Shared Situation Awareness as a Contributor to High Reliability Performance in Railroad Operations

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Abstract

Cooperative strategies of individuals within a distributed organization can contribute to increased efficiency of operations and safety. We examine these processes in the context of a particular work domain: railroad operations. Analyses revealed a variety of informal cooperative strategies that railroad workers have developed that span across multiple railroad crafts including roadway workers, train crews, and railroad dispatchers. These informal, proactive communications foster shared situation awareness across the distributed organization, facilitate work, and contribute to the overall efficiency, safety, and resilience to error of railroad operations. We discuss design implications for leveraging new digital technologies and location-finding systems to more effectively support these informal strategies, enhance shared situation awareness, and promote high reliability performance.

Keywords: cognitive task analysis, situation awareness, railroads, team cognition, cognitive field studies, human reliability, distributed decision making, naturalistic decision making

Complex socio-technical systems depend on the work of multiple individuals distributed in time and space. Examples include military command and control, space shuttle operations, air traffic control, and railroad operations. Performance depends on coordinated work among individuals that may not be collocated, have responsibility for different subsets of goals, different access to data, and different situation perspectives. There has been growing interest in understanding the cognitive and collaborative factors that enable such teams to work effectively (Klein et al. 2000; Smith et al. 2000; Salas and Fiore 2004). In this paper we examine distributed team processes in the context of railroad operations. We focus particularly on the role of informal strategies for maintaining shared situation awareness among roadway workers, train crews, and railroad dispatchers and enhancing overall efficiency and safety of operations.

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The Role of Shared Situation Awareness in Supporting Distributed Team Performance

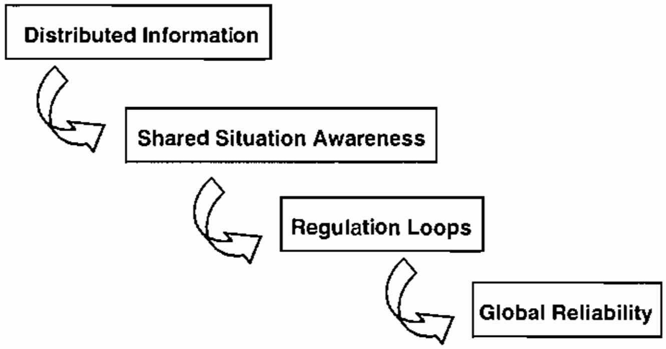
An area of growing consensus in the literature on teamwork is the importance of shared contextual knowledge in supporting coordination and facilitating work. Effective performance depends on shared information about both the situation and the other team members. This includes mutual knowledge and beliefs about the current situation, each other's goals, and current and future activities and intentions. Various labels have been used to denote this shared contextual knowledge, including *shared mental models* (Cannon-Bowers et al. 1993); *team cognition* (Espinosa et al. 2004), *common ground* (Clark and Brennan 1991; Klein et al. 2000, 2005); *shared situation awareness* (Endsley et al. 2003), and *shared work space awareness* (Gutwin and Greenberg 2004). This shared contextual knowledge, which we will refer to from here on as *shared situation awareness*, allows team members to efficiently coordinate work by enabling them to understand what is going on with the task, interpret what others are doing, and anticipate what will happen next. It enables team members to anticipate the information and support needs of other team members, resulting in reduced need for explicit communication and improved action coordination (MacMillan et al. 2004). Conversely, incorrect or incomplete mutual assumptions, knowledge, or beliefs can contribute to breakdowns in communication and coordination (Klein et al. 2000).

Most of the research on teamwork has focused on the role of shared situation awareness in the ability of teams to coordinate work efficiently. There has been less attention focused on the contribution of shared situation awareness to high reliability performance. Shared situation awareness can provide the foundation for cooperative team practices that contribute to system resilience to human error and unanticipated events, increasing overall safety (Hollnagel 2004; Reason 1997; Rochlin et al. 1987; Weick et al. 1999; Woods and Shattuck 2000; Hollnagel et al. 2006). This is particularly important in safety-critical work settings such as nuclear power plants, air traffic control, healthcare, and railroad operations where errors can result in a threat to the safety of people and the environment.

Rognin et al. (2000) have offered a conceptual framework that articulates the role of shared contextual knowledge in enabling teams to work cooperatively to enhance the error tolerance and overall reliability of complex socio-technical systems. The elements of the framework are depicted in Figure 1.

According to the framework presented by Rognin et al. (2000) team members engage in cooperative practices that contribute to resilient, high reliability systems. These cooperative practices depend on, and support, developing and maintaining shared situation awareness through information sharing, mutual knowledge, and mutual awareness. Shared situation awareness, in turn, enables team members to participate in mutual 'regulation loops' that provide the mechanism to catch and correct errors and adapt to dynamically changing demands. Examples include: the ability to monitor for errors through peripheral modes of perception such as overhearing or overseeing activities of others; and spontaneously adapting organizational

Figure 1.
Role of Shared Context in Contributing to Reliability of Socio-technical Systems
Source: adapted from Rognin et al. (2000)



structure to respond to changing situation demands (e.g. shifting responsibilities across team members to address overload situations or to capitalize on specific expertise).

In this paper, we examine the processes by which distributed teams develop and maintain shared situation awareness and the cooperative practices that contribute to enhanced safety in the context of railroad operations. The results are used to expand the theoretical knowledge base on the contribution of informal, cooperative practices of distributed teams to safety, and to point to ways technology can be deployed to more effectively support shared situation awareness and enhance overall safety.

Roadway Workers in Railroad Operations: An Example of Distributed Team Performance

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 in order to accomplish a common task. Some jobs require working at a particular location on the track (e.g. change a rail, troubleshoot a malfunctioning signal). Other jobs require moving across track, for example to perform track inspection.

Communication plays a central role in coordinating work and establishing and maintaining safe operations. Roadway workers communicate with dispatchers to obtain and release permission to work on particular segments of track as well as to communicate track problems that may require speed restrictions or taking portions of track out of service. They also need to communicate and coordinate with other roadway workers and with train crews.

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 particular focus of the study was on uncovering the cognitive and collaborative activities that roadway workers engage in to maintain safety.

The railroad industry is developing a number of new technologies that will affect roadway workers. This includes new forms of positive train control (PTC) that are designed to protect roadway workers and prevent train-to-train collisions by providing backup warnings and, if necessary, automatically stop trains that exceed speed restrictions or enter track segments for which they are not authorized. A second, related, technology that is emerging is portable digital communication devices intended to allow roadway workers to communicate more reliably.

A goal of the research was to understand the factors that affect roadway worker safety in today's environment so as to anticipate the likely impacts of these emerging technologies on roadway workers and to provide guidance for design and introduction of the technologies. This includes understanding the cognitive and collaborative activities that could be supported more effectively through the introduction of these new technologies. Equally important is identifying features of the existing environment that contribute to effective performance and safety and therefore should be preserved when deploying these new technologies.

Using Cognitive Task Analysis to Uncover Practitioner Strategies for Coping with Cognitive and Collaborative Demands in a Distributed Organization

Cognitive task analysis (CTA) methods were used to uncover the types of cognitive and collaborative demands faced by roadway workers and the informal strategies they have developed for coping with task demands and enhancing on-track safety.

CTA methods have grown out of the need to explicitly identify cognitive requirements inherent in performing complex work in naturalistic environments (Klein et al. 1989; Schraagen et al. 2000; Klein 2000; Potter et al. 2000). In performing CTA, two mutually reinforcing perspectives are considered. One perspective focuses on the *characteristics of the domain* and the cognitive and collaborative demands they impose. The focus is on understanding what factors contribute to making practitioner performance challenging. Understanding domain characteristics is important both because it provides a framework for interpreting practitioner performance and because it can help define the requirements for effective support. The second perspective focuses on *how today's practitioners respond* to the demands of the domain both as individuals and as cooperating teams. Understanding the knowledge and strategies that expert practitioners have developed in response to domain demands provides a second window for uncovering the challenges of the current work environment as well as effective strategies for dealing with those challenges. These strategies can be captured and transmitted directly to less experienced practitioners (e.g. through training systems), or they can provide ideas for more effective support systems that would eliminate the need for these compensating strategies.

A variety of specific CTA techniques have been developed that draw on basic principles and methods from the behavioral sciences (Cooke 1994;

Klein et al. 1989; Militello and Hutton 1998; Roth and Patterson 2005). These include structured interview techniques, critical incident methods, and field study methodologies. In practice, multiple converging methods are used as part of an opportunistic bootstrap process (Potter et al. 2000).

The present study combined structured interviews and field observations. The study attempted to elicit multiple perspectives on the challenges associated with working and maintaining safety on and around the track, by interviewing different types of roadway workers as well as dispatchers with whom they primarily interact.

Methods

Interviews and field observations were conducted at five locations in the United States and included passenger and freight rail operations. A total of 26 individuals were observed and/or interviewed, including 13 trackmen, who are responsible for inspection and maintenance of track; 8 signalmen, who are responsible for inspection and maintenance of signal systems; and 5 dispatchers, who control track usage.

Interviews with trackmen were conducted at three sites. At two of the sites interviews occurred while accompanying a trackman on high-rail track car rides and included discussion of the demands associated with track inspection and related documentation tasks. The interviews covered factors that impact roadway worker safety; the needs for communication and coordination with dispatchers, train crews, and other roadway workers; the challenges that arise; and how portable digital-based communication devices might impact their work. This included discussion of both formally prescribed communication protocols, and informal communications.

Interviews were conducted at two additional sites where advanced train control systems were being field tested. These interviews centered on the impact of the new train control technologies on roadway workers. Topics covered included new maintenance demands associated with the new technologies and the adequacy of support available for performing maintenance (e.g. the adequacy of manuals, training, availability of tools). The interviews also covered factors that affected roadway worker safety and the perceived impact of the new train control systems on roadway worker safety.

The dispatcher interviews were conducted with railroad dispatchers at a North East dispatch center to elicit dispatcher perspective on the challenges associated with communication with roadway workers and how portable digital-based communication devices might impact work. The study also leveraged the results of a prior CTA that specifically focused on demands and activities of dispatchers (Roth et al. 2001).

The interviewees were recruited through contacts with railroad management and labor union representatives. Interviews were conducted with individuals or groups of up to five people representing a single craft. Typically there were two to four interviewers that represented different behavioral research disciplines including human factors engineering and human reliability analysis. One interviewer led the interview sessions using a set of predefined interview questions. The other interviewers took notes and asked occasional follow-up questions. The predefined question set primarily served as a 'check-list' of topics to be covered. Actual questions asked and their order varied depending on participant responses. The set of predefined questions are presented in Roth and Multer (in preparation).

Interviews lasted approximately two hours and were tape recorded with the knowledge and permission of the individuals who were interviewed.

The tape-recorded interviews were transcribed and analyzed, with the goal of identifying recurrent themes across interviews as well as specific actual incidents described by interviewees that illustrate the themes.

The analysis focused on identifying: cognitive and collaborative demands in the current environment that contribute to performance difficulties and errors; skills and strategies that expert practitioners have developed to build and maintain shared situation awareness, to avoid or catch errors, improve efficiency and enhance safety; opportunities to enhance performance and/or improve safety through the introduction of new technologies; as well as concerns relating to potential new problems that could emerge with the introduction of new technologies.

Results

In this paper we present results relating to communication among the distributed team, the active strategies that roadway workers engaged in to build and maintain shared situation awareness, and the informal, cooperative strategies that emerged, that contributed to high reliability and resilience to error. Below we present evidence of these informal, cooperative strategies and their contribution to overall system efficiency and safety. Complete study results are documented in Roth and Multer (in preparation).

The Role of Communication in 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 information is communicated over two-way radio and is 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 (either by entering it into a computerized database or onto a written form). Observations and interviews revealed additional informal, proactive communication practices that have emerged that serve to increase efficiency of railroad operations as well as enhance overall safety.

Formal Communication Prescribed by Operating Rules

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 are (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.

Formal operating rules dictate the form and content of the information exchanged during these transactions. For example, when a roadway worker calls a dispatcher over the radio to request work authority for a portion of track, the dispatcher will enter into a computerized database the mileposts designating the start and end of the portion of track being authorized for roadway work and the start time (and sometimes an end time) for the authority. He or she will then read the information from the computer screen to the roadway worker, who is required to enter the information by hand onto a paper authorization form and then read the information back to the dispatcher. The dispatcher confirms that the information read back is correct, and only then is the authority to occupy and work on that portion of track put in place.

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). If they detect a problem in the track, the roadway worker will call to inform the dispatcher of the need to issue a speed restriction or to take the track out of service. The dispatcher then communicates the information to train crews.

Dispatchers will also contact roadway workers via radio. Formally prescribed reasons dispatchers call roadway workers include: (1) to request release of track; (2) to 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 insure 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 who 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 (up to 100 workers) that include multiple crafts and large numbers of equipment (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.

Proactive Communication Strategies that Facilitate Work and Enhance Efficiency of Track Usage

In addition to formally prescribed communication, we observed and were told about types of informal, cooperative communication strategies that were designed to facilitate the work of others within the distributed system. Roadway workers 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 in facilitating the work of roadway workers.

Roadway workers actively worked 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 interweaved 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 the work to be completed 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 so as 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.
- *Offloading 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 off the dispatcher since dispatchers typically operate under high workload conditions (Roth et al. 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 to 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 also exhibited active cooperative strategies that facilitated the work of roadway workers and improved overall track usage efficiency. Examples we observed or were told of included:

- *Proactively calling to provide track authority.* Dispatchers will act proactively to facilitate the work of roadway workers and improve overall track usage efficiency. As one roadway worker put it, 'a good dispatcher will call you and help to make your job easier'. An example we observed was a dispatcher who proactively called a roadway worker to offer time to work on a segment of track when a window of opportunity to squeeze in track work unexpectedly became available. Another example we observed was a case where multiple dispatchers of adjacent territories communicated and coordinated among themselves to enable a roadway worker on a track car to obtain permission to enter a freight yard several dispatch territories away. In the case in question, the roadway worker contacted the dispatcher of the territory he was in, who then coordinated with the adjacent Corridor dispatcher who in turn was in contact with the freight yard dispatcher. This provided the freight yard dispatcher with a 'heads up' to upcoming needs, enabling him to plan ahead and accommodate the needs of the roadway worker on the track car. This provides an example of railroad workers anticipating, cooperating, and coordinating across crafts to increase operation efficiency.

The above examples illustrate the kinds of proactive strategies that railroad workers have developed that enable individuals across crafts to anticipate, cooperate, and coordinate so as to level workload and improve the overall efficiency of the distributed organization.

Proactive Strategies that Enhance Shared Situation Awareness and Safety of Operations

In order to operate safely and efficiently, dispatchers, train crews, and roadway workers need to maintain shared situation awareness of the location, activities, and intentions of trains and roadway workers working in the same vicinity. Figure 2 summarizes the needs for shared situation awareness among the distributed team.

Interviews and observations provided evidence that railroad workers worked actively to build and maintain awareness of the location, activities, and intentions of others in their vicinity. In addition, informal cooperative communication practices have emerged that are specifically intended to enhance safety on the track by improving shared situation awareness of the location and activities of roadway workers and trains operating in the same vicinity. These informal cooperative practices are summarized in Table 1.

Individuals routinely alert 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 from an 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

Figure 2.
Elements of Shared Situation Awareness that Contribute to Safe and Efficient Operation

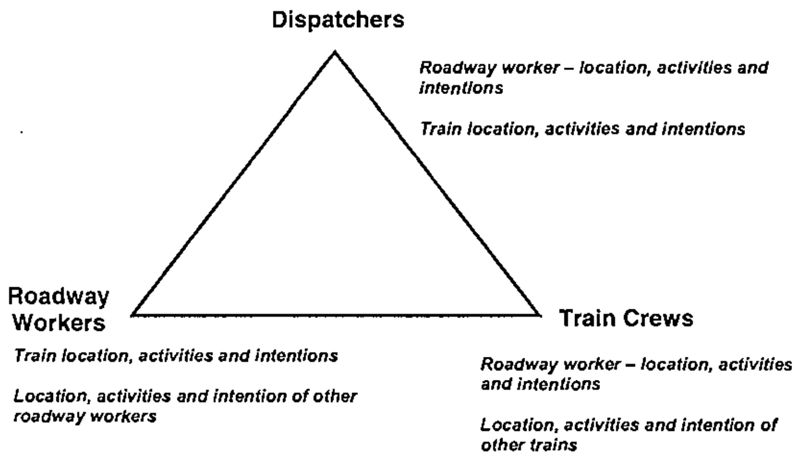


Table 1.
Proactive Strategies for Building Shared Situation Awareness Among Distributed Railroad Workers

Roadway workers monitor radio channels to extract information about trains in their vicinity
Dispatchers monitor communications directed at others to maintain awareness of location and activities of trains and roadway workers
Dispatchers call to alert roadway workers of trains, particularly if they are coming at a non-usual time or from an unexpected direction
Train crews call other trains to alert them of roadway workers in their vicinity
Roadway workers call other roadway workers to alert them of trains heading in their direction

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 redundancy 'safety net' that is provided through voluntary cooperative activities among railroad workers.

Similar informal communications that provide an important safety function have been observed among train crews. For example, if a train crew passes a roadway worker group working by the side of the track, he or she may call over the radio to alert other trains passing through the territory of the presence of the roadway workers. We also observed cases where roadway workers traveling on track cars called a roadway worker group that they had passed earlier to alert them to a train heading their way.

These practices are referred to as 'courtesies' by the roadway workers. They are not required by the operating rules. However, these informal, 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. These 'courtesies' contribute to the resilience of the railroad system to errors that might occur.

Proactive Strategies for Maintaining 'Shared Situation Awareness'

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

- Maintaining awareness of the physical location where they are working so as to insure that they are working at the location for which they have been provided authority;
- Maintaining awareness of trains expected in the vicinity (in both time and space) so as to avoid situations where a train approaches them without their awareness;
- Maintaining awareness of time so as to insure that they do not exceed track authority expiration times;
- Maintaining awareness of the location and activities of other roadway workers in a work group so as to insure mutual safety.

Interviews both with 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. In addition, as described below, the analysis also revealed that dispatchers and roadway workers engaged in significant cognitive work to build and maintain shared situation awareness of the location and activities of workers and trains in the territory.

Knowing the Territory and Maintaining Situation Awareness of Physical Location

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

Roadway workers and dispatchers need to be able to communicate location information accurately to insure a common understanding of the location where work authority is being requested and given. Failures in establishing 'common ground' understanding with respect to the location where work authority is being sought and provided can result in communication errors that have potential to impact roadway worker safety. Several instances were mentioned to us where roadway workers were working at a different location or on a different track than the one for which they had received authority to work at from the dispatcher. One case involved confusion between two locations with similar geographic landmarks. In this instance a roadway worker indicated he was working at one location when in fact he was working at a different one several miles away. Both locations were at bridges which created the source of confusion. The error was caught and corrected by the dispatcher based on the switch number. The dispatcher realized that there was no switch with that number at the location where the roadway indicated he was. This example reiterates the importance of detailed knowledge of the territory by both roadway workers and dispatchers for establishing and maintaining common ground and preventing communication errors. It highlights the role of the cooperative parties, building on their shared situation awareness to serve a 'regulation loop', monitoring each other's activities and catching and correcting errors.

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.

The discussion section describes technologies that can be used to foster shared situation awareness of roadway worker location, reducing the potential for failures in shared situation awareness of physical location or problems in communication.

Maintaining Awareness of Trains and Anticipating Trains

Being hit by a train represents one of the greatest risks confronted by roadway workers.

A review of an FRA roadway worker fatality data set that covered the period from 1986 through 2003 revealed that more than 65% of fatalities were caused by a train. A total of 34% occurred while working on the track on which the train was running, 17% occurred while working on an adjacent track, and 16% occurred while walking to or from the worksite.

Roadway workers need to be able to 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 them 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 be able to see the train. If they are working in a noisy environment (e.g. around noisy equipment) or are wearing protective headgear (e.g. in inclement weather) they may not be able to hear the approaching train.

Interviews with roadway workers and dispatchers indicate that roadway workers actively engage in building and maintaining awareness of trains in their vicinity to help them predict when trains are likely to approach and in what direction. Roadway workers are able to anticipate regularly scheduled trains based on review of train bulletins, timetables, and their own experiences on the territory. Anticipating unscheduled trains can be more challenging. Roadway workers have developed strategies to help them anticipate unscheduled trains. For example, the EIC will routinely monitor the road channel for train communication. This allows 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. This provides another example of capitalizing on the party-line aspect of radio communication to extract information important to building and maintaining broad situation awareness.

In addition, as described earlier, informal, cooperative practices have grown whereby others (including 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.

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 the time limit of the authority to occupy the track has been exceeded. Several factors can contribute to 'losing track of time'. The roadway worker may be engrossed in the work, or they may become distracted by another activity (e.g. phone call or a request to check on a particular 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, ranging from 500 feet (150 metres) to 10 or more miles (16 km).

In the discussion section we discuss technological approaches that could be used to provide alerts when track authorization time limits are about to expire.

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 roadway worker work zone. The EIC is responsible for keeping track of individuals working in the work zone that he or she is in charge of. One of the ways that railroad workers maintain shared situation awareness of the location and activities of roadway workers who 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.

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

In the discussion section we describe ways that this positive party-line attribute of radio communication that fosters shared situation awareness can be preserved as communication moves to digital communication technologies.

Limitations of Voice Radio for Communication and Fostering Shared Situation Awareness

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

The discussion section examines ways that digital communication technology can be used to overcome the limitations of analog radio, while preserving the positive party-line features that contribute to shared situation awareness.

Discussion

The results of the study highlight the active cognitive and collaborative processes that workers engage in to develop and maintain shared situation awareness of each other's location, activities, and intentions across a distributed system. These included active strategies for extracting relevant information by 'listen in' on radio communications directed at others. These active listening processes enabled individuals in the distributed 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. We were provided a number of instances where third parties overhearing conversations were instrumental in preventing accidents.

The results reinforce findings from other domains (e.g. space shuttle mission control, air traffic control, aircraft carrier operations) regarding the importance of 'listening in' on shared communication channels for supporting anticipation, contingency planning, and catching and recovering from error (Luff et al. 1992; Patterson et al. 1999; Rochlin et al. 1987; Smith et al. 2000).

We also observed cooperative communication practices that went beyond the requirements of formal operating rules, and served to foster shared situation awareness, facilitate work, and enhance on-track safety. Interestingly these communication practices were frequently referred to as 'courtesies', highlighting their optional nature and positive contribution.

The results build upon and extend the literature on teamwork and the role of shared situation awareness in facilitating work and enhancing safety. They provide concrete illustration of the framework developed by Rognin et al. (2000). We found that distributed railroad workers actively worked to build and maintain shared situation awareness of the location, activities, and intentions of roadway workers and trains in a given vicinity. This shared contextual knowledge in turn contributed to informal cooperative practices that enabled the distributed team to catch and correct errors with potential safety consequences, as well as level workload and improve the overall efficiency of the distributed organization. These informal practices provide concrete illustrations of what Rognin et al. referred to as 'regulation loops' and contribute positively to overall reliability of railroad operations (see Figure 3). The current results extend Rognin's framework by highlighting that these 'regulation loops' are not necessarily built into the formal organizational structure, but rather emerge as informal, proactive practices intended to increase system reliability and resilience to error.

These results reinforce the view that informal practices of domain practitioners can contribute substantively to system resilience and safety (Hollnagel et al. 2006). This contrasts with the more traditional perspective that emphasizes humans as a source of 'error' that can degrade an otherwise safe system.

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

New technologies are emerging that have the potential to facilitate communication and more effectively support the cognitive and collaborative processes required for maintaining shared situation awareness among roadway workers, dispatchers, and train crews. Portable roadway worker

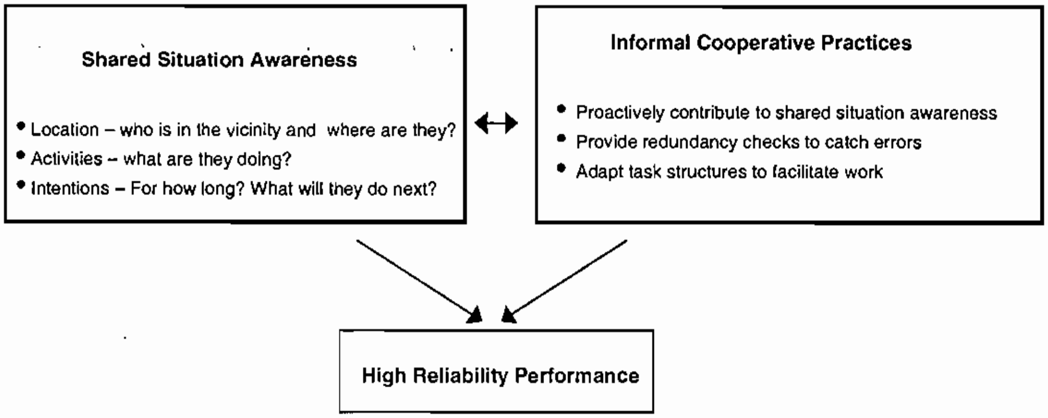


Figure 3. Informal Cooperative Processes Build on and Contribute to Shared Situation Awareness, Fostering Higher Reliability Performance and Increased Safety

devices could be developed that combine location-finding technologies (e.g. GPS) for more accurate location information and digital technologies for more reliable communication. In addition, the device could be integrated with PTC systems to enhance mutual awareness of the location of trains and roadway worker groups within the distributed organization and enhance overall safety.

These new technologies have the potential to reduce the challenges associated with analog voice radio communications while preserving the positive party-line aspects of radio, supporting cooperative strategies and fostering shared situation awareness across roadway workers, train crews, and dispatchers for increased efficiency and enhanced on-track safety. While 'listening in' strategies that depend on the party-line aspect of radio contribute to shared situation awareness, they also impose costs in terms of attention demands. Digital technology can be used to support shared situation awareness, while reducing the need to attend to irrelevant information.

Below we describe some of the support functions that could be provided.

Enhancing Shared Awareness of the Location of Roadway Workers and Trains

The study highlighted the importance for roadway workers to maintain broad situation awareness of their own location in relation to the location of other roadway workers and trains in the vicinity. Dispatchers also need to maintain broad situation awareness of the location and activities of roadway workers and trains in the territory they are controlling. This is important so as to facilitate their own decision making with respect to track allocation, as well as to provide a redundant layer of safety for roadway workers. Similarly, train crews work to maintain awareness of the location of roadway workers in the territory they are crossing so that they can blow their whistle to let them know they are approaching.

GPS technology, coupled with graphics display technology, can be used to create displays that enable roadway workers, dispatchers, and train crews to share common awareness of the location and activities of roadway workers and trains in a given vicinity. For example, a graphic display could be provided that shows the location of a roadway worker relative to work authority limits. The same graphic display of roadway worker location relative to work authority limits could be provided to both the roadway worker (on a portable display unit) and the dispatcher (on a display in the dispatch center) to facilitate shared understanding of location information being communicated and reduce the potential for error.

Similarly a graphic display could be developed for dispatchers to enable them to keep track of the location and dispersion of roadway workers and equipment in the territory they control. It would similarly be useful to enable EIC to electronically track roadway workers, other work groups or lone workers protected by their authority.

PTC technology, coupled with digital communication, could be used to enhance roadway worker situation awareness of trains in the vicinity. This could include providing graphic displays of the location of trains in the vicinity (e.g. on portable graphic devices), and providing alerts to approaching trains or trains approaching on adjacent tracks that are not included in working limits.

In addition to graphic means of fostering broad situation awareness, digital technology can be exploited to provide active alerts to direct attention to potential safety problems. Alerts can be provided in cases where a roadway worker (e.g. on a track car) is approaching the limits of authority as well as in cases where the authority limits have been violated to prevent an unintended excursion. Alerts can also be provided when the time limits of authority are about to expire.

Enhancing Shared Situation Awareness of Activities and Intentions

The results of the study highlighted the positive role of the party-line aspect of analog radio communication in enabling dispatchers, train crews, and roadway workers to maintain shared awareness of the activities and intentions of others by 'listening in' to communications that they were not a direct party to. There is opportunity to deploy new digital technology to more effectively support communications while preserving the positive features of analog radio that foster shared situation awareness. Examples include allowing the dispatcher to broadcast messages to multiple parties simultaneously to foster shared situation awareness of the activities and intentions of trains and roadway workers in a given vicinity. As one dispatcher put it: 'I would want people to know what is going on in the locations they are working in.' This broadcast capability would have the effect of reproducing the 'common ground' that is fostered by the party-line feature of radio communication.

Similarly it is important to enable roadway workers to broadcast information to multiple individuals simultaneously. This could be other roadway workers in the work group or trains in the vicinity.

Systems that provide some of these support functions are beginning to emerge. For example, a handheld digital communication device with integrated GPS technology designed for roadway workers has been developed and tested by Multer and his colleagues (Malsch et al. 2004; Masquelier et al. 2004; Oriol et al. 2004). The prototype device operates on a cell phone with integrated personal digital assistant capabilities coupled with a GPS receiver. It enables roadway workers to obtain real-time train and territory status information as well as request and receive work authorization from dispatchers. The integrated GPS technology provides an accurate means to identify and communicate roadway worker location information. The prototype handheld communication device allows information to be broadcast to multiple designated receivers and provides a promising model for leveraging the efficiency and reliability of digital communication while maintaining the ability to foster shared situation awareness that characterizes analog radio communication.

Conclusions

New technologies have the potential to facilitate communication and coordination across distributed organizations; however, if not carefully designed, they may disrupt existing strategies for building and maintaining the common ground that is critical to coordinating work and ensuring safe operations. This study contributes to our understanding of how individuals in distributed systems work to develop and maintain shared situation awareness and how shared situation awareness and informal cooperative strategies combine to facilitate work and enhance safety. It points to features that need to be incorporated in future systems to foster shared situation awareness and increase overall reliability of distributed work.

Effective support for distributed work will need mechanisms to enable distributed parties to maintain awareness of the activities and plans of others so as to be able to coordinate goals, synchronize activities, prevent coordination breakdowns, and create resilience in the face of unanticipated events and errors (Hollnagel et al. 2006).

A particular design challenge is how to preserve the benefits of 'listening in' strategies that naturally arises in the case of collocated groups and distributed groups connected via audio channels (e.g. voice radio) as digital technologies are introduced. The current work points to some promising directions; however, more research is needed. As pointed out by Klein et al. (2000), technologies that support 'listening in' will need to insure that the monitoring process does not disrupt the parties and activities being monitored. Equally important, the individuals engaged in monitoring need to remain peripherally aware of others' activities while still focusing on their own current tasks.

The goal is to develop systems that enable individuals in distributed organizations to integrate more information, broaden consideration of possibilities, and detect potential for side effects and errors. The ultimate objective is to create more resilient systems and improve safety.

Notes

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