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Federal Railroad Administration

Teamwork in Railroad Operations and Implications for New Technology

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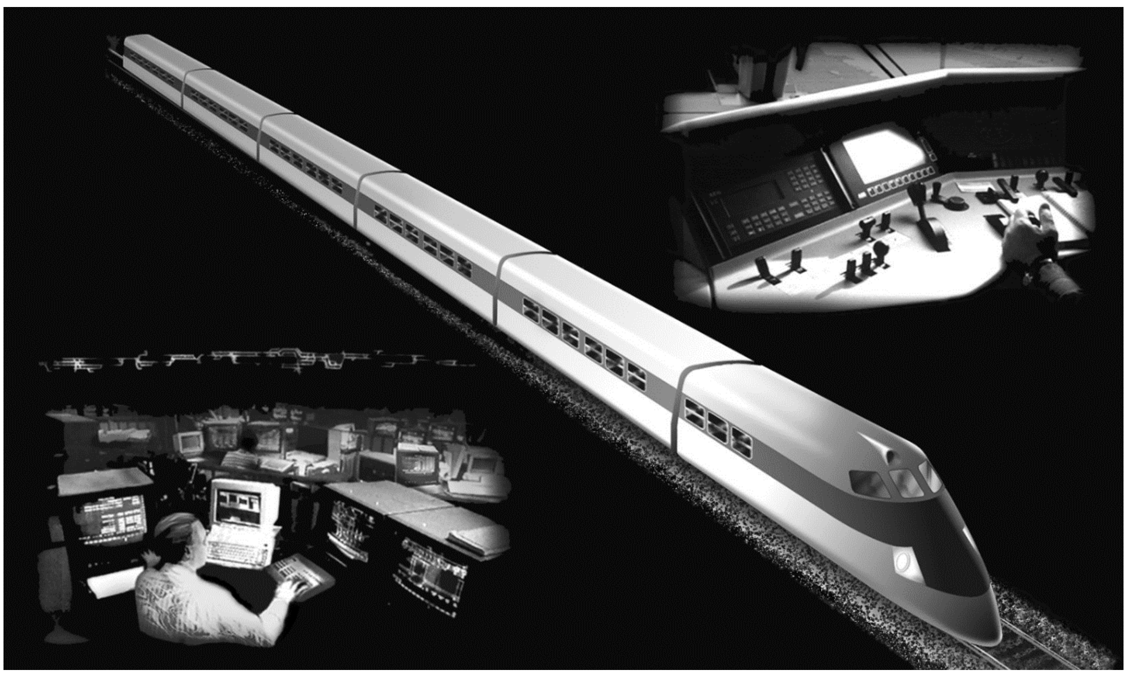
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

This report examines teamwork processes that contribute to railroad operation safety. It integrates findings from previously conducted Cognitive Task Analyses (CTAs) that analyzed the cognitive and collaborative work of dispatchers (Roth, Malsch, and Multer, 2001), roadway workers (Roth and Multer, 2007), locomotive engineers (Roth and Multer, 2009) and freight train conductors (Rosenhand, Roth and Multer, 2012). Examples from these CTAs illustrate how elemental teams (e.g., train crews) as well as distributed teams (e.g., dispatchers, roadway workers, and train crews) engage in informal cooperative activities that increase overall system efficiency, safety, and resilience in the face of unanticipated events. Examples, including an introduction of digital communication technology (e.g., datalink) and Positive Train Control (PTC), are used to illustrate how new technologies can enhance teamwork processes or disrupt them depending on how they are designed and implemented. The results highlight the importance of analyzing teamwork and considering support for teamwork processes as part of human system integration (HSI). It illustrates how CTAs can be used to uncover undocumented informal teamwork processes that contribute to safe and efficient performance, and to guide the development and implementation of new technology to enhance effective teamwork, and avoid disrupting critical team processes that contribute to overall system 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)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0		1			2			3		4			5
Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°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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We want to express our thanks to the railroad workers who participated in interviews and focus groups for prior cognitive task analyses.

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Executive Summary

Railroad operations depend critically on the ability of individuals to communicate and coordinate work for safe and efficient operation. From 2014 to 2015, the Federal Railroad Administration (FRA) sponsored the John A. Volpe National Transportation Systems Center (Volpe) to focus on issues related to teamwork, specifically communication and coordination within and across different railroad industry crafts (e.g., dispatchers, roadway workers, and train crews) that contribute to overall system safety. The report integrates findings across four FRA-sponsored cognitive task analysis (CTAs) that were previously conducted to analyze the cognitive and collaborative work of dispatchers (Roth, Malsch, and Multer, 2001), roadway workers (Roth and Multer, 2007), locomotive engineers (Roth and Multer, 2009), and freight train conductors (Rosenhand, Roth and Multer, 2012). It is the second of two CTA synthesis reports. The first CTA synthesis report (Roth, Rosenhand & Multer, 2013) provides guidance to the industry with respect to the need for human system integration (HSI) in the technology acquisition process, and how to use CTA methods and results as part of the HSI process. The present report emphasizes the importance of analyzing teamwork and considering support for teamwork processes as part of HSI. It illustrates how results of CTAs can be used to uncover undocumented informal teamwork processes that contribute to safe and efficient performance, and to guide the development and implementation of new technology to enhance effective teamwork, and avoid disrupting critical team processes that contribute to overall system safety.

Results from the locomotive engineer and conductor CTAs indicate that train crews, a primary example of an elemental team in railroad operations, exhibit characteristics of high performing teams that are found across industries. These include mutual performance monitoring—to catch and correct errors—and active support of each other's activities (e.g., fill in knowledge gaps, collaboratively problem-solve; and point out potential risks and how they can be mitigated). A key contributor to successful performance is establishing and maintaining a shared understanding—common ground—between the locomotive engineer and conductor with respect to goals, planned activities, potential risks, and ways to mitigate them. In turn, this depends on active communication, and particularly high quality initial job briefs as well as 'rolling' job briefs to maintain common ground. Significantly, these teamwork activities went beyond the requirements of formal operating rules and were not explicitly covered in training. Implications of the findings for design of training and introduction of new in-cab technologies, such as Positive Train Control (PTC) are discussed.

The CTAs also looked at informal cooperative practices that contribute to safe and efficient operation across the larger distributed team that is made up of dispatchers, train crews, and roadway workers. The results highlight the active cognitive and collaborative processes that workers engage in to develop and maintain common ground with respect to each other's collaborative location, activities and intentions across the distributed organization. These include active strategies for extracting relevant information by 'listen in' on radio communications directed at others. These active listening processes enable individuals in the distributed organization to identify information that had a bearing on achieving their own goals or on maintaining their safety. It also enables them to recognize situations where information in their possession was relevant to the performance or safety of others. Volpe identified several proactive strategies that were intended to facilitate collaborative work and improve overall safety. These informal practices included proactive communications intended to foster common

ground, redundancy checks intended to reduce the possibility of error, and proactive actions intended to level workload and facilitate work across the distributed organization.

As in the case of train crews, the research team found that these informal strategies went beyond the requirements of formal rules and procedures. They were referred to as 'courtesies' to emphasize their informal, discretionary nature. Nevertheless, these proactive activities contributed to the overall efficiency and resilience to error of railroad operations.

The implications of the results for training, as well as for the introduction of new technology, particularly position location (e.g., Global Positioning System [GPS]) and digital information transmission (e.g., datalink) technology, are described.

Examples from the dispatcher, roadway worker, locomotive engineer and conductor CTAs illustrated how new technology can facilitate or interfere with teamwork depending on how it is implemented. This included:

- Enhancing team processes, for example, by reducing the need for explicit communication, or enhancing common ground through new visualization
- Disrupting effective team processes, for example, by eliminating a source of information currently used to develop common ground, without providing an alternative means for obtaining that information
- Altering the distribution of functions and workload across team members, for example, by shifting a job function from one team member to another
- Creating new demands on teamwork, for example, new requirements for communication

The results highlight the importance of analyzing teamwork and considering support for teamwork processes as part of HSI. It illustrates how CTAs can be used to uncover undocumented informal teamwork processes that contribute to safe and efficient performance so as to inform design of new technology.

A broader implication of the current work is the value of conducting similar analyses in trying to understand and improve other aspects of railroad operation. Railroad operations encompass a wide variety of positions that go far beyond the specific positions (e.g., train crews, dispatchers, and roadway workers) that we have examined in the CTAs conducted to date. These other positions undoubtedly involve both formal and informal teamwork practices that contribute to safe an efficient operation.

It is important that teamwork practices that contribute to efficiency and safety are uncovered and documented to guide the design of improved training and new support systems. Teamwork analyses should be a standard part of HSI processes to inform design of more effective support systems and ensure that the introduction of new technology does not inadvertently disrupt teamwork practices that are critical to overall system safety.

1. Introduction

This report focused on issues related to teamwork, specifically communication and coordination within and across different railroad industry crafts (e.g., dispatchers, roadway workers, and train crews) that contribute to overall system safety. The report drew on the results of a series of railroad worker cognitive task analyses (CTAs) that were sponsored by the Federal Railroad Administration's (FRA) Office of Research, Development and Technology to show that teams often engage in undocumented, informal activities that increase overall system safety, efficiency, and resilience in the face of unanticipated events. It is important to understand that these informal activities more effectively support them, for example, through explicit training. The report also discusses the importance of considering the impact of the introduction of new technology into railroad operations on teamwork. Examples from prior FRA-sponsored CTAs were used to illustrate how new technologies can enhance teamwork processes or disrupt them depending on how they are designed and implemented.

1.1 Background

Railroad operations depend critically on the ability of individuals to communicate and coordinate work for safe and efficient operation (Roth, Multer and Raslear, 2006; Morgan, Olson, Kyte, Roop & Carlisle, 2006; TRB, 2011). The ability of individuals to interact and adapt to achieve shared goals is referred to as teamwork (Salas, Diazgranados & Lazzara, 2011).

With the introduction of new technology, the nature of the work associated with many railway worker positions (e.g., locomotive engineers, conductors, and roadway workers) is rapidly shifting from physically demanding to placing greater emphasis on cognitive demands (e.g., monitoring, decision-making, supervising automated systems, planning, communicating and coordinating, and handling unanticipated situations). CTA methods provide a means to explicitly examine the cognitive and collaborative demands associated with anticipating contributors of performance problems (e.g., lack of information, inaccurate understanding, and high communication demands) and specifying ways to improve individual and team performance—be it through new forms of training, user interfaces, or decision-aids. More details on CTA methods, their objectives and rationale can be found in Potter et al. (2000); Crandall, Klein, and Hoffman (2006); and Bisantz and Roth (2008). Within the railroad industry, CTAs have typically been conducted using a combination of field observations (e.g., observing workers in a dispatch center; and taking head-end rides in a locomotive to observe the interaction of train crews) and structured interviews conducted in a focus group setting (Roth, Rosenhand and Multer, 2013).

FRA sponsored four CTAs that were each focused on a different railroad craft. The first CTA focused on railroad dispatchers (Roth, Malsch, and Multer, 2001). A second CTA addressed roadway worker activities (Roth and Multer, 2007). The third CTA examined the cognitive and collaborative demands and activities of locomotive engineers (Roth and Multer, 2009). The last CTA report to date examined the cognitive and collaborative activities of freight train conductors (Rosenhand, Roth, and Multer 2012).

This is the second of two companion CTA synthesis reports that integrate findings across the four previously conducted CTAs. The first report drew on examples from the four FRA-sponsored railroad worker CTAs to illustrate the various ways in which a CTA can be used to inform successful deployment of new technology as part of a comprehensive HSI process (Roth, Rosenhand and Multer, 2013). Reinach and Jones (2007) define HSI as a "systematic, organization-wide approach to implementing new technologies and modernizing existing systems." They note that "an HSI approach to railroad technology acquisition and implementation" can increase user acceptance and usability of the technology, as well as increase the likelihood that it is deployed successfully. The first CTA synthesis report provides guidance to the industry with respect to the need for HSI in the technology acquisition process, and more specifically, how to use CTA methods and results as part of the HSI process. This second report emphasizes the importance of analyzing teamwork and considering support for teamwork processes as part of HSI. It illustrates how results of CTAs can be used to uncover undocumented informal teamwork processes that contribute to safe and efficient performance, and to guide the development and implementation of new technology to enhance effective teamwork, and avoid disrupting critical team processes that contribute to overall system safety.

1.2 Organization of the Report

Section 2 provides a brief introduction to frameworks for understanding characteristics of good teamwork, as well as frameworks for analyzing the impact of new technology on individual and teamwork processes.

Section 3 provides summaries of the main findings of the CTAs with respect to team processes that contributed to the effective performance of train crews that constituted an elemental team, as well as effective performance of the broader distributed team made up of dispatchers, train crews, and roadway workers. In each case, the researchers highlight the informal team processes that emerged that substantively contributed to safe and efficient performance and discuss implications for training and introduction of new technology including digital communication technology and Positive Train Control (PTC) technology.

Section 4 summarizes the results and discusses broader implications for incorporating analyses of teamwork and the impact of new technology on teamwork as part of HSI analyses in support of implementation of new technology into railroad operations.

2. Individuals, Teams and Distributed Cognition, and Joint Cognitive Systems

There is growing recognition that when analyzing work and how to best support it, either through new training or new technology, the appropriate unit of analysis is not the individual person, or teams of people, but the entire system under investigation that includes people and associated support technologies (Hutchins, 1995a; Stanton, Salmon and Walker, 2014; Woods and Hollnagel, 2006). This is the approach that was taken when conducting the FRA-sponsored CTAs. In this report, the primary focus is on teamwork and how aspects of the environment, particularly the introduction of new technology, can impact teamwork either positively or negatively.

This section provides a brief introduction to frameworks for understanding characteristics of good teamwork, as well as frameworks for analyzing the impact of new technology on individual and teamwork processes.

2.1 Teams and Teamwork

While the unit of analysis for training and design is often assumed to be the single individual (e.g., the locomotive engineer, the roadway worker, and the dispatcher), in practice work effectiveness most often depends on the joint efforts of multiple individuals that collectively work as a team. A team is generally defined as two or more individuals who interact and adapt to achieve shared and valued goals (Salas, Diazgranados and Lazzara, 2011). When developing training programs, or designing performance aids, it is not only important to consider the tasks and performance support needs of the individual worker, but also the activities associated with teamwork such as communication and coordination and how they can best be supported through training and design.

Elemental teams were co-located and explicitly worked in a coordinated manner. Examples in railroad operations are train crews, roadway workers working on a specific task at a particular time and location within visual sight of each other; and dispatchers working within a dispatch control center that must coordinate movement of trains across territories handled by different dispatchers.

Distributed teams are distributed geographically and the team participants may or may not be members of the same craft. Distributed teams include instances of individuals from the same craft working in different physical locations, such as roadway workers dispersed across space, or dispatchers coordinating work with other dispatchers in physically separate dispatch centers. Distributed teams also include individuals from the same craft who must coordinate work distributed in time, such as dispatchers working across different shifts that must engage in hand-offs. It also includes individuals across different crafts working in physically disparate locations that need to communicate and coordinate to accomplish work safely and efficiently. For example, dispatchers, train crews, and roadway workers, who all work in different locations and must actively communicate with each other to insure safe and efficient usage of track.

A good overview of characteristics of teams and the factors that contribute to effective teamwork in railroads can be found in a Transportation Research Board (TRB) circular that summarized the findings of a TRB conference that was held on teamwork in U.S. railroad operations (Transportation Research Board, 2011). Among the main findings is that high-performing teams are characterized by five critical features that Salas and his colleagues have termed 'the Big 5' of teamwork (Salas, Sims and Burke, 2005). Figure 1 provides a visual depiction of these five key competencies of high performing teams and how they interact to generate resilient team performance.

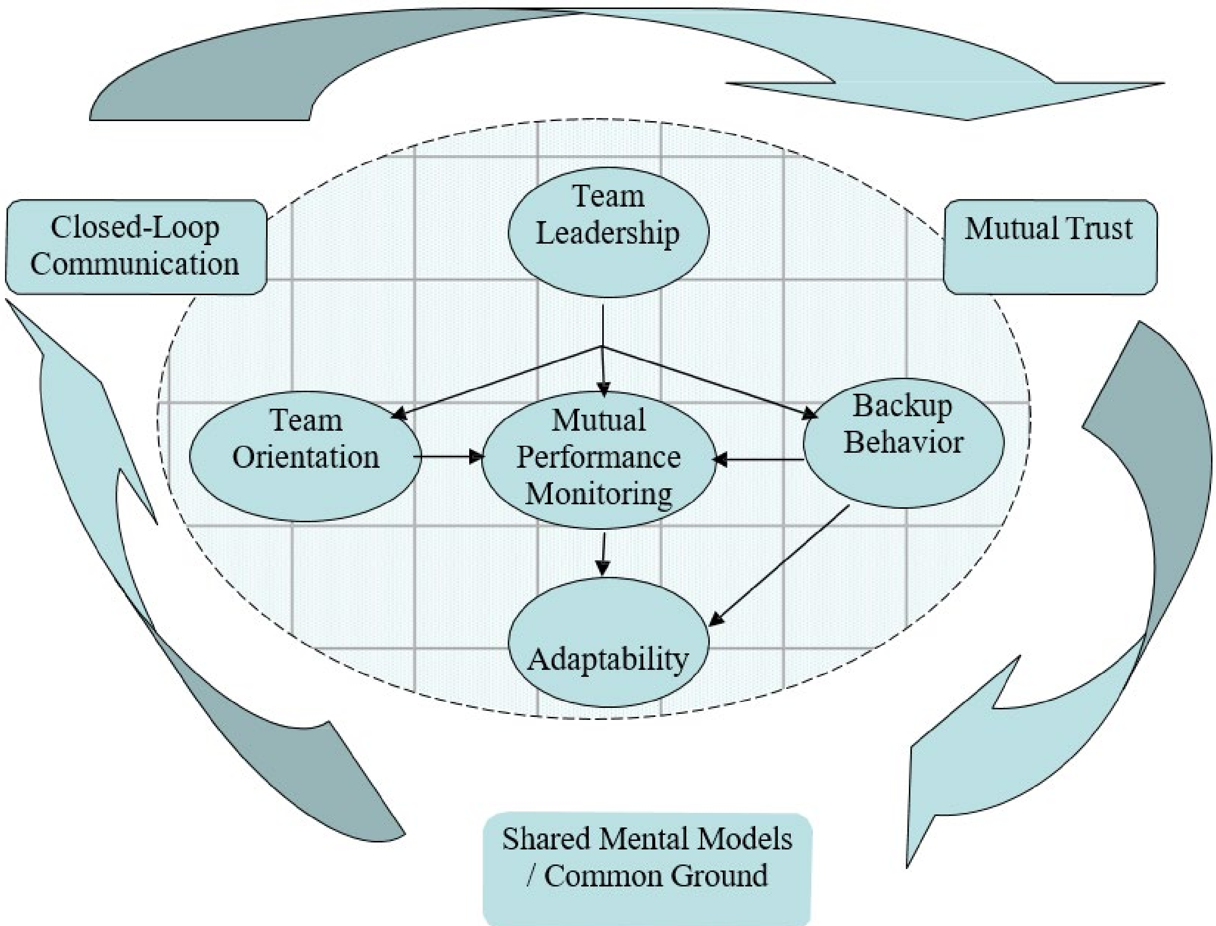

Figure 1. The 'Big 5' team competencies that characterize high performing teams. (Adapted from Salas, Sims, and Burke, 2005)

The Big 5 team competencies consist of:

- ***Mutual performance monitoring*** – High performance teams keep track of other team members' work while carrying out their own to detect and correct potential problems or misunderstandings early, before they have a chance to lead to negative consequences.
- ***Backup behavior*** – Members of high performance teams recognize when another team member needs aid and offers assistance. Elements of backup behavior include: providing feedback to improve performance; assisting a team member in performing a task; and shifting workload across members to achieve greater balance during periods of high workload or time pressure (Marks, Mathie, and Zaccaro, 2001). A related behavior observed in the railroad industry is to proactively provide needed information or support to another team member without having to be explicitly asked. Note that providing backup support depends of the ability of team members to know enough about other team

members' responsibilities to anticipate their needs.

- ***Adaptability*** – The ability to recognize that changes from a course of action are needed and to readjust actions and distribution of tasks across individuals in response (Salas et al., 2005). Mutual performance monitoring and backup behavior play a key role in enabling teams to function adaptively.
- ***Team leadership*** – The ability to define goals, procure necessary resources, direct and coordinate the activities of other team members, adapting to changing circumstances and creating a positive team climate. Effective leadership is a key driver of team adaptability (Kozlowski, Watola, Jensen, Kim and Botero, 2008).
- ***Team orientation*** – The ability to consider other people's feelings and inputs, and engage in mutual performance monitoring and backup behavior.

High performing team members demonstrate a team orientation and engage in mutual performance monitoring and backup behavior. This allows them to adapt to changing circumstances and respond resiliently in the face of unanticipated situations. For the purposes of this report, the meaning of resilient response is the ability to avoid or recover from error as well as the ability to respond appropriately to unanticipated situations.

As depicted in Figure 1, the five competencies of high performing teams depend on several additional factors. One factor is having *mutual trust* that team members have the appropriate knowledge and skills to perform their role. A second is that they have a shared understanding of the current situation, the goals to be achieved, and the intentions and actions expected of other team members to achieve those goals. A *shared mental model* refers to a shared understanding of the team's purpose and individual member's roles in accomplishing the task (Salas et al., 2011). *Common ground* is a related concept that refers to shared knowledge, beliefs and assumptions that support interdependent action (Clark and Brennan, 1991; Klein, Feltovich, Bradshaw and Woods, 2005). Common ground expands on the concept of a shared mental model in that it also covers having a shared understanding of the current situation. For example, in railroad operation, a key element of common ground is having a common understanding of the locations and activities of key actors in the environment such as the location of trains and roadway workers in the immediate environment that are important to keep track of for mutual safety.

Common ground allows team members to anticipate each other's actions and support when needed, as well as coordinate without explicit and lengthy communication. Section 3 describes the railroad workers, including train crews, roadway workers and dispatchers that devote a lot of effort in developing and maintaining common ground, which contributes materially to the overall safety of railroad operations.

Communication plays an important role in building and maintaining common ground. *Closed loop communication* refers to communication where the sender and receiver make an explicit effort to ensure that the message was appropriately received and understood. A typical method of ensuring closed loop communication in the railroad industry is to require that the receiver repeat back the message sent and that the sender confirm that the receiver's understanding is correct.

A key tool for developing and maintaining common ground is to engage in prebriefs prior to conducting a major task as well as debriefs at the completion of the task. Prebriefs allow team members to establish, as well as revise goals, plans, and priorities. It allows them to identify potential safety risks and how they plan to mitigate them. Section 3 also describes thorough prebriefs that are viewed as critical to the safe and efficient performance by train crews. They are similarly critical for effective and safe performance by other crafts such as roadway workers.

Debriefs provide an opportunity for teams to review performance, receive and provide feedback and identify lessons learned for task improvement.

A point to stress is that high performance teams engage in behaviors that go beyond requirements of standard procedures and protocols. These behaviors, while informal in the sense that they are non-mandated, often contribute substantively to safe and efficient performance. Several examples of informal behaviors within railroad operations that contribute to overall system safety and efficiency are described in Section 3.

Another important point to emphasize is that characteristics of high performance teams can be trained (Salas, Diazgranados and Lazzara, 2011; Entin, Duchon, Weil and Salter, 2011; Morgan, Olson, Kype, Roop and Carlisle, 2006). Training approaches include task work training and on-the-job training that emphasize development of teamwork competencies; cross training methods that enable team members to more fully understand the requirements and challenges of the different roles; and team self-correction methods that encourage teams to reflect upon and improve on teamwork performance (Salas, Diazgranados and Lazzara, 2011). Using these types of training approaches, team members can be trained to be proactive in anticipating and supporting the needs of other team members before they make a request; they can be trained to engage in more effective prebriefs, and to provide brief periodic situation reports to refresh everyone's understanding of the situation so as to reinforce common ground; and to monitor each other's performance and provide backup as needed. Crew resource management training is another example of a successful approach to training teamwork behaviors that contribute to overall safety (Morgan, Olson, Kyte, Roop and Carlisle, 2006).

2.2 Distributed Cognition

In analyzing and supporting work, in addition to considering the people in the system, it is also important to consider the broader environment within which the work takes place, including the physical environment and computer support technologies. Just as individuals can collaborate with each other, distributing the work across multiple parties (e.g., sharing responsibilities between the locomotive engineer and the conductor), elements of cognitive work can be offloaded onto physical systems. For example, a locomotive engineer can use an external memory aid, such as a sheet of paper that lists all temporary speed restrictions, to reduce memory requirements. A dispatcher can rely on computerized track displays to know which blocks of track are occupied (e.g., by a train or a piece of equipment). The external aids are part of a larger *distributed cognition* because some of the cognitive work (e.g., recalling temporary speed restrictions) that might have otherwise required mental work on the part of person(s) has been offloaded to an external representation such as a sheet of paper listing temporary speed restrictions (Hutchins, 1995a and b; Hollan, Hutchins and Kirsch, 2000).

Computerized systems can sometimes take on higher level cognitive functions such as providing guidance with respect to how to operate the train to minimize fuel usage which is done by energy management systems, or automatically triggering a penalty brake if it determines that the locomotive engineer exceeded speed limits or is about to exceed limits of authority, such as PTC occurrences. In those cases, the technology is a more active partner in the decision-making process. The term *joint cognitive systems* was conceived to cover situations where higher-level cognitive performance entails interaction between one or more people and/or one or more automated machine agents such as PTC technology (Woods and Hollnagel, 2006). In designing and evaluating these more active decision-support technologies it is important to consider the performance of the joint person-machine cognitive system, depending on how the technology is deployed, the performance of the joint system may be better or worse than the performance of either the individual or the automated aid operating alone (Woods and Hollnagel, 2006).

When considering the introduction of new technology, it is important to analyze the impact it is likely to have on the individual, elemental team, and distributed team cognitive and collaborative (e.g., teamwork) processes. Analyzing the impact of technology on individual and team processes is an important aspect of HSI analysis and design activities. Depending on how it is implemented, new technology has the potential to:

- Enhance team processes, for example, by reducing the need for explicit communication, or enhancing common ground through new visualizations
- Disrupt effective team processes, for example, by eliminating a source of information currently used to develop common ground, without providing an alternative means for obtaining that information
- Alter the distribution of functions and workload across team members, for example, shifting a job role from one team member to another
- Create new demands on teamwork, for example, new requirements for communication

Section 3 illustrates the ways that the CTAs summarize new technologies such as how PTC and data link can potentially impact teamwork performance, both positively and negatively, depending on how it is designed and implemented.

3. Teamwork in Railroad Operation

The series of railroad worker CTAs that were conducted highlighted the contribution of effective teamwork to safe and efficient operation. The CTAs examined both elemental and distributed teams. A primary example of an elemental team is a train crew, which is typically composed of a locomotive engineer and a conductor. Results from both the locomotive engineer CTA (Roth and Multer, 2009) and the conductor CTA (Rosenhand, Roth and Multer, 20012) revealed the importance of effective communication and collaboration between the locomotive engineer and the conductor. The CTAs revealed mutually supportive behavior of locomotive engineers and conductors that went beyond their respective formal roles and responsibilities. These undocumented, informal behaviors contributed to safe and efficient performance. Recommendations were made with respect to training, the results of the CTA, and the potential impact of new technologies such as PTC on crew performance.

The dispatcher CTA (Roth, Malsch and Multer, 2001) and roadway worker CTA (Roth and Multer, 2007) examined communication and cooperation among distributed teams, and how they contributed to safety and efficiency of railroad operations. This included examining cooperative strategies among dispatchers to build shared awareness of, and facilitate movement across territories managed by different dispatchers; strategies used by roadway workers to keep track of the locations and activities of other roadway workers for enhanced safety; as well as the cross-craft strategies employed by dispatchers, train crews, and roadway workers to enhance safety and efficiency. While in some cases these strategies were formally prescribed and documented in rule books, in many cases the strategies emerged informally. Nevertheless, these informal strategies were instrumental in enhancing safety of the railroad system. The CTAs pointed to opportunities to enhance effective teamwork through using new technologies, as well as recommendations with respect to the introduction of these proposed new technologies to ensure that aspects of the current environment that support effective team strategies are not disrupted, or that alternative, equally or more effective, means are provided to facilitate teamwork processes.

In Section 3.1, the researchers summarize the main findings of the CTAs with respect to team processes that contributed to the effective performance of train crews that constituted an elemental team, as well as the effective performance of the broader distributed team made up of dispatchers, train crews, and roadway workers. In each case, the researchers highlight the informal team processes that emerged that substantively contributed to safe and efficient performance, and discuss the implications of training and introducing new technology.

3.1 Teamwork Processes in Train Crews

Insights on train crew teamwork were obtained as part of two CTAs, one that focused on locomotive engineers (Roth and Multer, 2009) and one that focused on conductors (Rosenhand, Roth and Multer, 2012). The researchers began by providing a brief overview of the methodology of each of these CTAs followed by a summary description of the main findings relating to teamwork.

3.1.1 Overview of Locomotive Engineer CTA

An important aim of the locomotive engineer CTA was to identify cognitive activities that could be supported more effectively through the introduction of advanced technologies, such as PTC.

A second related aim was to anticipate new cognitive demands and complexities that the new technologies might pose.

The locomotive engineer CTA was based on a series of interviews and observations that were made at seven sites between February 2000 and September 2005. These sites included both intercity passenger operations, commuter operations, and freight operations. Five of the sites were at locations where railroads were in the process of field testing advanced train control technologies.

The CTA identified the major cognitive activities that underlie locomotive engineer performance and the factors that contribute to cognitive challenges. Important cognitive activities include maintaining broad situational awareness and developing an accurate current model of the immediate environment, including the location, activities, and intentions of other agents such as other trains and roadway workers in the vicinity; generating expectations and thinking ahead so as to know where to focus attention, prepare for anticipated actions, as well as plan for contingencies; actively engaging in sustained visual and auditory monitoring (e.g., monitoring radio communication); managing multiple demands on attention; prioritizing and managing multiple goals; and rapidly deciding what needs to be done in response to unanticipated conditions (e.g., a person or object obstructing the track). Importantly, the conductor CTA generated similar findings, and pointed to ways that conductors supported locomotive engineers in maintaining situation awareness, planning, and handling unanticipated situations.

The locomotive engineer CTA report concluded that while PTC technology is likely to have a positive impact on the overall risk of accidents, the new sources of cognitive demands associated with PTC have the potential to contribute to new forms of errors and accidents (Wreathall, Woods, Bing and Christoffersen, 2007; Wreathall, Roth, Bley and Multer, 2007). Careful consideration of these new sources of cognitive demand is needed during the HSI process to ensure that the design of the PTC automation and in-cab displays, as well as the development of accompanying training processes and procedures minimize the potential for new sources of error and accidents.

3.1.2 Overview of Conductor CTA

The objective of the conductor CTA was to document the role of the train conductor in freight rail operation, as well as to understand the implications of the Rail Safety Improvement Act (RSIA) of 2008 mandate for conductor certification and implementation of PTC on applicable freight and passenger rail lines. The goal was to understand conductor training programs currently in place, as well as upcoming training trends, to provide insight to FRA for the conductor certification effort and, to the extent possible, understand and anticipate potential impacts of PTC on the conductor's work.

The CTA was based on interviews, focus groups, and site visits conducted between January 2009 and April 2010. Site visits included a trip to the National Academy of Railroad Sciences facility in Kansas, the Union Pacific Railroad (UP) Beaumont Yard, and the UP Houston Yard. A total of 23 stakeholders, railroad practitioners, experienced conductors, conductor trainers, and training managers were interviewed.

The CTA identified cognitive tasks and associated challenges of freight train conductor work, specified key findings with respect to implementation of PTC and conductor certification, and pointed out future research needs.

The CTA identified multiple ways in which conductors contribute to safe and efficient train operations. During routine operations, conductors play an important role in augmenting the activities of the locomotive engineer; for example, by monitoring the outside environment through the cab window for potential obstacles and hazards and filling in knowledge gaps that locomotive engineers may have (i.e., particularly less experienced engineers). Conductors also serve an important role in keeping the locomotive engineer alert—and vice versa—on long monotonous trips where there is a risk of falling asleep. Conductors also play a critical role in handling unanticipated events, which include a variety of situations where conductors are required to troubleshoot the source of the problem and take appropriate action.

3.1.3 Contribution of Teamwork to Safe and Efficient Train Crew Operation

An important finding of the locomotive engineer and conductor CTAs is that conductors and locomotive engineers operate as a tightly coupled cooperative team. While each has a distinct set of formal responsibilities, the conductor is responsible for managing the train consist, and the locomotive engineer is responsible for running the locomotive, they jointly contribute to the set of cognitive activities required to operate the train safely and efficiently. This includes jointly monitoring outside the window, as well as participating jointly in planning activities, problem-solving, and identifying and mitigating risk.

It was also found that the results of the CTAs could perform effectively if the conductors and locomotive engineers engaged in behaviors that held characteristics of high performing teams across industries (Salas, Diazgranados and Lazzara, 2011; Salas, Sims and Burke, 2005). This included working to maintain common ground to avoid miscommunication, mutual performance monitoring to catch and correct errors, and offering backup support as needed.

Formal Responsibilities Relating to Teamwork

One of the conductor's primary formal responsibilities is to supervise the operation and administration of the train to promote safe and efficient operation, and compliance with all operating rules. Achieving this objective requires close coordination with the locomotive engineer. Conductors handle all radio communication and paperwork when the train is in motion so that the locomotive engineer can concentrate on operating the train. In addition, the conductor provides essential support and backup for the locomotive engineer. For example, the conductor reminds the engineer about upcoming signals and slow orders and provides 'look ahead' information to alert the engineer to hills, curves, grade crossings, and other conditions that impact how the locomotive engineer operates the train.

The conductor is also responsible for monitoring the performance of the locomotive engineer to ensure safety and compliance with all operating rules. If the conductor feels that the train is not being operated safely, it is the conductor's responsibility to alert the engineer, or, apply the emergency brake if necessary. While the locomotive engineer has full control over operating the train, the conductor is responsible for pulling the emergency brake to bring the train to an emergency stop if they suspect the train, themselves, or others outside the train are in danger.

Informal Teamwork Practices Contributing to Safe and Efficient Operations

In addition to performing their formal duties, conductors and locomotive engineers actively engage in informal activities intended to improve overall efficiency and safety. The CTA results revealed that conductors and locomotive engineers closely coordinate tasks with one another, adaptively share perceptual and cognitive load, and rely on one another to successfully accomplish the mission of the train. This includes contributing knowledge and backing each other up as necessary.

Conductors and locomotive engineers participate jointly in monitoring status and progress. They coordinate observations, catching and communicating information that the other may have missed. For example, when operating on the mainline, conductors serve as a 'second pair of eyes,' alerting the locomotive engineer to upcoming signals and potential hazards (e.g., activity at grade crossings, and people working on or around the track).

The conductor and locomotive engineer also extend each other cognitively, filling in knowledge gaps, reminding each other about upcoming tasks, and contributing jointly to problem solving and decision-making situations that arise. For example, conductors participate jointly with locomotive engineers in planning activities to perform along the route and identifying and mitigating potential risk. Locomotive engineers serve an important support role for conductors by assisting to fill in knowledge gaps, support planning, and help conductors anticipate and mitigate risks.

Importance of Active Communication in Building Common Ground

The results of the conductor CTA highlighted the importance of active communication in building common ground. Train crews stressed the importance of effective cab communication and job briefing skills for developing a shared understanding of the current environment, plan of activities, potential risks, and actions that need to be taken to mitigate risk. Actively building and maintaining common ground is critical for reducing the potential for miscommunication, facilitating work, and enhancing overall safety.

Communication is an active, ongoing process that begins with the initial job brief when the train crew first comes on duty. The initial job brief provides the core foundation for establishing common ground. The crew jointly reviews all the paper work, and discusses the work to be done and how they are planning to do it. The goal is to make sure that they share an understanding of the work, the rules that apply, and the potential risks. It is during this initial job brief that they will discuss their level of experience and how familiar each is with the territory. They will also discuss any rule changes to make sure they both understand the rule changes and how the changes may apply to the upcoming trip. This initial job brief enables the crew to gain a shared understanding of each other's knowledge and abilities as well as shared expectations of the trip ahead.

The train crew works actively to maintain and update common ground throughout the trip by engaging in 'rolling' job briefs. These are intermediate job briefs that are informally initiated enroute prior to performing particularly challenging tasks. They serve to promote shared situation awareness of task objectives, how the work is to be coordinated, including how intentions and activities will be communicated, awareness of potential hazards in the environment, and actions that need to be taken to mitigate risk. Discussing potential risks enables less experienced individuals to recognize potential hazards and how to identify and avoid the hazards unbeknownst to them. Equally important, the very act of discussing the potential hazards enables the conductor or engineer to be better prepared.

3.1.4 Implications for Training

The locomotive engineer and conductor CTAs clearly show that experienced train crews display 'the Big 5' characteristics of general high-performance crews. They engage in mutual performance monitoring and backup behavior, and demonstrate the ability to be adaptive in the face of unanticipated situations. These behaviors went beyond the formal individual job roles and included informal activities that clearly contributed to more safe and effective performance of the joint team.

Most importantly the CTAs illustrated the importance of communication for effective and safe performance. Train crews highlighted the importance of thorough initial job briefs as well as 'rolling' job briefs to maintain common ground. They emphasized the importance of identifying risks and discussing ways to mitigate the risks to promote safety. These results mirror the findings of high performance teams in general that place a premium on high quality prebriefs and debriefs.

The CTA revealed opportunities to improve train crew teamwork through training. For example, the CTAs revealed that to perform effectively, conductors and locomotive engineers need to know enough about the other's work to anticipate needs, provide help, and intervene when necessary to prevent error. For example, though it is the locomotive engineer's responsibility to know how to physically operate the train, the conductor must also understand the impact of various factors (e.g., operating restrictions due to train weight and length, upcoming crossings, and slow orders) on train handling to appropriately support the locomotive engineer and ensure safe train operation. This result highlights the importance of ensuring that conductors are taught the fundamentals of how various physical and environmental factors are likely to impact train handling, as well as the importance of insuring familiarity with the territory being covered.

Another area identified in the conductor CTA where more training would be valuable relates to teamwork skills, particularly, active communication including effective cab communication and job briefing skills. Conductor interviews suggested that these skills are not always explicitly taught and not sufficiently stressed during training. A greater focus on effective communication, particularly crew resource management training, would enhance teamwork and encourage joint problem-solving and decision making that could leverage the knowledge and skills of the train crew.

3.1.5 Implications for Insertion of PTC Technology

One of the questions that motivated the conductor CTA was how new technologies, such as PTC, would affect the role of conductors in the future. The CTA addressed this issue by laying out the multiple ways in which conductors contribute to safe and efficient train operations and contrasts these with anticipated features of PTC.

Anticipated features of PTC technology are designed to serve some of the cognitive support functions that conductors currently provide to locomotive engineers. These include providing reminders of upcoming signals, work zones, and speed restrictions to locomotive engineers. It also includes automatically applying emergency brakes to stop the train in cases where the train would otherwise exceed speed limits or limits of track authority. Both are functions that conductors currently provide.

Conductors also provide several additional cognitive support functions to locomotive engineers that PTC does not provide. These functions include supporting locomotive engineers in monitoring events outside the cab window for potential obstacles and hazards that would not be detected by automated systems (e.g., people working on or around the track; trespassers; cars at grade crossings). They also include filling knowledge gaps that locomotive engineers may have (e.g., knowledge of the territory; appropriate interpretation of operating rules) and supporting decision-making (e.g., where to stop to avoid blocking a grade crossing). Knowledge and decision-making support is especially important in the case of less experienced locomotive engineers. Conductors also serve an important role in handling unanticipated events and keeping the locomotive engineer alert, especially on long monotonous trips where there is a risk of falling asleep.

The introduction of PTC technology will clearly affect the functioning of the locomotive engineer and conductor as an integrated team. With the implementation of PTC, the joint cognitive system will encompass the locomotive engineer, the conductor, and the PTC system. The PTC system will take on some, but not all, of the engineer support functions that conductors currently provide (e.g., providing reminders of upcoming signals, work zones, and speed restrictions). Depending on the implementation, the PTC system may also alter the distribution of information directly available to the locomotive engineer and conductor. For example, depending on the location and content of the PTC display, there may be some information that will be directly available to the locomotive engineer, but not to the conductor. If that is the case, it may limit the ability of the team to maintain common ground and reduce the ability of the conductor to serve as a redundancy check.

It will also be important to empirically establish, through dynamic, person-in-the-loop, evaluations that the locomotive engineer and conductor will continue to be able to effectively accomplish their new roles and responsibilities as modified by the introduction of the PTC technology, so as not to introduce new vulnerabilities to error and risk.

3.2 Teamwork Processes across Distributed Teams—Dispatchers, Train Crews, and Roadway Workers

In addition to exploring teamwork processes within elemental teams, such as train crews that operate as a face-to-face working unit the CTAs also explored teamwork processes that contributed to safe and efficient operations across multiple crafts distributed in time and space. The analyses of distributed team processes were over a series of CTAs that examined the cognitive work of dispatchers (Roth, Malsch and Multer, 2001) and roadway workers (Roth and Multer, 2007). This is provided as a brief overview of the methodology of each of these CTAs, their general findings, and a summary of the key findings.

3.2.1 Overview of Dispatcher CTA

The dispatcher CTA (Roth, Malsch and Multer, 2001) examined how experienced dispatchers managed and scheduled trains, with the goal of providing information on the design of new support technologies, as well as identifying opportunities for improvement through new types of training. At the time the CTA was conducted (1998), digital communications technology was emerging to transfer information from the radio to a visual medium like the computer. An explicit goal of the CTA was to provide recommendations for how the deployment of digital communications technology could improve communication efficiency and effectiveness; this was achieved by examining how voice radio communication was used in its current environment.

The CTA consisted of four phases, each leveraging the results of the previous phase. Phase 1 involved 2 days of observing dispatchers as they went about their job in an Amtrak dispatch center in Boston that primarily handled passenger trains. Phase 2 consisted of structured interviews with a broader set of dispatchers and related personnel from the same dispatch center to confirm, clarify, and expand on initial understanding. Phase 3 involved field observations at a second dispatch center at Conrail in Pittsburgh, PA, that primarily handled freight trains. The objective of this phase was to assess the generality of the results obtained at the first dispatch center. Phase 4 involved a second set of field observations at the Phase 1 dispatch center. The objective was to verify and expand on the results obtained in the previous three phases.

The CTA revealed that dispatching is a complex, cognitively demanding task. Successful performance depends on the ability of dispatchers to monitor train movement beyond their territory, anticipate delays, balance multiple demands placed on track use, and make rapid decisions. To do this successfully, they must keep track of where trains are, whether they will reach their destination points on time or will be delayed, and how long the delays will be. Adding to the complexity of the job are the heavy attention and communication demands placed on dispatchers, who may be called on to monitor multiple activities in different parts of the territory at a time. The CTA revealed that displays in the dispatch centers did not provide the needed information for effective performance.

The CTA documented several strategies that experienced dispatchers have developed to enable more performance that is efficient. These included strategies to (1) off-load memory requirements; (2) extract information about train movement and track activity to support anticipation and planning; (3) act proactively, taking advantage of windows of opportunity to satisfy the multiple demands placed on track use; and (4) level workload.

Many of these strategies depend on communication and coordination among individuals distributed across time and space. This includes coordination among dispatchers managing abutting territories within a dispatch center as well as coordination among the various crafts within a railroad (e.g., locomotive engineers, train masters, dispatchers, and roadway workers).

Many of these strategies relied on the party-line nature of radio communication, which allowed dispatchers to extract needed information by 'listening in' to communication directed at others. The CTA revealed that although party-line voice radio communication was often noisy and congested, the 'broadcast' nature of radio communication provided a shared frame of reference that enabled dispatchers and others working on the railroad to anticipate situations and act proactively. The CTA concluded that any new communication system would need to preserve the kind of information provided by the party line (i.e., information that was determined to be critical to safety and productivity). This finding did not imply that party-line voice radio needed to be preserved as is, but, rather, that the support functions it provided needed to be retained.

3.2.2 Overview of Roadway Worker CTA

Roadway workers provide an example of a highly distributed organization that depends heavily on communication to coordinate work and maintain safe operations among individuals widely distributed in space. Roadway workers inspect, maintain, and repair railroad facilities and equipment including track, signals, communications, and electric traction systems. They may work alone or as part of a multi-person group that must coordinate their work to accomplish a common task. Some jobs require working at a particular location on the track (e.g., changing a rail; troubleshoot a malfunctioning signal). Other jobs require moving across track, for example to perform track inspection.

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. A focus of the roadway worker CTA was on uncovering the cognitive and collaborative activities that roadway workers engage in to maintain safety.

The railroad industry has been developing several new technologies that will affect roadway workers. This includes new forms of PTC designed to protect roadway workers and prevent train-to-train collisions by providing backup warnings and, if necessary, automatically stopping trains that exceed speed restrictions or enter train segments with no authorization. A second, related, technology that is emerging is portable digital communication devices intended to allow roadway workers to communicate more reliably.

An important aim of the roadway worker CTA (Roth and Multer, 2007) was to identify supported cognitive activities more effectively through the introduction of these types of advanced PTC and digital communication technologies. A second, related aim was to anticipate the impact of these new technologies on the ability to maintain roadway worker safety.

The research team performed interviews and observations in passenger and freight territories with trackmen, responsible for inspection and maintenance of the track (13 trackmen); signalmen who are responsible for inspection and maintenance of the signal systems (8 signalmen); and dispatchers who control track usage (5 dispatchers).

Interviews occurred individually or in groups of up to five people at six railroad sites around the country. Interview topics included the factors that impact roadway worker safety; the need for communication and coordination between 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 worker performance and safety.

The CTA identified cognitive and collaborative demands associated with roadway worker tasks, including track inspection, maintenance, and troubleshooting activities. Many of these tasks involve work on and around the track, which exposes roadway workers to the potential risk of a train striking them. Interviews and observations revealed that communication between roadway workers in one location, as well as among other railroad workers dispersed in space and time, plays a significant role in enabling the completion of tasks and creating safe working conditions. While many of these communications are mandated by formal operating rules, others are more informal. Importantly these informal strategies served to foster shared situational awareness (i.e., common ground) across the distributed team and created safety nets for roadway workers. These informal strategies are the primary focus of the following results.

3.2.3 Contribution of Distributed Teamwork to Safe and Efficient Railroad Operation

The results of both the dispatcher CTA and the roadway worker CTA made clear that dispatchers, roadway workers and train crews work collaboratively to facilitate work, improve efficiency, and contribute collectively to safe operation. These collaborative strategies depend heavily on both active direct communication between specific parties, and passive ‘listening in’ strategies that depend on overhearing communication intended for others. While some of the communication is formally mandated by policies and procedures, there are also informal communication strategies that emerged that foster common ground, facilitate work and enhance safety.

3.3 Formal Communication Supporting Distributed Work

Communication plays a significant role in accomplishing work objectives as well as in enabling roadway workers to establish and maintain safe working conditions. Generally, communication of information is over a two-way radio and governed by formal operating rules that prescribe the form and content of the information to be communicated. A formal communication protocol is used that requires the receiver to read back the information heard. Both the sender and the receiver are also required to document the information exchanged (i.e., either by entering it into a computerized database or onto a written form). CTA results revealed additional informal, proactive communication practices that have emerged that serve to increase efficiency of railroad operations as well as enhance overall safety.

Roadway workers communicate regularly with railroad dispatchers. For multi-person roadway worker groups, one employee, the Employee in Charge (EIC) communicates with the dispatcher via radio or, in some cases, cell phone. The primary reasons for roadway workers to contact dispatchers were (1) to obtain and release authority to work on a specific portion of track; and (2) to report conditions that may require track to be taken out of service or to impose speed restrictions. Roadway workers may also request movement authority to travel across a portion of track in a track car (e.g., to perform inspection of the track).

Dispatchers will also contact roadway workers via radio. Formally prescribed reasons that dispatchers may call roadway workers include: (1) request release of track; (2) alert them to reports of track conditions that require inspection or repair.

Communication also occurs among roadway workers within a work group both to coordinate work and to ensure the safety of the workers in the work group. Once the EIC receives authority to place track out of service to work on the track, the EIC becomes the 'owner' of that track and is responsible for coordinating work and maintaining safety within that work zone. Any roadway worker that wishes to perform work on that portion of track needs to obtain formal permission from and coordinate with the EIC. Before releasing track back to the dispatcher, the EIC must notify all affected roadway workers.

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 may involve large numbers of workers (i.e., up to 100 workers) that include multiple crafts and large numbers of equipment (i.e., up to 20 or 30 pieces of equipment) working in multiple subgroups spread out over a wide portion of track.

Roadway workers also communicate with train crews. An example of formal communication requirements between roadway workers and train crews are cases where trains require permission to pass through a work zone. In those cases, the train crew is required to contact the EIC via radio to obtain approval to enter the work zone.

Similarly, train crews communicate with dispatchers, other trains, and roadway workers over two-way radio. In many cases, formal operating rules prescribe the form and content of the information. Observations and interviews revealed additional informal, proactive communication practices, which have emerged that serve to increase efficiency of railroad operations as well as enhance overall safety.

Communication requirements depend on the signaling systems and operating rules in place. For example, under centralized traffic control, train movement is governed by signals, so no verbal communication with dispatchers is required if no system malfunctions occur. In dark territory, where no signals direct train movement, train movement authorities are provided through verbal communication between train crews and dispatchers over two-way radio. Communication between train crews and dispatchers also arise when problems occur with the signal system or new temporary speed restrictions arise that dispatchers need to communicate to the train crews.

Informal Cooperative Strategies across Crafts Contributing to Efficient Operations

The CTAs revealed numerous instances of railroad workers anticipating, cooperating, and coordinating across crafts to increase operation efficiency. These cooperative strategies emerged informally and go beyond the formal communication requirements mandated by policies and procedures.

Dispatchers displayed a variety of strategies that smooth the way for trains to pass through territories safely and efficiently and satisfy the multiple demands placed on track use. Dispatchers' planning and scheduling was proactive, anticipatory and opportunistic—taking advantage of windows of opportunities that arise to satisfy the multiple demands placed on track use. These strategies depended heavily on communication and cooperation among individuals distributed across time and space. For example, roadway workers and train crews worked cooperatively with dispatchers in providing the information needed by dispatchers to make efficient track allocation decisions and level workload. In turn, dispatchers worked cooperatively with train crews and roadway workers, in minimizing communication load, and facilitating work.

Dispatchers acted proactively to take advantage of windows of opportunity and increase train flow and track use efficiency. For example, if a dispatcher knows that a roadway worker needs additional time to work on the track, and he sees a window of opportunity (e.g., because a train has been delayed), he will proactively call the person and offer additional time. As one roadway worker said, "a good dispatcher will call you and help to make your job easier."

Multiple dispatchers of adjacent territories will also work collaboratively to increase train flow as well as facilitate the work of roadway workers. For example, we observed a case where multiple dispatchers on 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. This provided the freight yard dispatcher with a heads up to upcoming needs, enabling him to plan for and accommodate the needs of the roadway worker on the track car.

Roadway workers also displayed strategies to facilitate the work of dispatchers. In particular, they worked actively to support dispatchers in:

- *Understanding the work and implications for track availability.* Typically, roadway workers will let the dispatcher know the kind of track work they will be doing at the time that they request track authority. It is important to give the dispatcher an idea of the nature of the work that will be done, 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 knows that he/she can ask the roadway worker to stop and get off the track to let a train through. Other work disrupts the track and requires completion of the work before trains can pass through.

- *Projecting when track will become available for other uses.* Dispatchers will sometimes call roadway workers to check on the status of their work to be able 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 plot their next move.
- *Reducing communication demands.* Prior to calling the dispatcher to request time to work on a particular portion of track, the roadway worker may call trains scheduled to pass on that track around the time of interest to find out where they are and when they are anticipated to pass that portion of track. This is done as a way of shifting workload from the dispatcher since dispatchers typically operate under high workload conditions (Roth, Malsch and Multer, 2001). If the roadway worker learns that trains will be coming through at the time he or she was hoping to get time on the track, then the roadway worker does not need to contact the dispatcher—eliminating the need interrupt the dispatcher with a request that cannot be fulfilled. If the roadway worker finds out that the trains will not be passing through during the time window of interest, then the roadway worker can call the dispatcher with that information. This allows the dispatcher to know that there is time available to give to the roadway worker. Otherwise the dispatcher would have to stop what he or she was doing to find out where the trains are and what their intentions are which would impose additional workload.

Dispatchers and locomotive engineers also act cooperatively and proactively to increase communication efficiency between them, and facilitate train movement. For example, locomotive engineers are required to check with the dispatcher for messages before leaving a train station. If a dispatcher has the time, he will call the locomotive engineer before he reaches the station to let him know that there are no messages, and that he can leave the station whenever he is ready. This will allow the locomotive engineer to start the trip back in the other direction more quickly. In turn, locomotive engineers will sometimes act proactively to save the dispatcher time. For example, if a dispatcher sends a message over the radio directed at one locomotive engineer, but it is also relevant to others, the others will call in over the radio acknowledging receipt of the message. This eliminates the need for the dispatchers to call them individually.

Informal Cooperative Strategies across Crafts Contributing to Safe Operations

In addition to strategies for improving overall railroad operation efficiency, the CTA revealed that dispatchers, roadway workers, and train crews have developed informal strategies that substantively contribute to railroad safety. Dispatchers, roadway workers, and train crews actively work to develop and maintain awareness of the location, activities and intentions of trains and roadway workers in their proximity (i.e., in the case of train crews and roadway workers) or under their control (i.e., in the case of dispatchers). In this sense, they work actively to develop and maintain common ground.

Strategies for developing common ground include extracting relevant information by 'listening in' on radio communications directed at others. These active listening processes enable individuals in the distributed organization to identify information that had a bearing on achieving their own goals or on maintaining their safety. It also enables them to recognize situations where information in their possession is relevant to the performance or safety of others, as well as to identify and correct dangerous conditions. In addition to 'listening in' strategies, dispatchers, train crews, and roadway workers developed informal proactive communication strategies for providing information to others intended to foster common ground and enhance safety.

Figure 2 provides an overview of these informal proactive strategies. In combination, these strategies contribute substantively to performance that is more reliable and enhanced safety by enabling train crews and roadway workers to be aware of the locations, activities and intentions of each other, improving overall efficiency and avoiding potential accidents. Figure 2 shows more details on these strategies, and their contribution to improving safety.

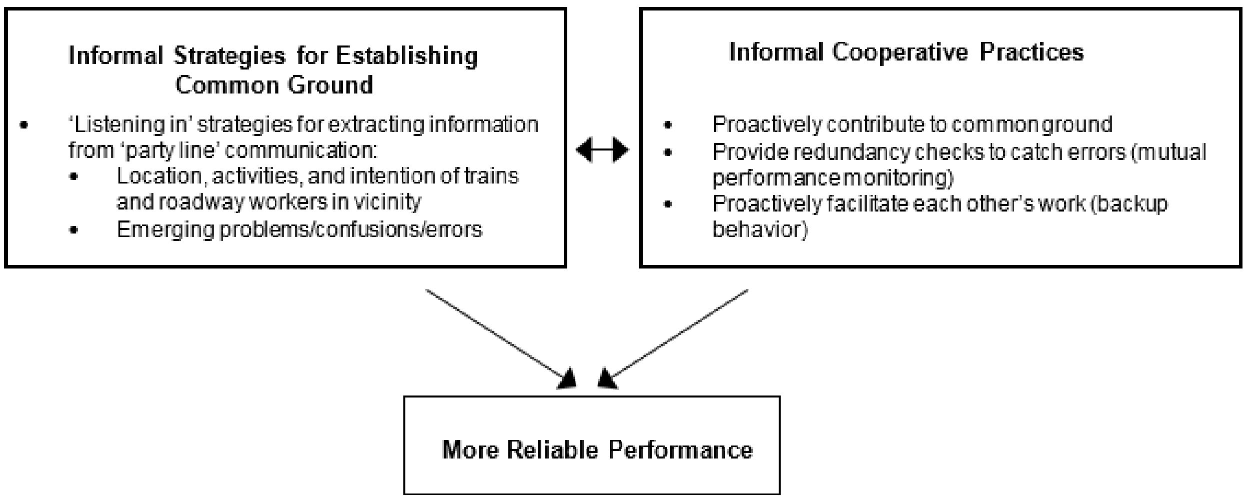

Figure 2. Distributed teams actively work to develop and maintain common ground contributing to more reliable performance and increased safety

Dispatchers, train crews, and roadway workers routinely take advantage of the radio party-line features to maintain broad situation awareness, anticipate, and plan. Dispatchers routinely "listen for" information on the radio channel that is not directly addressed to them but provides important clues to location and activities of trains and roadway workers under their control, potential delays, problems or need for assistance. Examples include:

- *Identifying and tracking train delays*. By overhearing communication between conductors and locomotive engineers, dispatchers are able to infer information about train location and potential delays. For example, a train conductor will generally tell the locomotive engineer when it is time to leave the station (e.g., "OK out of New London"), by comparing the time to the scheduled departure you can compute train delays.
- *Identifying equipment problems*. By overhearing conversations between the locomotive engineer and the mechanical department, the dispatcher gets early notice of malfunctioning train engines that will need replacing.
- *Listening for/heading off potential interactions and conflicts*. Dispatchers listen for commitments made by others that may affect activity in their territory. For example a

train may request approval from the dispatcher of an abutting territory to go toward his territory, while the dispatcher may have already given someone else approval to move on the same track in the opposite direction. The ability to listen ahead allows dispatchers to nip potential conflicts before they arise.

- *Listening for mistakes*. An experienced train dispatcher will pick up key information that may signal a misunderstanding, confusion, or error, such as a situation where a roadway worker is inadvertently working on unprotected track. Dispatchers mentioned that while instances of roadway workers working at the wrong location or on the wrong track are rare, they do occur. Dispatchers mentioned that the 'party line' aspect of radio communication that allows others to overhear conversations 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 where roadway workers were and what 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.

Similarly, roadway workers, whether working at a fixed location, or traveling across track, worked actively to establish common ground, including maintaining awareness of their own location, trains in their vicinity as well as the location and activities of other roadway workers. Interviews with both roadway workers and dispatchers emphasized the importance of building and maintaining the 'big picture' with respect to these various elements. Importantly many of the strategies relied on the ability to exploit the 'party-line' aspect of radio communication to extract information about the activities and intentions of distant parties.

- *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 *mutual* understanding of where work is to take place and the exact location of the limits of authority given to ensure that the roadway workers are properly protected. Failures in establishing 'common ground' understanding, with respect to the location where work authority is, can result in communication errors that have the potential to impact roadway worker safety.
- *Maintaining awareness of trains/anticipating trains*. Being struck by a train represents one of the greatest risks confronting roadway workers. Consequently, it is critical that roadway workers maintain awareness of trains in their proximity. This includes trains that may be traveling on the track on or near where they are working, and trains that are traveling on the adjacent track. While approaching trains are in principle detectable by seeing or hearing them as they approach, in practice this can be difficult. If the roadway workers are working with their backs toward the direction of the approaching train they may not see the train. If they are working in a noisy environment (i.e., around noisy equipment) or are wearing protective head gear (e.g., in inclement weather) they may not hear the approaching train. Therefore, roadway workers actively work to build and maintain 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, time tables 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 them 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 below, informal, cooperative, practices have grown whereby others (e.g., dispatchers, train crews, and other roadway workers) will routinely alert roadway workers of trains that may be about to reach them—particularly when these trains are coming at an unexpected time or from an unexpected direction. These informal, distributed, cooperative practices play an important role in increasing the safety of railroad operation by enhancing the situation awareness of members of the distributed system, enabling roadway workers to anticipate and prepare for trains heading their way. Additionally, there are formal procedures (i.e., related to "track authority") for controlling trains entering and transiting a work zone that include coordination between the work crew supervisor, dispatcher, and locomotive crew.

- *Maintaining awareness of time to track authority expiration*. In addition to maintaining awareness of physical location, roadway workers need to maintain awareness of time in relation to time limits of authorities to occupy and work on track. Roadway workers expressed concern of 'losing track of time,' failing to notice that they exceeded the time limit of their authority to occupy the track. Several factors can contribute to 'losing track of time.' The roadway worker may become distracted by work or another activity (e.g., phone call or a request to check on a problem). They mentioned that there were policies 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, there can be variable distance between control points (i.e., ranging from 500 feet to 10 or more miles).
- *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 within a given work zone. The EIC is responsible for keeping track of individuals working in the work zone. One of the ways that railroad workers maintain shared situation awareness of the location and activities of roadway workers that may be widely distributed geographically is by taking advantage of the 'party-line' aspect of radio communication. For example, one EIC mentioned that he liked to have the relevant roadway workers (e.g., people in track cars, flagmen) listen in over the radio when he obtains 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, fosters shared situation awareness of the location and activities of the roadway workers and reduces the potential for communication error.

Proactive Communication Strategies that Foster Common Ground to Enhance Safety

In addition to 'active listening' strategies, railroad workers have developed informal cooperative communication practices that are explicitly intended to foster improved common ground with respect to the location and activities of roadway workers and trains operating in the same vicinity, enhancing safety on the track. The research team found that dispatchers, train crews, and roadway workers routinely engage in informal communication for the sole purpose of enhancing each other's situation awareness (Roth, Multer, and Raslear, 2006). These informal cooperative practices are summarized in Table 1.

One example of a proactive communication intended to enhance safety occurs when individuals alerted roadway workers of unusual or unexpected conditions that may pose a safety hazard to them. Dispatchers often call roadway workers to alert them of a train coming by, particularly if the train is coming through at a non-usual time or unexpected direction. For example, if a roadway worker or roadway worker group have 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. Similarly, if a roadway worker group is working around a track (i.e., not on the track), the dispatcher would call to let them know to expect a train he or 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." This call is not strictly mandated by operating rules. It is part of the informal redundant 'safety net' that is provided through voluntary cooperative activities among railroad workers.

Table 1. Proactive Communication Strategies for Fostering Common Ground with respect to Trains and Roadway Workers in a Given Vicinity

Proactive Communication Strategies
Dispatchers call to alert roadway workers of trains, particularly if they are coming at a non-usual time or unexpected direction.
Dispatchers call train crews to alert them of unusual conditions.
Train crews call other trains to alert them to roadway workers, trespassers, and potential hazards.
Roadway workers call other roadway workers to alert them of trains heading in their direction.

Dispatchers will also call trains to alert them to unusual conditions that vary from their regularly expected routine. This informal communication helps train crews anticipate upcoming events and potential hazards so that they are in a better position to prevent problems. One example the research team observed was that a dispatcher called a locomotive engineer to alert him that he was approaching an unexpected signal and should prepare to stop. This event occurred because a train was stopped ahead. The dispatcher did not need to call the locomotive engineer because the signal aspect should have been sufficient to direct the train to stop. However, the dispatcher provided this redundant cue to reduce the possibility of error. The redundant cue served an important safety function. By alerting the locomotive engineer to the upcoming signal aspect, the dispatcher reduced the possibility that the engineer would miss the signal (i.e., because the engineer was not expecting it). Further, by explaining the reason for the signal aspect, he avoided the possibility that the locomotive engineer would wonder whether the unexpected signal aspect was a false signal. The dispatcher referred to the communication as a "courtesy."

Locomotive engineers actively engage in communication to improve awareness of the location and activities of other trains and roadway workers in their vicinity. They will routinely call other trains to find out where they are and to alert them to potential hazards, such as trespassers, kids throwing objects, and problems on the track. They will also call to inform each other of the location and activities of roadway workers in the vicinity.

One locomotive engineer explained that he routinely wrote down what trains were in the vicinity, which trains he expected to pass, and where he expected to pass them. He explained that one reason he did this was in case he saw something that was important to communicate. As an example, if kids were on the track, then he would want to alert other trains in the vicinity.

The engineers mentioned that it was the dispatcher's job to inform them of the location of other trains, but that they actively sought that information through direct communication with the other trains as a redundant safety check. As one locomotive engineer explained, "I imagine that dispatchers get busy too and things happen and there might be something they get wrapped up in and they can't communicate everything." These redundant safety checks provide an example of the kind of 'backup' behavior that is a characteristic of high performing teams.

Finally, roadway workers will also call other roadway workers to inform them of trains in their vicinity. For example, we observed roadway workers traveling on track cars call a roadway worker group that they had passed earlier to alert them to a train heading their way.

The results highlight the active cooperative processes that train crews, dispatchers, and roadway workers engage in that foster common ground and enhance overall safety of railroad operations (Figure 2). These cooperative communication practices go beyond the requirements of formal operating rules, and are not included in formal training. These emergent cooperative practices play an important role in increasing the safety of railroad operation by enhancing the mutual awareness of distributed team members. They reduce the possibility of accidents by enabling roadway workers to anticipate and prepare for trains in the vicinity and vice versa. Further, the examples of seemingly redundant communication, where the receiving party, in principle, would be expected to be aware of the information through other means (e.g., a dispatcher alerting a train crew to conditions that vary from expected routine; train crews actively seeking out information about other trains and roadway workers in their vicinity) are illustrations of redundant checks that contribute to the resilience of the railroad system to errors that might occur.

3.3.1 Implications for Training

The CTAs revealed a variety of informal strategies that roadway workers, locomotive engineers, and dispatchers have developed to establish common ground with respect to each other's location, activities, and intentions. As summarized in Figure 2, these included active "listening-in" strategies that enabled individuals in the distributed organization to extract information that had a bearing on achieving their own goals, as well as to recognize when information in their possession needed to be shared to support the performance or safety of others. It also included informal cooperative practices that served to facilitate work and enhance safety across the distributed organization. These informal practices included proactive communications intended to foster common ground, redundancy checks are intended to reduce the possibility of error; and proactive actions intended to level workload and facilitate work across the distributed organization.

Notably, these behaviors went beyond the actions required by formal rule book requirements. They were generally not spontaneously brought up during interviews with the railroad workers, and were primarily uncovered through field observations of actual work. Nevertheless, these behaviors clearly contribute positively to safe and efficient railroad operations.

A clear recommendation from the CTAs is the importance of uncovering these positive informal practices and incorporating them in formal training programs so that they can be more efficiently transmitted to new workers.

3.3.2 Implications for Adding New Technology

The CTAs highlighted the contribution of informal practices that enhance efficiency and safety across the distributed organization. These included active "listening-in" strategies that depend on the party-line aspect of radio communication to establish common ground, anticipate situations and act proactively. These findings have relevance for how new technologies, particularly position localization, and digital communication technologies, might best be deployed to foster common ground across the distributed work system. They also point to potential pitfalls to avoid.

Railroads are using new technologies such as position location (e.g., Global Positioning System [GPS]), digital information transmission and PTC. For example, railroads have been developing portable devices for roadway workers that integrate location-finding technologies (e.g., GPS) for more accurate location information and digital technologies for more reliable communication. Properly deployed, these technologies enhance mutual awareness of the location, activities, and intentions of trains and roadway worker groups within the distributed organization, increasing overall safety. However, these technologies have the potential to disrupt the strategies that practitioners currently use to build and maintain common ground that is critical to coordinating work and ensuring safe operations.

A design challenge is how to preserve the benefits of 'listening in' strategies that naturally arises in the case of distributed teams connected via audio channels (e.g., voice radio) as digital technologies are introduced. If digital technology were deployed to eliminate the party-line aspect of current radio technology, without providing an alternative means to foster common ground, it could degrade the ability of individuals to maintain awareness of each other's location, activities, and intentions. While digital communication technology is often implemented as a private communication channel where only the specified receiver has access to the information transmitted, this is not an inherent characteristic of the technology. It is possible to envision 'broadcast' versions of digital communications technology where multiple individuals can access a transmitted message or view common graphical displays regarding real time status of track and train information. The large wall-mounted displays that are present in many dispatch centers today are one good example of a common graphical display. They enable multiple dispatchers, each responsible for a different segment of territory to maintain a shared understanding of the status of the track and location and movement of trains across the larger system. Properly deployed digital communication technologies have the potential to reduce the challenges associated with analog radio communications while still providing the kind of situation awareness information that is now extracted indirectly from radio communication. Some types of information would clearly benefit from shifting from analog radio to data link where it could be sent privately, reducing radio congestion, and presented visually on a computer display. For example, long dialogues intended to convey detailed instructions or exact location information are best shifted to data link communication where they could be visually presented on a computer display to avoid misunderstandings and communication errors.

Other information could be shifted to digital communication while preserving the broadcast aspect of analog radio by transmitting digital messages to multiple individuals at once. For example, a dispatcher could specify multiple parties that should receive a given digital message to foster shared situation awareness of the activities and intentions of trains and roadway workers in a vicinity. Similarly, roadway workers and train crews could broadcast information to multiple individuals simultaneously to coordinate activities and foster shared situation awareness. This selective broadcast capability would have the effect of reproducing the "common ground" that is fostered by the party-line feature of radio communication without contributing to the communication congestion associated with analog radio where all messages are broadcast simultaneously to everyone. The difference lays in the deliberative conscious nature of decided which messages to share and with whom to share them.

Location-finding technology can also be leveraged to facilitate common ground. For example, location-finding technology makes it possible to develop graphic displays that directly show the location of roadway workers and trains within a given vicinity. The same information display could be made available to dispatchers (i.e., on a display in the dispatch center), roadway workers (i.e., on portable graphic devices), and train crews (i.e., on a display in the locomotive cab). Thus, location information that is important for common ground, which is now extracted indirectly (e.g., by listening in to radio communications directed at others), could be obtained more directly and with lower cognitive overhead.

The results of the CTAs also reaffirmed the potential benefits of PTC technology for enhancing roadway worker safety. PTC systems have been explicitly designed to stop trains before they enter work zones, which protect 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 work zones 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.

Portable devices carried by roadway workers that combine location information with digital communication have the potential to directly provide roadway workers the kind of information they currently should extract indirectly by monitoring radio communication directed at others. They have the potential to facilitate communication and coordination among roadway workers, dispatchers and locomotive engineers, and enhance safety by more directly fostering common ground. Possible benefits of portable roadway worker devices include an improved ability to keep track of and coordinate with other roadway workers in a work group; ability to obtain and release working limits from dispatchers more efficiently; ability to warn roadway workers when they are about to exceed their limits of authority (i.e., either going outside geographic limits, working on the wrong track or approaching time expiration); ability to warn roadway workers of approaching trains; and improved ability for dispatchers to maintain awareness of the location and dispersion of roadway workers and equipment in their territories.

4. Conclusion

This report summarized the results obtained by Volpe across multiple CTAs relating to teamwork in railroad operations. The findings emphasized the importance of informal proactive strategies across both elemental and distributed teams in contributing to safe and efficient operations. Implications for training and new technology deployment were described.

Train crews, a primary example of an elemental team in railroad operations, were shown to exhibit characteristics of high performing teams that have been found across industries. These include mutual performance monitoring and active support of each other's activities (e.g., backup behavior). A key contributor to successful performance is establishing and maintaining common ground between the locomotive engineer and conductor with respect to goals, planned activities, potential risks, and ways to mitigate them. In turn, this depends on active communication, and particularly high quality initial job briefs as well as 'rolling' job briefs to maintain common ground. Most of the behaviors that characterized high performing train crews went beyond the requirements of formal operating rules and were not explicitly covered in training. There was a discussion of the implications of findings for design of training and an introduction of new in-cab technologies, such as PTC.

The CTAs also looked at informal cooperative practices across the larger distributed team made up of dispatchers, train crews, and roadway workers that contributed to safe and efficient performance across the railroad. The results highlighted the active cognitive and collaborative processes that workers engage in to develop and maintain common ground with respect to each other's location, activities and intentions across the distributed organization. These included active strategies for extracting relevant information by 'listen in' on radio communications directed at others. These active listening processes enabled individuals distributed across the organization to identify information that had a bearing on achieving their own goals or on maintaining their safety. It also enabled them to recognize situations where information in their possession was relevant to the performance or safety of others. The research team also identified several proactive strategies intended to facilitate each other's work and improve overall safety. These informal practices included proactive communications intended to foster common ground, redundancy checks intended to reduce the possibility of error; and proactive actions intended to level workload and facilitate work across the distributed organization.

As in the case of train crews, we found that these informal strategies went beyond the requirements of formal rules and procedures. Nevertheless, these informal proactive activities contributed to the overall efficiency and resilience to variation in railroad operations.

One interesting question that was not addressed in this study is from where did these informal cooperative practices emerge; it is unclear as to what caused them to emerge, and how they are learned from one railroad worker to the next. The reason these are important questions is that prosocial behavior may arise from, and be reinforced by, aspects of the broader sociotechnical system. If changes are made without awareness of what influences these prosocial behaviors those changes may inadvertently disrupt or discourage these behaviors, resulting in unsafe systems.

The implications of the results for training, as well as for the introduction of new technology, particularly position location (e.g., GPS) and digital information transmission technology, were described. Effective support requires mechanisms to enable employees to maintain awareness of the activities and plans of others to coordinate goals, synchronize activities, prevent coordination breakdowns, and create resilience in the face of unanticipated events and errors (Hollnagel, Woods and Leveson, 2006). Common ground is currently accomplished by relying on the party-line aspect of radio communication to extract information indirectly. If carefully designed, new technologies involving position location and digital communication can be leveraged to provide equivalent or better support.

Examples from the dispatcher, roadway worker, locomotive engineer, and conductor CTAs illustrated how new technology can facilitate or interfere with teamwork depending on how it is implemented, such as:

- Enhancing team processes by reducing the need for explicit communication, or enhancing common ground through new visualizations (e.g., properly designed portable roadway worker devices combining location information with digital information)
- Disrupting effective team processes by eliminating a source of information currently used to develop common ground, without providing an alternative means for obtaining that information (e.g., digital communication deployments that eliminate the broadcast feature of radio communication)
- Altering the distribution of functions and workload across team members shifting a job role from one team member to another (e.g., deployment of PTC in a way that shifts some of the conductor functions to the technology and/or to the locomotive engineer)
- Creating new demands on teamwork, such as new requirements for communication (e.g., new displays that present information to only one team members that needs to be shared)

The examples highlight the importance of conducting teamwork and function allocation analyses as part of HSI analyses in support of new technology implementation.

Railroad operations encompass a wide variety of positions that go far beyond the specific positions, train crews, dispatchers and roadway workers, that have been examined in the CTAs conducted to date. These include positions involved in planning and scheduling of train movements, positions involved in management of train movements in and out of yards, and positions involved in troubleshooting and maintenance of equipment, among others. These positions are part of the larger distributed organization and undoubtedly involve both formal and informal teamwork practices that contribute to safe an efficient operation.

A broader implication of the current work is the importance of conducting similar analyses in trying to understand and improve other aspects of railroad operation. It is important that teamwork practices that contribute to efficiency and safety are uncovered and documented to guide the design of improved training and new support systems. Such analyses should be a standard part of new technology design and implementation processes to inform design of more effective support systems, and ensure that the introduction of new technology does not inadvertently disrupt teamwork practices that are critical to overall system safety.

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Abbreviations and Acronyms

ACRONYMS	EXPLANATION
CTAs	Cognitive Trask Analyses
EIC	Employee in Charge
FRA	Federal Railroad Administration
GPS	Global Positioning System
HSI	Human System Integration
Volpe	John A. Volpe National Transportation Systems Center
PTC	Positive Train Control
RSIA	Rail Safety Improvement Act of 2008
TRB	Transportation Research Board
UP	Union Pacific Railroad