have to monitor for communication from trains coming from several directions and calling on different radio channels.

Monitoring multiple channels for relevant communication can be a challenge. As one consequence, while roadway worker communication is supposed to occur on the maintenance-of-way channel, oftentimes roadway workers will communicate among themselves on the road channel. While some concern was expressed that inappropriate communication contributes to traffic congestion on the road channel, recognition also existed that the ability to overhear important communication on the road channel fosters shared situation awareness. One dispatcher mentioned that he liked to be able to hear communication among roadway workers over the road channel because it enabled him to know who was in the territory he was responsible for and monitor their activity. Similarly, a roadway worker mentioned that he liked to listen in on the road channel for train communication. This allowed him to hear the locomotive engineers calling out the signals as they passed them, enabling him to get an idea of their location and direction of movement. This allowed him to maintain situation awareness of the trains' movement around him, enhancing on-track safety.

Another problem raised by roadway workers is that it can sometimes be hard to reach the individual you are trying to contact. The roadway workers mentioned that in some cases the dispatchers do not immediately answer a radio call and that they have to repeatedly try to reach them. Sometimes, if they are unable to reach them over the radio, they will resort to using a cell phone. In some cases, this communication method has proved more successful.

Multiple reasons exist as to why dispatchers can be hard to reach. One major reason is heavy workload. The dispatcher may be in the process of communicating with someone else. During the dispatcher shift handover, all communications with the dispatcher are suspended. Although the shift handover may only take 15 minutes, there can be a period of up to 1 hour around the shift turnover during which the dispatchers can be difficult to reach.

Similarly, dispatchers and train crews report that it can be sometimes difficult to reach the roadway worker. Reasons include problems with radio reception (e.g., dead spots), transmitting on a channel different from the channel being monitored, and the roadway worker physically being out of reach of the radio. For example, when a track inspector physically exits a high-rail vehicle to inspect the track, he may not hear the in-vehicle radio.

One dispatcher gave a salient example where a dispatcher and a roadway worker simultaneously tried to reach each other without success due to problems in radio reception. She described a case where she had issued foul time to a track foreman and needed it back. She called him over the radio repeatedly but received no response back. It turns out that he heard her radio call and tried to reply to her over the radio. While dispatchers at other desks heard the track foreman calling her over the radio, she could not hear him.

3.2 Demands Associated with Establishing and Maintaining On-Track Safety

Because the activities of roadway workers are performed on or near railroad tracks, they are at risk of being struck by a train or other on-track equipment. FRA issued the Roadway Worker Protection regulation (49 CFR 214) in 1996 requiring all railroads to implement an on-track safety program by May 1997. The regulation provides clear delineation of responsibilities of employers and employees for a safe workplace environment. It prescribes the need for job briefings, annual training and skill qualifications, and specific methods of protecting employees working on or near the track.

This section begins by providing an overview of the different methods of establishing and maintaining on-track safety as specified by the Roadway Worker Protection regulation. This is followed by a discussion of some cognitive challenges associated with establishing and maintaining on-track safety that emerged from interviews and observations.

The FRA Roadway Worker Protection regulation specifies three main methods of establishing roadway worker protection: working limits, train approach warning, and individual train detection.

Working limits describes a method of protection whereby roadway workers are given authority to work on a specified portion of track defined by clearly identifiable physical markers or features that designate the working limits (e.g., fixed signals, station or clearly identifiable mileposts). All movements within working limits are under the control of the roadway worker in charge, referred to as the EIC. On controlled track, defined as track on which trains may not move without authorization from a train dispatcher or a control operator, working limits take the form of exclusive track occupancy or foul time. Exclusive track occupancy is a method of establishing working limits on controlled track in which movement authority of trains and other equipment is withheld by the train dispatcher or control operator, or it is restricted by flagmen. This form of protection is used in cases where the work involves on-track equipment or will disturb the track or the catenary structure, making it unsafe for trains to travel over the track at normal speeds. This includes cases where the track is removed from service and cases where a portion of in-service track is obstructed for maintenance and protected by stop signs.

In the case of in-service track protected by stop signs, the roadway workers must place red stop signs to designate the working limits. Yellow approach signs are placed ahead of the stop signs to provide indication that there is a stop sign designating a working limit ahead.

Once the EIC receives authority to place track out of service or to protect by stop signs a portion of in-service track that is obstructed for maintenance, the EIC becomes the owner of that track. Any train or on-track vehicle that wishes to enter that portion of track must obtain permission from the EIC. Similarly, any roadway worker who wishes to perform work on that portion of track needs to obtain permission from and coordinate with the EIC. The EIC must keep track of and notify all affected roadway workers before releasing working limits back to the dispatcher.

In the case of working limits that are designated by stop signs, the dispatcher, with the permission of the EIC, can line signals to allow a train to enter a block, relying on the stop sign to stop the train at the designated working limits. Once the train reaches the stop sign, the train crew must obtain permission from the EIC before entering the working limits. The EIC has authority to determine whether a train can enter the work zone and at what speed it can proceed.

If the work will not disturb the track or catenary structure or place equipment on the track, the roadway worker may request foul time. Foul time is a method of establishing working limits on controlled track in which a dispatcher or control operator notifies a roadway worker that no trains will operate within a specific segment of controlled track until the roadway worker reports clear of the track. One main difference between foul time and other forms of working limits is that the dispatcher can call at any time and request that the roadway worker give back the track.

The dispatcher cannot take the track back without getting explicit acknowledgement from the roadway worker, but the roadway worker is expected to be able to get off the track upon request.

Train approach warning is a method of establishing on-track safety by warning roadway workers of the approach of trains in ample time for them to move to a place of safety. This is accomplished by assigning one or more watchmen/lookouts to watch for approaching trains. Watchmen/lookouts assigned to provide train approach warning must devote full attention to detecting approaching trains and providing warning to the roadway worker group. They are not supposed to perform any other duties. Train approach warning is to be given in sufficient time to enable each roadway worker to move to a previously arranged place of safety at least 15 seconds before a train moving at the maximum speed authorized for that track can pass the location of the roadway worker.

Individual train detection describes a procedure by which a lone worker manages on-track safety by seeing approaching trains and leaving the track before they arrive. A lone worker who fouls a track while performing routine inspection or minor correction may use individual train detection. The Roadway Worker Protection regulation specifies a number of criteria for when individual train detection may be used. These criteria include:

- The worker is able to visually detect a train and move to a place of safety at least 15 seconds before the train or on-track vehicle reaches his/her position.
- The worker's ability to hear or see approaching movements is not impaired.

Roadway workers who perform maintenance work at a fixed location receive protection by working limits, train approach warning, or individual train detection. Roadway workers traveling across a portion of track in a track car receive protection by movement authority (Form D lines 2 and 3 in NORAC operating rules).

Whether working at a fixed location or traveling across track, certain cognitive knowledge and skills emerged as important to establishing and maintaining on-track safety. These skills and knowledge relate to the ability to maintain broad situation awareness and include:

- Knowing the territory and maintaining awareness of the physical location where they are working to ensure that they are working at the location for which they have been provided authority and protection.
- Maintaining awareness of what trains are expected in the vicinity (in both time and space) to avoid situations where a train approaches them without their awareness.
- Maintaining awareness of time so as to ensure that they do not exceed track authority expiration times.
- Maintaining awareness of the location and activities of other roadway workers in a work group so as to ensure mutual safety. This is particularly important in the case of the EIC who is responsible for ensuring that all roadway workers are clear of the track before allowing a train to enter a work zone or releasing a track authority back to the dispatcher.

Interviews with both roadway workers and dispatchers emphasized the importance of building and maintaining the big picture with respect to these various elements.

3.2.1 Knowing the Territory and Maintaining Situation Awareness of Physical Location

Roadway workers and dispatchers emphasized the importance of knowing the territory and maintaining awareness of the physical location where the work is taking place. It is important that roadway workers and dispatchers have a clear and accurate understanding of where work is to take place and the exact location of the limits of authority being given to ensure that the roadway workers are properly protected.

During the research team's interviews, respondents indicated that roadway workers must be qualified on their territory.[4] The roadway workers that the team interviewed felt that because they are qualified on the territory, it is unlikely that a roadway worker will become disoriented or confused about his/her location. Nevertheless, the roadway workers described several instances where a misunderstanding occurred between the dispatcher and the roadway worker with respect to the portion of track for which authorities were given versus the portion of track where the roadway workers were performing their work. In some territories, there can be multiple parallel tracks (2 or more), and misunderstanding can occur as to which track authority was requested and provided. Similarly, track inspectors can be responsible for very large territories to inspect (up to 100 miles of territory in some cases). This opens the possibility of misunderstanding or miscommunication as to the specific location being referred to in communication. The miscommunications may arise due to lack of territory familiarity on the part of the roadway worker or the dispatcher or by a failure to establish and maintain a common understanding of the location in question.

Respondents also stressed the importance of dispatchers' familiarity with the territory they control. They need to understand the major landmarks and geographic locations that names and mileposts refer to. They need to know the location of highway-railroad grade crossings by milepost and street locations where roadway workers can get on and off the track. Several roadway workers mentioned the importance of dispatchers taking rides along the track that they control so that they have a good understanding of the geography. This knowledge facilitates communication between dispatchers and roadway workers, as well as train crews.

Finally, roadway workers and dispatchers need to communicate location information accurately to ensure a common understanding of the location where work authority is being requested and given. As discussed in Section 3.3, communication errors can arise that have potential to impact roadway worker safety.

Section 3.4 discusses some technologies that can be used to foster shared situation awareness of roadway worker location, reducing the potential for failures in situation awareness of physical location or problems in communication.

3.2.2 Maintaining Awareness of Time to Track Authority Expiration

Another challenge that roadway workers mentioned was the need to maintain awareness of time in relation to track authorization time limits. They expressed concern of the possibility of losing track of time with the result that track authority time may expire and the roadway worker may fail to notice it.

[4] To be qualified on a territory means that they have received training on the territory and have undergone testing to establish that they are familiar with the characteristics of the territory.

Roadway workers mentioned several factors that can contribute to losing track of time. The roadway worker may be engrossed in the work, or he/she may become distracted by another activity (e.g., phone call or a request to check on a particular problem).

They mentioned that policies were in place to help them keep track of time. For example, every time they pass a control point, they are required by operating rule to stop and have a job briefing that includes reviewing track authority and checking the time. However, variable distance can exist between control points (ranging from 500 feet to 10 or more miles).

Section 3.4 discusses technological approaches that could be used to provide alerts when track authorization time limits are about to expire.

3.2.3 Maintaining Awareness of Trains and Anticipating Trains

Roadway workers need to maintain awareness of trains near their location. This includes trains that may be traveling on the adjacent track, as well as the track on which they are working (e.g., in the case of train approach warning and individual train detection methods of establishing protection).

In principle, trains are detectable by seeing them or hearing them as they approach. In practice, train detection can be difficult. If the roadway workers work with their backs toward the direction of the approaching train, they may never see the train. If they work in a noisy environment (e.g., around noisy equipment) or wear protective headgear (e.g., in inclement weather), they may not hear the approaching train. As trains get quieter, the ability to hear the approaching train becomes more difficult.

People can more quickly and accurately detect and respond to a stimulus if they expect it. For roadway workers, this means that they will more quickly detect an approaching train if they anticipate when trains are likely to be come through and in what direction.

The team’s interviews with roadway workers and dispatchers indicate that roadway workers actively engage in building and maintaining awareness of trains in their vicinity to help them predict when trains are likely to approach and in what direction. Train bulletins provide the first source of information on trains on what to expect. Roadway workers anticipate regularly scheduled trains based on review of train bulletins, timetables, and their own experiences in the territory.

Anticipating unscheduled trains can be more challenging. Roadway workers have developed strategies to help them anticipate unscheduled trains. For example, the EIC will routinely monitor the road channel for train communication. This allows him/her to hear communications among locomotive engineers and to hear locomotive engineers calling out signals as they approach them. This allows the EIC to build an understanding of the locations and intentions of trains in the general vicinity.

In addition, informal, cooperative practices have grown whereby other individuals (roadway workers, train crews, or dispatchers) will routinely alert roadway workers of trains that may be about to reach them. Both roadway workers and dispatchers mentioned that dispatchers will routinely call roadway workers to let them know that a train will be coming by on an adjacent track, particularly if the train is unscheduled (e.g., a freight train or a work engine) and/or if it is coming on a different track from usual or in an unanticipated direction. Similarly, the researchers observed cases of roadway workers traveling on track cars who called a roadway worker group that they passed earlier to alert them to a train heading their way. The research team observed similar behavior on the part of train crews who called roadway workers they passed to alert them to trains that were coming in their direction. Roadway workers refer to these practices as courtesies. Operating rules do not require this behavior. However, these informal, cooperative practices play an important role in increasing the safety of railroad operation by enhancing the situation awareness of individuals distributed in time and space. Roadway workers are better able to anticipate and prepare for trains heading their way because of the information provided by these informal communications within and across craft groups.

As discussed in Section 3.3, failing to detect an oncoming train or moving equipment on the track being worked on or on an adjacent track contributes to roadway worker accidents. Trains that are unexpected or coming from an unexpected direction pose a particular challenge.

Section 3.4 discusses technologies that could be used to alert roadway workers to approaching trains and trains on adjacent tracks.

3.2.4 Maintaining Awareness of Other Roadway Workers

Another important cognitive demand associated with establishing and maintaining track safety is the need to maintain awareness of the location and activities of everyone working under the same working limits. In particular, the EIC is responsible for keeping track of individuals in the work zone. If another roadway worker wishes to enter the territory, the roadway worker must get authority from the roadway worker in charge. The EIC needs to keep track of roadway workers whom he/she has given permission to work in his/her territory. The roadway worker in charge cannot give back the track to the dispatcher until all the roadway workers on that section of track have been notified and are clear of the track.

Keeping track of the location and activities of other roadway workers can be challenging when the work can occur over a geographic area larger than the EIC's visual range and when communication occurs primarily over the radio. Because of problems with radio communication (e.g., dead spots), it can sometimes be hard to reach roadway workers, and dispatchers are sometimes asked to pass messages among roadway worker groups whose radios cannot reach each other directly.

One of the ways that roadway workers maintain shared situation awareness is by taking advantage of the party-line aspect of radio communication. For example, the EIC attempts to have all the relevant parties listen in over the radio when a track authority is issued. This increases efficiency and reduces the potential for communication errors.

One of the dispatchers that the team interviewed mentioned that he routinely liked to listen in when the EIC gave permission for someone (e.g., a track car) to come into the work zone. This allowed him to keep track of who received permission to enter the work zone and what activities they were engaged in.

Similarly, it was mentioned that the EIC liked to have the relevant roadway workers (e.g., people in track cars, flagmen) listen in over the radio when he obtained a track authority from the dispatcher. This allows everyone who needs a copy of the track authority to hear and write it down at the same time. This eliminates the need for the roadway workers to contact the EIC individually to receive a copy of the track authority. This increases efficiency and reduces the potential for communication error.

Section 3.4 discusses ways that this positive party-line attribute of radio communication can be preserved as communication moves to digital communication technologies.

3.3 Sources of Error

Section 3.1 summarized communication needs and challenges associated with working on and around the track. Section 3.2 summarized additional cognitive activities related to safe operations on and around the track and associated challenges. This section summarizes the kinds of human errors that can arise as a consequence of the cognitive challenges described in Sections 3.1 and 3.2.

3.3.1 Communication Errors

As mentioned in Section 3.1, most communication currently occurs over voice radio channels.

Errors can occur during radio communications when the listener (roadway worker, train crew, or dispatcher) misses or mishears part of a communication due to poor radio quality, or because communication is stepped on or is blocked by another transmission on the same channel.

Errors occur more frequently in cases where items sound alike. As an example, roadway workers gave cases where location names sounded alike. A listener may mistake the location requested or granted due to similar sounding names. For example, two blocks or control points may have similar sounding names that are easily confused. Examples given to the researchers were 'NAS' for 'northern absolute block' and 'SAS' for 'southern absolute block.' A new dispatcher may not be familiar with the territory and may not understand what territory location is being requested because of the similar sounding names. The same types of confusions can occur with milepost locations. Roadway workers told the research team that sometimes very similar sounding mileposts can be within a few miles of each other (e.g., SP640, ASJ640, ASK640, ASG640).

Another contributor to communication errors is situations where multiple items have the same name. Roadway workers told the researchers of instances where track equipment had the same number as an engine, resulting in potential confusion with respect to who asked for permission and who received it.

The radio phenomenon called skip can lead to confusion as to who is being spoken with on the radio. Skip refers to atmospheric conditions where distant locations that normally are not able to reach each other can be heard clearly over the radio. For example, respondents told the team of cases where atmospheric conditions caused radios in Boston to receive communications from radios in New York and New Jersey. These communications came through louder than communications in their own territories. This phenomenon happens mostly at night and can lead to miscommunications. Several dispatchers told the researchers of several instances where a dispatcher thought he or she was talking to someone in his/her own territory, but someone in a distant territory responded. One Boston dispatcher mentioned a case where she issued a Form D to a roadway worker in her territory, then heard someone else over the radio say 'Roger,' and proceed to repeat the Form D authority. The response came from a railroad in New York where they used the same Form D format.

A standard convention in safety critical railroad radio communications is to use a readback-hearback procedure where the receiver repeats back what he/she heard. While this is useful, it does not catch all errors.

Section 3.4 discusses the use of digital communications technology that eliminates some of the problems in radio transmission and reduces the potential for communication errors.

3.3.2 Working on the Wrong Track or Location

While problems in communication constitute a significant potential for error, other sources of error relate to loss of situation awareness. As mentioned in Section 3.2.1, an important cognitive demand for maintaining safe operations on and around the track is to know and communicate the specific location where the roadway worker is working. Errors can arise if roadway workers confuse one track location with another when requesting limits of authority. Similarly, errors can arise if roadway workers or dispatchers communicate location information inaccurately when requesting limits of authority.

Roadway workers mentioned that they are qualified on the territory where they work, reducing the possibility of confusion about location or track number. Employees mentioned, however, several instances where roadway workers worked at a different location or on a different track than the one for which they had received authority from the dispatcher. One case involved confusion between two locations with similar geographic landmarks. In this instance, a roadway worker indicated he was working at one interlocking when in fact he was working at a different one several miles away. Both interlockings were at bridges, which created the source of confusion. The error was caught and corrected by the dispatcher based on the switch number. The dispatcher realized that no switch with that number was at the interlocking where the roadway indicated he was. This example reiterates the importance of detailed knowledge of the territory by both roadway workers and dispatchers.

Several cases were mentioned where track foremen traveling in high-rail vehicles went on a different track than the one for which they received authority. In one case, the track foreman traveled on track 1 heading east when the dispatcher thought he had given authority for track 2. Normally, traffic moved east on track 1. In this situation, however, the train moved westbound on track 1. Fortunately, the track foreman saw the train in time to call on the radio, and the train stopped in time.

Dispatchers mentioned that while instances of roadway workers working at the wrong location or on the wrong track are rare, they do occur. They mentioned that the party-line aspect of radio communication sometimes allowed dispatchers to catch and correct these kinds of errors. Several dispatchers mentioned that they liked to hear work-related conversations over the radio because it allowed them to keep track of the roadway workers' location and the activities they were engaged in. This allowed them to catch errors, such as unintentionally working outside the limits of authority for which protection was granted.

Section 3.4 describes ways that technologies, such as GPS, coupled with graphic displays can be used to enable roadway workers and dispatchers to more accurately determine and communicate location information, reducing the potential for error and increasing the ability to catch and correct errors that do occur.

3.3.3 Exceeding Track Authorization Time Limit

In addition to maintaining awareness of physical location, roadway workers need to maintain awareness of time in relation to track authority time limits. Roadway workers expressed concern that they may get engrossed in the work and lose track of time. Track authority time limits may expire, and the roadway worker may fail to notice it.

Section 3.4 describes technologies that can be used to provide alerts when track authorization time limits are about to expire.

3.3.4 Lack of Awareness of Oncoming Trains

Colliding with a train represents one of the greatest risks confronted by roadway workers. A review of an FRA roadway worker fatality data set that covered the period from 1986 through 2003[5] revealed that trains caused more than 65 percent of fatalities. Thirty-four percent occurred while working on the track on which the train was running, 17 percent occurred while working on an adjacent track, and 16 percent occurred while walking to or from the worksite.

As discussed in Section 3.2.3, approaching trains can be difficult to see or hear. If the roadway workers operate with their backs toward the direction of the approaching train, they may not see the train. If they work in a noisy environment (e.g., around noisy equipment) or wear protective headgear (e.g., in inclement weather), they may not hear the approaching train. As trains get quieter, the ability to hear the approaching train becomes more difficult. Detecting the approach of a train in time to clear the track may be particularly challenging in cases where the train is unexpected and/or if it is approaching from an unexpected direction.

Communication problems can also contribute to accidents involving trains. In work zones protected by working limits, the EIC must ensure that roadway workers are clear of the track before giving permission for a train to enter the work zone. As discussed in Section 3.3.5, however, miscommunication can occur between the EIC who is communicating with the train and the roadway foreman who is in charge of personnel working on a particular portion of track. There have also been cases of multiple trains coming through one immediately after the other, where the roadway workers were only expecting one train, due to problems in communication.

Another factor mentioned by roadway workers the team interviewed was the time delay between when the roadway workers are told to clear the track and when the train comes through. This inherent lag can create situations where a roadway worker may decide to get back on the track to do something quick, thinking that he/she has adequate time. As one roadway worker put it, "a roadway worker can hear the message, go in the clear, and then see something with the machine or something they need to quickly do, for example jump off the machine to grab a tool that had been misplaced."

3.3.5 Communication Failures Among Work Group Members

As stressed in Section 3.1.2, effective communication among roadway workers in a work group is critical to maintaining safety. The EIC is responsible to ensure that everyone in the work group is alerted to potential hazards. In large projects, however, multiple work groups may be working in different locations, and the EIC may be at a different location and depend on radio communication to direct and keep track of the work group members. The EIC may communicate with the roadway worker foreman in charge of the personnel, who in turn communicates with the roadway workers in his or her group. In some cases, where radio signals may be weak, they depend on the dispatcher to pass communication among the work group. The multiple communication chains create the possibility for communication failures; information may not be communicated, may be communicated erroneously, or may be misunderstood by the receiver.

[5] The researchers thank Christopher Schulte, FRA, for providing this data set.

Consider the close call example described earlier where an EIC let a train into a work zone without checking that everyone was off the track, and the roadway workers failed to detect the approaching train as it came by on the adjacent track. Several factors contributed to this failure. A miscommunication occurred between the person in charge of the track and a secondary foreman in charge of the personnel. It was an unscheduled train, so the roadway workers were not expecting it. Further, their attention was focused on a malfunctioning spiking machine, and noise from the machine masked the sound of the approaching train.

3.3.6 Lessons Learned from Roadway Worker Fatalities

As part of the analysis, the research team reviewed an FRA roadway worker fatality data set that covered the period from 1986 through 2003.[6] The researchers identified 24 cases that involved a train hitting roadway workers while working. This included 19 cases of trains hitting roadway workers on the track on which they worked and 5 cases of trains hitting roadway workers working on an adjacent track. Other fatalities (e.g., fatalities attributable to being struck by maintenance-of-way equipment or that occurred while walking to or from the work area) were excluded from the analysis. The purpose of the analysis was to identify the situational factors that appeared to contribute to the roadway worker accidents.

The results of the analysis reinforced the conclusions drawn from the interviews with roadway workers. Problems in communication, failures in situation awareness with respect to the location and activities of others (trains, roadway workers), and unusual conditions that violate expectations emerged as main contributors to accidents:

- Communication problems were explicitly identified in 5 of the 24 incidents (20 percent).
- Unusual or unexpected conditions were explicitly identified in 5 of the 24 incidents (20 percent). This included three instances where multiple trains passed in immediate succession and two instances where the trains came from an unexpected direction.
- Roadway workers facing away from the train was explicitly mentioned in 4 incidents (17 percent).
- Dispatchers and/or the train crew not being aware of the roadway workers was explicitly mentioned in 4 incidents (17 percent).

The results point to the potential value of aids that:

- Facilitate communication among roadway workers, dispatchers, and train crews
- Enhance the ability of roadway workers to be aware of approaching trains
- Enhance the ability of dispatchers and train crews to be aware of the location of roadway workers
- Enhance the ability of roadway workers to be aware of the location of other roadway workers

3.4 Opportunities to Facilitate Communication, Support Performance, and Enhance Safety

The analysis of cognitive demands summarized in Sections 3.1-3.3 highlighted the importance of communication and coordination in both facilitating the work of roadway workers and enhancing on-track safety. It revealed the value of the party-line aspect of voice radio communication that

[6] The researchers thank Christopher Schulte, FRA, for providing this data set.

allows individuals to monitor communications between other parties, fostering situation awareness of the location and activities of others that may impact their own work or safety. More generally, it revealed the importance for roadway workers to remain aware of their location and the location and activities of other roadway workers and trains in their vicinity. The analysis also discussed the importance of the informal cooperative activities that roadway workers, dispatchers, and train crews engage in to build and maintain shared situation awareness of each other's location and activities.

The emergence of new technologies have the potential to facilitate communication and to support the cognitive and collaborative processes required for maintaining shared situation awareness among roadway workers, dispatchers, and train crews. A portable device for roadway workers could include the following functions:

- GPS for more accurate location information
- Digital technologies for more reliable communication
- Communication, and data storage, retrieval, and computation functions to support maintenance and inspection tasks.

This section summarizes some of the concepts that have been proposed for a portable communication device and prototypes that have been developed within the railroad industry. The section lists the specific functions that a portable digital communication device with integrated GPS could provide to facilitate roadway worker performance and enhance on-track safety.

3.4.1 Concepts and Prototypes of Portable Digital Communication Devices

In a report on PTC technologies as they relate to roadway workers (November 2004), the RSAC PTC Working Group Roadway Worker Protection Task Force provided a conceptual description of a portable communication device for roadway workers and how it is envisioned to facilitate performance and enhance safety. The committee envisioned that roadway workers would be equipped with portable terminals, which they can use to request authority to occupy track and to release authorities.

FRA funded a research and development effort through the Volpe Center to prototype and test a handheld digital communication device for roadway workers (Malsch, Sheridan & Multer, 2004; Masquelier, Sheridan & Multer, 2004; Oriol, Sheridan & Multer, 2004). Digital technology uses bandwidth more efficiently than analog communications. Information transmitted digitally can be presented aurally or visually. This allows for more reliable communication of complex transactions, like a track authorization, than is possible over radio channels.

The prototype device operated on a cell phone with integrated personal digital assistant (PDA) capabilities coupled with a GPS receiver. It enabled roadway workers to obtain real-time train and territory status information, as well as request and receive work authorization from dispatchers. The integrated GPS technology provides an accurate means to identify and communicate roadway worker location information. The prototype transmits roadway worker location information to a display intended for dispatchers. The roadway worker position information can be presented on either of two graphic views: a track display or a street map display. Preliminary user feedback from roadway workers and dispatchers has been positive.

The RSAC PTC task force report (November 2004) mentioned another research and development project to develop a compact portable remote terminal (PRT) for use by the EIC of roadway workers to provide a wireless, functional link to the train control system. Envisioned features include the ability for the EIC to:

- Communicate authorization for a train to enter a work zone
- Communicate a maximum speed, other than restricted speed, to a train entering a work zone (e.g., track bulletin, Form B, etc.)
- View train lineup and work zone information to assist in planning on maintenance-of-way work tasks

3.4.2 Candidate Functions for Portable Digital Communication Device

Portable digital communication devices can incorporate support functions to facilitate roadway worker job performance and enhance on-track safety. In particular, digital communication technology, coupled with technology for identifying physical location, can facilitate communication among roadway workers, dispatchers, and locomotive engineers. Portable devices can also incorporate data storage, computation, and transmission capabilities that can be used to facilitate roadway worker maintenance and inspection tasks.

The following specifies some of the support functions that could be provided by portable communication devices. This set of desirable support functions was generated based on the analysis of the cognitive and collaborative demands of roadway worker activities that the team conducted, as well as through direct suggestions made by roadway workers, dispatchers, and train crews that were interviewed as part of this project. In many cases, the RSAC PTC task force made similar recommendations for support functions as part of their recommendations for best practices for PRTs to be utilized with PTC systems.

Support Communication Among Roadway Workers, Dispatchers, and Train Crews

Roadway workers need to reliably communicate with other roadway workers in their workgroup, as well with dispatchers and trains in their vicinity. Analog radio communication, however, is not always reliable. The signal may be weak, dead zones may exist, or interference that prevents or degrades communication may occur. There is opportunity to deploy new digital technology to more effectively support communication. Table 2 presents specific types of communication that could benefit from a shift to digital communication media.

Table 2. Proposed Support Functions for a Portable Communication Device to Enhance Communication Among Roadway Workers, Dispatchers, and Train Crews

Support Communication with Dispatchers:
Request authority to occupy track and release authorities.* Request civil speed limits (within working limits and adjacent tracks not included in working limits).* Communicate temporary civil speed restrictions (e.g., slow orders based on track problems they detect) to the dispatcher. Communicate track out of service to the dispatcher.
Support Communication with Trains:
Communicate authorization for a train to enter a work zone.

Communicate a maximum speed, other than restricted speed, to a train.
Support Communication Among Roadway Workers:
Communicate between members of a work group.
Communicate back to the yard office maintenance problems that require work orders to be issued.
Provide Broadcast Capability:
Preserve the benefits of the party-line aspect of radio communication by allowing the dispatcher to notify multiple people when providing authority for track occupancy or forwarding other information.[7]
Preserve the benefits of the party-line aspect of radio communication by allowing roadway workers to broadcast information to multiple individuals simultaneously. This could include other roadway workers in the work group or trains in the vicinity.[8]

* Indicates support functions also recommended by the RSAC PTC task force.

Foster Shared Situation Awareness

The results of the cognitive analysis highlighted the importance for roadway workers to maintain broad situation awareness of their own location in relation to the location of other roadway workers in the workgroup and trains in the vicinity. This is especially true for the EIC who is responsible for keeping track of the location of roadway workers within the territory he or she controls and making sure they are alerted and are clear of the track before allowing a train to enter a work zone. It is also important for roadway workers working under train approach warning or individual train detection to be aware of trains approaching on the track they are working on or around, as well as on the adjacent track.

The results of interviews with dispatchers revealed that they also felt a need to maintain broad situation awareness of the location and activities of roadway workers in the territory they control. This is important to facilitate their own decisionmaking with respect to track allocation, as well as to provide a redundant layer of safety for roadway workers. If a dispatcher maintains awareness of who is working on the track and where they are working, he or she is in a better position to ensure that roadway workers clear the track before a train is allowed through.

Similarly, train crews work to maintain awareness of the location of roadway workers in the territory they are crossing so that they can sound their whistle to let them know they are approaching. Maintaining mutual awareness of the location of trains and roadway workers contributes to roadway worker safety.

[7] Dispatchers that the researchers spoke with felt it was important to foster shared situation awareness by broadcasting messages to multiple individuals simultaneously. As one dispatcher put it, "I would want people to know what is going on in the locations they are working in." A message broadcast capability would enhance common knowledge of ongoing activities among individuals working in a given territory, preserving a positive feature of current party-line radio communication.

[8] Roadway workers stressed to the researchers that in some cases it is desirable to have everyone (e.g., everyone in a work group) on the same communication loop to support communication and coordination. For example, if there is a broken rail in one place, they have to get some rail from another place, they have to bring in workers from a third place, and the supervisor is in yet another place, it would be useful for the supervisor to be able to talk to everyone at once and have everyone listening in.

Location finding technology, coupled with communications and graphics display technology, can be used to display information that would enable roadway workers, dispatchers, and train crews to share common awareness of the location and activities of roadway workers and trains in a given vicinity.[9]

Table 3 presents specific functions that a portable digital communication device with integrated GPS could provide to enhance shared situation awareness among roadway workers, dispatchers, and train crews.

Provide Support Functions for Maintenance and Inspection Work

While part of the value of a portable digital communication device lies in facilitating communication and enhancing shared situation awareness, the same device can also include functions to facilitate roadway worker maintenance and inspection work. This includes functions that provide ready access to information from operating rules and maintenance manuals needed to support inspection and determining appropriate action, as well as data recording and transmittal to support recording and transmitting results of inspection activities.

Table 4 presents specific functions that a portable digital communication device with integrated GPS could provide to more effectively support maintenance and inspection work.

Table 3. Proposed Support Functions for a Portable Communication Device to Enhance Shared Situation Awareness

Provide Own Location Information:
Provide graphic display of the roadway worker's location relative to work authority limits.* Provide the same graphic display of the roadway worker's location relative to work authority limits to the roadway worker (on a portable display unit) and dispatcher (on a display in the dispatch center) to facilitate shared understanding of location information being communicated, reducing the potential for error.
Provide Alerts to When Approaching Limits of Authority:
Facilitate the extension of time limits or release of track authority by reminding the EIC to contact the dispatcher. Provide an alert when a roadway worker (e.g., on a high-rail vehicle) is approaching the limits of authority, as well as in cases where the authority limits have been violated to prevent an unintended excursion.*[10] Provide an alert when the time limits of authority are about to expire.[11]

[9] Masquelier, Sheridan and Multer (2004) report development and testing of a prototype system that included a graphic display for dispatchers, which provided location information on roadway workers on the track. The graphic display did not produce as much benefit in performance as hoped, suggesting the need for more research and development in this area.

[10] According to the RSAC PTC task force, Burlington Northern Santa Fe has already begun the installation of an authority limits warning device on its high-rail vehicles. A similar device could be installed on roadway maintenance machines to provide the same warning or even automatically stop movements.

[11] Roadway workers at the CSX Montefiore Yard in Jacksonville, FL, suggested the proposal to include an alert indicating time limit expiration. They indicated that such an alert would be particularly important in the case of rule

Provide Location Information of Other Roadway Workers in the Vicinity:
Enable the EIC to electronically track other work groups or lone workers protected by their authority.*
Provide Information on Trains in the Vicinity:
Provide ability to access train schedule. Provide alerts to approaching trains or trains on adjacent track to working limits.*[12] Display the location of trains in the vicinity on a portable graphic device. Notify the EIC of train approaching authority boundaries.*
Provide Information to Dispatcher on Location of Work Groups:
Provide a graphic display to dispatchers to enable them to keep track of the location and dispersion of roadway workers and equipment in a work zone.[13]
Provide Information to Train Crews on Location of Work Groups:
Provide a display to train crews to enable them to keep track of the location and dispersion of roadway workers and equipment in a work zone.

* Indicates support functions also recommended by the RSAC PTC task force.

Table 4. Proposed Support Functions for a Portable Communication Device to Support Maintenance and Inspection Tasks

Store and display electronic copies of rule books.
Display FRA standards and railroad-specific standards for rail defect repair (tolerances and time limits for repair requirements).[14]
Record the location and nature of track defects (using GPS for location information), and communicate the information back to the track department.[15]

707 authority because when the time expires, the track automatically reverts to the dispatcher's control. The dispatcher could conceivably give authority away to someone else, causing a safety risk. In contrast with rule 704, the roadway worker must explicitly give up authority; it does not automatically revert back to the dispatcher when the time expires.

[12] The RSAC PTC task force specifically called for the ability to announce trains approaching on an adjacent track not included in working limits. They specified that the PRT device should have an interface to enable the warning to link to on-track equipment loud speakers.

[13] Dispatchers indicated a desire to receive more information on the location and dispersion of roadway workers in the territory they control. As one dispatcher put it: "Sometimes a foreman might come out there and he might have five, six, seven, eight pieces of equipment with him, it would be nice to know how spread out through the track they are."

[14] Roadway workers indicated that it would be useful to incorporate the rules on defects, appropriate remediation, and the time by which they need to be fixed. This information is now found in the FRA book and CSX standards documents (e.g., some rail defects may have to be fixed within 7 days). Currently roadway workers have to synthesize information from several pages to determine appropriate action. A simplified table could be included in the portable device that integrates this information into a readily accessible and usable form.

Record and store track inspection data to allow for comparison over time to help the inspector make judgments about the nature and severity of problems (e.g., is this a problem that is degrading rapidly and should be addressed soon or a slow-changing problem?).

Prepare and transmit track inspection-generated repair requirements to maintenance supervisor in yard office for issue of work orders.

[15] The RSAC PTC task force report indicates that some railroads now equip their track inspectors with handheld units, which record the location and nature of track defects, using GPS for location information.

4. Demands Associated with Inspection, Maintenance, and Troubleshooting

A second focus of the CTA related to the cognitive and collaborative activities associated with inspection, maintenance, and troubleshooting of equipment and the impact of advanced digital technologies, such as PTC systems on roadway worker maintenance activities. Introduction of new systems can create new maintenance and troubleshooting challenges. If appropriate maintenance support systems are missing (e.g., quality manuals and training, organizational support), maintenance errors can impact the reliability and safety of railroad operations.

This section of the report provides a summary of the human factors literature on system factors (e.g., equipment design factors, organizational factors, training factors) that impact inspection, maintenance, and troubleshooting of systems. This is followed by the results of interviews with signalmen and mechanical maintenance personnel relating to new performance demands associated with the new digitally based systems that they were responsible for inspecting and maintaining.

4.1 Lessons Learned from Related Industries

Experience from other industries indicates that maintenance errors can be an important contributor to risk (Stubler, Higgins & Kramer, 2000; Patankar & Taylor, 2004). Hobbs (1999) reports that approximately 15 percent of major aircraft accidents involve maintenance error. In the nuclear power plant industry, maintenance errors account for approximately half of human performance problems associated with potentially serious events (Reason & Hobbs, 2003).

Hobbs (1999) reports a study that was conducted by the Bureau of Air Safety Investigation (BASI) where it collected information on over 120 aircraft maintenance errors based on interviews with airline personnel and review of incident reports. BASI found that over 80 percent of the maintenance errors fell into 1 of 5 categories:

1. *Memory Lapses* (24 percent): These generally occurred when individuals were interrupted to go and do something else or were working on several things at once.
2. *Work-Arounds* (23 percent): Work-arounds typically involved performing a task without all the necessary equipment or in a way that deviated from approved procedures.
3. *Problems in Situation Awareness* (18 percent): These typically involved situations that differed from the normal, expected case or where the individuals were not aware of actions that had been taken by others.
4. *Lack of Expertise* (10 percent): These related to cases where the individual lacked the knowledge, skills, or experience to perform all aspects of the job. Often these errors could be traced to lack of experience and deficiencies in training.
5. *Action Slips* (10 percent): These related to situations where an individual took an action different from what he/she had intended (e.g., putting engine oil into the hydraulics system of an aircraft when he/she had intended to put in hydraulics fluid because the fluids were stored in nearly identical containers in a dark storage room).

Review of maintenance errors across industries shows similar results. The occurrence of maintenance errors is strongly influenced by factors that are part of the environment in which the person is working (Patankar & Taylor, 2004; Reason & Hobbs, 2003). Error-producing conditions in the immediate workplace are commonly referred to as local factors. Wider system problems that reflect the organizational culture are referred to as organizational factors.

Based on a review of maintenance accidents and incidents across a variety of industries, Reason and Hobbs (2003) developed a model of the factors that contribute to maintenance errors. Figure 1, adapted from Hobbs (1999), illustrates the elements of the model. Maintenance errors typically arise from specific unsafe acts (e.g., failing to put a part back or putting it back incorrectly). These unsafe acts may result from individual factors, such as a temporary memory lapse, a lack of knowledge, or an action slip. In turn these are influenced by problems in the local workplace that include factors, such as incomplete, ambiguous, or unworkable procedures; lack of tools, equipment, or spare parts; and problems in communication between personnel (e.g., across shifts). They are also influenced by systemic organizational problems, such as failure to provide effective initial training and refresher training, failure to develop and update manuals and procedures, failure to learn from prior incidents and institute changes in response, and problems in safety culture.

The model also emphasizes the importance of instituting safeguards to reduce the consequences of errors. Safeguards include error capture mechanisms that allow errors to be caught and corrected before a safety problem results. Instituting independent inspections of work is an example of a safeguard intended to catch errors before they can cause harm. Another safeguard strategy is to design error tolerant systems that minimize the consequences of errors should they occur. An example is to include redundant systems (e.g., multiple engines on an aircraft) and to institute a policy to avoid performing identical maintenance actions on the redundant systems at the same time. In this way, should an error occur, its consequences will not jeopardize safety.

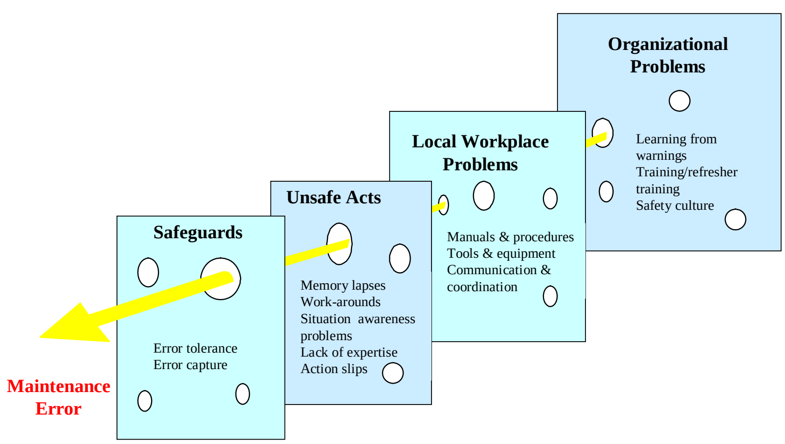

Figure 1. A Model of Factors that Contribute to Maintenance Errors

Reason and Hobbs (2003) identified factors that repeatedly emerged as contributors to maintenance errors across industries. These include:

- *Manuals and Procedures:* Guidance documents, such as manuals and written procedures, that are ambiguous, inaccurate, incomplete, or too technical may promote errors. Procedures that are unworkable or unrealistic are likely to lead to procedure violations and work-arounds. In the nuclear power industry, nearly 70 percent of all human performance problems have been traced to poor manuals and procedures.
- *Training and Experience:* Lack of training or insufficient training or experience can result in error due to lack of knowledge or skill. Hobbs (1999) specifically called out lack of refresher training as a significant contributor to maintenance errors in the BASI aviation industry study. Periodic refresher training is important to enable personnel to keep up with technological changes, as well as changes in regulations and company procedures.
- *Tools and Equipment:* Lack of appropriate tools and equipment is one of the most commonly cited contributing factors to maintenance performance problems.
- *Communication and Coordination:* Problems in communication and coordination (e.g., between different crafts, across shifts) is another leading contributor to maintenance error. In an Australian survey of aircraft maintenance, 12 percent of maintenance errors involved problems, such as misunderstandings, poor teamwork, or incorrect assumptions (Reason & Hobbs, 2003).
- *Time Pressure:* Maintenance personnel often face pressure to get a system (e.g., aircraft, locomotive, power plant component) back in service as quickly as possible. Time pressure can cause individuals to hurry or take shortcuts, resulting in errors. In an Australian survey of the aircraft maintenance personnel, time pressure was the most frequently mentioned factor leading to incidents. In addition, 32 percent of respondents reported that on occasion they had not done a required functional check because of a lack of time (Hobbs, 1999).
- *Physical Ergonomics:* Another problem relates to the physical ergonomics of a system, the design of the physical aspects of the equipment, and the physical environment in which the maintenance activities take place. If the equipment that needs to be maintained is hard to reach, hard to grasp, or hard to see and requires the person to get into or maintain awkward physical positions, it can lead to physical fatigue, injury, and maintenance error (Reason & Hobbs, 2003).
- *Fatigue:* Working while fatigued can lead to error. After 18 hours of being awake, mental and physical performance on many tasks is affected as though the person had a blood alcohol concentration of .05 percent (Reason & Hobbs, 2003).

4.2 Factors Contributing to Maintenance Challenges in Railroads

As part of the present study the research team interviewed system maintainers of the ASES and ITCS to explore factors that contribute to maintenance challenges in the railroad industry. Interviews were conducted with signalmen who install, test, and maintain the wayside equipment and mechanical department personnel who install, test, and maintain the in-cab systems. The interviews explored to what extent the types of factors identified in the general human factors literature on maintenance performance apply in the railroad industry. The interviews particularly probed for any additional maintenance challenges or safety-related factors associated with the maintenance of advanced train control technologies. The following sections summarize the primary issues that emerged.

4.3 Training

The quality of training impacts the ability of maintenance personnel to inspect, maintain, and troubleshoot equipment. Inadequate training of maintenance personnel can contribute to maintenance errors that reduce system safety and reliability.

The maintenance personnel that the team interviewed all felt that they received insufficient training. In some cases, training was relatively brief (on the order of 4 hours) and involved a basic introduction given by a vendor representative that covered how the system worked and what it was supposed to do when it worked appropriately. Uniform consensus existed among the maintenance personnel that the training did not go into enough detail on how to diagnose and fix problems that arose.

In addition to training requirements associated with learning the specific system, new systems, such as PTC systems, may incorporate technologies that differ from more traditional relay logic systems. This imposes new human performance requirements (e.g., new knowledge and skills), as well as introducing new opportunities for improved performance (e.g., better diagnostics).

The PTC systems use advanced digital technologies that require new knowledge and skill to maintain. In addition to training on the specific system to be maintained, the maintenance personnel needed more general knowledge of electronic systems and how to troubleshoot them. The signalmen working on ITCS provided one successful model. They requested and received an FRA grant to develop a general electronics maintenance course that was offered at a local community college. It was 40 hours in duration and was designed to provide them with a basic level of knowledge in electronics. The signalmen reported that the course was extremely beneficial in enabling them to troubleshoot and maintain the ITCS wayside equipment, even though it did not cover ITCS equipment specifically.

They felt that the general knowledge that they gained from this course enabled them to understand how ITCS worked and troubleshoot it more effectively. This training experience was so successful that it prompted one of them to go back and get a degree in electronics at a community college.

One of the concerns the signalmen raised was how to train new people who come on board but did not have the opportunity to take this basic course in electronics.

4.4 Availability and Quality of Maintenance Manuals

It is important to provide manuals that provide comprehensive guidance in how to diagnose and fix equipment problems that occur.

Maintenance personnel reported that their manuals were incomplete, difficult to understand and follow, and were not tailored clearly to the task of troubleshooting PTC equipment. The maintenance personnel reported that they experienced trouble with the reliability of the PTC systems and had difficulty localizing the source of the problem (e.g., was it due to a problem with the in-cab equipment, the wayside equipment, or both? Was it due to something the locomotive engineer did or did not do?). The manuals lacked sufficient guidance to isolate and repair these problems. Equipment displayed cryptic error codes, making it impossible to identify the fault. The manuals did not always provide sufficient help to understand the fault and how to correct the fault.

As an example, signal maintainers described their difficulty in using a manual for maintaining wayside equipment. The manual appeared to be based on a final design review document that provided information intended to help in troubleshooting the software design. It was not written specifically for the signal maintainers to troubleshoot the equipment. The error codes provided diagnostics at the software level (e.g., a registered overflowed) rather than at the level required to troubleshoot the equipment.

Another area of concern mentioned by the maintenance personnel was that the PTC systems were still in the process of changing and that the manuals were not kept up to date. As a result, if the new software gave an error code, it may not have been reflected in the manual.

4.5 Quality of Support from Vendors

One point raised by the maintenance personnel interview was the quality of technical support from the vendors of the wayside and in-cab equipment. Vendors were typically responsible for initial training, preparation and updating of manuals, upgrading of equipment, and technical support in cases where problems arose that could not be solved.

All the groups that the team interviewed indicated problems in troubleshooting equipment failures that required help from vendors. In many cases, the system error codes were cryptic, and the manuals did not provide sufficient guidance to isolate and correct the fault. As a consequence, the maintenance personnel needed to contact the vendors for help in tracking down the source of the malfunction.

Among the groups interviewed, some had mixed reactions with respect to the quality of the technical support provided. Some groups reported that the vendor representatives were easy to reach and knowledgeable. Other groups indicated that the technical support from the vendors was not always sufficient to support diagnosing and correcting system problems. In some cases, the problems exhibited by the system were difficult to diagnose and correct even for the vendors.

4.6 Availability of Testing Equipment

Lack of appropriate tools and equipment is one of the most commonly cited contributing factors to maintenance performance problems across industries. One of the primary tools for testing and maintaining of advanced digital technology systems are portable computers. Maintenance personnel carry them into the field to test and upgrade software in the wayside and in-cab systems. The maintenance personnel that the team interviewed mentioned a shortage of portable computers as a factor in limiting productivity and turnaround time.

4.7 Communication and Coordination

Problems in communication and coordination (e.g., between different crafts, across shifts) contribute to maintenance errors across industries. The maintenance personnel the team interviewed confirmed the importance of communication and coordination for timely and accurate diagnosis of equipment problems.

Close communication and coordination is often required between personnel in the signal and mechanical departments to track down the source of abnormal system behavior. In many cases, the system exhibited problems that occurred intermittently, making it difficult to track down. In those cases, close interaction was required between signalmen and mechanical department personnel to determine whether the problem resulted from a malfunction of onboard cab equipment or wayside equipment. The maintenance personnel indicated that generally close communication and sharing of information occurred between the two crafts in troubleshooting the new systems.

Maintenance personnel indicated that information from the train crew was also valuable in attempting to troubleshoot a train control system malfunction. They suggested that it would help if they had better documentation from the locomotive engineer explaining the context surrounding a malfunction (e.g., exactly when and where the malfunction occurred and what he or she saw out the window). Some information can be downloaded from the train control system, but things, such as what the crew saw out the window (e.g., wayside signal aspects), can only be obtained from the train crew.

In some cases, the maintenance personnel indicated that train crews were supposed to fill out forms explaining malfunctions that occurred during a trip but that the maintenance personnel did not always get a copy of the form.

In some cases, they called the locomotive engineer on the radio to find out more about where the problem occurred and the context in which it occurred. Sometimes it was hard to track down the locomotive engineer (e.g., because of rest days). In some cases, days went by before they spoke with him/her, by which point the locomotive engineer may have forgotten the details of what happened.

4.8 Physical Ergonomics

Another source of problem that has been reported in the general literature on maintenance errors relates to the physical ergonomics of a system: the design of the physical aspects of the equipment and the physical environment in which the maintenance activities take place. Interviews with the maintenance personnel revealed instances of poor physical ergonomic design.

The mechanical department described one case concerning the maintenance of the ASES cab signal system. Performing the 60-day inspection of the cab signal system required an employee to go into the cabinet, remove the door, and kneel down to read data values off of a display and record them by hand. He/she needed to stay in this kneeling position, writing down values for 15 minutes, leading to physical fatigue and potential for error.

Signalmen working on the ASES described another instance of poor physical ergonomics. They mentioned that testing a transponder can be time consuming. It can take up to 30 minutes to obtain transponder test readings that involve reading and manually recording long strings of characters off of a difficult-to-read display. An alternative is to dismantle the transponder and perform the test back in the shop where the physical test conditions are better, but it can take 20 minutes to dismantle the transponder. Improved physical ergonomics that would include more readable displays, less need to manually record long strings of characters, and easier methods to dismantle the transponder would make the test process faster and more reliable. Multer, Rudich, and Yearwood (1998) provide guidelines that should be considered in designing railroad equipment for maintenance needs.

4.9 Self-Diagnostics

In the age of microelectronics, software has the capability to self-diagnose. Systems should provide easy-to-understand explanations of the malfunction and easy-to-follow procedures for how to fix it. This behavior can facilitate testing and maintenance of systems, reducing the potential for error.

Maintenance personnel working on the ASES and ITCS suggested that the systems lacked adequate self-diagnostics. Displayed error codes were cryptic and required reference to a manual to decode. In some cases, the error codes were missing from the manual.

4.10 Software Version Control

Another issue that arises with the introduction of digital technology is the need for software version control. Over the life of a system, new software versions will be released to correct problems identified in prior versions and/or introduce improvements. It is important to put a process in place to ensure that PTC systems have the latest version of software installed. Failure to put in place a process for software version control can result in a wrong version being installed, possibly leading to problems in system reliability.

While the maintenance personnel did not identify any cases where an incorrect software version led to reliability problems, a case was mentioned where a vendor sent a system that had been repaired back to the maintenance department with the wrong software version installed.

They also mentioned that locomotives differed in the version of the software installed. Since upgrades were being made to system software on a regular basis, multiple versions of the software were installed on different locomotives. The existence of multiple versions of software in the field at the same time can complicate system troubleshooting and maintenance. It can also create the possibility that an older version of software that is less reliable or that has unanticipated negative interaction with newer systems will be inadvertently installed, leading to problems in system reliability.

4.11 Increased Workload

A byproduct of the introduction of new technologies is the potential to introduce new sources of workload for maintenance and operation personnel. Some sources of workload relate to new tasks required to operate the system (for example, entering temporary speed restrictions and work zones into the system). Other sources relate to new tasks associated with inspecting, troubleshooting, and fixing the systems. In both ASES and ITCS, the maintenance personnel reported that they experienced problems in system reliability that required significant time to track down and correct. Unreliable systems can divert maintenance attention and resources from other safety areas.

4.12 Implications for Design of Systems and Processes to Facilitate System Inspection, Maintenance, and Troubleshooting

The interviews with signalmen and mechanical department personnel revealed that many of the human factors problems related to equipment maintenance that have been identified in other industries are also present in the railroad industry. This includes:

- Inadequate training and lack of sufficient refresher training
- Maintenance manuals that are incomplete, inaccurate, and not tailored to the requirements of maintenance personnel
- Shortage of test equipment
- Cryptic error codes and lack of adequate self-test diagnostics
- Inadequate support from vendors
- Communication problems across crafts
- Poor physical ergonomic design of equipment

The emergence of new systems that utilize advanced digital technology exacerbate existing problems and introduce additional challenges.

Testing and maintenance of new systems may require different knowledge than systems that use older technologies. For example, the new systems require general knowledge of electronics that maintenance personnel who have worked on traditional relay logic systems may not possess. In addition to system-specific training, it may be necessary to ensure that the maintenance personnel have the necessary general electronics background knowledge needed to test and maintain new digital-based systems.

Equally important is the availability of comprehensive maintenance manuals that are tailored to the needs of maintenance employees, up to date, and easy to understand and use. Cryptic error codes and incomplete documentation can make it difficult to diagnose and repair system malfunctions. This can lead to delays in getting a system back online and contribute to safety-related errors.

Manuals need to be specifically written to support installing, testing, and maintenance of new equipment. The manuals should be comprehensive. They need to cover all error codes that can appear and provide specific procedures for troubleshooting and correcting system malfunctions. Processes should be put in place for upgrading maintenance manuals when changes to the system are made.

User evaluations should be performed to establish that the manuals are complete, easy to understand, and followed by the maintainers that are supposed to use them. These tests should be conducted using actual system maintainers as test participants, and their feedback should be used to correct any problems that were identified.

Advanced digital systems offer particular troubleshooting challenges and vulnerability to human error (Stubler et al., 2000). As a consequence, increased emphasis needs to be put on built-in tests and self-diagnostics that provide easy-to-understand explanations of the malfunction and easy-to-follow procedures for correcting the problem.

Another issue associated with advanced digital systems is the need for software version control. Failure to put in place a process for software version control can result in multiple versions of software in the field at the same time, complicating system troubleshooting and maintenance. Inadequate software version control can also result in the wrong version being installed, impacting system reliability. It is important that a process is put in place to ensure software version control and testing.

Communication and coordination among different crafts is important for rapidly tracking down and correcting system malfunctions, particularly in cases where the system malfunction is difficult to reproduce and localize. Procedures should be put in place to ensure that train crews document the contextual details surrounding a malfunction that are not automatically recorded by the system and are important to tracking down the source of a problem and that this information is passed to the maintenance personnel.

Finally, new systems can introduce new sources of workload that can divert attention and resources. This can result in increased error or sources of risk in other safety areas. It is important to anticipate and accommodate additional sources of workload associated with the operation and maintenance of the new system.

5. Discussion and Conclusions

The CTA focused on two aspects of roadway worker performance: (1) the cognitive and collaborative demands associated with working on and around the track and their impact on roadway worker safety and (2) the cognitive and collaborative demands associated with inspection, maintenance, and troubleshooting of railroad systems.

A primary objective was to identify and document cognitively challenging aspects of roadway worker tasks to anticipate potential impacts of new technologies on roadway worker performance and safety and provide guidance for the design and introduction of new railroad systems.

The results revealed numerous activities that railroad workers engage in that improve overall efficiency of railroad operations and enhance roadway worker safety on and around the track. These include cooperative activities within and across crafts, including dispatchers, train crews, and roadway workers. Some of these activities are codified in formal operating rules. Others have developed informally. The results point to the potential benefits of introducing portable digital communication systems with GPS capabilities and suggest specific design recommendations. The results also suggest potential benefits of implementing PTC systems for enhancing roadway worker safety.

The CTA also examined the cognitive and collaborative activities associated with inspection, maintenance, and troubleshooting of railroad systems. The results suggested opportunities to improve maintenance performance through improved support systems (e.g., better training, better manuals, more self-diagnostics). This is particularly true as next generation systems that utilize digital technology are introduced.

The following summarizes the study findings that point to opportunities to improve roadway worker performance and safety through the introduction of new technologies. The section discusses potential benefits that can be realized with new technologies while also providing some implementation recommendations.

5.1 New Communication Technology

The results of the CTA pointed to opportunities to enhance roadway worker performance and on-track safety through the use of digital communication technologies. Specifically, portable roadway worker devices that combine technologies for more accurate location information with digital communication technologies for more reliable communication have the potential to facilitate communication and coordination among roadway workers, dispatchers, and locomotive engineers. Further, by incorporating broadcast capabilities that enable a given message to be sent to multiple individuals at the same time, it is possible to preserve some of the positive party-line aspects of analog radio communication that fosters shared situation awareness of the locations and activities of others working in the same vicinity. The prototype handheld communication device developed and tested by the Volpe Center provides a promising model for leveraging the efficiency and reliability of digital communication while preserving the positive party-line aspects of analog radio (Malsch et al., 2004; Masquelier et al., 2004; Oriol et al., 2004).

Potential benefits of portable digital communication devices coupled with GPS technology include:

- Ability to obtain and release working limits more efficiently (e.g., through reduction in failed attempts to reach a party due to radio congestion, dead zones, etc.)
- More reliable communication and reduced potential for communication errors
- Opportunity to warn roadway workers when they are about to exceed their limits of authority (either going outside geographic limits, working on the wrong track, or approaching time expiration)
- Opportunity to warn roadway workers of approaching trains (both on the track they may be working on or near, and on adjacent tracks)
- Improved ability to keep track of and coordinate with other roadway workers in a work group
- Improved ability to maintain awareness of trains in the vicinity
- Improved ability for dispatchers to maintain situation awareness of the location and dispersion of roadway workers and equipment in their territories

In addition to these direct benefits, the RSAC PTC task force suggested that portable communication devices, coupled with PTC technology, would likely have far-reaching benefits on roadway worker safety and railroad operations efficiency. They suggested that by making it easier and more efficient to obtain and release working limits, digital portable communication devices may encourage the use of more positive forms of on-track safety, such as working limits over other forms of on-track safety (e.g., train approach warning and individual train detection). This would enhance roadway worker safety. They also suggested that it would promote more efficient use of track, increasing track occupancy time available for the movement of trains and track maintenance activities.

5.2 PTC Technology

The results of the CTA reaffirmed the potential benefits of PTC technology for enhancing roadway worker safety. PTC systems have been explicitly designed to stop trains before they enter working limits. This protects roadway workers from trains exceeding their limits of authority due to train crew error or communication failures.

PTC technology can also be used to enhance roadway worker safety in other ways. For example, PTC technology is being installed on roadway equipment, preventing them from going beyond their limits of authority.

In addition, PTC technology, coupled with digital communication technology, could also be used to enhance roadway worker safety in cases where working limits protection does not apply. This includes cases where roadway workers are operating under a train approach warning or individual train detection forms of on-track protection and cases where they have been provided working limits on the track they are working on but not on the adjacent tracks where trains are allowed to run. In those circumstances, PTC technology, coupled with digital communication technology, can provide roadway workers with accurate information on the location and movement of trains in their vicinity and alerts when trains are approaching their location.

The RSAC PTC task force conducted an analysis of roadway worker fatalities that occurred between 1986 and 2003. They report that 31 of the 47 roadway worker fatalities that occurred on main track (66 percent) occurred where no working limits existed on the track where the fatality occurred. Their analysis suggested that these events might have been mitigated by enhanced communications.[16] They stressed that this was an important finding that clearly demonstrates the need for a more enhanced communication system.

PTC technology could be used to enhance roadway worker situation awareness of trains in the vicinity. This could include providing visual displays of the location of trains in the vicinity (e.g., on portable graphic devices) and providing alerts to approaching trains or trains approaching on adjacent tracks that are not included in working limits. These features would provide needed cognitive support for situation awareness of approaching trains. Currently, roadway workers largely rely on informal cooperative practices of dispatchers, train crews, and other roadway workers to call them on the radio to alert them of approaching trains. PTC technology, coupled with digital communication, could provide a more standardized, reliable vehicle for providing this support.

5.3 Technology to Support Maintenance Inspection and Documentation

As described in Section 3.4, portable communication devices with built-in data storage and computation capabilities can be used to facilitate roadway worker maintenance and inspection work. This includes functions that provide ready access to information from operating rules and maintenance manuals needed to support inspection and determining appropriate action, as well as data recording and transmittal to support recording and transmitting results of inspection activities.

A handheld device could support the track inspector in recording problems, determining and tracking the severity of problems over time (how does it compare to the recorded value the last time the inspection was conducted), and determining whether safety violations have been exceeded and actions need to be taken.

5.4 Maintainability Considerations in New Technology Design and Introduction

The results of the CTA also revealed a need for more effective support for maintenance activities. This includes more training (including refresher training), better manuals, better self-diagnostics, and more technical support from vendors. The need for more effective support is particularly important as new, advanced digital systems are introduced that require different knowledge and skills to troubleshoot and maintain. It is important to consider the need for maintenance during the design stage.

The roadway worker CTA revealed that many of the human factors problems related to equipment maintenance that have been identified in other industries are also present in the railroad industry. This includes:

- Inadequate training and lack of sufficient refresher training
- Maintenance manuals that are incomplete, inaccurate, and not tailored to the requirements of maintenance personnel
- Shortage of test equipment
- Cryptic error codes and lack of adequate self-test diagnostics
- Inadequate support from vendors
- Communication problems across crafts

[16] In its report, the RSAC PTC task force indicated that examples of enhanced communications include but are not limited to digital authority transmissions that could be facilitated by a PTC system, digital/satellite telephone, and computer-based displays (page 6 of the Task Force Report: November, 2004).

- Poor physical ergonomic design of equipment

As new systems are developed, it is important to consider issues of maintainability as part of the system design and evaluation process. This includes consideration of physical ergonomics (ability to reach, ability to see), as well as cognitive aspects of task performance.

5.5 Facilitating Cross-Craft Cooperative Strategies

The CTA revealed the importance of communication and coordination across multiple individuals, spanning multiple crafts, distributed in space and time for facilitating work and enhancing safety. Railroad personnel have developed informal cooperative strategies, across roadway workers, dispatchers, and train crews that contribute to overall safety of railroad operations. These strategies are not codified in operating rules and are often described as courtesies. Nevertheless, they foster shared situation awareness and create safety nets. The analysis identified a number of instances where these informal cooperative strategies enabled errors to be caught and recovered from before severe consequences resulted. It is important to recognize the existence and value of these informal cooperative strategies to guide the design of more effective support systems. This will also ensure that new technology that is introduced does not inadvertently disrupt informal communication and coordination processes that contribute to overall system safety.

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Appendix A.

Focus Group Questions: Impact of New Technologies on Roadway Workers

Introduction

The Volpe National Transportation Research Center and FRA are participating along with representatives of Amtrak and other railroads, as well as representatives of labor on an RSAC working group that is looking at the impact of new train technologies on train operations and safety. The objective is to learn from the experiences of systems such as XXX to provide input for the design, operation and evaluation of future Positive Train Control Systems.

By safety we mean reducing the potential for accidents leading to deaths and injuries to crews, roadway workers and the public.

As part of this work we are conducting interviews and focus groups to obtain input from locomotive engineers, conductors, roadway workers, signal maintenance personnel and mechanical department maintenance personnel to understand the impact of XXX from their perspective.

Our particular concern is on Human Factors Issues. How XXX impact your ability to do your job and to maintain safety. One topic we are interested in is maintenance issues associated with the introduction of new technologies such as XXX. We are interested in how easy new systems such as XXX are to maintain, what new maintenance challenges these new technologies pose and what new training requirements and activities they bring.

We are also interested in your perspective on how XXX improves safety. We are interested in any problems that you have encountered with XXX and any concerns you might have on its impact on safety.

Your opinions and suggestions are very important to us and will help shape the kinds of new technologies that are introduced in the future. Both your National and Local labor representatives and NJT support this effort and hope that you will give your honest opinions and suggestions.

With your permission we would like to tape record the session because we don’t want to miss any of your comments. Your comments will remain strictly confidential.

While we will be writing a report summarizing what we learned, inputs of individuals will remain anonymous.

Also, if at any point you would like us to turn off the tape recorder or erase something said earlier we will do so. Is it OK to tape record?

Keep in mind that we're just as interested in negative comments as positive comments, and at times the negative comments are the most helpful.

We expect that you will have different points of view. Please feel free to share your point of view even if it differs from what others have said.

If you want to follow up on something that someone has said, you want to agree, or disagree, or give an example, feel free to do that. We are here to ask questions, listen, and make sure that everyone has a chance to share. We're interested in hearing from each of you. So if you're talking a lot, I may ask you to give others a chance. And, if you aren't saying much, I may call on you. We just want to make sure we hear from all of you.

Opening Questions:

Tell us who you are, and a little about your railroad background.

What territory do you cover? What proportion is XXX territory?

Maintenance Activities

Can you tell us some of the major signal maintenance activities associated with XXX? Installation activities?

What are some of the most common problems that have arisen with XXX?

What are some of the most difficult aspects of maintaining XXX? Troubleshooting XXX problems when things go wrong?

Do you get involved in maintaining XXX software? Upgrading software? Is version control an issue?

Were there any issues that arose during the XXX installation process?
Training

Can you tell us what training you received on XXX? Do you feel the training was sufficient?

Challenges to Maintenance

One of the areas we are concerned about are factors that can make maintenance more challenging and contribute to maintenance errors that can impact safety. Experience from other industries such as aviation suggest a number of factors that can contribute to maintenance errors.

I'm going to mention some of the factors that have been identified as challenges to maintenance in other industries and ask if they are an issue for you, and particularly if they are an issue with respect to maintenance of XXX systems.

- Lack of appropriate tools/equipment – Need to ‘jury-rig’ equipment
- Problems in the physical environment
- Inadequate documentation
- Unworkable procedures/need for work-arounds
- Need to maintain private ‘brain book’
- Time pressure
- Communication problems
  - Within a team
  - During shift turn-over
  - Communication with vendors who supply the equipment and provide hardware and software upgrades
  - Communication with users of the equipment.
- Fatigue
- Lack of training/experience
- Organizational Problems
  - Inadequate supervision
  - Inadequate policies

Errors and Near Misses:

Have there been any recent cases where a maintenance error or ‘near-miss’ occurred? Can you describe the factors that contributed to it?

Section Ending

From the perspective of ease of maintenance and prevention of maintenance errors, if you had five minutes to talk with key designers, what would you say?

- Are there any minor modifications to XXX that you would suggest to make it easier to maintain and reduce the potential for maintenance errors?
- Any major redesign? How about recommendations with respect to training, documentation or policies?

The Role of XXX in increasing worker protection

One of the objectives of the XXX system is to provide an additional level of ‘protection’ to roadway workers by ensuring that a train cannot enter their work limits or exceeds the maximum authorized speed specified in a slow order.

First we’d like to understand what kinds of accidents happen and why when the XXX system is not there (in non-XXX territory) and then we’d like your input on whether XXX helps prevent these types of accidents and how.

Let’s start with trains exceeding their maximum authorized speed limits set by a slow order:

In a non-XXX territory (or this territory before XXX) how are slow orders communicated to train crews?

What indications does a train crew have that they are about to enter a restricted speed zone?

What things might lead to a train to exceed the maximum authorized speed limits set by a slow order?

Have you ever experienced or heard about a case where a train exceeded a slow order speed limit? What factors contributed to it?

How does XXX ensure that a train doesn't exceed the maximum authorized speed limit specified by a slow order?

Do you have confidence that the XXX will keep trains from exceeding slow order speed limits?

Have you ever experienced or heard of a case where XXX failed to prevent a train from exceeding a slow order speed limit?

Do you have any concerns about the reliability or effectiveness of XXX?

Are there any other issues you can think of relating to the introduction of XXX? Any concerns you might have?

Another role of PTC technology is to prevent trains from entering a work limit without authority.

How are work limits protected?

How does a train get authority to enter a work limit?
What indications does a train crew have that they are approaching a work zone?

What things might lead to a train to enter a work limit without authority?

Have you ever experienced or heard about a case where a train entered a work limit without authority?

How does XXX keep trains from entering work limits?

Has XXX changed communication between roadway workers and train crews? Has it changed how train crews use horns and whistles to alert roadway workers of their presence?

Do you have confidence that the XXX will keep trains from entering work limits?

Do you have any concerns about the reliability or effectiveness of XXX?

Other contributors to roadway worker accidents – injuries and deaths

So far we've talked about accidents that occur because a train is exceeding a speed restriction or is somewhere it isn't supposed to be. These accidents are explicitly addressed by XXX.

We'd also like your perspective on other types of accidents where a train strikes a roadway worker. Our aim is to understand how new PTC or related technologies could be used to reduce those types of accidents as well.

A recent review of roadway worker fatalities found that 34% were the result of being struck by a train while working, 17% were caused by being struck by a train on an adjacent track and 16% were caused by 'walking into a train'–on the way to or back from a job.

Can we talk about each of these, what are some of the things that contribute to those types of accidents?

Let's start with 'Struck by Train While Working'

What kinds of situations are there where a train is allowed to travel on track where roadway workers are working? [Working limits vs. train approach warning vs. individual train detect]

How are roadway workers alerted that a train is approaching?

What factors might cause a roadway worker to fail to clear the track in time?

- Training
- Experience
- Weather
- Visibility/hearing
- Communication errors
- Complacency
- Fatigue
- Other factors?

Are the factors the same for working limits, vs. train approach warning vs. individual train detect?

What might cause a roadway worker to be outside their limits of authority? Wrong track? Wrong portion of territory? Wrong time? (authority expired)

What about 'struck by a train on adjacent track'?

Is it common to have situations where a roadway worker would be working on a track and a train could be going by on an adjacent track?

In those XXX, how would the roadway worker know that a train might be coming through on the adjacent track?

How are roadway workers alerted that a train is approaching?

Would there by a ‘lookout’ assigned to look out for a train?

Would the train be informed that there were roadway workers on the track?

What factors might cause a roadway worker to inadvertently foul the adjacent track and be struck?

- Training
- Experience
- Weather
- Visibility/hearing
- Communication errors
- Complacency
- Fatigue
- Other factors

Are the factors the same for working limits, vs. train approach warning vs. individual train detect?

What about ‘walking into train’?

What factors might cause a roadway worker to walk on a track where a train might come by – either on the way too or back from work?

- Training
- Experience
- Weather
- Visibility/hearing
- Communication errors
- Complacency
- Fatigue
- Other factors

Additional Opportunities to Improve Roadway Worker Safety

We’ve talked about several types of roadway worker accidents that are not explicitly addressed by XXX, do you feel that new PTC technology could help prevent those types of accidents?

Do you have suggestions for how new technologies such as GPS or new communication technologies could be used to reduce the potential for roadway worker accidents?

For example, a handheld device that would include GPS that would help to locate where the roadway workers were and provide alerts to approaching trains?

Ending

All things considered, do you think that XXX is a good system?

Do you think it makes train operations safer?

If you had five minutes to talk with key designers, what would you say?

- Are there any minor modifications to XXX that you would suggest to increase its impact on safety?
- Any major redesign?

Are there any things you would suggest trying to do better in the next PTC system based on the lessons learned from XXX?

Is there anything that we should have asked about but didn't? Anything that you came wanting to say that you didn't get a chance to say?

Appendix B.

Focus Group Questions: Roadway Worker Communication

Introductory Questions:

Our focus today is communication that roadway workers have with dispatchers, other roadway workers, and maybe also train crews over radio and also phone.

Can you say a little about who you tend to communicate with over radio and also over the cell phone?

Communication over the Radio

What types of things do you typically call dispatchers about?

What types of things do dispatchers typically call you about?

Can you talk about some of the problems that come up in communicating with Dispatchers over radio or phone?

Probes: Make sure cover both 'Process' (mechanics) of the radio communication media as well as 'Content' (what people say over the radio)

How about other roadway workers (e.g., Roadway foreman, other roadway gangs). What types of communications happen over the radio among different roadway workers? How about over the phone?

Can you talk about some of the problems that come up in communicating with other roadway workers over radio or phone?

How about with Train Crews. What types of communications happen over the radio with train crews? (E.g. do train crews' call to request permission to enter a work zone). How about over the phone?

Can you talk about some of the problems that come up in communicating with train crews over radio or phone?

Party Line

One of the things about radio communication is that it has a 'party-line' aspect, you can overhear communication between others and others can overhear your communications.

Can you talk about some of the benefits of this 'party-line' aspect? Are there situations where it helps to overhear others or have others overhear you?

Can you talk about some of the drawbacks of this ‘party-line’ aspect? Are there situations where this ‘party-line’ aspect causes problems?

Communication Errors

Have you ever experienced situations (or heard of situations) where a roadway worker was working on a track that was different from the track that the dispatcher gave permission for (e.g., due to communication misunderstandings; or disorientation on the part of the roadway worker?) [10]

Are there other examples of errors or confusions in communication with dispatchers that you have experienced or heard about?

How about errors or confusions in communication with other roadway workers?

How about errors or confusions in communication with train crews?

Are there any cases you have experienced or heard of where a train entered a work zone without having prior authority?

Maintaining the ‘Big Picture’

One of the things we are interested in is how you maintain ‘the big picture’. How do you keep track of where you are? Where other roadway workers are? Where trains are?

Global positioning technology now makes it possible to get very accurate location information.

If we could give you accurate information on where you are on the track (on a display) would that be useful to you?

If we could give you accurate information on the location of trains would that be useful to you?

How about information on where other roadway workers or track cars are on the tracks (say on a display) do you think it would be helpful to you?

Acronyms

ASES	Advanced Speed Enforcement System
BASI	Bureau of Air Safety Investigation
CTA	Cognitive Task Analysis
EIC	employee in charge
FRA	Federal Railroad Administration
GPS	global positioning system
ITCS	Incremental Train Control System
NORAC	Northeast Operating Rules Advisory Committee
PDA	personal digital assistant
PRT	portable remote terminal
PTC	positive train control
Volpe Center	John A. Volpe National Transportation Systems Center