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Supporting Railroad Roadway Worker Communications with a Wireless Handheld Computer: Volume 2: Impact on Dispatcher Performance

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Human Factors in Railroad Operations

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Final Report
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13. ABSTRACT (Maximum 200 words)

This report is the second in a series documenting the development and evaluation of a software application to facilitate communications for railroad roadway workers. The roadway worker can perform two types of communication related tasks with the application: request information about train status and territory without assistance from the dispatcher and request track authority. Using a global positioning system (GPS) receiver, the application can also show the location of the device. The study's goal was to understand the safety implications of digital wireless communications and positioning technologies on roadway worker safety and performance.

The current prototype operated on a cell phone integrated with a personal digital assistant (PDA). It was connected to a GPS receiver and exchanged messages with the dispatcher using wireless Internet access.

Roadway workers and dispatchers participated in focus groups to acquire information about the tasks they perform and to identify usability concerns.

An experiment was conducted to evaluate the current prototype's impact on the dispatcher. Overall, interactions between dispatchers and roadway workers using digital communications were slower but more accurate than the same interactions over the radio. Dispatcher valued the tracking display based on GPS information, although it increased workload.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

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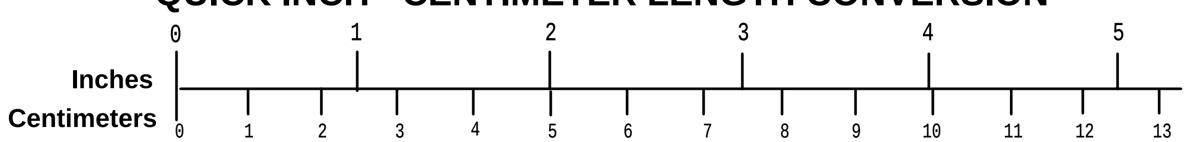
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

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

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

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The authors would like to acknowledge several people who helped in the development of this work. First, Nicolas Oriol, from MIT developed the first prototype for railroad roadway workers that served as the launch pad for the current project. Nicolas Malsch and Santanu Basu, also from MIT, designed the train dispatcher simulator used to evaluate our system. John K. Pollard, Andrew Kendra, Monica Gil, and, Ed Lanzilotta from the Volpe National Transportation Systems Center, and Emilie Roth, from Cognitive Engineering provided help in their own field of expertise.

George Fitter from Amtrak, helped to organize observation sessions on track cars. Glenn Underwood, from Amtrak, provided the invaluable help of arranging visits to the Central Traffic Control Center at Boston South Station, and focus groups with dispatchers, as well as gathering volunteers for our evaluation experiment. All the participants, who were willing to test the system, provided excellent ideas to improve it and showed great enthusiasm.

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EXECUTIVE SUMMARY

This report describes the continuing development and evaluation of an application to enable roadway workers to communicate using digital communications. The original application was developed on a handheld computer with a wireless modem. The application was moved to another hardware platform (a cell phone with an integrated handheld computer) that provided improved communication functionality and the ability to provide location information using global positioning system (GPS). The report also documents the additional user requirements identified by observing and talking with railroad employees who might use it or interact with it.

New technology in the form of digital communications and location finding systems offer the potential to improve the safety and productivity of railroad operations. The use of digital communications has been proposed as a medium to supplement voice radio. Digital communications uses bandwidth more efficiently than analog communications. Information transmitted digitally can be presented aurally or visually. These characteristics offer solutions to the limitations posed by voice radio. However, if the needs and limitations of operators are not clearly understood, new technology may adversely impact safety and productivity.

The first task was to continue the process of identifying user requirements of roadway workers, begun by Oriol, Sheridan, and Multer (2004). The communication link between roadway workers and train dispatchers was of particular interest. To accomplish this objective, a cognitive task analysis was conducted. Data was collected through focus groups and observation sessions with dispatchers and roadway workers. Communications between the two groups were observed at the Traffic Control Center and in the field. Dispatchers were interviewed about their conversations with roadway workers, and roadway workers were interviewed about their conversations with dispatchers. In the initial work, user requirements were identified for track foreman. In this study, the requirements of track inspectors were also identified.

The current analysis of user requirements supported Oriol et al. (2004) findings. Messages exchanged between dispatchers and railroad workers fell into two categories: structured and unstructured. Structured messages followed a protocol governed by the railroad's operating rules that prescribe their content and format. Examples include movement permits, authorization to foul the track, authority to pass a stop signal, and submission of speed restrictions. Unstructured messages varied in format and content. Examples include verbal permission for signal maintenance, detailed description of job being performed on the track, and updates about expected time to complete a given job.

Communications took place over the radio and the cell phone, with the radio serving as the primary communication device. There was a consensus among all interviewed persons that the voice radio channel was overloaded. Since few channels are available, interruptions on the same channel are frequent.

The current study identified lack of situation awareness related to their location on the track as contributing to unsafe events. Track crews working at fixed locations as well as track inspectors occasionally lost their bearing when working on or near the track. Location finding technology like GPS could support the roadway worker in monitoring their track location. In addition, this information could enable the dispatcher to determine the position of track cars and crews without requiring voice communication.

The first prototype enabled roadway workers to request real-time train and territory status information and request work authorization. A second prototype was created that added two features: two-way asynchronous communications and location determination.

The first prototype was limited to one-way asynchronous communication. The operator of the application could not receive timely notification when the dispatcher responded to a work request. The operator had to check the application to see if the dispatcher had replied to a request.

Wireless devices with two-way asynchronous communications make it possible for the roadway worker to receive timely notification of messages initiated by others. The Short Message Service (SMS) provides a mechanism to reach the handheld device from the web. The prototype evaluated in this study, a cell phone with an integrated Personal Digital Assistant (PDA), included this feature.

An external GPS receiver was attached to the hardware via a serial cable. Because of the small size and low resolution of the display, an application displaying the device's location on the display itself, was not developed. Instead, an application was created for the dispatcher that could display a map of the railroad worker's surroundings based on the GPS information. Two types of map displays were created, one showing location on a street map, the other showing the location on a track display. The application shows movement over time. When the location report feature was activated, the handset periodically retrieved the location from the GPS receiver and sent it to a web server where the dispatcher could retrieve the information.

To evaluate the prototype, it was first demonstrated to railroad workers, and dispatchers. Global feedback was positive, and everyone welcomed a system that could solve the radio congestion problem. The GPS functionality seemed to have the most benefit to localize track cars. Nevertheless, some railroad workers did not like the idea of being tracked and others seemed reluctant to use new information technologies.

An experiment was conducted to evaluate the prototype from the dispatcher's perspective. The main questions were how dispatching efficiency and global railroad safety could be enhanced if the railroad workers used the handheld device instead of the radio. The experimental participant was in charge of routing trains on a railroad dispatcher simulator and dealing with railroad workers using either the radio or the new device.

Digital communications between dispatchers and railroad workers, although slower, produced fewer errors compared to the same interactions over the radio. Some aspects of performance (blocking errors, routing errors) were improved with the device. The tracking display was expected to have more impact. The task seemed to be too demanding for the subjects to fully benefit from the tracking display.

All the participants showed great enthusiasm and gave constructive feedback regarding use of the handheld application. They thought it would improve communications by reducing radio congestion and communication errors and assist in locating track vehicles and roadway workers on the right-of-way.

Adapting to the new technology for both dispatchers and roadway workers poses a variety of challenges. For example, monitoring the location of all roadway workers on the track would substantially increase a dispatcher's workload. Many of the dispatchers also felt that the willingness to adopt the new technology would vary with age. Younger people were expected to learn and take advantage of the new technologies more quickly and with greater enthusiasm. They also worried about the intangible (i.e., non-verbal) aspects of communication that may be lost moving from a predominantly oral communication medium to a visual medium. The dispatchers were also concerned about rule compliance with respect to the use of GPS and other location finding technologies. The application of this technology would only assist them, if they "turned the feature on" when the roadway workers were on the track right-of-way.

Roadway workers were also concerned about how the new information technologies would affect them. While many roadway workers showed enthusiasm for the application, some were reticent about relying upon it as a safety-critical device. Roadway workers also expressed concern about how their privacy would be affected when their location could be tracked by the application. They were particularly concerned that their location might be monitored when they were not working on the track, despite the fact that the GPS receiver that reports this information, was under the control of the roadway worker.

The current set of features was evaluated from the dispatcher's perspective in a laboratory experiment. In this experiment, work authorization transactions took longer in the data link condition than with voice radio. This behavior contrasted with Malsch et al., (1999) results where data link reduced transmission of work authorization times by a factor of two. This difference between the two experiments suggests that the design of the dispatcher interface plays an important role in its usability and effectiveness in facilitating dispatcher performance. The information on the dispatcher displays was organized differently. In addition, information showing requested track segments was displayed on the monitor showing the track network in Malsch's study, but not in Oriol's. Seeing the requested track in the context of other activities taking place may have contributed to faster decision-making by the dispatcher.

In both studies, there were fewer communications errors in the data link condition than in the radio condition. Malsch et al., (1999) also observed this behavior in their study. Auditory communications were more prone to errors because their transient nature placed higher memory demands on the dispatcher.

The number of protection and routing errors were also smaller in the data link condition. It was less taxing for dispatchers to process the work authorization requests in visual form than to have to listen to the radio and write down parameters, while planning train movements and authorizing maintenance work. This would explain why mental workload was rated higher in the radio condition.

While the tracking display appeared to be useful in assisting the dispatcher to locate track cars, monitoring roadway workers on the track posed a greater challenge. The dispatchers identified only 40 percent of roadway workers working without authorization and no location reporting errors were caught. The task seemed to be too demanding for the subjects to fully benefit from the tracking display. The tracking display was expected to have more impact. The dispatcher's mental workload may be too high for him/her to fully benefit from a tracking display.

1. INTRODUCTION

1.1 Improving Railroad Safety through Better Communication

Safe and efficient railroad operations require continuous coordination among key groups of railroad operating personnel. Mainline railroad operations involve three main groups of employees:

- **Railroad dispatchers** allocate track for the movement of trains or for maintenance. Their most important responsibilities are to ensure safe movement of trains and personnel on the tracks, ensure that passenger trains meet schedules, and in case of emergency, coordinate rescue missions. The dispatcher is responsible for the proper separation of trains, track equipment, and personnel.
- **Locomotive engineers and conductors** operate the trains, and are responsible for following the directions dictated by wayside signals and dispatchers.
- **Roadway workers** engage in the inspection, construction, maintenance, or repair of railroad tracks, bridges, roadway, signal, and communication systems, electric traction systems, roadway facilities, or roadway maintenance machinery on or near the tracks.

To maintain safety, trains, track equipment, and roadway workers must be separated in both space and time. Railroad communication systems enable the key groups to coordinate their activities and maintain safe separation. Current technology supporting railroad communications relies primarily on voice radio.

The characteristics of voice radio and the way railroad operations are conducted contribute to several problems. First, the available voice radio bandwidth is inadequate to support current communication needs (Federal Railroad Administration, 1994; Roth, Malsch, and Multer, 2001). The Federal Communications Commission (FCC) has allocated 96 channels for railroad operations. However, within any geographic region a much smaller number of channels are available (e.g., 3 or 4). Voice communications for main line operations are typically restricted to a single channel. In addition, only one person can communicate on a channel at a time. Other workers who want to use the same channel must wait until it is clear. As a result, voice radio channels are congested.

Second, the temporal nature of information communicated by voice radio imposes a significant burden on the operator's memory. Railroad workers must often record important information on paper. However, the time it takes to record this information places a burden on the dispatcher's memory and increases workload.

Depending upon the type of territory, railroad employees may also receive information through the track infrastructure. In signal territory, the track equipment provides dispatchers with information about signal states, switch states, and train location. In signal territory with track circuits, trains shunt (activate) the track circuit at the block entrance and exit. The track infrastructure relays this information to the dispatcher and indicates the train's location. However, a train's location is known only within a given block, which can vary in length from several hundred feet to many miles. Some track equipment like hi-railers (see glossary) do not reliably shunt track circuits. As a result, track inspectors riding in a hi-railer report their position frequently to the dispatcher. In dark territory, this information is unavailable. The dispatcher must rely solely on voice communications with the train crew to learn their track location.

New technology in the form of digital data link communications and location finding systems such as GPS offer the potential to improve the safety and productivity of railroad operations. The use of digital telecommunications has been proposed as a communication medium to supplement voice radio. Digital communications uses this bandwidth more efficiently than voice radio. Information transmitted digitally can be presented aurally or visually. These characteristics offer opportunities to address the limitations posed by voice radio. However, if the needs and limitations of operators are not clearly understood, new technology may adversely impact safety and productivity. Simply providing additional bandwidth could adversely impact the dispatcher's performance, if the design of the system does not consider the communication load the dispatcher can handle safely.

A significant percentage of the communications between railroad employees revolves around locating railroad assets in the form of trains, track equipment, and roadway workers. Maintaining adequate separation between these vehicles requires following railroad operating rules that promote safe separation. The operating rules require a set of structured exchanges between the dispatcher and the train crew or roadway crew to obtain the authority to occupy a section of track. A key element in each of the messages is the track location being requested. The reference to a location is normally by milepost, a sign posted on the track that specifies the track location numerically. However, the reference may be approximate. For example, a roadway crew may request track authority between milepost 110.3 and 120.5. However, relationship of the milepost signs to an actual location on the ground is approximate. The reference to tenths of mile is a judgment on the part of the roadway worker and there may be some error in this reference. Similarly, knowing the location of a train in signal territory is approximate. The dispatcher knows a train is in a particular block, but does not know where in the block, with any confidence.

Some accidents may be attributed to roadway worker or train crew disorientation. In some cases, roadway workers or train crews lose track of the limits of their authority and move outside those limits. For example, in multiple track territory, a roadway worker may receive permission to work on one track, but mistakenly work on another track for which there is no protection. Conversely, a train crew may plan to stop before entering a work zone, but fail to stop in time because they miss the visual cues that signal the beginning of the work zone. Either situation can result in the injury of a roadway worker.

Crews can avoid these accidents if they receive more accurate information of train location, their own location, the location of others, and equipment on the track. New technologies for locating people and equipment make it possible to address this problem. Currently, two train location technologies are under development and are being tested for use in North America:

- Transponder/Interrogator system: transponders are placed along the track at suitable intervals and key locations. Each equipped train carries an interrogator (consisting of a reader and an antenna) that activates the transponder by emitting a signal to it when the locomotive approaches. In response, the transponder transmits back some identification information (including location).

- Global positioning system (GPS): trains use onboard GPS receivers (or differential GPS receivers) to compute their positions.

A location determination system may also consist of a combination of two or more systems such as:

- GPS for calculating position
- Tachometer for dead reckoning
- Fiber-optic gyro for detecting curves
- Digital track map in an on on-board computer

1.2 Research Objective

The current study was part of a research program to measure how digital communications impacts human performance in railroad operations. A goal of this study was to understand the safety implications and usability requirements for roadway workers to take advantage of such technology.

The first study examined the potential of digital communications from the dispatcher's point of view (Malsch, Sheridan, and Multer; 2004). The use of digital communications by dispatchers was compared to voice radio, using a human-in-the-loop railroad dispatcher simulator. The results indicated messages intended to convey detailed information were more accurately understood using electronic communications than when voice radio was used. Dispatchers liked receiving more information to help decide the order in which they answered requests from trains or work crews in compared to voice radio. Voice radio calls were more likely to be answered on a first-come first-served basis. With this architecture, they could assign priorities to incoming messages and deal with the most important ones first. The dispatchers valued avoiding the need to repeat a message many times due to low quality radio transmissions.

Oriol, Sheridan, and Multer (2004) examined the use of digital communications from the roadway worker's perspective. The first prototype of a communication application was designed to operate on a handheld computer with a wireless modem (Palm VII™). The application was evaluated for its usability and the ability of roadway workers to perform their communication tasks compared to voice radio. Interactions between dispatchers and roadway workers were slower but more accurate with the handheld application compared to the same interactions using the voice radio.

This report describes the continuing development and evaluation of the application to enable roadway workers to communicate using digital communications. The application was moved to a different hardware platform that provided additional communication functionality and the ability to provide location information using GPS. The report also documents the additional user requirements identified by observing and talking with the railroad employees who might use it or would interact with it.

The purpose of the experiment described in this report was to evaluate its impact on dispatcher performance when roadway workers use this device in addition to voice communications.

2. IDENTIFYING USER REQUIREMENTS

This section describes the communication-related tasks performed by dispatchers and several types of Amtrak roadway workers, and the information requirements needed to support those tasks. The information described here adds to roadway worker requirements reported by Oriol, Sheridan, and Multer (2004).

2.1 Methodology

2.1.1 Observation Sessions

Observations were made during two track car rides with Amtrak track inspectors. Both trips took place on the Northeast Corridor between Boston and New Haven. The first trip went from Cove, Massachusetts to Plains, Massachusetts, and the second trip went from Kingston, Rhode Island, to Transfer, Massachusetts. During both trips, the track inspectors were questioned about the tasks they perform and their interactions with dispatchers. Observations of dispatchers were also made at Amtrak's Central Traffic Control Center in Boston, Massachusetts.

2.1.2 Focus Groups

Two focus groups were conducted with dispatchers at Amtrak's Central Traffic Control Center, in Boston, Massachusetts. The goal was to document the dispatcher's interactions with roadway workers and to obtain feedback on the revised prototype. Each session lasted 2 hours. The first hour was devoted to documenting the interactions between dispatchers and roadway workers in general, and the second hour was devoted to demonstrating the prototype and soliciting feedback to improve its usability. (See Prototype Evaluation for the results of the second part). Appendix F lists the questions asked during each session. Both sessions were tape-recorded.

There were two participants in the first focus group and three in the second group. All participants were professional Amtrak dispatchers from the Boston division. Three dispatchers had less than 3 years of experience, one dispatcher had 13 years experience, and one dispatcher had 26 years of experience.

2.2 Communication between Roadway Workers and Dispatchers

Information is currently exchanged mostly over the radio and occasionally over the telephone. Messages exchanged between dispatchers and roadway workers can be divided into two types: structured and unstructured. Structured messages followed a protocol governed by operating rules that everybody must follow. These messages included various forms of movement authorities and authorization to work on the track. Unstructured messages comprised all other messages and did not follow a formal protocol. Examples of each message type are discussed in the following sections.

2.2.1 Structured Messages

Different kinds of structured messages are exchanged over the radio. For safety reasons, the receiver must always repeat a structured message to make sure the information was accurately heard and understood. However, as one dispatcher said, "We are not automatons. You'd be hard pressed to find someone who literally communicates the way the book says."

Here are several examples of structured messages that dispatchers use on the Northeast Corridor between Boston and New Haven:

1. Form D movement authority and additions to Form D.

    The dispatcher issues Form Ds to authorize or restrict movements (NORAC operating rules, 1999). Form Ds are also issued to convey instructions not covered in the operating rules. Although Form Ds are intended mainly for train movements, according to one of the interviewed dispatchers, 90 percent are issued to work crews and only 10 percent to trains. A roadway worker may receive a Form D line 4 “if the work involves on-track equipment or will disturb the track or catenary structure so that it would be unsafe for normal speed.” Appendix E shows a Form D.

    The Form D provides several kinds of authority. One type of authority is used to take a track out of service (Form D, Line 4).[1] A second authorization gives track cars and other mobile equipment (Form D Line 2 and 3) track movement authority. Line 2 indicates the parameters for the limits of authority and the direction in which the equipment can move. Line 3 indicates the trains or track cars ahead, as well as stop signals that the vehicle is allowed to pass.

    Once a dispatcher issues a Form D, very limited information may be added to it. This information includes: cancellation facts, permission to continue to operate a track car in a given direction under new limits (line 2), and “track is clear” information (line 13), train or track car ahead has cleared the limits of the following track car’s (line 2). Appendix E provides a more detailed description of a Form D.

2. Foul Time (track and time).

    A qualified roadway worker whose duties will not disturb the track or catenary structure may receive verbal authorization to foul the track from the dispatcher. Granting Foul Time to roadway workers (also referred to as track and time) has become a major part of a dispatcher’s job in the Northeast Corridor. Depending on the territory under consideration, a dispatcher controlling territory between Boston and New Haven may easily have three to seven active Foul Time authorizations in effect at the same time.

3. Rule 241: Authority to pass a stop signal.

    Rule 241 enables trains or track cars to pass a stop signal. Railroad operating rules normally prohibit trains and track cars from going past a stop signal. A dispatcher will most often issue authority to pass a stop signal to track cars since they need this authorization to enter each interlocking. Almost every time permission to operate a track car is issued (Form D Line 2), it is followed by permission for the track car to proceed past a stop signal (Form D Line 3 or rule 241). The choice of authority to pass a stop signal depends on the dispatcher’s preferences.

4. Speed restrictions.

    Repair crews dictate new speed restrictions to dispatchers. These speed restrictions are sent daily to trains and dispatchers and may be included in a Form D.

[1] The reference to line 4 indicates where on the Form D the authorization is written.

2.2.2 Unstructured Messages

Before requesting work authorization, a roadway worker may call the dispatcher for schedule updates and for unscheduled train information. This kind of unstructured communication occurs frequently.

Dispatchers also spend a lot of time relaying information, between a roadway worker crew and the foreman, or between different crews. Dispatchers may relay messages between different crews or among members of a work crew when they are too far apart to communicate by radio directly. The work crews carry radios that are less powerful than those available to the dispatcher.

Another type of interaction between dispatchers and roadway workers occurs while the latter are already working under protection. Dispatchers frequently ask work crews for details related to the time component of their work authorization. For example, how long will it take to remove equipment from the track? Dispatchers also ask for details about the work being performed on the track. This information gives them information about track availability in case it is needed unexpectedly for other purposes.

Dispatchers occasionally call track cars to determine their current position. Indeed, a track car's position is usually known only as being within a given section where it has movement authorization (Form D Line 2 and 3), and these sections are sometimes very large.

A number of different situations can arise in railroad operations when a dispatcher must issue verbal permission to a roadway worker. For example, a signal worker may need verbal permission to put an interlocking into local mode or to temporally shut it down. These verbal permissions do not always follow the same pattern.

2.2.3 Radio Communication Problems

There was a clear consensus from all of the interviewed dispatchers and roadway workers that voice radio channels are congested. Few channels are available; therefore, interruptions by other calls are very frequent. Radio seems adapted to short messages, but long dialogues intended to convey detailed information should be conducted in a more private way. One dispatcher remarked, "There have been times when I've had to repeat myself five to six times to get some information across, or ask someone to repeat himself four, five, or six times before I can get everything I need from them. When the radios are blocking each other out, we don't know it. We can't tell that this is happening."

It was indicated that very often, when dispatchers are attending to one request, other calls come on the radio on other channels. The dispatcher can attend to only one call at a time and so these other calls temporarily go unanswered. In the field, some people call repeatedly, because they believe that the dispatcher is ignoring them, when in fact the dispatcher is aware of them, but communicating with someone else on another channel. This situation is mutually frustrating for both the dispatcher and the individuals trying to reach the dispatcher.

Dispatchers reported that roadway workers often used the radio for non work-related communications, and unnecessarily overloaded the channels. "A lot of times, they are joking around," said one dispatcher.

From the roadway worker's point of view, obtaining work authorization can be time-consuming. When a channel is in use by someone else, the roadway worker has to wait for the channel to become free before calling the dispatcher. When a roadway worker's request for work authorization is taking place, it may be interrupted by communications between others on the same channel. If a structured message is interrupted, the process must be repeated resulting in a longer transaction.

The dispatchers also described equipment-related problems. Some dispatchers reported receiving radio communications from outside their territories such as the New York and Maryland areas. In some instances, the train numbers or milepost locations from these communications outside their territory were the same and created confusion for the dispatcher. The phone and radio communication systems occasionally bleed through each other, deteriorating communication quality. Finally, the presence of dead spots (where radio communication is blocked) along the tracks impeded communications with train crews and roadway workers.

2.3 Track Foreman's Tasks

Roadway workers' tasks include inspection, construction, maintenance, or repair of railroad track, bridges, roadway, signal, and communication systems, electric traction systems, roadway facilities, and roadway maintenance machinery on or near the track. According to the instructions given in the Amtrak Roadway Worker Protection Class, and in written materials (Amtrak Roadway Worker Protection Manual, 1997) whenever a roadway worker wants to perform a job on the track, the following steps must be followed:

1. Collect information.
    - Identify milepost number.
    - Identify track numbers.
    - Identify the type of territory.
    - Identify the dispatcher who controls the territory.
    - Find out train schedule around working site.
2. Conduct a job briefing with entire crew.
3. Call for Foul Time or Form D when necessary.
4. Give the track back to the dispatcher on time.
5. At the end of the tour of duty, make sure work area is safe and secure.

In step 1, the track foreman must read the schedule and territory information from their Operating Rulebook. On Amtrak's Northeast Corridor, this book only contains scheduled passenger trains. Unscheduled trains (freight, work-extra trains, etc.) and commuter trains with higher frequency are not shown in the rulebook. The track foreman must obtain current information about the location of all the trains that could interfere with their work. The roadway worker calls the dispatcher for schedule changes and for nonscheduled train information.

In step 3, the roadway workers exchange structured messages with the dispatcher as in the previous section.

2.3.1 Unsafe Actions Associated with Lack of Situation Awareness

Besides the radio communication problems described above, roadway workers are confronted with a variety of other challenges related to situation awareness.

One problem is orientation. Roadway workers may lose their bearing and work on the wrong track in multiple track territory or work outside the limits of their authority. This disorientation can lead to critical mistakes, such as asking for work authorization on the wrong track, or watching for approaching trains in the wrong direction.

Another problem is the presence of unscheduled and delayed trains, as roadway workers must always ask the dispatcher about unscheduled or delayed trains before asking for work authorization. However, in territories where scheduled operations predominate, they sometimes rely on their memory (or time tables) to judge if a track is available. They may forget about possible unscheduled trains, and foul the track without permission.

Finally, roadway workers sometimes leave their work sites and forget to cancel their track authority. Failure to cancel a track authority can delay train movements and other maintenance activities.

2.4 Track Inspectors' Tasks

2.4.1 Description

The track inspector is in charge of inspecting the tracks for defects. They request movement authority to operate on a specific track section. Since track vehicles normally do not shunt the track, they call the dispatcher each time they clear an interlocking to let the dispatcher know their position. When a train approaches a track vehicle on an adjacent track, the track vehicle will stop (by law), and turn off its headlights (by courtesy).

Track inspectors monitor the condition of the following items:

- Ties, rails, clips, track surface, ballast
- Track alignment and settlement
- Drainage problems
- Broken rails
- Missing clips or rail fasteners or loose bolts.

On the track between Boston and New Haven, each track is normally inspected twice a week and a report is written after each inspection. A typical track car ride takes 4 to 6 hours. The track may be inspected more often if conditions warrant (i.e., a heat inspection is conducted if the air temperature rises above 85^{o} F).

Table 1 describes the actions taken for problems of different importance. For minimal problems, the track inspector will fix it on the spot. For moderate problems, inspectors typically will record the data on track conditions on a blank piece of paper and then type out the information on a form once they get back to the office. For serious and critical problems, Amtrak inspectors use the MW1000 rulebook (a book of inspection rules and tolerance levels) to assist them in deciding what actions to take. For example, if a rail is bent an inspector will measure the curvature, and then look in the rulebook to determine the appropriate speed restriction. The rulebook also specifies how many miles from the problem warning signs should be placed. For serious problems, an inspector may impose a speed restriction and then notify the dispatcher. The dispatcher will then relay the speed restriction to the trains. For critical problems, an inspector calls the dispatcher to remove the track from service.

Table 1. Problems on the Tracks

Problem Importance	Track Inspector Action	Example
Minimal	Fix it yourself	Stone on the track
Moderate	Write in daily report	Missing clip
Serious	Restrict speed	Bent rail
Critical	Remove track from service	Broken rail

Unsafe events related to lack of situation awareness

Track inspectors described several unsafe situations related to the loss of situation awareness. Track inspectors were occasionally confused about their location. One interviewee described a case where a track inspector thought he was at one interlocking when he was actually at another. The two interlockings shared similar characteristics. One track inspector commented, “One can get distracted… can get comfortable and lose track of things.”

Another kind of unsafe situation occurs when the track inspector misunderstands the limits of the work authority. The track inspectors interviewed for this study indicated that being on the wrong track (at a given mile post) was a more common error than being at the wrong location entirely (i.e., at the wrong milepost or interlocking).

Unscheduled trains also posed a concern for track car operators. For safety reasons, a track car must stop whenever a train passes by on the adjacent track. The track inspector appreciated a warning when a train approached, and helpful dispatchers would alert the track inspector when an unscheduled train approached on the adjacent track.

2.5 Dispatchers’ Tasks

2.5.1 Overview

Dispatchers route trains and allocate track to roadway workers. Their most important responsibilities are to ensure safe movement of trains and personnel on the tracks, ensure that passenger trains meet schedules and, in case of emergency, coordinate rescue missions.

The current study focused on signal territories, where dispatchers receive automatic indication of train location. The existing train location system uses track circuits that trains shunt (activate) at the entrances and exits of blocks. Consequently, a train’s location is known only within a given block, which can be more than 10 miles long. An experienced dispatcher will estimate a train’s position from the train’s speed and the time it entered a block. In the Northeast Corridor, a few trains are GPS-equipped, but the GPS information is not currently integrated in the main computer system. If desired, dispatchers could retrieve the GPS information, but it is not generally done.

Each dispatcher is in charge of a specific territory where he/she has authority to route the trains, take tracks out of service, and grant work authorizations. Each dispatcher has a workstation to control the switches and signals. This workstation also displays a representation of the track (see

Figure 1). Track displays use scale compression extensively to show more details around crucial points such as stations and interlockings. Table 2 shows the meaning of the colors shown for the status of each block.

Table 2. Representation of Color Code for Monitoring Track Status

Color	Meaning
White	Indicates that the track segment is available for routing trains or other uses.
Red	Means train or track vehicle occupancy. A train currently occupies that block.
Green	Indicates that the track segment has been cleared (authorized for use) for train movement. The train has not yet entered this block.
Blue	Indicates that a track section is authorized for track maintenance. This means that a portion of track has been protected for use by maintenance of way crews or track equipment. When the dispatcher gives track authority to a work crew, the dispatcher temporarily loses control over that section of track. Trains cannot enter this track segment unless authorized by the roadway worker responsible for that block.

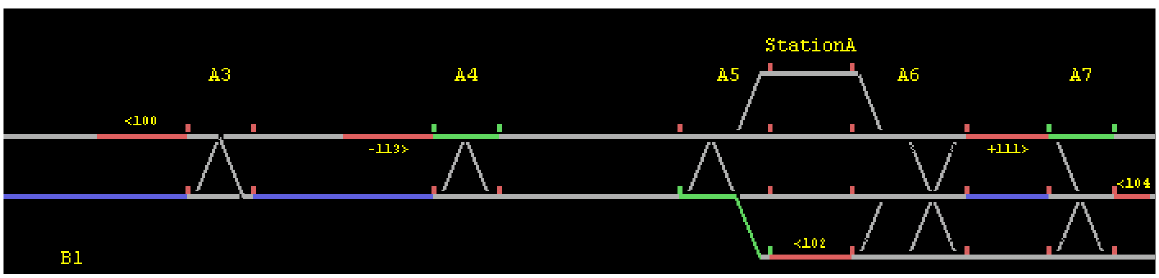

Figure 1. Track Chart Display

2.5.2 Observed Interactions with Roadway Workers

On the territory between Boston and New Haven, interactions between dispatchers and roadway workers comprise a larger percentage of their communication workload, than interactions with train crews. The interviewed dispatchers estimated that, about 90 percent of radio and telephone communications took place with roadway workers and track inspectors. The remaining 10 percent of communications took place with train crews and other dispatchers.

When a dispatcher received a request for roadway worker protection, the following steps were followed. After receiving the request, the dispatcher decided whether to grant, modify, or deny the request. Normally, the dispatcher granted the request only if it did not delay any train. If the request was denied, the roadway worker might submit another request or negotiate with the dispatcher to obtain track authorization.

If the dispatcher intended to grant work authorization, the dispatcher proceeded to protect the requested track. At the Traffic Control Center, the dispatcher could use the track display to protect the track segment in question using software that controlled various switched and signals in the field. Where the dispatcher could not protect the track remotely, the work crew can apply a blocking device (see glossary) to the switches and signals that control access to the track.

Operation of these switches is restricted and the protected track will display stop signals at both ends.

Once a track is blocked, the dispatcher temporarily loses authority over that track. The dispatcher will not be able to reverse or normalize a switch that is part of the blocked track. If a change in switch is called for, the roadway worker can change the switch local mode or ask the dispatcher to make the change. This is a common request. In this situation, dispatchers unblock the track, reverse or normalize the switch, and block the track again.

While the roadway worker crew works, the track foreman communicates intermittently with the dispatcher. These interactions include modifying the existing work authorization, requesting additional work authorizations, submitting speed restrictions, and requesting information such as updates on train location. Once the job is complete, the roadway worker returns control of the track to the dispatcher, who releases the track for other uses.

2.5.3 Interaction with Track Cars

Track cars place a significant demand on the dispatcher's attention because they normally do not shunt (activate) the track circuits used to detect the presence of trains. Therefore, dispatchers don't know where they are within their limits of authority.

Track sections can be very long (10 miles or more), and track cars usually travel very slowly. The vehicle used for track inspection between New Haven and Boston moves at a maximum speed of 30 miles per hour. Moreover, track car operators frequently stop to inspect the tracks. Therefore, it is very hard for dispatchers to accurately determine a track car's position.

Dispatchers need timely information about their location to manage track use in the safest and most productive way. For these reasons, dispatchers and track inspectors communicate frequently. Between Boston and New Haven, track car operators call the dispatcher when they have cleared an interlocking. Dispatchers call track cars very often to know their positions.

2.5.4 General Considerations

Many factors make the dispatcher's job challenging. High communication workload strains the dispatcher's attention and memory. Demands on track use are high and the margin for flexibility can be low. In passenger operations, trains need to stay on schedule and there are limited routing options available. Dispatching requires keeping track of the progress of multiple trains, some of which are outside the area controlled by the dispatcher center.

Lastly, efficiently managing the track requires knowledge that is not readily available from workstation displays (i.e., speed limits, characteristics of trains, location of nearby streets, track elevation, bridge height). Dispatchers acquire this information with experience. With the centralization of dispatching facilities, dispatchers have little opportunity to "walk the tracks" to learn a territory's characteristics. Dispatchers often have trouble visualizing the physical layout of the tracks and surrounding geography.

The track display is an abstract representation, as it does not display information related to physical characteristics of the track (curves, grade crossings, roads in the neighborhood of the tracks etc.). This knowledge becomes critical during unplanned events like grade crossing accidents, derailments, and track washouts when the dispatcher must find solutions to these track outages. More information about dispatchers' cognitive demands can be found in Roth, Malsch, and Multer (2001).

2.6 Prototype Design Goals

2.6.1 Improve Communication

The analysis of user requirements suggests a number of areas where new technology can support railroad employees' information-related tasks and communications. Field observations and interviews conducted for this study reinforce the findings of Roth, Malsch, and Multer (2001) and Oriol (2000), suggesting that digital communications can enable roadway workers to obtain information while reducing workload for the dispatcher. The verbal exchanges between dispatchers and roadway workers and train crews are subject to errors resulting from the limitations of voice radio. Using digital communications for electronic exchange of movement authorizations and work authorization can reduce these communication-related errors. Shifting some communications to data link may alleviate the congestion and address other problems associated with voice radio. A wireless handheld device carried by roadway workers could serve this purpose. Given the encouraging results that Oriol received with the first prototype (Oriol, 2000), a second prototype was developed.

2.6.2 Improve Situation Awareness

The analysis of user requirements also indicated that roadway workers can become disoriented when working on the track. A positioning device would be useful to solve orientation problems and location errors. The ability to locate roadway workers, trains, and track equipment could benefit roadway workers, train crews, and dispatchers alike. It might also contribute to lowering the amount of communications related to locating personnel and equipment on the track.

Many applications for roadway workers could be developed based on this location information. For example, an alarm system could automatically send a warning to a roadway worker when a train is approaching. Alternatively, location information would be useful to automatically alert a track car operator when approaching the limits of their authority.

2.6.3 Better Problem Reporting

The analysis of user requirements also identified a need for better reporting of track problems. A handheld device could support the track inspector in recording problems, tracking the history of problems over time (e.g., how does it compare to the recorded value the last time the inspection was conducted), and actions to be taken. Location information (provided by a positioning device) could be automatically associated with a reported problem, to make sure the problem site is accurately located.

3. DESCRIPTION OF THE CURRENT PROTOTYPE

3.1 Overview

This section briefly describes the application's functions and how it operates. Appendix A describes the system architecture in more detail.

The application enables the roadway worker to request information about the territory such as train status, rules in effect, and track out of service. The application can also be used to request and cancel work authorizations. The current application had functions that were lacking in the first prototype: a positioning capability, and an asynchronous two-way communication capability (text messaging).

The first prototype, which was developed on a Palm VII, was transferred to a Qualcomm® pdQ™ Smartphone 800. The Smartphone shown in Figure 2 is a cell phone containing an integrated PDA. The PDA used the same Palm operating system as the first prototype, enabling the application to perform the same tasks as the first prototype. The current prototype also exhibited the ability to send and receive short text messages (SMS). This enabled the dispatcher or roadway worker to alert each other when a request for track authorization was initiated or answered. It addressed a shortcoming in the first prototype in sending and receiving messages in a timely fashion.

The Qualcomm® pdQ™ Smartphone was also connected via its serial port to an Axiom Smart Antenna GPS receiver, shown in Figure 3. The phone is also connected by a wireless modem to a web server and a dispatcher workstation, as illustrated in Figure 4. The dispatcher workstation communicated with the server through a standard web browser. The mobile elements (cell phone and GPS receiver) were light and small enough to be carried easily by roadway workers.

Figure 2. Qualcomm® pdQ™ Smartphone

Figure 3. Axiom Smart Antenna GPS Receiver

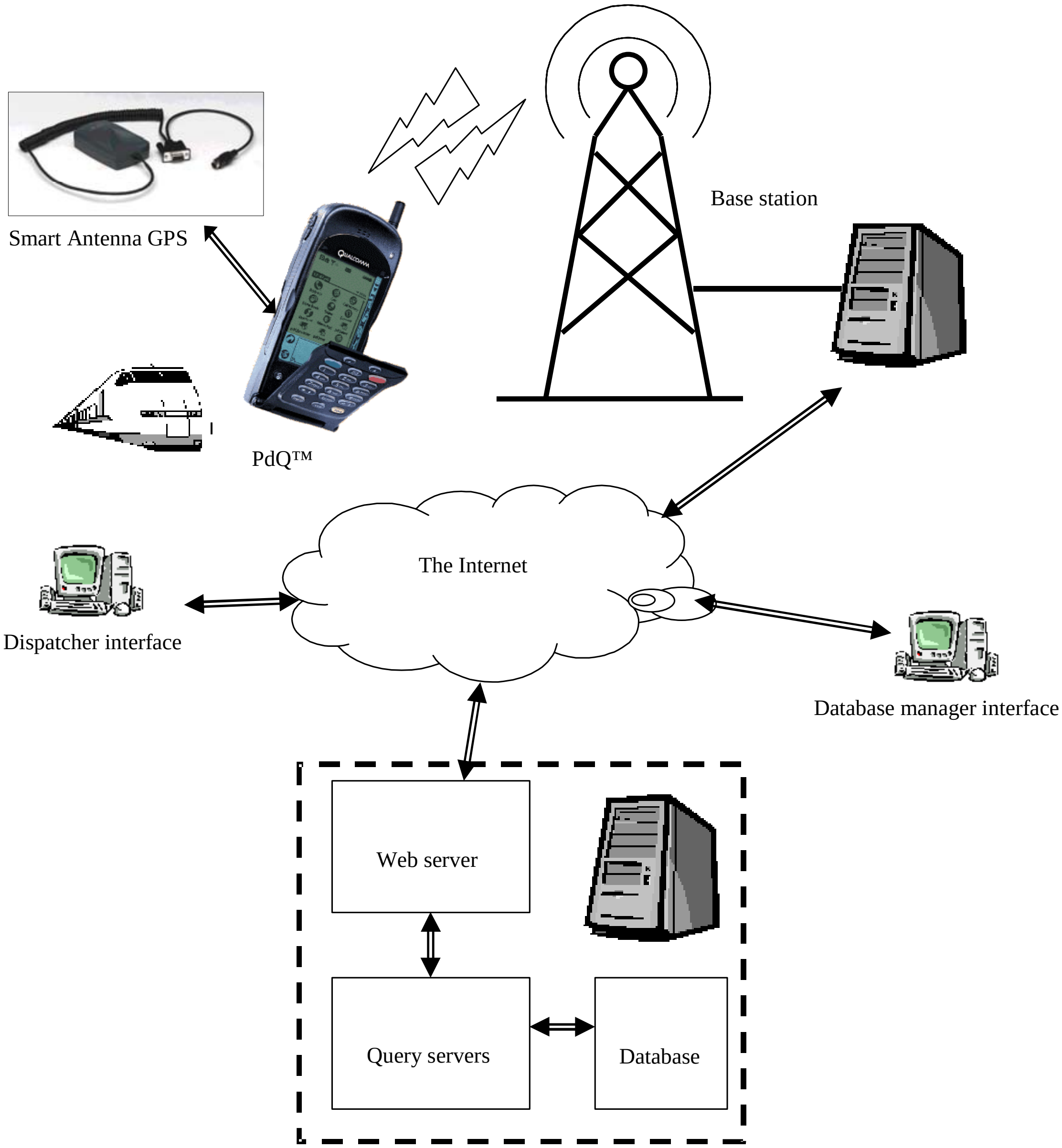

Figure 4. System Architecture

3.2 Operating the Device

The handheld device enables a roadway worker to perform two kinds of actions: request information about trains and territory, and request work authorization. To perform these tasks, the operator selects options and enters information using a pointing device or stylus on a touch-sensitive screen. The operator begins by selecting the type of information to be obtained or the type of work authority to be requested from the main menu shown in Figure 5. Selecting an option results in another screen showing the appropriate parameters for requesting information or work authorization. Where appropriate, a drop-down menu shows the potential options for each field. The operator selects an option using the stylus. In the other fields, the operator uses the stylus to enter text or numerical information using the built-in displays. After completing all the relevant fields on the request form, information is communicated through a wireless link to a web server. If an information request is sent, the server sends the requested information back to the roadway worker directly. If a work authorization is sent, the server relays the request to the dispatcher for action and sends the message “Please Wait” to the roadway worker.

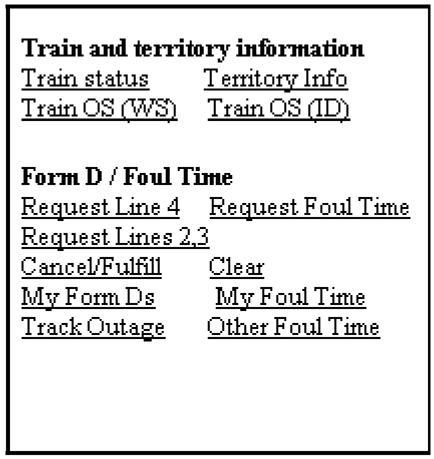

Figure 5. Main Menu

3.2.1 Request Information

The application is intended to enable a roadway worker to get real time information about trains by querying the same information used by the dispatchers to determine track status. The precision of train and track equipment location is dependent upon the type of train control system. A system with Central Traffic Control could show train location at the block level. Like the dispatcher, the roadway worker could determine what block a train was in, but not where in the block the train was located. In dark territory or for equipment that does not shunt track circuits, the precision with which train location is known is lower. Location can be determined only to the extent the limits of the authority are known. As a result, the benefits of this application would be considerably greater in signal territory. The benefits of using this application will improve in dark territory as technologies such as Global Positioning System (GPS) are introduced that provide information about train location to the dispatcher.

Nevertheless, this database can be updated to provide the timeliest snapshot of train status and track usage. Since the prototype could not access Amtrak’s information system, the train timetable between Boston and New Haven was used on the web server. The application can query this database to get the following kinds of information:

- Train Status (the last known location of a train) given a train number.
- Train On Sheets (timetables) given a track section and a time window, or train numbers.
- Territory Information (speed limit, rules that apply) given a track section.

Figure 6 and Figure 7 show an example request for “Train On Sheet” (timetable) and the results of this request.

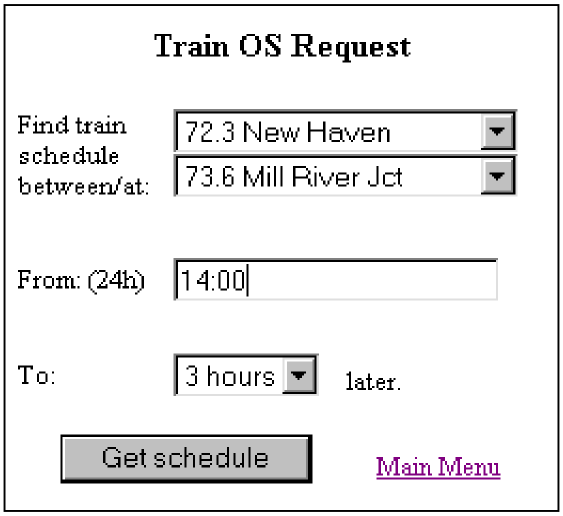

Figure 6. Train OS Request

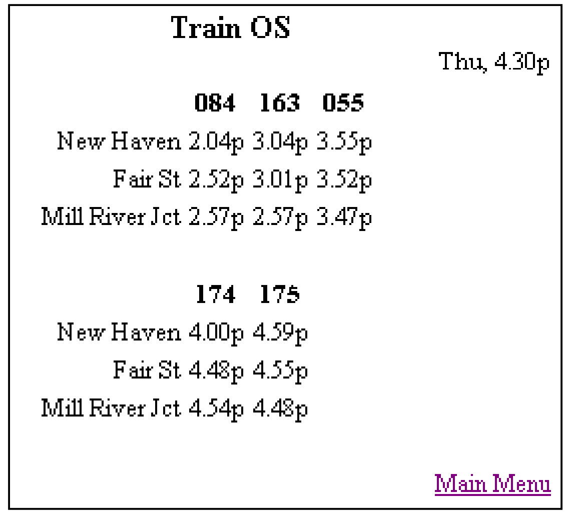

Figure 7. Train OS Response

3.2.2 Request Work Authorization

The application software also handles the several types of work authorization requests and cancellations (Foul Time and Form Ds). In all cases, the roadway workers communicate with the dispatcher through an Internet browser interface. The work authorization procedures include:

- Request work authorization (requires dispatcher consent);
- Cancel work authorization (automatic);
- Show work authorizations the roadway worker owns and their status (automatic); and
- Show active work authorizations on a specific track section (automatic).

In actual railroad operations, the dispatcher would communicate with the roadway worker through the computer aided dispatch (CAD) system. For this study, a fictitious CAD system was developed to play this role. In this fictitious system, the dispatcher's workstation communicated with the server through a standard web browser. It displayed all the work authorization requests in a list, and enabled the dispatcher to accept or reject them. The system also displayed active, rejected, or canceled work authorizations.

Figure 8-Figure 13 show the screens that the roadway worker and dispatcher would see in a transaction in order to successfully request Foul Time. In Figure 8, the roadway worker completes a Foul Time request form and sends the request. In Figure 9, the roadway worker receives a message to wait for the dispatcher to answer. When the Foul Time request is sent, the dispatcher sees the request appear in the middle frame labeled "Requested Foul Time" shown in Figure 10. Selecting this item shows the details of the request in the right hand frame of Figure 10. The dispatcher can grant, modify, or deny the request. If the dispatcher grants the request, the dispatcher reenters all the parameters (for safety purposes) and sends the response.

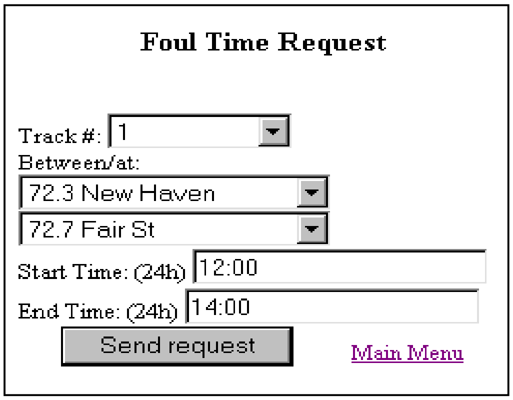

Figure 8. Foul Time Request (Roadway Worker Screen 1)

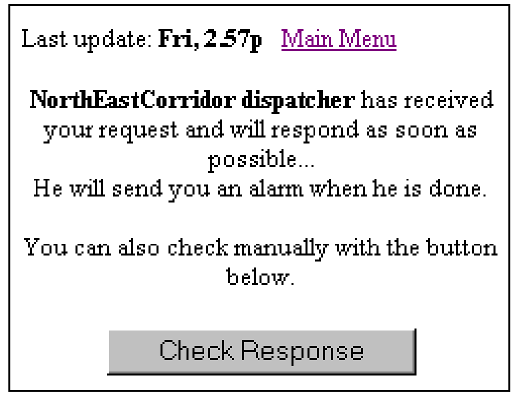

Figure 9. Foul Time Request (Roadway Worker Screen 2)

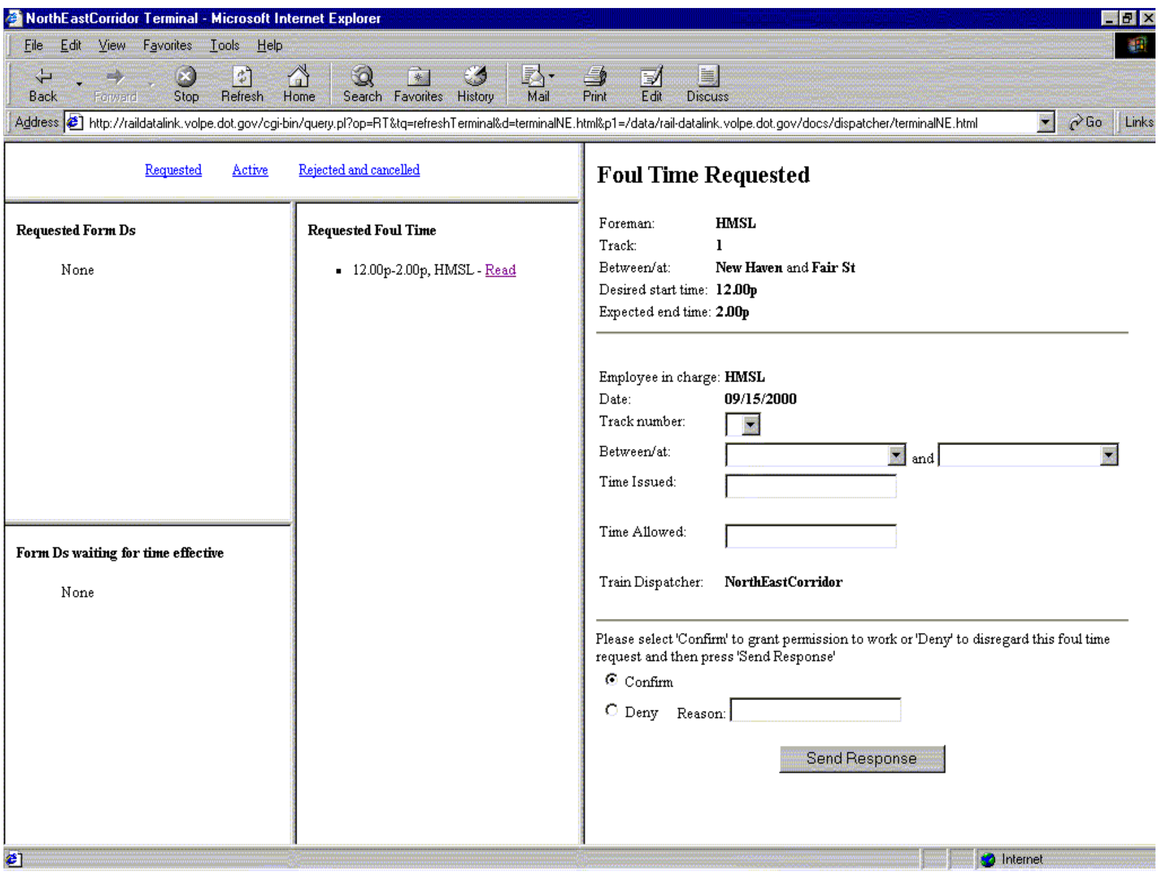

Figure 10. Foul Time Request (Dispatcher Screen 1)

After granting the initial request, the roadway worker receives a message that summarizes the Foul Time granted by the dispatcher as shown in Figure 11. The roadway worker must acknowledge receiving the Foul Time request granted by the dispatcher by selecting “Accept” or reject the Foul Time granted by the dispatcher. If the roadway worker accepts work authorization granted by the dispatcher, a confirmation message is displayed on the device as shown in Figure 12, and sent to the dispatcher. The dispatcher will see "Foul Time Request" disappear from the "Requested Foul Time" frame, and appear in the frame marked "Active Foul Time" as shown in Figure 13. The Foul Time work authorization will remain on this screen until it is cancelled.

Figure 11. Foul Time Request (Roadway Worker Screen 3)

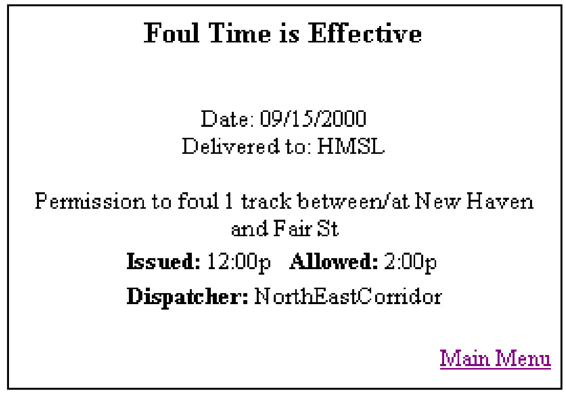

Figure 12. Foul Time Request (Roadway Worker Screen 4)

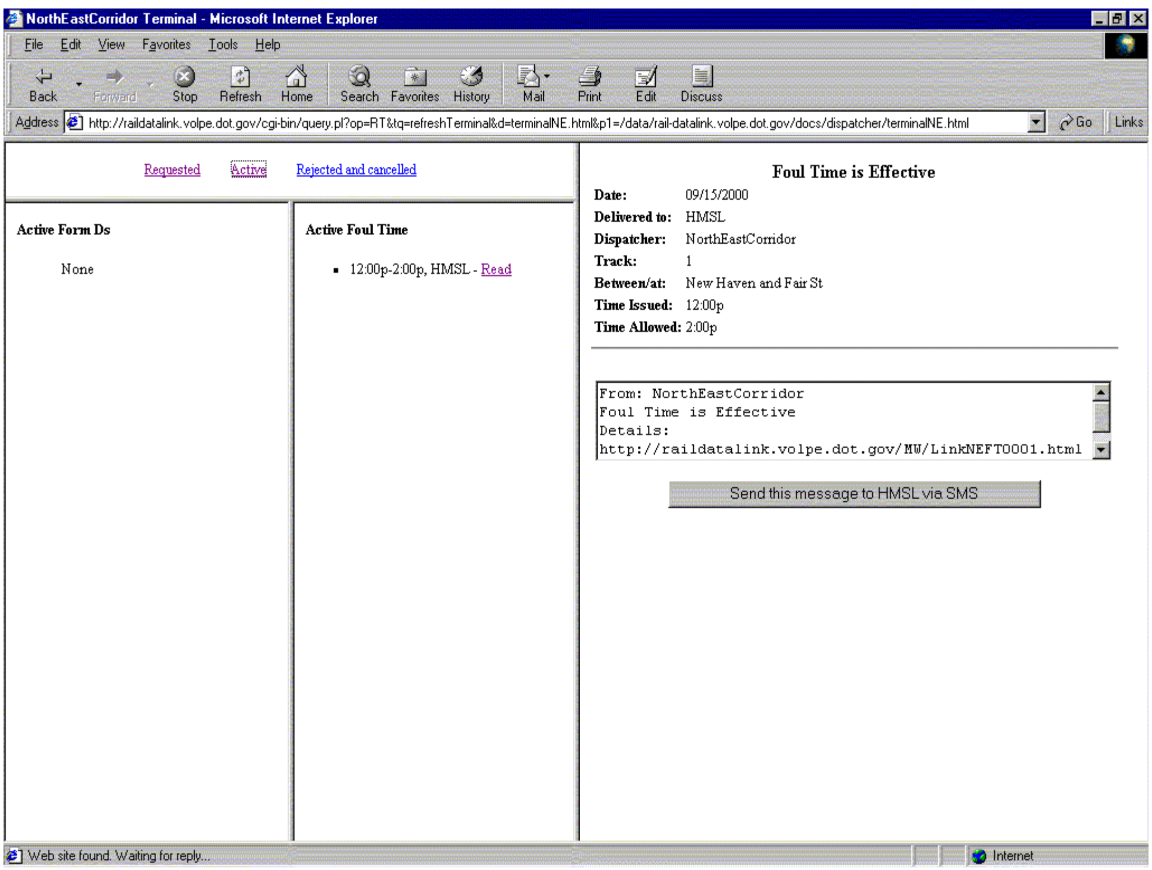

Figure 13. Foul Time Request (Dispatcher Screen 2)

3.3 New Features

3.3.1 Timely Asynchronous Communication

One of the first prototype's main limitations was its ability to receive messages. The operator of the Palm VII™ always had to initiate a communication. The dispatcher had no way to directly contact a roadway worker in a timely manner through the prototype unless the roadway monitored the device continuously. For example, after sending a work authorization request, the roadway worker had to check periodically if the dispatcher had responded. Continuous monitoring of the device for new messages would increase the roadway worker's time devoted to communication related tasks.

Short Message Service (SMS) provides a form of asynchronous communication to reach the handheld device from the web. Like paging services, SMS enables someone to send brief text messages to a recipient over the Internet. The current hardware platform can use SMS to send and receive messages. SMS is also discussed in Appendix F.

SMS enabled the following new functions to be implemented:

- Notification when a Foul Time request has been granted or refused.
- Notification when a Form D has been processed.
- Notification when a Form D has received a Time Effective.
- Sending a message by clicking on a roadway worker on the tracking display
- Sending an unstructured message to anybody at anytime.

3.3.2 Locate Track Position

The cognitive task analysis (CTA) suggested that providing more precise location information would help in addressing roadway worker orientation problems and communication workload. Knowledge of roadway workers location could benefit both the roadway workers and dispatchers. A GPS-based system could be used to warn roadway workers when they approach the limits of their authority. This information would also be useful to alert the dispatcher when the roadway worker works outside their limits of authority, as well as tracking more precisely the location trains, track equipment, and work crews.

After reviewing location-finding technologies, standard GPS technology was incorporated into the current prototype. Appendix F summarizes the technologies considered. When the location report feature is activated, the handset periodically retrieves the location from the GPS receiver via the serial port and sends it to the web server (the period can be changed, a test was performed with 1 minute and 5 minute periods). The dispatcher workstation can display this information in several ways.

For a dispatcher's workstation, a street map display and a GPS track display were developed to show the location and movement of equipment and employees on the track. One type of display (Figure 14) shows location as a function of street location. This type of display is useful when the dispatcher needs information for tasks such as routing taxis to pick up and drop off train crews, determining where Hi-railers are getting on and off the track, and finding the nearest street to a malfunctioning grade crossing. The current prototype can show the roadway worker's location on a map of the roadway worker's surroundings based on the GPS information. The second type of display, shown in Figure 15, shows the location of the GPS receiver on the track. These displays are consistent with the visual representation with which the dispatcher normally works.

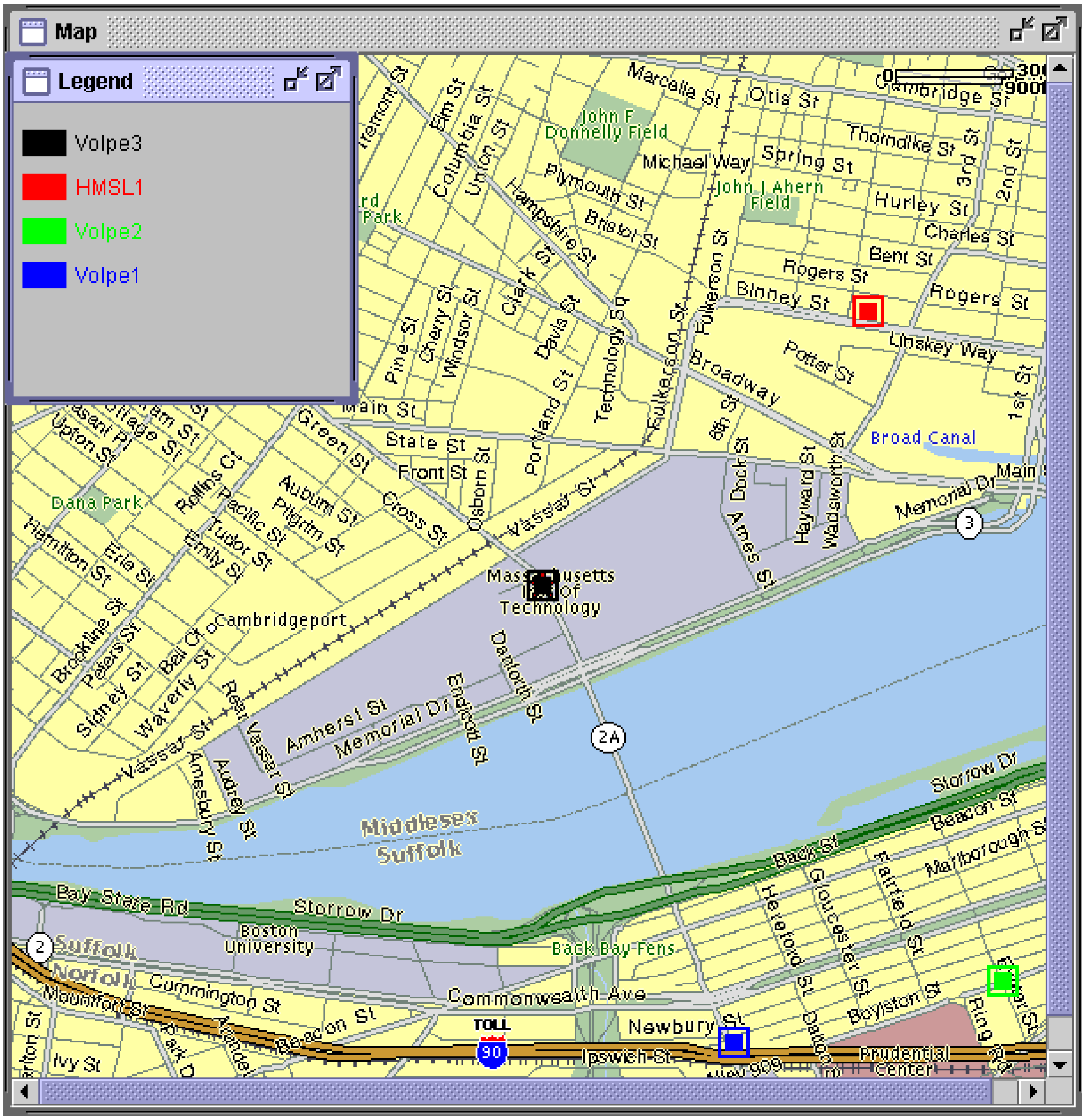

Figure 14. Street Map Display

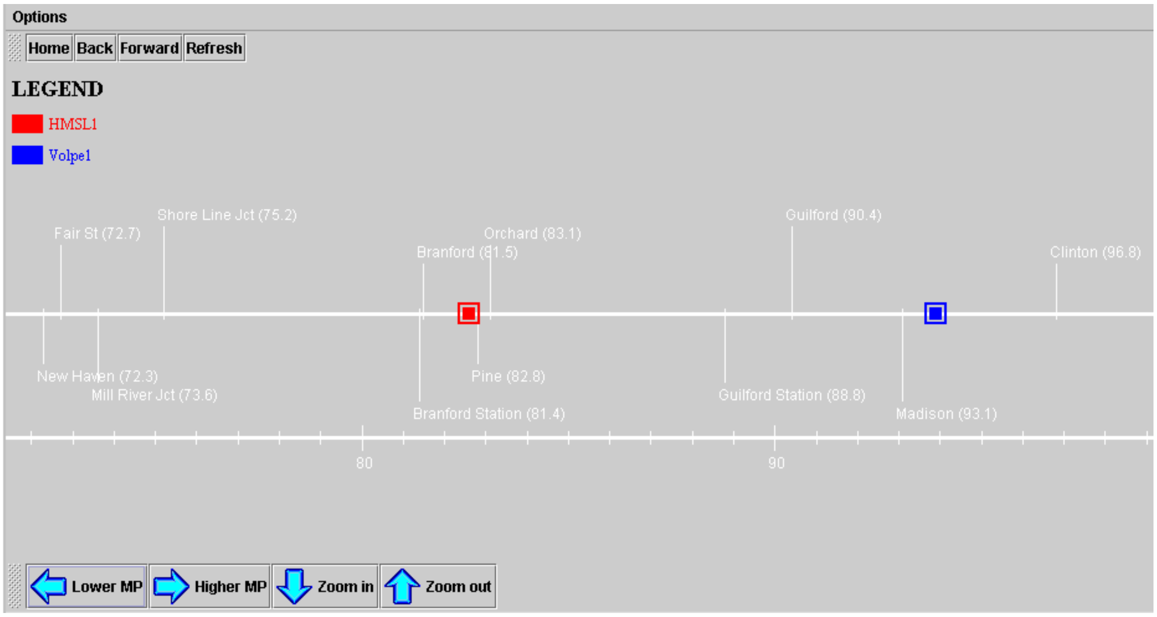

Figure 15. GPS Track Display

The street map and GPS track displays share the following features:

- Show location over time;
- Provide detailed information at a location (i.e., roadway worker's name, location report time, validity, latitude, longitude, mile post);
- Able to send an SMS to the roadway worker;
- Access history of roadway worker's movements;
- Panning and zooming capabilities.

The GPS tracking information was not integrated into the current track display that dispatchers use (Figure 1) to monitor the track, for two reasons:

- In territories with multiple tracks, the track display shows the adjacent tracks. However, GPS positioning technology is not accurate enough to discriminate between track numbers. Therefore, the information display could show the roadway worker's location on the wrong track or on multiple tracks.
- Track displays are not drawn to scale. They show more detail around interlockings and stations and fewer details around other areas. Accurate to within only 60 feet, GPS may not provide enough precision to indicate location at some points on the track display[2].

[2] The use of Nationwide Differential Global Positioning System (NDGPS) could provide significantly better precision than GPS alone.

4. PROTOTYPE EVALUATION

4.1 Overview

To evaluate the current prototype, the application was demonstrated to roadway workers, track car operators, and dispatchers to obtain user feedback. Next, a laboratory experiment was conducted to evaluate the application using objective measures.[3] Oriol (2000) previously evaluated the application in a laboratory experiment from the roadway worker's perspective. The current experiment measures the impact of the GPS and 2-way asynchronous communication devices from the dispatcher's perspective. It compared dispatching efficiency and safety for two modes of communication with roadway workers: data link, using the current application, and voice radio.

4.2 Demonstration and Feedback

4.2.1 Roadway Workers

The application was informally demonstrated to several roadway workers at Amtrak's Boston Maintenance of Way facility. The procedures for obtaining Train On Sheet information and Foul Time were demonstrated. Roadway worker impressions varied with their age. Some of the older roadway workers regarded the new device as a toy and remarked that the concept was interesting, but they would never use it in place of the radio. Younger roadway workers seemed more willing to accept the handheld device. Roadway workers' willingness to try new technologies could be a potential obstacle for the adoption of this application.

4.2.2 Track Inspectors

The prototype was also demonstrated to an Amtrak track inspector during a track car ride from Kingston, Rhode Island to Transfer, Massachusetts on the Boston/New Haven line. During the trip, the location of the vehicle was monitored and recorded on the device and Train OS request was demonstrated. Figure 16 shows the tracking information on the street map display.

Among the interviewed persons, the tracking function evoked a concern that they could be monitored constantly. Roadway workers were concerned that someone could track their location whether they were "on or off the job." Roadway workers often wait for an available time window before working on the tracks and do not want to be tracked when they are off the track. This concern is not unique to railroad employees. Transportation workers in other industry report these concerns when GPS was introduced (Stearns, Sussman, and Belcher; 1999). The location-reporting feature is under the control of the roadway worker and can be switched off at anytime.

[3] Ideally, the usability and effectiveness of the application should be evaluated in a field environment. Until the authors can obtain permission to work with a railroad to test the application in the field, the laboratory environment provided an interim solution to testing the application.

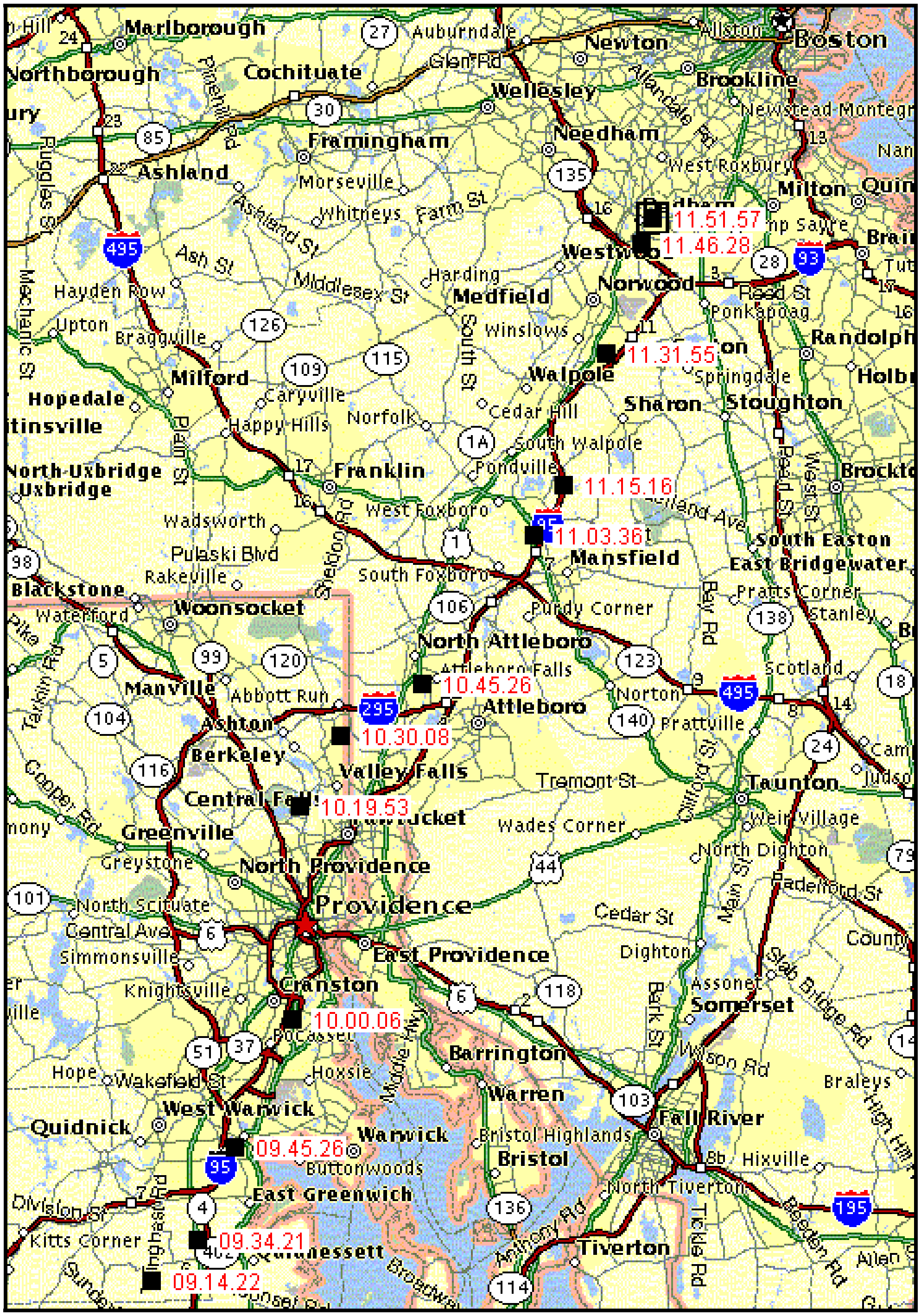

Figure 16. Track Car Ride Seen from the Street Map Display

4.2.3 Dispatchers

Two focus groups were conducted with dispatchers (see Section 2.1 for a description of the methodology). Instructions on how to perform two tasks were given: a Train On Sheet request, a Foul Time request, as well as the use of the tracking displays. The discussions focused on the interactions between dispatchers and roadway workers (in particular track inspectors) and the use of the handheld application.

Global feedback was positive, and dispatchers expressed enthusiasm for the application. The dispatchers welcomed a device that would reduce radio congestion and workload. Most dispatchers liked the tracking function and thought it would enhance track safety. The dispatchers thought both display types were useful. They saw the most benefit for monitoring track cars, which do not shunt the tracks. The dispatchers particularly liked the feature for contacting a roadway worker via SMS, by right clicking on a point on the tracking display with a mouse.

However, some of the dispatchers thought that keeping track of all workers on the tracks was just too much responsibility. A related concern was who should carry the device on the tracks. Everyone agreed that not all roadway workers in the same crew would need the device, but they agreed the crew foreman would need one. However, when the foreman is physically far from the crew, at least one other person in the crew should carry the device.

Another concern of the voice radio condition was being able to overhear the conversations of others. Some dispatchers regarded overhearing conversations on the radio as dangerous, since it enables roadway workers to work on the track without protection. Those dispatchers thought that the prototype's function that enables a roadway worker to see other people's Form Ds was equally dangerous. In a related concern, some dispatchers were afraid that the opportunity for roadway workers to obtain the same information available to the dispatcher might empower roadway workers to the point that they would not need to speak to the dispatcher anymore.

Other dispatchers believed that the ability to monitor conversations or see the Form Ds in effect by others was beneficial. For example, if a crew took a track out of service and a second crew was aware of that activity and desired to work on the same track, the second crew could contact the first one directly. This could minimize dispatcher workload by eliminating the need to relay information through the dispatcher. The dispatchers who liked this feature asked if a function could be added that permitted a dispatcher to carbon-copy other people after giving track authorization to the foreman making the request.

Listening to the conversations of others was identified as beneficial by some dispatchers. They often monitored the radio to hear the train crews or Maintenance of Way crews talking to each other. They felt that this activity facilitated their situation awareness and sometimes enabled them to detect errors made by the other parties. Dispatchers were concerned about losing this information if radio was negated.

4.3 Dispatcher Experiment

The participant routed trains on a railroad dispatcher simulator and interacted with roadway workers and track inspectors using either the radio (radio condition), or the message console and the tracking display (data link condition). The experimenter and one assistant played the role of roadway workers and track inspectors who communicated with the participant (dispatcher). Figure 17 shows an overview of the experimenter and dispatcher workstations.

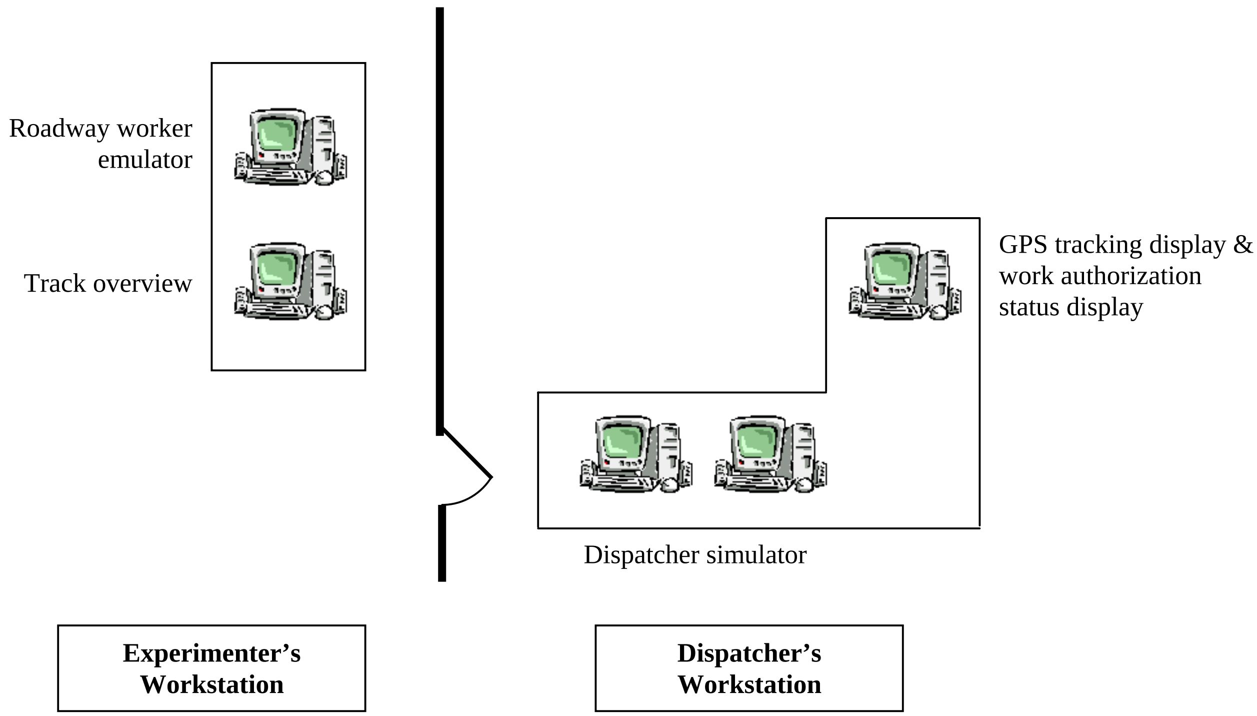

Figure 17. Layout of Dispatcher Simulator

Dispatcher's Workstation

The MIT/Volpe Railroad Dispatcher Simulator was designed for managing track in CTC territory. A complete description of the simulator can be found in Basu, (2001). The dispatcher can view the track on two monitors and can allocate track to trains, and track equipment or roadway workers using a variety of keyboard and mouse commands. Trains were moved on the tracks according to a schedule.

For the data link condition, the dispatcher also used:

1. The message display (Figure 10).
2. The GPS tracking display (Figure 15). The tracking display also contained a work authorization status window below the window containing the tracking information (for easier comparisons). As shown in Figure 18 the work authorization status display consisted of four windows showing the following types of messages:
    - Active Form D
    - Active Foul Time
    - Cancelled Form D
    - Cancelled Foul Time

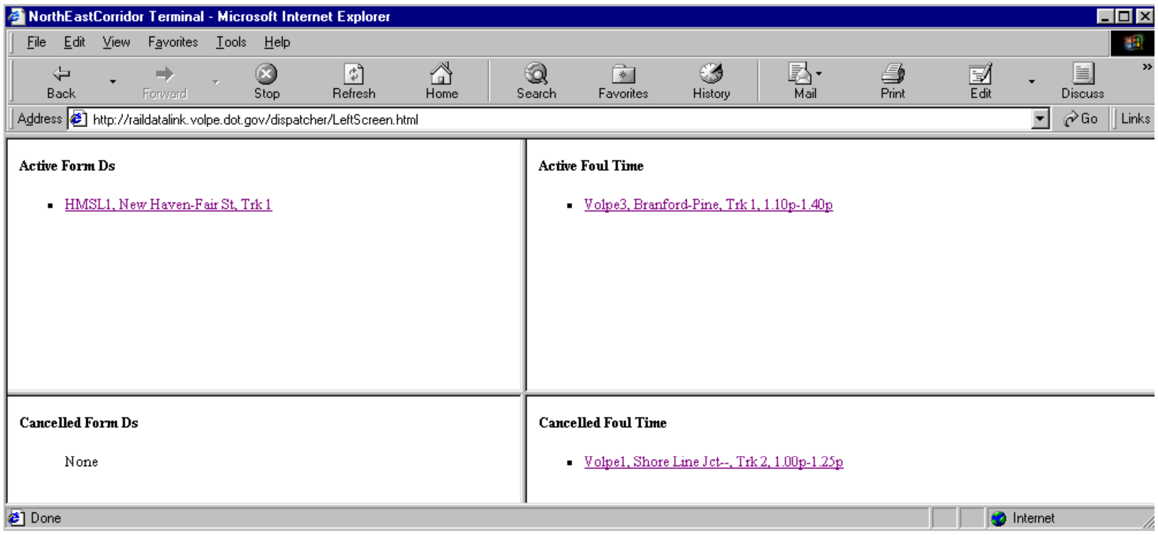

Figure 18. Work Authorization Status Display

For the radio condition, the dispatcher used the following materials:

1. A radio.
2. Paper work authorization forms (Foul Time and Form D sheets shown in Appendix E).
3. Two boxes to place cancelled and rejected work authorization sheets.

Experimenter's Workstation

There were two monitors at the experimenter's workstation. One monitor gave an overview of the tracks (both track chart display and tracking display), and the other monitor emulated roadway worker's activities.

Simulation software was used to emulate the behavior of roadway workers. This software sent requests to a web server exactly the way the handheld prototype did. Work authorization requests and cancellations, as well as GPS location reports were simulated. The software performed a list of scheduled tasks associated with track work. The experimenter can skip tasks to adapt to the dispatcher's answers. The application also timed the delay between a work authorization request and the dispatcher's response. Details of this software can be found in Appendix B.

4.3.1 Experimental Design

Independent variable

The independent variable was a type of communication system. It had two levels, voice radio and data link. Each dispatcher experienced both levels. The experiment was counterbalanced so that half the participants started with voice radio and the other half started with the data link condition.

Dependent variables

Data was collected on the following dependent variables:

- **Work authorization transaction times:** the duration (in seconds) between the time a work authorization (Foul Time and Form D) was requested and the time it was granted or refused.
- **Train delays:** time delay with respect to the schedule for each train.
- **Track car call frequency:** (radio condition only) frequency of the number of times a dispatcher called the track car to obtain its position.

In addition, data was collected for the data link condition on the following two variables:

- **Detect failure to request work authorization:** in the simulation, roadway workers sometimes go on the tracks without asking for work authorization, or stay even if work authorization was refused, or stayed after it is cancelled. The dispatcher was asked to note each time this happened. The number generated by participant was compared with the actual number. It assumes the GPS location report function is activated all day long, and that a roadway worker shows up on the display only if he/she is entered into the traffic envelope.
- **Detect roadway workers' errors in location reporting:** in the simulation, roadway workers mistake their location (i.e., show up somewhere on the tracking display, and ask for work authorization somewhere else). The percentage of the mistakes the dispatcher caught were measured.
- **Dispatcher's errors:** The frequency of the following errors were recorded:
    - Communication errors:
        - Omission errors in work authorization parameters (i.e., participant forgot the track number).
        - Commission errors in work authorization parameters (i.e. parameters a roadway worker said or typed did not match the parameters the dispatcher said or typed).
    - Block protection errors:
        - Blocking a track section after granting the work authorization (the dispatcher was asked to block the track before granting the work authorization).
        - Blocking the wrong track section.
        - Forgetting to block a track section.
        - Releasing the track section before the work authorization is cancelled.
        - Forgetting to release a track section. An error was recorded if the track was not released within 30 seconds after cancellation of the work authorization.

- Routing errors:
    - Trains colliding with each other.
    - Trains colliding with Maintenance of Way crews.
    - Trains colliding with track cars.
- **Workload ratings:** A subjective rating scale adapted from the NASA TLX was used (see Appendix D). The participant completed this scale after each condition.

<u>Questionnaire</u>

Each participant completed a questionnaire that documented their familiarity with computers and GPS and provided an opportunity to give feedback on the new device (see Appendix C).

<u>Scenario description</u>

Two equally demanding variations of the scenarios were created (see Appendix B for technical details). Scenario 2 consisted of a variation of Scenario 1, but used different permutations of locations and track numbers. The common characteristics are listed below:

- Duration: about 70 minutes
- One mobile track car and three stationary Maintenance of Way crews involved
- Track car inspector asks for Form Ds five times
- Maintenance of Way crews asks for Foul Time 21 times
- Maintenance of Way crew makes a mistake in reporting location twice in the data link condition
- Maintenance of Way crew goes on the track without work authorization six times

To simplify the simulation, the participant was asked:

- To grant all the Form Ds, but not necessarily when they were requested.
- To grant each Foul Time with the exact requested parameters or deny request. Negotiations were not allowed.

4.3.2 Participants

Six professional dispatchers from Amtrak's Boston Division of the Northeast Corridor were recruited for this experiment. Each participant was paid at the same hourly rate they received to perform their normal duties. The dispatchers were all men and ranged in age from 32 to 52 with a mean age of 42. The dispatchers ranged in experience from 2 to 26 years with a mean of 10 years.

4.3.3 Procedure

The experiment lasted approximately 5½ hours. After arriving, the participant completed a brief questionnaire. The experimenter explained the operating rules and the scenarios. There were two trials, one with each communication device. Prior to each trial, the experimenter trained the participant to operate the dispatcher simulator using the appropriate communication device (radio or data link). The participant practiced operating the simulator for approximately 15 minutes. During each 90-minute trial, the participant routed trains and interacted with roadway workers. After completing each trial, the participant completed a modified NASA TLX workload rating scale. After completing the second trial and modified NASA TLX workload scale, the participant completed another questionnaire.

4.3.4 Results

Work authorization transaction time

Transaction times were recorded for both Foul Time and Form Ds. Since granting track authorizations requires more steps than denying track authorization, the two activities were separated. For Foul Time authorizations, processing times were separated according to whether the dispatcher granted or denied the request. As a result, there were six categories: granted Foul Times, refused Foul Times, and granted Form Ds, for both the radio and the device experiments.[4]

Figure 19 compares the processing times for three transaction types by communication mode: granting Foul Time, denying Foul Time, and granting a Form D. Each data point shows the average transaction times and the 95 percent confidence interval. The processing times were on average about 1.5 times longer with the PDA compared to radio. For two comparisons, granting Foul Time and denying Foul Time, the differences between the radio conditions and the data link conditions was statistically significant ($t_{n=100}$ =3.84, $p < 0.0002$ for granted Foul Times; $t_{n=95}$ =3.95, $p < 0.0001$ for denied Foul Times). The difference between the radio condition and the data link condition for Form D transactions was not statistically significant, although the difference was consistent with the behavior observed with the Foul Time transactions.

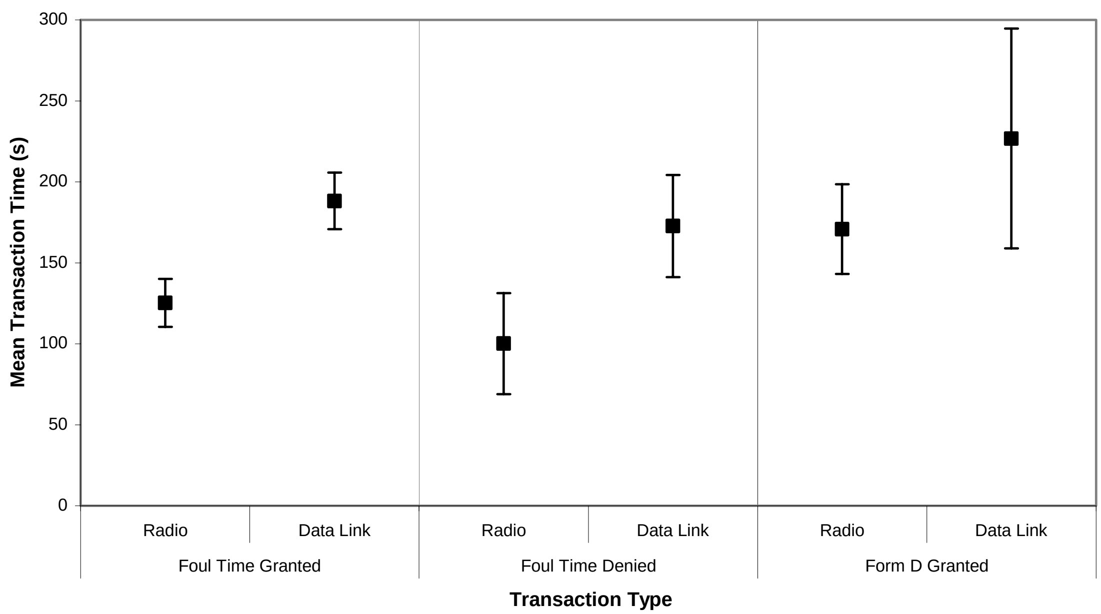

Figure 19. Work Authorization Processing Times

[4] The participant was asked to grant all Form D requests in an effort to simplify the experiment.

In some cases, the dispatchers did not respond to requests in the data link condition. It appeared that the dispatcher forgot about the outstanding requests. Failure to answer a work authorization request did not happen in the radio condition.

The differences between the radio and use of the handheld application can be explained partly by the dispatcher's greater experience using voice radio. The dispatchers use the radio everyday. One dispatcher said during the radio practice scenario, "You know, I don't need to practice. This is what I do every day. We can start the experiment right now."

On the other hand, the dispatchers had only 1½ hours to learn how to use the data link device. The dispatchers also varied in their familiarity with using computers (see questionnaire results).

A similar experiment comparing the use of data link communications with radio suggests another explanation. Malsch et al., (2004) compared dispatcher performance in the use of radio to a form of data link modeled after an email system. This data link system displayed work authorizations in visual form, like the current system. The data link interface also displayed track requests on the track display used by the dispatcher to monitor and control train movements as well as protect the track. In the Malsch et al., study, dispatchers performed better in the data link condition sending complex messages (i.e., granting Foul Time) than in the radio condition, and they performed worse for simple messages (i.e., denying Foul Time). Similarly, dispatchers were less likely to forget to answer messages in the data link system compared to the voice radio condition. Variations in the interface design and the features present may have contributed to the differences.

These differences contributed to higher physical workload. While the number of messages to answer was lower in the current study, the transaction times were higher. The mean transaction time was 196 seconds in the data link condition compared to 154 seconds in Malsch's study. In the current study, the dispatchers rated the data link condition as requiring greater physical workload than the voice radio condition.

<u>Train delays</u>

The percentage of scheduled trains delayed and the length of the delay were measured for each condition. More than twice as many trains were delayed with the data link application as with the radio. Approximately 29 percent of trains were delayed in the data link condition compared to 12 percent in the radio condition. Although, the average delay in the data link condition was twice as long in the data link condition, the difference of 24 seconds between the two conditions is probably not meaningful. The largest train delay between the two conditions differed by 4 minutes.

Table 3. Train Delay by Communication Mode

	Condition	
	Radio	Data Link
Percentage of delayed trains	12%	29%
Mean train delay (s)	24	48
Maximum delay (m)	6.5	10

Requests for track car position (Radio only)

The percentage of calls the dispatcher made to request track car position as a function of all radio communications was calculated in the radio condition. The track car calls represented about 10 percent of the total communication transactions. These communications could be avoided if track cars were equipped with GPS and reported their position to the dispatcher as they did in this study.

Detection of roadway workers' location errors (Data link only)

In the data link condition, the dispatcher was asked to check the roadway worker's location on the tracking display before granting work authorization. Dispatchers detected none of the 12 location errors made by roadway workers (i.e., they appeared on the track display in a different location from the authorized track). Dispatchers detected 41 percent of the errors committed by roadway workers working without authorization.

In both cases, a higher detection rate was expected. The attention associated with filling out forms in the data link condition may have contributed to dispatchers spending less time monitoring the track display. Another possibility is that the track display on which the roadway worker's position was shown contributed to difficulties in accurately locating their position.

Dispatchers' communication errors

Table 4 shows the dispatcher's errors by communication mode. The error data was normalized to account for differences in exposure in each trial. Communication and protection errors were normalized by dividing the number of communications by the total number of work authorization requests. Routing errors were normalized by dividing the number of errors by the total number of trains.

Table 4. Dispatchers' Errors

Error Category	Radio (%)	Device (%)
Communication errors as percent of work authorization requests		
Omit work authorization parameter	18	0
Incorrect work authorization parameter	17	6
Protection errors as percent of work authorization requests		
Block track section after granting work authorization	1	0
Block incorrect track section	5	1
Remove protection before the work authorization cancelled	2	0
Forget to protect track section	2	2
Forget to release track section	9	5
Routing errors as percent of number of trains		
Train collides with another train	0	0
Train collides with MOW crew	10	0
Train collides with track car	0	0

The data link condition resulted in fewer errors than the same interactions over the radio. Dispatchers forgot to enter required parameters for a work authorization request 18 percent of the time compared to zero errors in the data link condition. The error checking routines in the data link condition ensured that the dispatcher entered information in all the required fields. The error checking routines did not eliminate entering incorrect parameters in preparing a work authorization. However, the number of incorrect errors was considerably less in the data link condition. The dispatcher made almost three times as many errors using incorrect parameters in the radio condition as in the data link condition. In this error category, the dispatcher gave a work authorization parameter that didn't match the parameters given by the roadway worker.

The dispatcher also made more protection errors in the radio condition. For all categories, except one (forgetting to protect a track section), the dispatcher made more protection errors in the radio condition. Using paper copies of work authorizations was not as safe as using electronic work authorizations.

Finally, the percentage of routing errors resulting in a hazardous event was smaller in the data link condition. Overall, routing errors were non-existent for two of the three categories. There were no collisions between trains or between trains and track cars. The dispatcher made routing errors that could lead the train to collide with the maintenance of way (MOW) crew 10 percent of the time. No errors were made in the data link condition. This improved performance in the data link condition may be attributed to the roadway crews carrying GPS receivers, which gave the dispatcher more precise knowledge of the crew's track location.

Workload ratings

Table 5 shows the participant's workload ratings, for both radio and data link. Each dimension was rated on a scale from zero to ten, where zero represented the lowest workload and ten the highest workload.

Table 5. Workload Ratings

Scale	Description	Radio	Device
Mental Demand	How much mental and perceptual activity was required? (e.g., thinking, deciding, estimating, anticipating, remembering, looking, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?	7.2	6.2
Physical Demand	How much physical activity was required (e.g., pointing, clicking, typing)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?	5.3	6.2
Temporal Demand	How much time pressure did you feel due to the train routing activity and the work authorization requests frequency? Was the pace slow and leisurely or rapid and frantic?	6.3	7.2
Performance	How successful do you think you were in playing the role of dispatcher (i.e., how many routing errors, trains delayed, uncaught RW errors, granted or refused work authorizations by mistake, etc.)? How satisfied were you with your performance?	6.2	5.0
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?	6.0	6.7
Frustration Level	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?	4.2	5.5

Dispatchers rated their workload level lower in the data link condition for only one measure, mental demand. The dispatchers rated the mental demand higher in voice radio than the data link scenario. This attribute may be associated with the memorial requirement of voice radio. Voice radio placed a higher burden on the dispatchers memory compared to data link, where the dispatcher could view most of the essential information on the computer monitor.

For the remaining workload ratings, physical demand, temporal demand, performance, and effort the dispatchers rated their workload level to be lower in the voice radio condition. Physical demand was rated higher in the data link condition. This may have been due to data entry requirements in completing the electronic forms. Temporal demand was also rated higher with data link. This belief is consistent with the fact that work authorization transactions took about 1.5 times longer on average in the data link condition.

Dispatchers felt their performance was better with voice radio. This rating is consistent with their performance processing work authorization requests and scheduling train movements. In all cases, work authorization requests were processed faster in the radio condition. There were also fewer train delays in the radio condition. It may also reflect the dispatchers familiarity with the radio which they use everyday in their job. Similarly, dispatcher effort was rated lower in the voice radio condition. Again, this is not surprising since the dispatchers use the radio everyday, but they had only 90 minutes to learn how to operate the handheld application.

5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

An analysis of track foreman user requirements supported the previous work of Oriol (2000). Improving communications between track foremen and dispatchers requires an application that supports two tasks: requesting information about trains and track condition, and the ability to request work authorizations. The current study also identified a safety concern that could be addressed using digital communications and GPS. Roadway workers sometimes become disoriented on the track. Incorporating a GPS receiver into the handheld device could improve the roadway worker's situation awareness and minimize the likelihood of disorientation. Providing the location of roadway workers on the tracks and in track vehicles could also reduce the communication load for dispatchers and enhance their situation awareness. This capability was added to the current application.

An evaluation of the current set of features was analyzed from the dispatcher's perspective in a laboratory experiment. In this experiment, work authorization transactions took longer in the data link condition than with voice radio. This behavior contrasted with Malsch et al., (1999) results where data link reduced transmission of work authorization times by a factor of two. This difference between the two experiments suggests that the design of the dispatcher interface plays an important role in its usability and effectiveness in facilitating dispatcher performance. There were fewer communications errors in the data link condition than in the radio condition. Malsch et al., (1999) also observed this behavior in their study. Auditory communications were more prone to errors because their transient nature placed higher memorial demands on the dispatcher.

The number of protection and routing errors were also smaller in the data link condition. It was less taxing for dispatchers to process the work authorization requests in visual form than to have to listen to the radio and write down parameters, while planning train movements and authorizing maintenance work. This would explain why mental workload was rated higher in the radio condition.

While the tracking display appeared to be useful in assisting the dispatcher to locate track cars, monitoring roadway workers on the track posed a greater challenge. The dispatchers identified only 40 percent of roadway workers working without authorization and no location reporting errors were caught. The task seemed to be too demanding for the subjects to fully benefit from the tracking display. The tracking display was also expected to have more impact on the dispatcher's workload. The dispatcher's mental workload may be too high for him/her to fully benefit from a tracking display.

Trains tend to be delayed more with the data link condition, but again it is believed that delays should decrease with use. Malsch (1999) found similar delays for data link.

All the participants showed great enthusiasm and gave constructive feedback regarding use of the handheld application. They thought it would improve communications by reducing radio congestion and communication errors and assist in locating track vehicles and roadway workers on the right-of-way.

Adapting to the new technology for both dispatchers and roadway workers poses a variety of questions and challenges. For example, would the dispatcher take on the responsibility for monitoring every roadway worker's position or just the track foreman responsible for communicating with the dispatcher? Monitoring the location of all roadway workers on the track would substantially increase dispatcher's workload. Given current workload levels, some dispatchers felt that the additional work required to keep track of all roadway workers was just too much responsibility for the dispatcher. One dispatcher suggested that if such a system were implemented, the size of the dispatcher's territory should be reduced to compensate for the increase in workload.

Many of the dispatchers also felt that the willingness to adopt the new technology would vary with age. Younger people were expected to learn and take advantage of the new technologies more quickly and with greater enthusiasm. They also worried about the intangible (i.e., nonverbal) aspects of communication that may be lost moving from a predominantly oral communication medium to a visual medium. The dispatchers were also concerned about rule compliance with respect to the use of GPS and other location finding technologies. The application of this technology would only assist the dispatchers, if the roadway workers "turned the feature on" when they were on the track right-of-way. Finally, integrating this kind of a visual display into existing visual displays will present a challenge to system designers. Current information displays distort the geographic representation of track to present large quantities of information to the dispatcher in a form that is useful. The resolution of such displays with respect to the actual location of trains, equipment, and roadway workers is relatively low. The ability to more precisely locate these assets will require designers to think about how dispatchers will use this information.

Roadway workers were also concerned about how the new information technologies would affect them. While many roadway workers showed enthusiasm for the application, some were reluctant about relying upon it as a safety critical device. Roadway workers also expressed concern about how their privacy would be affected when their location could be tracked by the application. They were particularly concerned that location might be monitored when they were not working on the track. The GPS receiver that reports this information is under the control of the roadway worker, and this feature could be switched off at any time.

5.2 Recommendations

This section makes suggestions for improving the roadway worker communication application. Dispatchers and roadway workers made many of the suggestions during the focus group, observation sessions, and the experiment.

The current prototype represents an interim solution to providing a hardware and software interface for roadway workers to communicate more effectively with dispatchers. Computer, communications, and location finding technologies continue to improve. The current prototype has a form factor the size of a brick, which makes it possible to view more information on most cell phones today. However, the prototype is heavy compared to most cell phones.

The prototype's display can be difficult to see in bright sunshine. New generations of PDAs display information at higher resolutions and can display color. The current generation of wireless communications devices sends information at the relatively slow speed of 14.4 kilobytes/second. The next generation of wireless devices should be able to send information at considerably higher rates allowing the communication of graphics as well as text. The current prototype uses a GPS receiver, external to the communication device. Newer handheld devices will incorporate location-finding technologies into the communication hardware.

Because track foremen are highly mobile and must carry their communication devices on their bodies, the hardware must be relatively small and easily portable. Their current communication related tasks mean that a simple, easy-to-use application tailored to the needs of these specific tasks (requesting information and work authorization) would suffice.

Other roadway workers have different communication-related requirements and work in a different environment. This means that the tasks that need to be supported and the interface that supports them may be different from the interface designed for track foremen. For example, track inspectors work in vehicles that can support a larger display. A display the size of a 13-inch CRT could support the display of a graphic interface similar to the dispatcher's. Roadway workers could also have greater data entry requirements and could benefit from a keyboard to enter text-based information. The Burlington Northern Santa Fe Railroad is currently testing a device with these characteristics for requesting work authorizations.

5.2.1 Develop Hazard Alerts for Roadway Workers

A warning notification could be sent to the roadway worker when trains are approaching a work zone or passing by on an adjacent track. A reliable alarm could also assist crew watchmen in their jobs. This information would provide an additional source of information to the crew watchman, charged with watching for approaching trains.

Similarly, operators of track vehicles could receive a warning when approaching the limits of an authority. BNSF is currently developing such an application for use in Hi-railers. Such a system would be useful to prevent cases of a roadway worker going outside the limits of their authority.

5.2.2 Evaluate Effectiveness of Graphic Display

The current prototype displays territory information in textual form. This was necessary in the current prototype because the graphically displayed information requires greater bandwidth than the same information presented in text form and the slow transmission rate of current technology would result in an unacceptably slow response rate. With greater bandwidth and faster transmission rates, it will become possible to provide information graphically. The challenge will be to determine if and how graphic information can be displayed in a usable form. Some of the questions that need to be answered include:

- What kind of graphic display should be used (i.e., a track chart display)?
- What information should be shown (tracks, interlockings, stations, trains, track car, maintenance of way crews, etc.)?
- Are multiple formats necessary (e.g., track layout vs. street map), and what navigation controls will be needed to enable the roadway worker to quickly find the information being sought?

5.2.3 Decision Support and Reporting Tool for Track Inspectors

The CTA indicated that track inspectors use their paper-based rulebook for evaluating the nature of track problems they identify. They also must report these problems currently using paper-based forms. These activities could be facilitated with computer-assisted support. The following examples show the kind of computer-assisted support that could improve the track inspector's productivity:

- Store the electronic form that reports problems observed during track inspection.
- Automatically determine location associated with reported problems.
- Store the MW 1000 rulebook.
- Store the data recorded to allow for comparison over time to help the inspector make judgments about what recommendations to make to the track department supervisor (e.g., is this a problem that is degrading rapidly and should it be addressed soon, or is it a slowly changing problem?).

The Federal Railroad Administration (FRA) is developing an application for FRA track inspectors that contain some of these features.

5.2.4 Track Work Authorization Status for Dispatchers

Several dispatchers suggested providing audio alarms whenever new work authorization requests arrive, and are cancelled. The alarms may help dispatchers retain new work and cancellation requests when workload levels are high.

5.2.5 Improve Processing of Work Authorizations

The dispatchers who participated in the experiment offered three suggestions for managing work authorizations:

- The dispatcher should confirm the cancellation of work authorizations.
- Add a comments field to electronic work authorization forms for additional unstructured messages.
- Provide the capability to notify others besides the primary recipient when a work authorization is given.

APPENDIX A. SYSTEM ARCHITECTURE

Overview

The system involves a Qualcomm® pdQ™ Smartphone 800 connected via its serial port to an Axiom Smart Antenna GPS receiver, a dispatcher terminal, and a web server (see Figure 4). The phone connects to the Internet via an integrated wireless modem to communicate with the web server. The dispatcher terminal communicates with the server through a standard web browser. Below is a complete description of each element.

Axiom Smart Antenna GPS Receiver

Specifications

The Axiom Smart Antenna is an integrated GPS and antenna packaged in a sturdy plastic enclosure and supplied with a DB-9 interface cable (normally designed to use with Notebook PCs), see Figure 3. The output data protocol is per NMEA standard at 4800 bauds. The Smart Antenna is differential ready (RTCM-104 format of differential correction). Here are some specifications:

- Channels 12
- Voltage 3.0 to 5.5V DC
- Current 160mA @ 5.5V DC
- Baud Rate 4800 bauds 8N1
- Data Protocol NMEA format
- Size 3.5” x 2.15” x 1.15”
- Weight 4.0 ounces (including magnets, not including cable)

More information can be found at http://www.axiomnav.com/smart.asp

GPS configuration

To connect the GPS to the phone, a DB-9 Male/DB-9 Male null modem adapter (small connector that exchanges pins 2 and 3) was used along with a pdQ™ data cable. For power, a 7.2V radio controlled car battery was used. Diodes were used to drop the voltage. The 2200mAh battery capacity was sufficient to power the GPS receiver for more than 10 hours.

Qualcomm® pdQ™ Smartphone

Specifications

The pdQ™ Smartphone has a large touch screen for a cell phone. However, the main drawback of the pdQ™ is probably its size. The cell phone’s form factor is the size of a brick, making it bulky compared to other cell phones. The screen is also more dim and difficult to read in bright light than the prototype using the Palm VII™. The pdQ™ 800 functions just like a Palm III with a wireless modem. Table A-1 shows the main characteristics:

Table A-1. Smartphone Operating Characteristics

Characteristic	Description
Operating system	Palm OS ® 3.0
RAM	2 MB
Internet access	PPP connection within 3-5 seconds
Modem speed	14.4 kbps
Touch screen	36x12 characters, 1.9x2.4 inches, 160 x 240 pixels
Size	6.2” x 2.6” x 1.4” (15.7 cm x 6.7 cm x 3.5 cm)
Weight	10 ounces (285 g)

Additional information on the Smartphone can be found at http://www.kyocera-wireless.com/classic/pdq/pdq_series.htm

HTML forms

To handle the data base queries and work authorization requests and cancellations, HTML forms stored on the pdQ™ were used (see Description of the current prototype for screen shots).

The pdQ™ was sold with a web browser called a pdQ Browser™, which provides limited web surfing. Images and JavaScript were not supported. The HTML forms used to query the web server were stored in the pdQ Browser™ cache memory. When a form is submitted, the handset connects to the Internet automatically (if not already connected), and the form data is sent to the web server using a post method.

Location report application

A small Palm OS ® application was written to report location periodically. The period is a parameter that can be changed. Tests were performed with 1 minute and 5 minute periods.

The application was written in a C-like language using Code Warrior® for the Palm OS® Platform as a development environment. Functions were also used from the libraries of the pdQ™ Software Development Kit.

Here are the tasks performed by this application:

- Opens the serial port.
- Fills a buffer with GPS data (NMEA sentences).
- Finds latitude, longitude, UTC time and validity (char that takes the value ‘A’ if data are valid, ‘V’ otherwise).
- Sends data to the web server using the `PDQRegProcessURL(registryRefNum, URL)` function of the pdQ™ Software Development Kit.
- Sets an alarm that will launch this application at t = now + period.
- Closes the serial port.

Mapping application

Although this feature has not been evaluated yet, some software was installed to display maps of the roadway worker's surroundings based on the GPS information. Some commercial Palm OS® software by GPSPilot.com was used: Atlas v3.12 and GPS Pilot Cartographer 3.5

Atlas displays a map of the surroundings based on GPS latitude and longitude, and it pinpoints the users' location. If you are moving, it displays an arrow to indicate where you are heading. It can also give speed, direction in degrees, latitude, longitude, altitude, and UTC time.

Cartographer is a Windows application that enables the user to create their own map database and download it into the Palm OS™ device. Cartographer supports .bmp Windows bitmaps, gif, and JPG maps.

Web server

The web server is now running on a computer at the Volpe National Transportation Systems Center.

Perl script

A CGI script in Perl was written to build an interface between the web server and the Java query servers. It reads the HTML forms as sent by the handheld device, stores a file with the request and finally reads and returns the requested information to the handset.

Java server

The Java server consists of 5 query servers written in Java: database, dispatcher, file, dispatcher terminal refresh, and simulation query servers. Every second, these query servers look for requests sent by the handheld device or by a dispatcher. When a request has arrived, the appropriate query server reads the request, processes it, and writes the answer for the CGI script to send it back to the original petitioner. A detailed description of the purpose of each server can be found in Oriol, 2000.

Two new types of requests, as shown in Table A-2, were defined to handle the GPS location reports when a roadway worker clears the tracks.

Table A-2. New Types of Requests

Type of request	Location Report	Track clearing
Parameters	- tq = di - op = GPS - d = %phone_number% - p1 = validity (‘A’ or ‘V’) - p2 = UTC time - p3 = latitude - p4 = longitude	- tq = di - op = CT - d = %phone_number%
Action	Writes GPS data (validity, time, latitude, and longitude) in a text file (see format below) (that will be read by the tracking applet). The text file is named `%roadway_worker’s_name%.txt` and put in directory:	Removes the GPS data text file `%roadway_worker’s_name%.txt` so that the roadway worker disappears from the tracking display.
HTML Response	Message for the roadway worker to let him/her know that his/her position has been successfully reported.	Message for the roadway worker to let him/her know that his/her tracking file has been cleared.

GPS data were written in tracking files (text files) on the server, which were read by the tracking applet (see next paragraph). Those text files were named `%roadway_worker’s_name%.txt` and put in a directory. Comma-separated values were used for the variables shown in Table A-3.

Table A-3. Tracking Files Format

Variable	Description	Format
Date	Date when location reported on the server	mm/dd/yyyy ddd
Time	Time when location reported on the server	hh.mm.ss
UTC	UTC time	hh:mm:ss
Validity	Validity of the GPS data:	‘A’=normal, ‘V’=warning
Latitude	Latitude: -90<Latitude<90,	2 digits for degrees and 4 for minutes (e.g., 4807.038 means 48 deg 07.038’ N)
Longitude	Longitude: -180<Longitude<180	3 digits for degrees and 4 for minutes. (e.g., -01131.324 means 11 deg 31.324’ W)
Mile Post	Milepost at which roadway worker is located	Computed from the latitude and longitude and the track profiles
Branch	Branch where roadway worker is located	Computed from the latitude and longitude and the track profiles

Since access to Amtrak’s track profiles was unavailable, the computation of the branch and the milepost was simulated.

Dispatcher terminal

Message console

When the system is running, any web browser can be turned into a dispatcher message console. To enter the system, the dispatcher must enter the correct web address and select a territory. Next, the dispatcher must login using the appropriate password. The system will show all the incoming messages that affect the selected territory.

The message console consists of a set of HTML frames. It displays requested Form Ds and Foul Times and enables the dispatcher to grant or deny them by posting HTML forms to the web server. It can also display active, cancelled, and rejected work authorizations. The message console refreshes periodically.

Tracking applet

Overview

The tracking application consists of a Java applet that can run on any Java-enabled web browser. The applet uses Java 2.0 Swing software for Graphical User Interface (GUI) classes. Most browsers today are not Swing enabled, but a plug-in to run Swing applet can be downloaded for free from http://java.sun.com/products/plugin/1.3/

The applet periodically checks for new tracking files (or new lines in an existing tracking file) and updates the roadway worker's locations if needed. It can show position on the track and street map displays to pinpoint the worker's positions. Both kinds of displays can show previous locations. By right clicking on a worker, the dispatcher can:

- Send an SMS
- Get more information about a point (i.e., roadway worker's name, time, validity, latitude, longitude, mile post).
- Access the roadway worker's location file showing the history of where the person or vehicle associated with the GPS receiver has been.
- View a local street map from Mapblast.com® based on the latitude and longitude.

Street map display

The street map display was designed to work with a set of maps (possibly of different scales). The maps should be in GIF or JPEG format and use the format shown in Table A-4. Explanations about the format can be found in Table A-5.

Table A-4. Map Data base Format

Name	File	Height	Width	LatTopL	LongTopL	LatBotR	LongBotR
MIT	mit.gif	600	600	42.371751	-71.110177	42.346185	-71.077817

Table A-5. Map Data base File Format

Field	Explanation
Name	Map name used in the applet
File	Name of the map file
Height	Map height in pixels
Width	Map width in pixels
LatTopL	Latitude at the top left corner (between –90 and 90)
LongTopL	Longitude at the top left corner (between –180 and 180)
LatBotR	Latitude at the bottom right corner (between –90 and 90)
LongBotR	Longitude at the bottom right corner (between –180 and 180)

Location tracking display

The location tracking display has been designed to work with different track branches. For each of them, it handles zooming and navigation along the track.

For simplicity, the same track information files as those of PDA were used (see Oriol, 2000). Nevertheless, only the location's names and mileposts were read.

APPENDIX B. QUESTIONNAIRES

QUESTIONNAIRE

Biographical information

1. Name (first and last): ______________________________
2. Complete address: ______________________________

   ____
3. Social security number: ______________________________
4. Sex (M/F): M F
5. Age: ______________________________
6. Job title: ______________________________
7. Years of experience in railroad industry: ______________________________
8. Years of experience as a dispatcher: ______________________________

Computer background

9. Please rate your level of familiarity with the following devices or service:

	Very Unfamiliar	Unfamiliar		Familiar	Very Familiar
PC	1	2	3	4	5
World Wide Web	1	2	3	4	5
Netscape	1	2	3	4	5
E-mails	1	2	3	4	5

GPS background

10. Are you familiar with GPS technology?

	Very Unfamiliar	Unfamiliar		Familiar	Very Familiar
GPS	1	2	3	4	5

11. Have you already used the GPS technology for private use? ____________
12. Have you already used the GPS technology for professional use? ____________

About the device

13. Do you think the new device will reduce the need for communication between roadway workers and dispatchers? ______________________________
    In what way? ______________________________
    ____
    ____

14. Do you think the new device will improve communication between roadway workers and dispatchers? ______________________________
    In what way? ______________________________
    ____
    ____

15. Do you think the tracking functionality is useful? ______________________________
    In what way? ______________________________
    ____
    ____

16. What obstacles do you see in using the new system? ______________________________
    ____
    ____
    ____

17. All things considered, do you think the new device will improve the global RW safety? ______________________________
    In what way? ______________________________
    ____
    ____

18. Some dispatcher mentioned the value of being able to issue a Form D to multiple roadway workers at a time. Do you think it is a good idea? Why? ______________________________
    ____
    ____
    ____

19. What other features/enhancements would you recommend for the new device? ___

____

____

____

____

20. Is there anything else you want to say about the new device? __________________

____

____

____

APPENDIX C. ADAPTED NASA TLX RATING SCALE

Workload Subjective Ratings

Name: ______________________________________

Type of experiment (Radio or Device): R D

Please rate on a 0-10 scale the following criteria, for both the radio and for the new device (Circle answers).

Title	End Points	Description	Rate
MENTAL DEMAND	Low / High	How much mental and perceptual activity was required? (e.g. thinking, deciding, estimating, anticipating, remembering, looking, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?	0 1 2 3 4 5 6 7 8 9 10 Very Low — Medium — Very High
PHYSICAL DEMAND	Low / High	How much physical activity was required (e.g. pointing, clicking, typing)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?	0 1 2 3 4 5 6 7 8 9 10 Very Low — Medium — Very High
TEMPORAL DEMAND	Low / High	How much time pressure did you feel due to the train routing activity and the work permission requests frequency? Was the pace slow and leisurely or rapid and frantic?	0 1 2 3 4 5 6 7 8 9 10 Very Low — Medium — Very High
PERFORMANCE	Poor / Good	How successful do you think you were in playing the role of dispatcher (i.e. how many routing errors, trains delayed, uncaught RW errors, granted or refused work permissions by mistake etc)? How satisfied were you with your performance?	0 1 2 3 4 5 6 7 8 9 10 Very Poor — Medium — Very Good
EFFORT	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?	0 1 2 3 4 5 6 7 8 9 10 Very Low — Medium — Very High
FRUSTRATION LEVEL	Low / High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	0 1 2 3 4 5 6 7 8 9 10 Very Low — Medium — Very High

APPENDIX D. FORM D AND FOUL TIME

Form D

NORAC MOVEMENT PERMIT FORM D 100

FORM D NO. ________

FORM D NO.(S) ________________
DELIVERED TO ________________

DATE ___ / ___ / ___

TO

	FORM D CANCELLED TIME	DATE	DSPR
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	

1. TEMPORARY SPEED RESTRICTIONS

LINE	TRK(S)	BETWEEN/AT	SPEED PSGR	SPEED FRT	SPEED SIGNS DISPLAYED YES	NO

2. OPERATE IN ________ DIRECTION(S) ON ________ TRK BETWEEN ________ AND ________
ON ______ TRK BETWEEN ________ AND ________ DSPR ______ TIME ______
ON ______ TRK BETWEEN ________ AND ________ DSPR ______ TIME ______
ON ______ TRK BETWEEN ________ AND ________ DSPR ______ TIME ______
3. TRAINS OR TRACK CARS AHEAD ________________
TC PROCEED PAST STOP SIGNAL(S) AT ________________
4. ______ TRK OUT OF SERVICE BETWEEN/AT ________________ IN CHARGE OF ________
______ TRK OUT OF SERVICE BETWEEN/AT ________________ IN CHARGE OF ________
5. ________ LINE ________ TRK OBSTRUCTED FOR MAINTENANCE BETWEEN ________ AND ________
6. NON-SIGNALLED DCS RULES IN EFFECT ON ________ TRK(S) BETWEEN ________ AND ________
7. INT AND CP SIGNALS OUT OF SERVICE ON ________ TRK(S) AT ________________
8. REMAIN AT ________________ ON ________ TRK UNTIL ENGINE ARRIVES TO ASSIST
9. OPERATE AT RESTRICTED SPEED ON ________ TRK TO ________________ WHERE TRAIN IS DISABLED
10. TBS IN SERVICE AT ________________
11. CSS RULES OUT OF SERVICE ON ________ TRK(S) BETWEEN ________ AND ________
12. PROTECT CROSSING(S) ________________
13. OTHER INSTRUCTIONS/INFORMATION ________________

TRAIN DISPATCHER ________________ TIME EFFECTIVE ________ M.

A brief explanation of the use of the different lines of a Form D follows (see rules 160-173). The brackets indicate the rules that apply for each line from the NORAC Operating Rulebook.

1 [175]: Speed restrictions. Train Speed Restriction Bulletins (TSRB) are used in place of line 1.

2 [400,402-405, 502, 803, 805, 806, 808]: Direction of travel. Written to give authority to track cars to operate on a specific track between two interlockings.

3 [803, 805, 806, 807]: Written to inform track cars about trains or track cars ahead. A track car is allowed to move behind trains, never in front of them. The second part of line 3 is used to give permission to pass a stop signal. Rule 241 is usually used in place of second part of line 3. Some dispatchers use line 3 and not rule 241.

4 [132-134]: Track goes out of service in charge of some employees (flagman/conductor/ foreman).

5 [132, 135]: Rebuild grade crossing without disturbing the track. Just nearby road.

6,7 [406]: Form D Control System (DCS), Control Point (CP) (see rules 400).

8,9 [137]: Used when a rescue train is heading towards the train being rescued.

10 [174]: Temporary Block Station.

11 [561]: Cab Signal System (CSS).

12 [138]: Used when a grade crossing malfunctions.

13 [132, 177, 400, 404, 406, 506, 507, 805, 806]: General purpose. Used for example to describe where barricades are.

Dispatchers most frequently use lines 2, 3, and 4. Lines 2 and 3 are issued to track cars and work-extra trains. Line 4 is issued to repair crew foreman, flagmen, and point conductors.

Foul Time

FOUL TIME

DELIVERED TO ___________________

ON _____ TRK BETWEEN ___________________ AND ___________________

MILE POST ___________________

START TIME ___________________

END TIME ___________________

TRAIN DISPATCHER ______________________________________

This Foul Time sheet was adapted from the NORAC operating rules.

APPENDIX E. FOCUS GROUP QUESTIONS

Draft Focus Group Questions

Introduction

Welcome.

Thanks for taking the time to join in this group discussion on New Tools for Dispatcher/Roadway Worker Communication.

I'm Emilie Roth, and I work as a contractor for the Volpe National Transportation Systems Center.

This is Timothee Masquelier and Monica Gil who are working with me on this project for the Volpe Center.

The Volpe National Transportation Systems Center and the Human-Machine Systems Laboratory of MIT are developing new tools to support communications between dispatchers and roadway workers. For example, we are developing a handheld device that could be used by roadway workers to transmit and receive messages digitally (e.g., Form D) instead of using voice radio.

As part of this work we are conducting focus groups to obtain input from dispatchers to help in developing the new tools. We will also be conducting similar group meetings with roadway workers.

The goals of the focus group are to obtain:

- input on the kinds of communication that occur between dispatchers and roadway workers, the things that contribute to effective communication, and the things that can get in the way, that should be considered in designing new tools;
- feedback on a prototype handheld communication device that we are going to be demonstrating to you; and
- suggestions for additional features that would enhance the usefulness and acceptance of the new tools.

Your opinions and insights are very important to us and will help shape the kinds of aids that we develop.

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

We are tape-recording the session because we don't want to miss any of your comments. No names will be included in any reports. Your comments are confidential.

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

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

Feel free to get up and get more refreshments if you would like. Let's begin.

Opening Question:

Tell us who you are, what territory/territories you control, and a little about your railroad background [5 min.]

Introductory Questions:

Our focus today is communication that dispatchers have with roadway workers over radio and phone.

First, can you say about what proportion of your radio and phone communication is with roadway workers [5 min.]

What type of roadway workers do you communicate with most? [5 min.]

Probes: Get a sense of frequency and duration

Transition Questions

What types of things do roadway workers typically call you about? [5 min.]

Probes: Get a sense of priority level of these communications

What are the types of things you typically call roadway workers about? [5 min.]

Can you talk about some of the problems that come up in communicating with roadway workers over radio or phone? [10 min.]

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

Key Questions:

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

Party Line

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

Can you talk about some of the benefits of this ‘party-line’ aspect? Are there situations where it helps to overhear others or have others overhear you? [10 min.]

Can you talk about some of the drawbacks of this ‘party-line’ aspect? Are there situations where this ‘party-line’ aspect causes problems? [5 min.]

GPS

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

If we could give you more accurate information on the location of roadway workers on the tracks (say on a display) do you think it would be helpful to you? [5 min.]

How about more accurate information on the location of trains, right now you know that a train is occupying a block, do you think that would be helpful to you to have more precise location information? [5 min.]

DEMO

Part II - Focus on handheld device:

KEY Questions:

Which features of the ones we have demonstrated or described seem most useful? [10 min.]

Do you think this device will meet the communication needs of roadway workers and dispatchers? In what way? [5 min.]

Do you think this device will improve communication between roadway workers and dispatchers? In what way? [5 min.]

Do you think this device will reduce errors in communication between roadway workers and dispatchers? In what way? [5 min.]

What obstacles do you see in using/success of this system? [10 min.]

What other features/enhancements would you recommend for making your work easier? [5 min.]

What other features/enhancements would you recommend for improving overall safety? [5 min.]

OK, a couple of specific questions:

- How often should we update the locations for roadway workers and track cars (15 min? 5 min? 1 min?) [5 min.]

Probe: Why is this update rate necessary?

- In your opinion, what would be the best way to display the location of roadway workers and track cars?
    - Should we integrate the roadway worker location into your existing track layout displays, or should we have separate displays that you can bring up?
    - Is it better to display their location on a track chart or a 2-D map? [5 min.]

Ending Questions

All things considered, do you think that a handheld device like the one we demonstrated to you is a good idea? [5 min.]

Is there anything that we should have asked about but didn't? Anything that you came wanting to say, but you didn't get a chance to? [5 min.]

APPENDIX F. WIRELESS TECHNOLOGY PROTOCOLS AND POSITIONING TECHNOLOGIES

Before selecting a wireless technology protocol and a positioning technology for our prototype, we reviewed several state-of-the-art technologies. The results are described in this appendix.

Wireless technology protocols

Wireless Internet

Several technologies enable wireless connection to the Internet.

Regular PPP connection through a wireless modem

Point-to-Point Protocol (PPP) is the Internet standard for transmission of IP packets over serial telephone lines. The handheld device establishes a PPP connection to an Internet Service Provider (ISP) through a wireless modem (internal or external), exactly as a PC would do. This technology is being used by most PDAs (and very few cell phones) to connect to the Internet. Once connected to the Internet, the device has access to hosts and services, such as e-mail and web pages.

Wireless modem connection speeds are slower when using personal computers through a landline. A typical PDA connection speed ranges between 9,600 to 14,400 bps. Dial-up connections through the phone line are most frequently 56,000 bps. Next generation wireless applications will communicate at faster speeds. The second challenge is that web pages are designed for regular desktop PC's with their larger, color monitors. Compared to the typical 15" or 17" computer monitor, PDAs have tiny screens with low resolution, and are predominantly monochromatic. This is changing as well, and one can expect to see more color in the future.

Wireless Application Protocol (WAP)

WAP (Wireless Application Protocol) is an open specification that allows wireless devices such as phones, pagers, and PDAs to retrieve information from the Internet. WAP differs from PPP in that the client is not the mobile device itself. The WAP gateway serves as an intermediary between the device and Internet (Figure F-1). This gateway translates mobile device requests (WAP requests) into HTTP requests, and redirects the web server's HTTP responses to the mobile device through WAP.

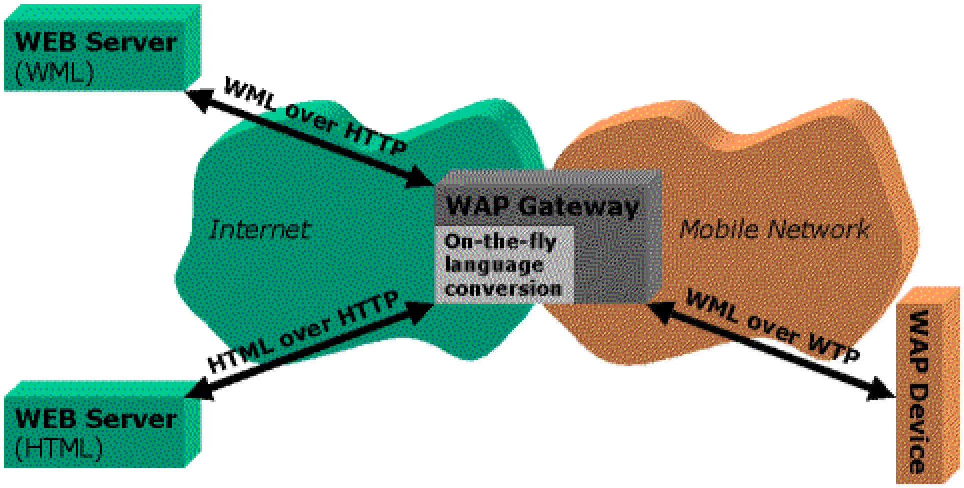

Figure F-1. WAP Architecture

Navigating normal web pages with a cell phone would be difficult. Cell phones lack a pointing device for selecting and entering information. Therefore, a part of the WAP standard outlines how to design Internet pages that are cell phone friendly. These pages are written in WML (WAP Markup Language) and can be navigated using the numbers on the cell phone keypad. WAP web pages cannot be viewed in a normal web browser and a cell phone cannot view the HTML pages on traditional web sites.

Palm VII™ technology

3Com® has developed it's own proprietary wireless Internet technology using a packet oriented protocol. Standard web browsing is not supported, but the handheld device is able to query a proxy server in 3Com® Corporation's Data Center (Figure F-2). This proxy server is responsible for converting the standard Internet protocols and content from a web page into a form that is tuned for transmission across a wireless network and display on a small device.

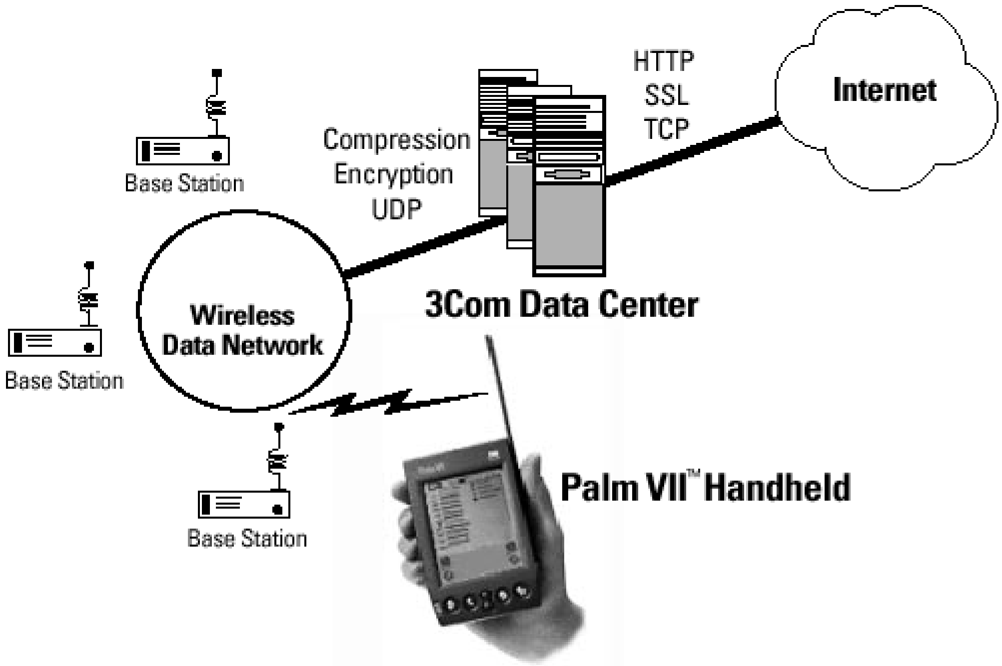

Figure F-2. Palm VII™ Architecture

Short Message Service (SMS)

Short message service (SMS) is a globally accepted wireless service that enables the transmission of alphanumeric messages between mobile subscribers and external systems such as web servers, electronic mail, paging, and voice-mail systems. Messages must be no longer than 160 alphanumeric characters. SMS is a reliable, low-cost communication mechanism for brief messages.

Positioning technologies

Global positioning system (GPS)

The global positioning system (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites in geo-synchronous orbit around the earth and their ground stations. Today, designers have shrunk GPS receivers to fit on a few integrated circuits. They have also become inexpensive consumer appliances.

The GPS receiver computes its position using triangulations from satellites, whose positions are known. Measurement of the distance from one satellite gives a sphere on which the receiver is located. Two measurements from two satellites give a circle (intersection of two spheres). Three measurements from three satellites give two points (intersection of a circle and a sphere). To decide which one is the true location requires a fourth measurement. However, one of the two points is usually a ridiculous answer (either too far from earth or moving at an impossible velocity) and can be rejected without a measurement. In fact, it will be shown in the next paragraph that a fourth measurement is needed, but for different reasons.

The distance from a satellite is measured by timing how long it takes for a signal sent from the satellite to arrive at the receiver. Since the travel times are tiny (60 ms assuming the satellite is right above the receiver), one needs to know when the signal was sent very accurately. An error of a thousandth of a second would lead to approximately 200 miles of error. This is the reason why the satellites have atomic clocks. GPS receivers lack atomic clocks because they are too expensive (between $50,000 and $100,000). Instead, a fourth satellite is used. Because of the GPS receiver clock error, the fourth sphere will not intersect the three others. The receiver can then compute a single time correction that, once subtracted from all its timing measurements, would cause them all to intersect at a single point. Consequently, any GPS receiver needs to have at least four channels so that it can make the four measurements simultaneously.

The satellite positions must be known precisely. On the ground, all GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment. The basic orbits are quite exact but some ephemeris errors remain, and that is why the GPS satellites are constantly monitored by the U.S. Department of Defense. Once the Department of Defense has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals that it is broadcasting.

Until February 5th 2000, the U.S. government degraded the accuracy of the civil GPS signal. The policy was called "Selective Availability" or "SA," and the idea behind it was to make sure that no hostile force or terrorist group could use GPS to make weapons with accurate guidance systems. Fortunately, the Department of Defense has now stopped adding noise into the GPS signals. The decision to discontinue SA is the latest measure in an on-going effort to make GPS more responsive to civil and commercial users worldwide. To ensure that potential adversaries do not use GPS, the military is now dedicated to the development and deployment of regional denial capabilities in lieu of global degradation.

Nevertheless, several kinds of errors still decrease system accuracy. First, the speed of light is only constant in a vacuum. The GPS signal slows down when crossing the ionosphere and the troposphere. Second, when it gets to the ground, the signal may bounce off various local obstructions before arriving at the receiver. Third, tiny inaccuracies remain in the satellite atomic clock and in its estimated position. Due to these errors, the GPS signal is accurate to about 60 feet.

Differential global positioning system (DGPS)

The differential global positioning system (DGPS) is a technology that eliminates most of the GPS errors using ground stations whose positions are known. The idea is that the satellites are so far out in space that the little distances traveled here on earth are insignificant. Therefore if two receivers are fairly close to each other (say within a few hundred miles) the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same errors. The ground stations receive the same GPS signals as the roving receivers but instead of working like a normal GPS receiver they attack the equations *backward*: instead of using timing signals to calculate their positions, they use their known positions to calculate timing. The ground stations determine what the travel time of the GPS signals *should* be, and compares it with what they actually *are*. The difference is an "error correction" factor. The error corrections for all satellites are then encoded into a standard format and transmitted to the roving receivers via a radio data link. Thanks to these corrections, each roving receiver is able to compute its location much more accurately.

Many new GPS receivers are being designed to accept corrections (“differential ready” GPS), and some are even equipped with built-in radio receivers. Many federal agencies (i.e., United States Coast Guard, the Federal Aviation Administration’s Wide Area Augmentation System) broadcast corrections. DGPS accuracy can reach 15 feet in moving applications and in some cases even less, depending on the distance from the differential beacon. Nationwide DGPS (NDGPS) expands DGPS developed by the Coast Guard to support FRA’s Positive Train Control initiative and the Federal Highway Administration’s Intelligent Transportation System provides support for DGPS on a nationwide scale.

Inverted DGPS

Inverted DGPS is a smart permutation of DGPS that can save money in certain tracking applications. The idea is to use mobile standard GPS units that transmit their positions to the tracking office via a wireless data link, and apply differential corrections only there.

Therefore, only one differential correction receiver is needed, and the GPS units do not have to be differential ready. The drawback is that the mobile units do not know their precise position.

Cell phone location technologies

Many mobile network-based technologies used to locate cell phones are available on the market. Accuracy varies a little from one technology to another, but is usually around only a few tens of feet. When the user makes a phone call, the local antennas measure some of the signal characteristics in order to compute the cell phone location. There are three main methods (and many hybrid ones):

1. **The Time Difference of Arrival (TDOA) method:** the wireless phone’s signal is received at various antenna sites. Since each antenna is at a (usually) different distance from the caller, the signal arrives at a (very) slightly different time. The technique requires signal timing information from at least three different antenna sites. The receivers, each synchronized by an atomic clock, send the caller’s voice call and timing data on to the mobile switch, where the times are compared and computed to generate a latitude and longitude for the caller.
2. **The Angle of Arrival (AOA) method:** the wireless phone’s signal is received at various antenna sites. Each antenna site is also equipped with additional gear to detect the compass direction from which the caller’s signal is arriving. The receivers send the caller’s voice call and compass data on to the mobile switch, where the angles are compared and computed to generate a latitude and longitude for the caller.
3. **The Location Pattern Matching (LMP) method:** the receivers send the caller’s voice call to the mobile switch, where sophisticated equipment analyzes the acoustic radio signal, and then compares it to a data base of standard signal characteristics. These characteristics include signal reflections (multi-path), echoes and other signal “anomalies.” When a computerized match is made, the location of the caller can be determined. The technique is effective in urban environments where tall buildings and other obstructions are located.

SnapTrack® technology

SnapTrack® Inc., has developed a server-aided GPS technology to locate cell phones. The idea is that the handset's position is first estimated using cell phone location technologies. Then a server, connected to a DGPS sends aiding data to the phone: a list of satellites in view from the handset, and their relative Doppler offsets. SnapTrack® technology is currently the fastest, most accurate (about 12 feet in an open site), and most cost-effective wireless device location technology.

GLOSSARY

Block Signal: A fixed signal displayed to trains at the entrance to a block to govern use of that block. [1]

Block: A length of track with defined limits on which train movements are governed by block signals, cab signals, or Form D. [1]

Blocking device: A lever, plug, ring or other method of control that restricts the operation of a switch or a signal. [2]

Cab signal: A signal that is located in the engine control compartment, which indicates track occupancy or condition. The cab signal is used in conjunction with interlocking signals and in lieu of block signals. [1]

Controlled track: Track upon which the railroad's operating rules require that all movements of trains must be authorized by a train dispatcher or a control operator. [2]

Conductor: The person officially in charge of the train's overall operation.

Dark territory: A section of track that is not signaled. In dark territory, the train dispatcher does not get automatic indication of the location of the trains, nor does the train get automatic signals allowing movement through the territory. [3]

Data link: Technology that enables information that is now transmitted over radio links to be transmitted over data lines. [3]

DGPS: Differential GPS. Positioning technology that uses both satellites and ground stations.

Engineer: The person primarily responsible for operating the locomotive.

Fixed signal: A signal at a fixed location that affects the movement of a train. [1]

Flagman: When used in relation to roadway worker safety, means an employee designated by the railroad to direct or restrict the movement of trains past a point on track to provide on-track safety for roadway workers, while engaged solely in performing that function. [2]

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

Fouling a track: Placement of an individual or an item in such a proximity to a track that the individual or equipment could be struck by a moving train or on-track equipment, or in any case is within four feet of the field side of the near running rail. [2]

Foreman: Roadway worker whose only duty is to protect other members of the crew by dealing with the dispatcher.

Crew Watchman: A person assigned to signal others of the approach of a train. [2]

GIF: (Graphics Interchange Format) bit-mapped graphics file format. GIF supports color and various resolutions. It also includes data compression, making it especially effective for scanned photos.

Global positioning system (GPS): A satellite based positioning system. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time. Four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock.

Hi-railer: A motor vehicle equipped to move on either the highway or railroad tracks.

HTTP: (Hyper Text Transfer Protocol) underlying protocol used by the World Wide Web. HTTP defines how messages are formatted and transmitted, and what actions web servers and browsers should take in response to various commands.

Interlocking: An interconnection of signals and signals appliances such that their movements must succeed each other in a predetermined sequence, assuring that signals cannot be displayed simultaneously on conflicting routes. [2]

JPEG: (Joint Photographic Experts Group) "glossy" compressed graphic file format supporting 24-bit, over 16 million colors.

Movement Permit Form D: A form containing written authorization(s), restriction(s), or instruction(s), issued by the dispatcher to specified individuals. [5]

NDGPS: Nationwide Differential Global Positioning System. An augmentation of GPS operated by the U.S. Coast Guard provides integrity monitoring of GPS and positioning accuracy of one to three meters.

NORAC: Northeast Operating Rules Advisory Committee.

NMEA standard: National Marine Electronics Association's standard for data communication between marine instruments (e.g., GPS).

On-track safety: State of freedom from the danger of being struck by a moving railroad train or other railroad equipment, provided by operating and safety rules that govern track occupancy by personnel, trains, or on-track equipment. [6]

PPP: (Point to Point Protocol) Communication protocol for a modem to connect to the Internet through an access provider.

Roadway worker: Any employee of a railroad, or of a contractor to a railroad, whose duties include and who is engaged in the inspection, construction, maintenance, or repair of railroad tracks, bridges, roadway, signal and communication systems, electric traction systems, roadway facilities, or roadway maintenance machinery on or near the track or with the potential of fouling a track, and employees responsible for their protection. [1]

Shunt: Activate block or interlocking signals when present on track. [7]

SMS: (Short Message Service) Globally accepted wireless service that enables the transmission of instant alphanumeric messages between mobile subscribers and external systems such as web servers, electronic mail, paging, and voice-mail systems.

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[5] NORAC operating rules

[6] Roadway Worker Protection Manual (RWP manual)

[7] Roth, E.M. and Malsch, N.1999

TCP/IP: (Transport Control Protocol / Internet Protocol) Suite of communications protocols used to connect hosts on the Internet.

Track car: Equipment, other than trains, operated on a track for inspection or maintenance. Track cars might not shunt track circuits. [2]

Traffic Envelope: Area between clearance points (25 feet from the centerline of outside track) and rails and overhead power lines.

Train dispatcher: Railroad employee assigned to control and issue orders governing the movement of trains on a specific segment of railroad track in accordance to the operating rules of the railroad that apply to that segment of track. [2]

Train On Sheet (Train OS): Dispatcher's term that refers to train schedule usually with time updates.

Wireless Application Protocol (WAP): Is an application environment and set of communication protocols for wireless devices designed to enable manufacturer, vendor, and technology-independent access to the Internet and advanced telephony services.

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