DESIGN AND EVALUATION OF A GPS-AIDED COMMUNICATION DEVICE FOR RAILROAD WORKERS

by

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ABSTRACT

Communications in current railroad operations are heavily based on voice links. Radio congestion is often a problem when railroad workers try to establish communication with dispatchers at the Traffic Control Center. This problem is expected to grow with the introduction of new rail services. At the same time, roadway worker fatalities still occur every year. Moreover, railroad workers' disorientations also cause accidents, and train dispatchers would often value knowing the railroad workers' locations.

This report documents the design and evaluation of a GPS-aided wireless "data link" communication device used to enhance railroad worker safety. Personal safety is achieved when a person has sufficient warning before taking an action that exposes him or her to risk. The focus of the study was to understand the safety implications of both data-link and positioning technologies.

The prototype device consists in a hand-held information appliance with wireless access to the Internet, connected to a GPS receiver. We demonstrated this device to railroad workers and dispatchers and their feedback has been gathered in this report. They provided excellent ideas to improve it and showed great enthusiasm.

An experiment designed to evaluate the concept from the dispatcher's perspective was conducted. Although the prototype was shown to have room for improvement, the results of our experiments were encouraging. Digital interactions between dispatchers and railroad workers were slower but more accurate than the same interactions over the radio. Dispatcher valued the tracking display based on GPS information, although it increased the mental workload.

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1 INTRODUCTION

1.1 Overview of information flows in railroad operations

Humans involved

Railroad operations involve three main groups of employees: railroad dispatchers, locomotive engineers and roadway workers.

- **Railroad dispatchers**: they are in charge of routing the trains. They command signals and switches from the dispatcher center. Their most important responsibilities are to insure safe movement of trains and personnel on the tracks, insure that passenger trains meet schedule and, in case of emergency, coordinate rescue missions.

- **Locomotive engineers and conductors**: they operate the trains, and are responsible of following the directions dictated by wayside signals and dispatchers.

- **Roadway workers**: roadway workers are employees of a railroad, or of a contractor to a railroad, whose duties include and who are 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 tracks or with the potential of fouling a track, and employees responsible for their protection. They need work permission from dispatchers before starting any work on the tracks.

Role of the equipment

A communication system enables the above-mentioned group of employees to communicate. It is mostly based on radio communications, but the phone is used occasionally. Radio communications can be overheard, which enables employees to get information that indirectly concern them: it is the so-called party line effect.

The track equipment currently provides dispatchers with information about signal states, switch states, and train locations (except in the so called "dark territories").

Existing train location systems usually use track circuits that trains shunt (activate) at the entrances and exits of blocks and interlockings. Consequently, a train’s location is known only within a given block. Another drawback of the current system is that track cars (see glossary) might not shunt the track circuits. Dispatchers often have to call a track car using the radio to know its position.

Currently, two primary train location determination systems are under development and testing for railway 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 on board GPS receivers (or differential GPS receivers) to compute their positions.

The location determination system may also consist of a combination of two or more systems: transponders/interrogators, a tachometer for dead reckoning, a fiber-optic gyro for detecting curving, and GPS for calculating position.

The equipment also insures that switches and signals are modified accordingly to the dispatcher’s commands at the center.

At the dispatcher center, a wall display shows an external representation of the track called a track chart, with the train locations and the switch and signal state (except in the dark territories).

In the dark territories, train dispatchers do not get automatic indication of the location of the trains, nor do trains get automatic signals allowing movement through the territory. The employees have to rely uniquely on the radio.

**Information flow diagram**

Figure 1 summarizes the basic information flows in railroad operations. It does not show all possible communication channels. Informal communications also occur between roadway workers and engineers, essentially due to a party line effect. The new generation of track infrastructure is also exchanging data with the trains via a transponder/interrogator system. But the vast majority of the current railroad networks, especially in the US, operate under a communication pattern similar to Figure 1.
1.2 Roadway worker safety

Concern regarding hazards faced by roadway workers has existed for many years. In 1996, after an initial petition from the Brotherhood of Maintenance of Way Employees (BMWE), the Federal Railroad Administration amended Part 214 (Railroad workplace safety) of Title 49 (Transportation), Code of Federal Regulations, by adding a new subpart, Subpart C: Roadway Worker Protection (see FRA web page). This new subpart was the result of the work done by the Roadway Worker Safety Advisory Committee. This committee was established on December 1994 and comprised 25 members of different organizations including unions, railroads, FRA, American Public Transportation Association and several brotherhoods of locomotive engineers and maintenance of way employees.

Apart from the government effort to regulate roadway worker safety, it is worth analyzing the relevance of roadway worker accidents in the past. The figures in this section have been obtained from the Federal Railroad Administration (Railroad Safety Statistics, Annual Report 1999).

The total number of roadway worker fatalities seems to be slowly decreasing, as shown in Figure 2. These figures include roadway workers from all the different railroads in the US. 64 roadway workers were killed in the past 14 years.
The number of injuries is of course considerably higher. 2,093 roadway workers were injured in 1999, totalizing 58,882 absent from work days.

Roadway worker fatalities are a serious issue in the railroads worldwide. As an example, let us mention that during the same 14-year period, more than 100 railroad workers were killed in Japan. In January 2000, two roadway workers were struck by a freight train and killed in Spain while operating a crane under very low visibility conditions due to dense fog. In November 1999, in Boston, the latest T-line train - that happened to be unusually delayed - killed a roadway worker who was not aware of this delay.

There are also accidents due to disorientation of the roadway worker. One is the case of a roadway worker that had asked the dispatcher for appropriate protection to work on a track that he was not really occupying. He was working unprotected on the wrong track, because he was unaware of this.

Some other accidents are due to the abuse of current means of communication. One is the case of a work crew who had heard over the radio that another crew was working under protection some miles down the same track. Not following the rules, they did not call the dispatcher for protection. They monitored the radio just in case the other crew finished their job and gave the track back to the dispatcher. They were misusing the party line feature of radio communication. The fact was that the second crew had finished their job and had given the track back to the dispatcher using an acceptable regular phone call, not the radio. The first crew never heard that the protection was removed and got hit by a train.

Some, not all, of these accidents may have been avoided if the crews had had real time information about train location. The accident due to wrong orientation in the track could have been avoided if the roadway worker had carried a positioning device (such as a GPS receiver) that would have sent his/her exact location to the dispatcher center. The accident due to the misuse of another crew’s protection may have been avoided if the crew had had real time information about what track was out of service.
Dispatchers know near real-time information about train location. We propose giving this information to the work crews in real time. For this purpose we recommend data link technologies.

1.3 Previous work

This project is included in a program conducted at Volpe National Transportation System Center, sponsored by the Federal Railroad Administration’s Office of Research and Development, whose goal is:

"To explore the information flow in railroad operations and look for potential uses of new information technologies in order to enhance safety in railroad operations. In particular, the use of data link has been proposed as an alternative communication medium to supplement voice radio."

Earlier studies had looked at data link potential from the point of view of the dispatchers (Malsch, 1999 and Basu, 1999). Results were encouraging. Messages intended to convey detailed information were more accurately transmitted using electronic communications. Dispatchers liked the idea of data-link technologies. They valued the fact that they could receive requests from trains or work crews in an e-mail like fashion instead of radio calls that had to be answered in a first-come first-serve basis. With this architecture, they could assign priorities to incoming messages and deal with the most important ones first. They enjoyed not having to repeat a message many times due to low quality radio transmissions, and welcomed a system that helped to solve the radio congestion problem.

Another study started looking at the data-link potential from the roadway worker’s perspective (Oriol, 2000). A first prototype was designed: the Personal Information Device (PID), using a Palm VII™ organizer. The PID was evaluated, and results were encouraging. Digital interactions between dispatchers and roadway workers, although slightly slower, were more accurate than the same interactions over the radio. That study was our starting point for this project.

1.4 Overall objective

This project, included in the above-mentioned program, aimed at understanding the roadway workers’ cognitive tasks and interactions with dispatchers so as to design a new handheld electronic aid for them.

Given the encouraging results that Oriol obtained with his above-mentioned PID (see Oriol, 2000), we decided to design a second prototype derived from this first device. Our objective was to find out what could be improved on the PID and what functionalities could be added. In particular, we wanted to examine the possibility of adding GPS functionality into the device and its impact on human performance.

We first wanted to conduct a roadway worker’s Cognitive Task Analysis, then design a new prototype and finally evaluate it.
2 IDENTIFYING ROADWAY WORKER USER REQUIREMENTS

This section describes the communication related tasks performed by several types of Amtrak roadway workers and dispatchers, and the information requirements needed to support those tasks. It completes Oriol's Cognitive Task Analysis (Oriol, 2000). New data were collected through focus groups and observation sessions.

2.1 Methodology

Observation sessions

We did two track car rides with Amtrak track inspectors in Autumn 2000. Both of them were on the Boston/New Haven line: the first one from Cove, MA to Plains, MA, and the second one from Kingston, RI, to Transfer, MA. We could observe the way track inspectors work, the way they interact with dispatchers, and ask questions informally.

We also spent an afternoon at the Central Traffic Control Center, Boston, Massachusetts and observed dispatchers at work.

Focus groups

We conducted two focus groups with dispatchers at the Central Traffic Control Center, Boston, Massachusetts in Autumn 2000. The goal was to focus on the interactions they had with roadway workers, and to get some feedback on our prototype. The sessions lasted 2 hours each. We had two participants for the first focus group, three for the second. All of them were professional Amtrak dispatchers from the Boston division – North East Corridor. Three of them had less than 3 years of experience, one 13 and, one 26. There were two parts in each focus group: the first one was about interactions between dispatchers and roadway worker in general, and the second was about the prototype, after a demonstration (see Prototype Evaluation for the results of the second part). We tape-recorded the sessions. See Appendix F for the list of questions.

2.2 Information exchanged between roadway workers and dispatchers

All the information is currently exchanged mostly over the radio and occasionally over the phone. We identified two types of messages exchanged between dispatchers and roadway workers. The first type includes those messages following a protocol governed by operating rules that everybody must follow. We called this type a structured message. The second type includes all other messages and was called an unstructured message. Examples of each message type are listed below:

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 transmitted. But 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 the different kinds of structured messages:
1. Movement permit Form D and additions to Form D.

According to the operating rules (NORAC operating rules, 1999), “the dispatcher issues Form D’s to restrict or authorize movements. Form D’s are also issued to convey instructions not covered in the Operating rules”. Although Form D’s are mainly designed to be sent to trains, according to one of the interviewed dispatchers, 90% are issued to work crews and only 10% 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.”

There are two main kinds of Form D. The first one is called “Form D Line 4”. It is used to take a track out of service. The track section is written on line 4, whereas lines 2 and 3 are not used (see Appendix E for a Form D copy). The second one is called “Form D Line 2 and 3” and is used by track cars and some other mobile equipment. It gives authorization to move on a specific track from a specific point to a specific point, in a specific direction (those parameters are written on line 2). Eventual trains or track cars ahead are indicated on line 3, as well as stop signals that the track car is allowed to pass.

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

A more detailed description of a Form D is given in Appendix E. See NORAC operating rules for a full description of Form D.

2. Foul Time.

A qualified roadway worker whose duties will not disturb the track or catenary structure may receive verbal authorization to foul the track (Foul Time) from the dispatcher. Granting Foul Time (also referred to as track and time) to roadway workers has become a major part of a dispatcher’s job. Depending on the territory under consideration, a dispatcher may easily have three to seven active Foul Times in his/her or her territory at the same time. This is why Foul Time is actually written in a standard form. See NORAC operating rules for a full description of Foul Time.

3. Rule 241 authority to pass a stop signal.

Rule 241 authority is used to let trains or track cars pass a stop signal. It is issued most often to track cars since they need this authorization to enter each interlocking. Almost every time a Form D line 2 (permission to operate a track car) is issued, it is followed either by a Form D line 3 (track car proceed past stop signal) or a rule 241. Which authority to pass a stop signal is issued to the track car depends on the dispatcher’s preferences. See NORAC operating rules for a full description of rule 241.

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.
Non-structured 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 very often.

Dispatchers also spend much time relaying information, between a roadway worker gang and the foreman, or between different gangs.

Another type of interaction between dispatchers and roadway workers occurs while the latter are already working under protection. Dispatchers frequently ask work crews about details on time restrictions. How long will it take to remove equipment from the track is a frequently asked question. Dispatchers also ask for details about a job being performed on the track. This information gives them an idea about time restrictions as well as about availability of the track in case it is suddenly needed 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 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 needs verbal permission to put an interlocking in local mode or to temporarily shut it down. These verbal permissions do not always follow the same pattern and are not very common.

Radio Communication problems

There was a clear consensus among all interviewed persons that the radio is now overloaded. Few channels are used; 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 told us:

“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. Simply because the radios are blocking each other out, and we don’t know it. We can’t tell that this is happening.”

Dispatchers indicated that very often, when they are attending to one request, other calls come on the radio on other channels. Of necessity, these calls get delayed in being answered. But some people call again and again, thinking that the dispatcher is ignoring them, when in fact the dispatcher is aware of them, but attending to someone else on another channel that they do not receive. This situation is mutually frustrating for both the dispatcher and the individuals trying to reach him/her.

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

They also complained that they receive radio communications from other territories such as the New York and Maryland areas. In some instances, train numbers or locations from these communications outside their territory are the same and can create confusion for the dispatcher.
Lastly, at the Central Traffic Control Center at Boston South Station, the phone and radio communication systems bleed through each other, deteriorating the communication quality.

From the roadway worker’s point of view, obtaining work permission can be time-consuming. He/she sometimes has to wait for a channel to be free before calling a dispatcher. Once he/she has requested work permission, he/she must concentrate on the radio permanently to catch the dispatcher’s answer, while some other communications can occur on the same channel. And if any of the structured messages is interrupted, they often have to start all over again.

Finally, the presence of lot of dead spots (where radio communication is blocked) along the tracks is also a big problem.

2.3 Roadway workers’ tasks

Description
Regular 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 Roadway Worker Protection Class whenever a roadway worker wants to perform a job in the track, he/she needs to go through the following steps:

1. Collect information.
   - Identify milepost number.
   - Identify track numbers.
   - Identify the type of territory.
   - Identify what dispatcher 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 of the work procedure, the roadway worker must read the schedule and territory information from the Operating Rules book. This book only contains scheduled passenger trains. Unscheduled trains (freight, work extras, etc.) and commuter trains with higher frequency are not shown in the book. The railroad worker needs updated information about the location of all the trains that could interfere with his/her job so he/she calls the dispatcher for schedule updates and for nonscheduled train information.

In step 2 and 3, the roadway workers use structured messages described above.

There are also roadway workers whose only duty is to protect other members of the crew. These are called flagmen. They are employees 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, and are engaged solely in performing that function. They also follow the steps described above.
Finally, some roadway workers are assigned exclusively to signal others of the approach of a train. These are called gang watchmen. They do not do anything but watch constantly for coming trains, and they must not be disturbed in any way.

**Known problems**

Besides the radio communication problems described above, roadway workers are confronted with more specific problems.

Disorientation is one of them. One roadway worker reported he had once lost the north direction, so he could not figure out which of the two tracks was track 1, and which was track 2. This disorientation can lead to critical mistakes, such as asking for work permission on the wrong track, or watching for eventual approaching trains in the wrong direction.

Another problem is the presence of unscheduled trains (such as freight trains or work engines) and delayed ones. Roadway workers always have to ask the dispatcher about them before asking for a work permission (see above step 1). But they are often very used to the regular schedule, so they sometimes rely on their memory (or time tables) to know if a track is available, forgetting about possible unscheduled trains, and foul the track without permission.

Some roadway workers also rely on information overheard on the radio to “steal time”. For example, roadway workers might go to work on a track without asking the dispatcher if they have heard that the track has already been taken out of service by another crew. The main problem here is that the dispatcher is unaware of their presence, and will put the track back on service as soon as the first crew is done. But if the roadway workers stealing time miss the work permission cancellation on the radio (or if the other crew use the phone to cancel the work permission), they expose themselves to serious danger.

Finally, roadway workers sometimes leave their work sites forgetting to cancel their work permission.

### 2.4 Track Inspectors’ tasks

**Description**

The inspector is in charge of inspecting the tracks (track alignment and settlement). They request movement authority (Form D Line 2 and 3), to operate on a specific track section. They must call the dispatcher each time they have cleared an interlocking. When a train comes along on the adjacent track, the track car needs to stop (by law), and turn off headlights (by courtesy).

Track inspection consists in monitoring:

- Ties, rails, clips, track surface, ballasts.
- If one rail is lower than the other.
- Drainage problems where mud spots develop.
- Broken rails.
- Missing clips or rail fasteners or loose bolts.

It is a job with a great deal of responsibility since one is personally liable for a mistake (potential large fines and jail time). On the track between Boston and New Haven, each track is inspected
twice a week and a report is written after each inspection. A typical track car ride takes 4 to 6 hours. Some of the track cars are computerized and perform automatic measurements, but most are not.

Table 1 describes the actions taken for problems of different importance.

**Table 1 – Problems on the tracks**

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<thead>
<tr>
<th>Problem importance</th>
<th>Track Inspection Action</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Minimal</td>
<td>Fix it yourself</td>
<td>Stone on the track</td>
</tr>
<tr>
<td>2 - Moderate</td>
<td>Write in daily report</td>
<td>Missing clip</td>
</tr>
<tr>
<td>3 - Serious</td>
<td>Put a speed restriction</td>
<td>Bent rail</td>
</tr>
<tr>
<td>4 - Critical</td>
<td>Remove track from service</td>
<td>Broken rail</td>
</tr>
</tbody>
</table>

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 a rulebook called MW1000 (a book of inspection rules and tolerance levels) that contain tables to assist them in figuring out the actions to be taken. For example, if a rail is bent an inspector will measure the curvature, then look in the book for the right table and determine the speed restriction to apply. The rulebook will also specify how many miles away from the problem the signs should be placed.

For serious problems, an inspector puts the right speed restriction signal at the right distance, and then calls the dispatcher to inform him/her of this speed restriction. The dispatcher will then relay this information to the trains.

For critical problems, an inspector calls the dispatcher and asks him/her to remove the track from service.

**Known problems**

Track car drivers mentioned that errors could happen. “One can get distracted... can get comfortable and lose track of things” said a track inspector.

Track inspectors sometimes are confused about where they are. We heard of a case where a track inspector worker thought he was a one interlocking (Forest) when actually at another interlocking (Cole at Plains) – both interlocking are at bridges. Most of these errors could be avoided using a GPS.

Another kind of error is being somewhere where they think they have work permission, whereas the work permission was for another place. It seems that being on the wrong track (at a given mile post) is a more common error than being at the wrong location entirely (at the wrong milepost/interlocking etc.). Some of these errors could be avoided using a GPS.

Unscheduled trains also pose a problem for track car drivers. For safety reasons, a track car driver has to stop whenever a train is coming on the adjacent track, so he/she appreciates being warned. A “nice” dispatcher will alert a track car driver if an unscheduled train is approaching on the adjacent track.
2.5 Dispatchers’ tasks

Overview

Dispatchers are in charge of routing the trains. They command signals and switches from the dispatcher center. Their most important responsibilities are to insure safe movement of trains and personnel on the tracks, insure that passenger trains meet schedules and, in case of emergency, coordinate rescue missions.

We focused on fully equipped territories, where dispatchers get automatic indication of the location of the trains (unlike in dark territories). The existing train location system uses track circuits that trains shunt (activate) at the entrances and exits of blocks and interlockings. 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 within a block from the train’s speed and the time it entered the block. Some trains are GPS-equipped, but the GPS information is not currently integrated in the main computer system. Dispatchers could retrieve this information using another system, but they do not generally do it.

In Amtrak territory from Boston to New Haven, 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 permissions. Each dispatcher has his/her own computer from where he/she can command the switches and signals. This computer also displays an external representation of the track called a track chart (see Figure 3). Track charts use scale compression extensively to display more details around crucial points such as stations and interlockings. They do not take tracks’ curves into account. The following color code is used:

- White indicates that the track segment is available for routing trains or other uses.
- Green indicates that the track segment has been cleared for train routing. When a train reaches that portion of track in the designated direction it will automatically have clear signals to go through.
- Red means “train or track vehicle Occupancy”. There is a train in that block.
- Blue indicates that that section of track is blocked for track maintenance. This means that that portion of track has been sectioned off for a specific purpose, such as to protect maintenance of way crews or other activities that are not automatically detected by the automatic block signal system. Trains cannot enter a blocked segment of track unless authorized by the roadway worker given authority for that block.

![Figure 3 - Track chart display](image-url)
Although dispatchers interact with both train crews and roadway workers, we are focusing on the interactions between dispatchers and roadway workers.

**Interactions with roadway workers**

Along the territory managed by Amtrak between Boston and New Haven, interactions between dispatchers and roadway workers are extremely frequent. Among all the dispatchers’ radio and phone communications, about 90% are with roadway workers and track cars. “They call every two minutes all day long” said one dispatcher.

When a dispatcher receives a request for protection from a roadway worker he/she usually follows the same steps. Right after the request has arrived, the dispatcher has to decide whether or not to grant it. Usually, he/she should grant it only if it does not delay any train. With experience this thought process does not usually last long and the main criteria are the schedule and the current delays of the trains.

Assuming that the dispatcher has granted permission to work (under Foul Time, Form D or verbal permission) he/she must block the track where the roadway worker is going to be. At the Traffic Control Center, blocking a track protects the roadway worker since it prevents the dispatcher from routing trains on that track. At the job site, it is like applying a blocking device (see glossary) to the switches and signals that control access to the track. Operation of these switches will be restricted and the blocked track will show stop signals in both ends in such a way that no track vehicle may enter it. 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 roadway worker wants to change the state of a switch, he/she can do it either by using the switch local mode or by calling the dispatcher and asking him/her to do it. This is a very common request. Dispatchers have to unblock the track, reverse or normalize the switch and then block the track again because it still is under the authority of the work crew.

While the roadway worker is doing his/her job, he/she may interact with the dispatcher. These interactions include further permissions, speed restrictions submitted by work crews to the Traffic Control Center and mostly updates on train location.

Once the job is done and the roadway worker gives the track back to the dispatcher, it has to be unblocked.

**Interaction with track cars**

Track cars require attention because most of the time, they do not shunt (activate) the track circuits used to detect the presence of trains. Therefore, dispatchers cannot know where they are. So all dispatchers know is that a track car is (or should be) somewhere within its Form D track section. Track inspectors ask for movement permit Form D Line 2 and 3, which allow them to move in a specific direction within a specific track section.

Track sections can be very long (a few tens of miles), and track cars usually travel very slowly. The one used for track inspection, for instance, has a maximum speed of 30 miles per hour. Moreover, track car drivers frequently stop to do some work or inspection on the tracks, therefore it is very hard for dispatchers to estimate a track car’s position.

But the dispatchers need this piece of information very often (for instance to know when they will be able to get the track back, to anticipate next moves, etc.). That is the reason why dispatchers and track car drivers communicate almost constantly. Track car drivers have to call
the dispatcher when they have cleared an interlocking, and dispatchers call track cars very often to know their positions. On the Boston/New Haven line, track inspectors know their milepost thanks to signs on the catenary poles.

**Difficulties**

Many factors make the dispatcher's job difficult. In general workload, attention and memory demand are high.

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 outside the area controlled by the dispatcher center. Lastly, a lot of knowledge is required that is not readily available from workstation displays (speed limits, characteristics of trains, etc.).

Another difficulty is that the track display does not take physical characteristics of the track into account (curves, grade crossings, roads in the neighborhood of the tracks etc.). Dispatchers often have troubles visualizing the physical layout of the tracks and surrounding geography. This can be a major problem in an emergency.

More detailed information about dispatchers' tasks can be found in Roth and Malsch, 1999.

### 2.6 Towards a prototype design

**Use of wireless data-link technology**

Given all the problems encountered with the radio, shifting some radio communication to another media seems necessary. The superiority of data-link technology over the radio for long structured messages has already been noted (Malsch, 1999). Congestion problems would be solved. A wireless handheld device carried by roadway workers could provide this data-link. Here are the functionalities that could be implemented.

- Roadway worker's side
  - Ability to query a real time train database that would include unscheduled trains and take delays into account. With such functionality, roadway workers would not need to look in timetables anymore and ask the dispatcher about unscheduled trains before requesting a work permission.
  - Ability to request and cancel electronically both Foul Time and Form D's.
- Dispatcher's side
  - Access to the requested work permissions, the active ones, and the cancelled ones.
  - Ability to grant or refuse a requested work permission. Requested work permissions should appear in a stack, so as to allow the dispatcher to process them one by one.

**Use of positioning technology**

Our Cognitive Task Analysis clearly showed that a positioning device would be useful to solve disorientation problems and location errors. It seems that a technology accurate enough to differentiate adjacent tracks would be better.
The location of roadway workers should be available to both the roadway workers themselves and the dispatchers (tracking functionality). The position tracking functionality would enable the dispatchers to make sure that every roadway worker is at the right place, that nobody is stealing time or has left without canceling his/her work permission. Global roadway worker safety should be enhanced. The tracking functionality would also be very useful for track cars, which do not shunt the track circuits. It seems that such tracking information should be displayed both on track chart style maps (to be compatible with current displays), and usual 2D maps with the surrounding geography (to give dispatchers more information about the physical layout of the tracks, and to better coordinate rescue missions).

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 whenever a train is coming on an adjacent track. Gang watchmen, who are constantly watching for coming trains, or track car drivers, who have to stop each time a train is coming on an adjacent track, would probably appreciate that. Another useful system could automatically alert a track car driver when he/she is about to approach the location where permission to travel ends. This would prevent cases where he/she goes past where permission has been granted because of a brief mental lapse.

**Inspection applications**

Our Cognitive Task Analysis showed that track inspector could use an electronic aid. A handheld device could support the inspector in recording problems, determining tracking severity of problems over time (how does it compare to the recorded value the last time the inspection was conducted) and determining whether safety violations have been exceeded and actions need to be taken. The location information (provided by the positioning device) could be automatically attached to any recorded problem, to make sure the problem is accurately localized.
3 SELECTIVE REVIEW OF WIRELESS DATA-LINK
AND POSITIONING TECHNOLOGIES

Given the requirements we identified for our prototype we had to choose a wireless data-link technology and a positioning technology. Before making a choice, we did a review of State-of-the-Art technologies. The results are given in this section.

3.1 Wireless data-link technologies

*Wireless Internet*

Several technologies enable wireless connection to the Internet.

**Regular PPP connection through a wireless modem**

The handheld device establishes a PPP (Point to Point Protocol) connection to an Internet Service Provider through a wireless modem (internal or external), exactly as a PC would do. This is the technology that is being used by most PDAs (and very few cell phones) to connect to the Internet. Once connected, the device has access via TCP/IP to the usual hosts and service on the Internet, such as regular e-mail, standard HTTP web browsing, etc.

Nevertheless, the modem connection speeds are slower than what people are used to these days. A typical PDA connection speed is usually in the neighborhood of 9,600 to 14,400 bps. One can expect this to improve in the future. The second challenge is that web pages are designed for regular desktop PC’s with their big, color monitors. PDAs of course have tiny screens, which are usually gray scale (no color). That is changing too – 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. The main difference is that now the client is not the mobile device itself. There is an intermediary between the device and the Internet: the WAP gateway (Figure 4). This gateway translates mobile device requests (WAP requests) into HTTP requests, and redirects the web-server’s HTTP responses to the mobile (again, through WAP).
This technology is being used extensively by cell phones. Navigating normal Internet pages with a cell phone would be difficult. Cell phones do not have a mouse (like a PC) or a stylus (like a PDA) to point and click with. So a part of the WAP standard outlines how to design special WAP Internet pages that are cell phone friendly. These pages are written in WML (WAP Markup Language) and can be accessed and navigated using the numbers on the phone keypad and other standard cell phone buttons. WAP Internet pages cannot be viewed in a normal web browser. And a cell phone cannot view the HTML pages one finds on traditional Internet 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 5). 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.
Short Message Service (SMS)

Short message service is a 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. Messages must be no longer than 160 alphanumeric characters.

SMS is a reliable, low-cost communication mechanism for concise information. It is ideal to deliver notifications and alarms.

3.2 Positioning technologies

Global Positioning System (GPS)

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites around 11,000 miles up in space and their ground stations. Today, GPS receivers have been miniaturized to just a few integrated circuits and so are becoming very economical. This makes the technology accessible to virtually everyone.

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 one could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from earth or moving at an impossible velocity) and can be rejected without a measurement. In fact, we will see in the next paragraph that we do need a fourth measurement, 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 almost 200 miles of error. This is the reason why the satellites have atomic clocks on board. GPS receivers do not use atomic clocks because they are much too expensive (between $50K and $100K). 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 very accurately. 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 DoD 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 US 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 accurate weapons. 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 the system accuracy. First the speed of light is only constant in a vacuum. The GPS signal gets slowed down a bit when crossing the ionosphere and the troposphere. Second, when it gets down to the ground, the signal may bounce off various local obstructions before it gets to the receiver. Third, some tiny inaccuracies remain in the satellite atomic clock and in its estimated position. Due to all these errors, today the GPS is accurate to about 20 meters.

**Differential Global Positioning System (DGPS)**

The Differential Global Positioning System (DGPS) is a technology that enables elimination of 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 we travel here on earth are insignificant. Therefore if two receivers are fairly close to each other (say within a few hundred kilometers) 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. They figure out 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 own 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 public agencies (The United States Coast Guard, the FAA Wide Area Augmentation System for example) now broadcast corrections that one can use for free. DGPS accuracy, can reach 5 meters in moving applications and in some cases even less, depending on the distance from the differential beacon.

**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 main drawback is that the mobile units do not know their position precisely.

**Cell phone location technologies**

Many mobile network-based technologies to locate cell phones are available on the market. When the user gives 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 database 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 that include tall buildings and other obstructions.

Accuracy varies a little from one technology to another, but is usually around only a few tens of meters.
**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 4 meters in an open site), and most cost-effective wireless device location technology. SnapTrack enabled cell phones are expected on the U.S. market in autumn 2001.
4 DESCRIPTION OF THE CURRENT PROTOTYPE

This part describes briefly our system functionalities and justifies the choices we had to make. More technical details can be found in Appendix A: System Architecture.

4.1 Overview

We developed a prototype handheld electronic aid for roadway workers (and track inspectors). According to the requirements we identified in the previous section.

Our application was developed on a Qualcomm® pdQ™ Smart Phone connected via its serial port to an Axiom Smart Antenna GPS receiver, a dispatcher terminal and a web server (currently the Volpe National Transportation Research Center web server), as diagrammed in Figure 6. The phone is able to connect to the Internet via an integrated wireless modem and to communicate with the web server. The dispatcher terminal communicates with the server through a standard web browser. The mobile elements (cell phone and GPS receiver) are light and small enough to be carried easily by roadway workers.

We did not build this system from scratch, but extended the Personal Information Device (PID) system designed by Oriol that initiated this project (see Oriol, N. 2000). The PID handled work permission requests and cancellations, as well as train database queries. We added a positioning functionality, and a two-way communication functionality.
4.2 The Personal Information Device's functionalities

Overview

This section briefly describes the Personal Information Device that began this project. A complete description of the PID can be found in Oriol, 2000. At that time, the handheld device was a Palm VIITM. We have now upgraded to a Qualcomm® pdQ™ cell phone (see next paragraph) but the PID's functionalities described in this section are still available.
Roadway worker's side

The handheld device enables a roadway worker to perform two kinds of actions: request information about trains and territory and request work authorization. He/she accesses to these functionalities via a main menu (see Figure 7), clicks on a function, and fills a corresponding form (see examples below). Then the handset connects to the Internet (if not connected already), queries the server and receives an answer (either the information required or a “Please Wait” message if the request involves a dispatcher).

<table>
<thead>
<tr>
<th>Train and territory information</th>
<th>Territory Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train status</td>
<td>Train OS (WS)</td>
</tr>
<tr>
<td>Train OS (ID)</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7 – Main menu**

Database requests

The PID could enable a railroad worker to get real time information about trains by querying the company real time database. Since we do not have access yet to Amtrak’s database, we implemented our own on the Volpe server based upon the Boston/New Haven train timetable. This database can be updated to take the delays into account via a database manager interface. The handheld device 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 8 and Figure 9 show how a train On Sheet (timetable) can be obtained, given a working site and a time window:
Work permission requests

The PID’s software also handles the work permission requests and cancellations (for both Foul Time and Form Ds) by allowing the roadway workers to communicate with the dispatcher through a web interface. Here are the several functionalities:

- Work permission requests for a specific track section and time window (need a dispatcher).
- Work permission cancellations (automatic).
- Ask what work permissions you own and their status (automatic).
- Ask if any work permissions are active on a specific track section (automatic).

Dispatcher’s message console

The dispatcher’s message console communicates with the server through a standard web browser. It displays all the work permissions requests in a stack, and enables the dispatcher to accept or reject them. It can also display all the active work permission and the rejected or canceled ones.

Here is an example of the way Foul Time can be granted:
The roadway worker fills a form with all the Foul Time parameters (track number, track section, time window), as in Figure 10, and sends the request. Then he/she receives a message that tells him/her to wait for the dispatcher to answer (Figure 11).

![Figure 10 – Foul Time request (roadway worker screen 1)](image1)

![Figure 11 – Foul Time request (roadway worker screen 2)](image2)

![Figure 12 – Foul Time request (dispatcher screen 1)](image3)
The dispatcher sees the request appear in the “Requested Foul Time” frame (Figure 12). Then he/she can either deny it or grant it. If he/she chooses to grant it (as in the example), he/she has to repeat all the parameters (for safety purposes) and send the response.

Figure 13 – Foul Time request (roadway worker screen 3)

Figure 14 – Foul Time request (roadway worker screen 4)

Then the roadway worker receives a message that summarizes the Foul Time granted by the dispatcher (Figure 13), and has the possibility to accept it or refuse it. If he/she accepts it (as in the example), he/she receives a confirmation message (Figure 14).
Finally, the dispatcher sees the Foul Time disappear from the “Requested Foul Time” frame, and move to the “Active Foul Time” one, where it stays until cancellation (Figure 15). He/she can access this Foul Time information anytime.

**Evaluation**

The PID was evaluated and results were very encouraging (see Oriol, 2000). Ability to receive real time information about train locations seemed to greatly improve the roadway worker’s situation awareness. Structured digital interactions between roadway workers and dispatchers, although slightly slower, were more accurate than the same interactions over the radio.

### 4.3 Two-way communication functionality

One of the first prototype’s main limitations was that it was a one-way communication system. The Palm VII always had to initiate a communication. The dispatcher had no way to reach a roadway worker. For example when a work permission request was sent, the roadway worker had to check periodically if the dispatcher had answered him/her. Two-way communication wireless devices are now available on the market: the Short Message Service or SMS (see Selective Review of Wireless Data-Link and Positioning Technologies) provides us with a way
to reach the handheld device from the web. That's why we decided to upgrade our system with a mixed SMS/Wireless Internet handheld device.

Here are the new functionalities that SMS enabled us to implement:

- 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.

SMS devices are usually cell phones. Most of the roadway workers already carry a cell phone to communicate with dispatchers using normal voice communication. Upgrading our system with an SMS-enabled cell phone would enable them to carry only one device.

4.4 Positioning functionality

Selecting the technology

Our Cognitive Task Analysis showed that a positioning technology would be very helpful, both for the roadway workers to know where they are, and for the dispatchers to track them (see Identifying Roadway Worker User Requirements).

We had to choose one technology among those available on the market (see Selective Review of Wireless Data-Link and Positioning Technologies). According to our CTA, a technology accurate enough to determine which track one is on would be useful. Nevertheless, this goal seems hard to achieve at this moment, because:

- Adjacent tracks are very close to each other (about 4 meters), which means we would need a 2-meter accurate technology. Today, only DGPS with a close base station achieves this accuracy.
- To determine which track one is on from latitude and longitude one needs very accurate track profile files.
- A roadway worker is likely to move from the track he/she is working on, and the system might conclude that he/she is working on another track, unless he/she leaves the handheld device on the track.
- The technology would have to be very reliable, since a track error could lead to a fatal accident.

We decided to build a prototype using standard GPS technology (that is not accurate enough to know which track one is on), keeping in mind that upgrading to differential GPS (or Inverted DGPS) was an option. That's why we chose a differential ready GPS receiver (see paragraph).

SnapTrack's cell phone location technology also seemed very attractive (see Selective Review of Wireless Data-Link and Positioning Technologies), but we could not afford to wait for this product to be commercially available (in fall 2001).

Here are the functionalities that GPS enabled to develop:
**Graphic map display**

An application is able to display a simple map of the roadway worker's surrounding based on the GPS information (Figure 16). The speed and direction are also displayed. This feature has not yet been evaluated though.

![Graphic map display](image.png)

*Figure 16 – Graphic map display*

**Tracking functionality**

We developed software to track roadway workers, both Maintenance of Way workers and track cars (which do not shunt the tracks). This software is intended for the dispatcher. It is essentially a Java applet that runs on his/her computer and queries our web server.

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 via the Internet (the period can be changed, we performed a test with 1 minute and 5 minute periods). Then the dispatcher terminal retrieves this information and displays:

- 2 dimensional real time maps with each track car and railroad worker's position (Figure 17). This is useful as the dispatcher sometimes has trouble to visualize the physical layout of the track and surrounding geography (see Cognitive Task Analysis). 2 dimensional displays are also useful in case of emergency, to determine the shortest way to reach a point on the tracks, the nearest cities, hospitals, fire stations etc.

- 1 dimensional real time maps along the track with each track car and roadway worker's position (Figure 18). 1 dimensional maps are closer to the external representation of the tracks that dispatchers already use (track charts, Figure 3), and therefore to the mental models they build.
Figure 17 – 2 dimensional tracking display example
The two kinds of displays have many features in common:

- Possibility to display previous locations
- By right-clicking on a point, you can:
  - Send an SMS to the roadway worker.
  - Get some more information about the point (roadway worker's name, location report time, validity, latitude, longitude, mile post).
  - Access the complete roadway worker's location file where all the previous locations have been stored.
  - Get a local 2D map from Mapblast.com® based on the latitude and longitude.

The 2D display has not been evaluated yet, but it is designed to work with a map database in GIF format. The maps should cover the whole track, with more precise maps at important points.

The 1D display handles zooming and navigating along the track.

We also thought about integrating the tracking data into the current track chart display that dispatchers use (Figure 3). Here are the two reasons why we did not do it:

- Track chart displays differentiate the adjacent tracks and so far, our positioning technology (GPS) is not accurate enough to determine which track one is on. Therefore, a roadway worker should appear on the display on all adjacent tracks of a same branch, which might be confusing for the dispatcher.
- Track chart displays use scale compression extensively. They are far more detailed around interlockings and stations, where an uncertainty of 20 meters (which is what we have with GPS now) would result in a confusing blotch on the screen.

If the system were to be upgraded to DGPS though, it might be a good idea to integrate the tracking data to the track chart display.

4.5 Selecting the hardware

**Handheld device**

As we noted above, we decided to use a mixed SMS/Wireless Internet handheld device. We also needed a device with a serial port to plug the GPS. Among the devices available on the market, the Qualcomm® pdQ™ Smart Phone seemed to be the most interesting, because:

- It has a huge touch screen (for a phone): 36x12 characters, 1.9x2.4 inches, 160 x 240 pixels.
- It is Palm OS® 3.0 compatible. Palm OS® is becoming a standard in PDAs' operating systems. Many applications for Palm OS® are available on the market. The Palm developer community is huge, and it is easy to get some information and help through books, web sites, and mailing lists.

The pdQ™ establishes a PPP connection to the Internet service provider within 3-5 seconds. Once connected, an application has access via TCP/IP to hosts and services on the Internet. The wireless modem rate is 14.4 kbps.

The main drawback of the pdQ™ is probably its size. Once again, we expect smaller and lighter device on the market soon. We were more concerned about evaluating our concept as soon as possible. The screen is also dimmer and more difficult to read in bright light than the prototype using the Palm VII™.

![Qualcomm® pdQ™ Smart Phone](image.png)

Figure 19 – Qualcomm® pdQ™ Smart Phone
**GPS receiver**

Our GPS applications work with any NMEA GPS receiver with DB-9 output cable (so as to match the pdQ™ output cable). Choosing a unit, we were mostly concerned about the size, the weight, the power consumption, and the differential readiness.

Axiom Smart Antenna GPS receiver appeared to be a good choice: it is smaller than a PC mouse, differential ready, and cheap. See Appendix A for technical specifications.

For the power we used a radio controlled car battery that can power the GPS for more than 10 hours. See Appendix A for technical specifications.

![Figure 20 – Axiom Smart Antenna GPS receiver](image-url)
5 PROTOTYPE EVALUATION

5.1 Overview

To evaluate our prototype, we first demonstrated it to roadway workers, track car drivers, and dispatchers. Their comments are described below.

Then we wanted to conduct an experiment to evaluate our device using objective measures. We first thought of an experiment from the roadway worker’s perspective. Oriol had already evaluated the PID from that perspective using a laboratory experiment (Oriol, 2000). We were mostly concerned about measuring the impact of the GPS functionality and the 2-way communication functionality and thought such functionalities were difficult to test in a laboratory and had to be evaluated in situ. We wanted to design a field experiment to measure how location information and near real time information about nearby trains could enhance the roadway worker’s situation awareness and safety. Unfortunately, we were not able to gain access to Amtrak’s real time train database and track profiles in time. For this reason we decided to conduct a laboratory experiment from the dispatcher’s perspective, using a simulated railroad environment.

Our dispatcher experiment aimed at evaluating how dispatching efficiency and global railroad safety could be enhanced if the roadway workers used our prototype instead of the radio. The experiment is described below.

5.2 Demonstrations and first feedback

Roadway workers

We first demonstrated our prototype at the Amtrak’s Boston Maintenance of Way facility, and got some informal feedback. We demonstrated how a real Train On Sheet (glossary) and a Foul Time could be obtained. Roadway workers seemed impressed. Some of them, nevertheless, usually the ones with many years of experience, regarded the new device as a toy and told us that the concept was interesting but that they would never use it instead of the radio. Younger roadway workers seemed more ready to accept the handheld device.

Track car drivers

We also demonstrated our prototype during a track car ride in the Providence (RI) area. We went from Kingston, RI and Transfer, MA (approximately 60 miles), on the Boston/New Haven line. We demonstrated a Train OS request and the track car driver was impressed to see that the predictions were correct. During all the ride, the location report feature was activated. Figure 21 shows the tracking information on the 2D display (previous locations and report times).
It is worth mentioning that among all the interviewed persons, the tracking functionality produced the same feeling of “Big Brother fear”. Nobody enjoys knowing that somebody else can know where you are continuously. This is true especially because roadway workers are not busy all the time and they often have to wait for an available time window before working on the tracks. It is very important to keep in mind that the location report feature can be switched off.
**Dispatchers**

Two focus groups were conducted with dispatchers (see Identifying Roadway Worker User Requirements for the methodology). We focused on the interactions between dispatchers and roadway workers (in particular track car drivers) and on the use of the new device in that context. We demonstrated a few features: a Train On Sheet request (glossary), a Foul Time request, the tracking displays.

Global feedback was positive and dispatchers showed great enthusiasm. They welcomed a device that would reduce the radio congestion. Most of them enjoyed the tracking functionality and thought it would enhance global safety on the tracks. They thought both 1D and 2D displays were useful. They saw the most benefit for track cars, which do not shunt the tracks. They especially enjoyed the fact that it is possible to contact a roadway worker via SMS by right clicking on a point on the tracking display.

Some of them, nevertheless, thought that knowing where all the workers were on the tracks was just too much responsibility for the dispatcher, whose job is already very demanding.

One of the main concerns was who should have the device on the tracks. Everybody agreed that all the roadway workers in a same gang would not need to have it. For sure the foreman would need one. But sometimes the foreman is physically far from the gang(s) he is protecting. So we concluded that also at least one additional person in each gang should carry the device.

One other concern was the suppression of the party line aspect (ability to overhear conversations over the radio). Some dispatchers regarded the party line aspect as dangerous, since it enables roadway workers to work on the track without work permission. Those dispatchers even thought that our prototype’s functionality that enables a roadway worker to see other people’s Form Ds was deadly. But for some other dispatchers, the party line aspect has many advantages. For example if a crew takes a track out of service and if a second crew is aware of that and wants to work on the same track, the second crew member will directly contact the first one, so the dispatcher will not have to relay information. And those dispatchers asked us if we could add a functionality that would allow a dispatcher to send a Form D to a foreman while carbon-copying other people (that is definitely doable).

Some dispatchers were concerned about the fact that the ability to query the train database might empower the roadway workers too much, to the point that they would think they would not need to speak to the dispatcher anymore.

Some dispatchers also suggested that the train On Sheet should include the track numbers. That is definitely doable if we create an interface to Amtrak’s real time train database.

**5.3 Dispatcher experiment**

**Overview**

Our goal was to evaluate our prototype from the dispatcher’s perspective. The main question was how dispatching efficiency and global railroad safety could be enhanced if the roadway workers used our device instead of the radio.

The experimental subject was in charge of routing trains on a dispatcher simulator and dealing with roadway workers using either the radio (“Radio Experiment”), or the message console and the tracking display (“Device Experiment”). Two different scenarios were used.
We played the role of roadway workers and track cars asking for work permissions from another room, using either the radio, or emulated handheld devices. We were assisted by some simulation software (see Appendix B for software description).

**Set up**

We used two separated rooms. The subject played the role of the dispatcher in one room while two experimenters played the role of roadway workers and collected data in another room. Here is an overview of the set up:

![Diagram showing set up](image)

**Figure 22 – Set up (Device Experiment)**

**Dispatcher’s side**

We used the MIT/Volpe Railroad Dispatching Simulator. It simulates a whole railroad environment from the dispatcher’s perspective. The user is in front of a track chart display (see Figure 3), and can clear, unclear, block and unblock tracks. Trains are moving along the tracks and have a schedule to meet. In addition to the conventional map displays, the simulator also includes a message console to communicate with trains and roadway workers, but we did not use it, since we were not interested in the communications between trains and dispatchers and as far as roadway workers are concerned, we used either our own message console or the radio. So only two PCs were used for the simulator. A complete description of the simulator can be found in Basu, 2001.

For the Device Experiment we also used:

1. One PC for our message console (Figure 12).
2. One PC for the 1D tracking display (Figure 18) and a work permission reminder display right below it (for easier comparisons). The work permission reminder display consists in four frames that are just copies of the message console frames:

- Active Form D frame
- Active Foul Time frame
- Cancelled Form D frame
- Cancelled Foul Time frame

For the radio experiment, we also used:

1. A radio
2. Foul Time and Form D sheets (Appendix E).
3. A classifier for cancelled and rejected work permissions (while the active work permission were lying on the dispatcher's desk).

Experimenter’s side

On the experimenter’s side, one PC gave an overview of the tracks (both track chart display and tracking display), and one PC emulated roadway workers. Two experimenters were both collecting data and playing the role of roadway workers.

We developed some specific simulation software to emulate roadway workers. This piece of software can send requests to our web sever exactly the way our handheld prototype would do. Work permission requests and cancellations, as well as GPS location reports can be simulated. The application creates a set of virtual workers that have a list of scheduled tasks to do on the tracks (this list is given in the scenario file), and ask for work permissions. The experimenter can skip some of these tasks, to adapt to the dispatcher’s answers. The application also times the delay between a work permission request and the dispatcher’s response. Technical details can be found in Appendix B.

Experimental design

The independent variables

There were two independent variables:

- **Type of system (R or D):** communication system used in the simulation that is either the radio (“Radio Experiment”) or the prototype device (“Device Experiment”).
- **Scenario number (1 or 2):** we wrote two different scenarios (see below). They were designed to be equally demanding. Therefore they were not expected to have different effects on the dependant variables.

We were interested in comparing the two systems, and not in comparing the dispatchers to each other. Therefore the dependent variables for each system were computed using the total data collected with all the dispatchers.

The dependant variables

During both experiments, two experimenters were collecting the following data from the experimenters’ room:
• **Work permission processing times:** The simulation software measures the delay between the time a work permission (Foul Time and Form D) is requested (i.e., the time the emulated device sends a request or the time a radio communication starts) and the time it is either granted or refused. The result is stored in an output file (see Appendix B for details).

• **Train delays:** Delay with respect to the schedule for each train.

• **Number of track car calls:** (only for the Radio Experiment) we counted the number of times a dispatcher called the track car to know its position. Indeed, the dispatcher sometimes needs this piece of information to know when he will be able to get the track back, to anticipate next moves. Knowing the track car’s position is also useful when a Maintenance of Way crew asks for a Foul Time at a specific mile post in a block within which a track car is moving, and on the same track. The dispatcher wants to know if the track car has already gone past this milepost. We wanted to get a sense of the proportion of calls that could be avoided using GPS.

• **Ability to catch roadway workers stealing time:** (only for the Device Experiment) in the simulation, roadway workers sometimes go on the tracks (i.e., show up on the tracking display) without asking for work permission, or stay even if work permission is refused, or stayed after it is cancelled. We asked the dispatcher to write a note each time this happened, and compared those records with the true number. This is a very simplified way to measure the dispatcher’s ability to catch roadway workers stealing time. It assumes the GPS location report function is activated all day long, and that a roadway worker shows up on the display only he/she is enters the traffic envelope.

• **Ability to catch roadway workers’ mistakes in location:** (only for the Device Experiment) in the simulation, roadway workers sometimes make mistakes in location (i.e., show up somewhere on the tracking display, and ask for work permission somewhere else). We measured the proportion of these mistakes the dispatcher caught.

• **Dispatcher’s errors:** we wrote down all the dispatcher’s errors using the following classification:
  
  o Communication errors:
    
    • Omission in work permission parameters (for instance the subject forgot to say/type the track number).
    
    • Errors in work permission parameters (i.e., the parameters a roadway worker said/typed don’t match with the parameters the dispatcher said/typed).
  
  o Blocking errors:
    
    • Blocking a track section after granting the work permission (the dispatcher was asked to block the track before granting the work permission).
    
    • Blocking a wrong track section.
    
    • Unblocking before the work permission is cancelled.
    
    • Forgetting to block a track section.
- Forgetting to unblock a track section (we counted an error each time the track was still not unblocked 30 seconds after the work permission cancellation).

  - Routing errors:
    - Trains colliding with each other.
    - Trains colliding with Maintenance of Way crews.
    - Trains colliding with track cars.

- **Workload subjective ratings:** we used a subjective rating scale adapted from the NASA TLX (see Appendix D). This scale was given to the subject after each experiment (Radio Experiment and Device Experiment).

**The questionnaire**

We also used a questionnaire (see Appendix C). The first page was given to the subject before the experiment, and designed to evaluate his/her familiarity with computers and GPS. The last two pages were used at the end to ask subjects their feedbacks on the new device (concerns, suggestions, etc.).

**The scenarios**

Two different scenarios were used: Scenario 1 and Scenario 2 (see Appendix B for technical details). Those two scenarios are very similar: Scenario 2 was written from Scenario 1 using permutations over locations and track numbers. Here are the common characteristics:

- Duration: about 1h10.
- One track car (mobile) and 3 Maintenance of Way crews (stationary) involved
- Track car asks for 5 Form D L2,3
- Maintenance of Way crews ask for 21 Foul Times
- Twice a Maintenance of Way crew makes a mistake in location (only in the Device Experiment).
- 6 times a Maintenance of Way crew goes on the track without work permission ("stealing time").

It is worth mentioning that since many events are inter-correlated (see Appendix B) and depend on the subject’s answer (whether he/she grants a work permission) the scenarios led each time to a new story.

To simplify the simulation, the subject 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 to refuse it. No negotiations could take place.

**Procedure**

Each subject spent about 5h30 in the lab. Food and drinks were provided. Here was the procedure:
- **Questionnaire – 0h05:** first page (Appendix C).

- **First Training – 1h30:** The subject is given explanations about:
  - The dispatcher simulator
  - Work permissions
  - One system (device OR radio)
  - Dispatching rules and pieces of advice
  - The scenarios
  - The subject familiarizes with the system during a short practice simulation (about 15 minutes).

- **First experiment – 1h15:** either a radio or a device experiment with either Scenario 1 or Scenario 2.

- **First Workload Subjective Rating – 0h10:** Adapted NASA TLX Rating Scale (Appendix D).

- **Second Training – 0h45:** the subject is given explanation about the other system (device OR radio). Then he/she familiarizes with the other system during a short practice simulation (about 15 minutes).

- **Second Experiment – 1h15:** similar to the first one but using the other system and the other scenario.

- **Second Workload Subjective Ratings – 0h10:** Adapted NASA TLX Rating Scale (Appendix D).

- **Questionnaire – 0h20:** last 2 pages (Appendix C).

The test assignment scheme

We used six dispatchers. Given the two independent variables (Type of system = R or D, Scenario number = 1 or 2), we chose the following test assignment scheme:

<table>
<thead>
<tr>
<th>Dispatcher</th>
<th>R-1 / D-2</th>
<th>R-2 / D-1</th>
<th>D-1 / R-2</th>
<th>D-2 / R-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disp #1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disp #2</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disp #3</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Disp #4</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Disp #5</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disp #6</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

R-1 / D-2 means that we started with the Radio Experiment using Scenario 1, and then did the Device Experiment with Scenario 2.

Such a testing scheme takes two counterbalancing effects into account:
- Half of the dispatchers start with the device, half with the radio.
- Half of the dispatchers start with Scenario 1, half with Scenario 2.

**Participants**

The six participants were professional Amtrak dispatchers from the Boston division – North East Corridor. They were all men. Two were about thirty years old, two about forty, and two about fifty. Three of them had more than 10 years of experience as dispatcher; three of them had less than 5 years of experience.

**Results**

**Work permission processing times**

All the processing times were stored for both Foul Time and Form Ds, for both experiments. It seemed pertinent to distinguish the granted Foul Times from the refused one, as granting a Foul Time usually took more time (essentially because it involves the blocking of a track section). Therefore, we ended up with six categories: granted Foul Times, refused Foul Times, and Form Ds, for both the radio and the device experiments. We had about 50 data points for each Foul Time category and 25 for each Form D category. For each category of work permission, the mean, maximum, minimum, and standard deviation are given below.

We also performed some statistical analysis to compute a $\alpha = 95\%$ confidence interval for the mean. We assumed that the distribution of mean was a Normal distribution. The general formula for developing confidence intervals for the population mean based on a sample is:

$$\bar{x} \pm t_{a/2} (n-1) \cdot \frac{S}{\sqrt{n}}$$

where:

- $n$ is the size of the sample
- $\bar{x}$ is the mean of the sample
- $S$ is the standard deviation of the sample
- $t_{a/2} (n-1)$ is the interval coefficient providing an area of $a/2$ in the upper tail of a $t$ distribution with $(n-1)$ degrees of freedom, which can be found from a $t$ distribution table.

The results for each category are shown below.

<table>
<thead>
<tr>
<th>Table 3 – Granted Foul Times’ processing times (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Times (s)</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Standard deviation</td>
</tr>
<tr>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
</tr>
</tbody>
</table>
Figure 23 – Granted Foul Times’ processing times

Table 4 – Refused Foul Times’ processing time (seconds)

<table>
<thead>
<tr>
<th>Processing Times (s)</th>
<th>Radio</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>100</td>
<td>175</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>60</td>
<td>111</td>
</tr>
<tr>
<td>Min</td>
<td>28</td>
<td>53</td>
</tr>
<tr>
<td>Max</td>
<td>282</td>
<td>507</td>
</tr>
</tbody>
</table>

Figure 24 – Refused Foul Times’ processing times
Table 5 – Form Ds’ processing times (seconds)

<table>
<thead>
<tr>
<th>Processing Times (s)</th>
<th>Radio</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>170</td>
<td>223</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>71</td>
<td>153</td>
</tr>
<tr>
<td>Min</td>
<td>53</td>
<td>79</td>
</tr>
<tr>
<td>Max</td>
<td>355</td>
<td>803</td>
</tr>
</tbody>
</table>

Figure 25 – Form Ds’ processing times

We first observe that processing times are on average about 1.5 times higher with the device. This is understandable if one considers that all the dispatchers use the radio everyday, and all of them had at least two years of experience. One dispatcher even 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, they had only 1h30 to learn how to use our software, including a 15 minutes practice scenario.

As far as the standard deviation is concerned, it is about 2 times higher with the device. The range is also much wider. There are many reasons for this difference:

- All the dispatchers didn’t have the same familiarity with computers in general (see questionnaire results). Thus some of them were much faster than others using the software, while everybody was about as fast using the radio.
- Each dispatcher was usually faster at the end of the device experiment, because he knew the software better and better. The radio processing times, on the other hand, were about the same during the whole radio experiment.
- Some electronic requests were completely forgotten by the dispatchers. This didn’t happen with the radio since the experimenters would communicate back to the
dispatcher. That’s why the maximum processing times is always high. This is one of the reasons why we are now thinking of implementing audio alarms (see Next Steps).

Train delays

### Table 6 – Train delays

<table>
<thead>
<tr>
<th>Delays (min)</th>
<th>Radio</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>6.5</td>
<td>10</td>
</tr>
</tbody>
</table>

Trains were about twice as much delayed with the device than with the radio. This must be because using some new software was demanding for the dispatcher, and they paid less attention to the trains. The standard deviation was higher, and the range was wider, probably for the above-mentioned reasons.

**Number of track car calls (only for the Radio Experiment)**

We counted the number of track car calls and divided this number by the total number of radio communications. It turns out that in our simulation, track car calls represented about 10% of the total number of communications. These communications could be avoided with the GPS.

**Ability to catch roadway workers stealing time**

In the Device Experiment, dispatchers caught about 40 percent of the roadway workers stealing time. But again, we used a very simplified way to measure this ability. This figure just gives a rough idea about the impact of the tracking display on catching people stealing time.

We expected a slightly higher rate. It seems that the task was too demanding to allow the subject to constantly monitor the tracking display. If such a system were implemented, the territory each dispatcher is in charge of should probably be smaller, to compensate for the increase in mental workload due to the tracking display.

**Ability to catch roadway workers’ mistakes in location**

Among the 12 mistakes that roadway workers made in location (i.e. they showed up somewhere on the tracking display, and asked for a work permission somewhere else), none of them was caught by the dispatchers.

We obviously expected a higher score. The dispatcher was supposed to check a roadway worker’s location on the tracking display before granting work permission, but it seems that this order was not rigorously respected. Again, it seems that the task was too demanding to allow the subject to monitor the tracking display carefully.

**Dispatchers’ errors**

*Error! Reference source not found.* shows all the errors that happened during the experiments.
Table 7 – Dispatchers’ errors

<table>
<thead>
<tr>
<th>Errors</th>
<th>Radio</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication errors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omission in work permission parameters</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Errors in work permission parameters (track numbers, locations, times etc.)</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td><strong>Blocking errors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocking a track section after granting the work permission</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Blocking a wrong track section</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Unblocking before the work permission is cancelled</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Forgetting to block a track section</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Forgetting to unblock a track section</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td><strong>Routing errors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trains colliding with each other</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trains colliding with MW crews</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Trains colliding with track cars</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Digital communications between dispatchers and roadway workers seems much more accurate than the same interactions over the radio. No parameter omission occurred during the Device Experiments, that is, no dispatcher forgot to enter a parameter in the electronic forms. 24 omissions occurred in the Radio Experiments (typically the dispatchers forgot to say a parameter while granting a work permission). Three times as many errors in parameters occurred in the Radio Experiments as in the Device Experiments (i.e. the parameters a roadway worker said/typed didn’t match with the parameters the dispatcher said/typed).

A lot more blocking errors occurred during the Radio Experiments. It seems that using paper copies of work permissions is not as safe as using electronic ones.

As far as the routing errors are concerned, the device seems to be a safer system too.

Workload subjective ratings

Table 8 shows the subjects’ workload subjective ratings, for both the radio and the device experiments. Each variable was rated on a 0-10 scale.

Table 8 – Workload subjective ratings

<table>
<thead>
<tr>
<th>Title</th>
<th>Description</th>
<th>Radio</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>MENTAL DEMAND</td>
<td>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?</td>
<td>7.2</td>
<td>6.2</td>
</tr>
</tbody>
</table>

56
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 permission 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 permissions 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 |

Surprisingly, mental demand seems to be higher with the radio. This might be because radio calls interrupt the dispatcher all the time, unlike electronic requests.

Physical demand is higher with the device, probably because most dispatchers were not used to filling out electronic forms.

Temporal demand is higher with the device. This seems coherent with the fact that work permission processing times (see above) were about 1.5 longer on average with the device.

Dispatcher felt their performance was better with the radio. This is coherent with the train delay results (see above). But they didn’t realize they made fewer communication errors with the device.

Effort and frustration level were higher with the device. Again, this is not surprising since the dispatchers use the radio everyday, but had only 1h30 to familiarize themselves with the software.

Questionnaire
This paragraph gives the results of the questionnaire (Appendix C).

• Computer and GPS background

Table 9 shows the participants’ familiarity with computers and GPS, rated on a 1-5 scale.

<table>
<thead>
<tr>
<th>Familiarity with</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>3.0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>World Wide Web</td>
<td>3.2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Netscape</td>
<td>1.7</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>E-mails</td>
<td>2.5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>GPS</td>
<td>2.3</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>
To summarize, the dispatchers seemed reasonably familiar with PCs and the World Wide Web, but not that much with GPS. None of them had ever used one, neither for private use nor for professional use.

- **About the device**

This section comments the dispatchers’ answers, question by question.

13. **Do you think the new device will reduce the need for communication between roadway workers and dispatchers?**

   In what way?

Five dispatchers out of six answered yes to this question. The main reason was the tracking functionality, which enables the dispatcher to know where track cars and roadway workers are, in particular if they are cleared of all tracks. One dispatcher was concerned about the fact that “sometimes more information needs to be given to people in the field than the device will allow”.

14. **Do you think the new device will improve communication between roadway workers and dispatchers?**

   In what way?

Five dispatchers out of six answered yes, one was uncertain. The main reasons were the ability to process work permissions one by one without interruptions, the suppression of the radio background noise, the printed text aspect, and the fact that a copy of each form was saved on the computer.

15. **Do you think the tracking functionality is useful?**

   In what way?

Six dispatchers out of six answered yes to this question, saying that it would eliminate confusion in location, help the dispatcher plan his/her movements of trains and that always knowing the location of all the workers would be a big plus.

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

The main obstacles they saw were: the loss of “the human element of the person you’re dealing with”, “bringing people up to speed on new technology and their willingness to adapt”, the problem of rule compliance, and the GPS accuracy.

17. **All things considered, do you think the new device will improve the global RW safety?**

   In what way?

Five dispatchers out of six answered yes, one was uncertain. The reasons they gave were that the tracking functionality could enhance the roadway worker safety, there would be less time stealing, roadway workers would always know where they are, communications would be more concise and fewer miscommunications would occur. One dispatcher thought the tracking functionality would be really useful only if accurate enough to differentiate adjacent tracks. One said that safety would be improved, but at the cost of efficiency.
18. Some dispatchers 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?

Five dispatchers out of six answered yes (this specific question referred to a suggestion we had during the focus groups with dispatchers, namely that we were concerned about the suppression of the party line effect with the handheld device). The main reason was that it would save time. One dispatcher, nevertheless, answered no because he was afraid of some people forgetting to clear the tracks on time.

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

The dispatchers suggested four main enhancements. The first one is to use audio alarms whenever new work permission requests arrive, and when they are cancelled. They also thought that the dispatcher should have to confirm the work permission cancellations. They suggested the electronic forms should have more room for additional information: “Everything is not black and white, yes and no”, said one dispatcher. Finally, they really thought a technology accurate enough to differentiate adjacent tracks would be useful. Using such a technology, the tracking information should be integrated in the current displays.

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

The dispatchers said such a system had great potential, and would be standard equipment in a few years, but still needed to be fine tuned a little (and they referred to what they had written above).

Conclusions

Our dispatcher experiment showed that work permission processes were slower but more accurate with the device than with the radio. We believe that the processing times would decrease a lot after more practice.

The tracking display appeared to be useful essentially to localize the track car. Relatively few roadway worker stealing time were caught (40%), and no error in location was caught. The task seemed to be too demanding for the subjects to fully benefit from the tracking display.

Trains tend to be more delayed with the device, but again we believe delays should decrease with more practice.

All the test users showed great enthusiasm and gave constructive feedback. Many asked us if this system was going to be implemented at the Central Traffic Control Center, Boston, Massachusetts, and when. They believed in the device’s potential, even though there was room for improvements (see Next Steps).
6 NEXT STEPS

This section gathers all the improvements we thought of for the device. Most of them were suggested by dispatchers and roadway workers during the observation sessions, the focus groups, and the dispatcher experiment.

6.1 Using a new positioning technology

Our first prototype uses standard GPS technology, which has about 20-meter accuracy. This accuracy is enough to have a good idea of where a roadway worker is along a track, but does not enable one to determine which track he/she is on. We saw that obtaining this information was possible (though difficult), using DGPS technology. Since many dispatchers suggested differentiating adjacent track was primordial (see Prototype Evaluation), we are thinking about upgrading our system.

SnapTrack’s cell phone location technology seems attractive too (see Selective Review of Wireless Data-Link and Positioning Technologies). Snap Track® enabled cell phones are expected on the market in Fall 2001. Using one of them, we would get a much better accuracy (about 4 meters in an open site). Besides, the roadway workers would have to carry only a phone, which would be much better in terms of weight and size.

6.2 Using a new communication device

PDA and cell phone technologies are improving impressively fast in terms of size, weight, and wireless data rates. The Qualcomm® pdQ™ Smart Phone, although the device that best suited our needs at the time of prototype design, is very likely to become obsolete soon. We are following these technologies, and might decide to use a new device.

6.3 Alarms for roadway workers

Assuming we have access to the real time train database, we could develop a SMS alarm application based on the train and roadway worker’s locations, which would let a roadway worker know when a train is about to come on the adjacent track. Today, (see Cognitive Task Analysis), some roadway workers called gang watchmen are in charge of watching constantly for coming trains, engaged solely in performing that function. Developing a reliable alarm system could make this job obsolete.

We could also develop a system that would automatically alert a track car driver about to approach the location where his/her permission to travel ends. Such a system would be useful to prevent cases of going past where he/she has permission because of a brief mental lapse.

6.4 Alarms for dispatchers

The dispatchers who participated in the experiment suggested we could implement audio alarms whenever new work permission requests arrive, and when they are cancelled. With such alarms, they would not have to monitor constantly the message console.
6.5 Work permission processing system

The dispatchers who participated in the experiment have suggested three main enhancements:

- The dispatcher should have to confirm the work permission cancellations.
- Electronic forms should have more room for additional unstructured messages.
- The dispatcher should be able to send work permission to multiple workers.

6.6 Inspection daily report and MW1000 rulebook

Our CTA showed that our handheld device could assist track inspectors in their work (see Cognitive Task Analysis). We could develop an application that would:

- Store the electronic form to be filled out that reports problems observed during track inspection.
- Automatically attach location information to any recorded 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?).

6.7 Graphic map display evaluation

Although the prototype can display a map of the surroundings based on the GPS information (Figure 16), this feature has not been evaluated yet. It would be interesting to look at issues such as:

- Do railroad workers prefer a usual 2D map or a track chart style map of the surroundings?
- What do they want to see (tracks, interlockings, stations, trains, track car, maintenance of way crews etc.)?

What does such a display bring in terms of Situation Awareness and railroad safety?
7 CONCLUSIONS

Our first prototype of GPS-aided communication device for roadway workers has a great potential. Everybody welcomed a system that could solve the radio congestion problem. Digital interactions between dispatchers and roadway worker seemed slower, but more accurate than the same interactions over the radio. The GPS system appeared to have the most benefit to localize track cars.

Some dispatchers, nevertheless, thought that knowing where all the workers were on the tracks was just too much responsibility for the dispatcher, whose job is already very demanding. If such a system were implemented, the territory each dispatcher is in charge of should be reduced, to compensate for the increase in mental workload due to the tracking display.

Roadway workers seemed unequally ready to use new information technologies. Most of them showed enthusiasm but some were reticent about confiding their lives to “our toy”. If such a system were implemented, the training period shouldn’t be overlooked.

Another concern among roadway worker was the “Big Brother fear” due to the GPS system. Nobody enjoys the fact that somebody else can know where you are continuously. This is true especially because roadway workers are not busy all the time and they often have to wait for an available time window before working on the tracks. It is very important to remind the roadway worker that the location report feature can be switched off.

There is obviously a lot of room for improvements. Many interesting ideas were suggested during the observation sessions, the focus group, and the dispatcher experiment. Most of them are technically doable.
APPENDIX A. SYSTEM ARCHITECTURE

Overview
The system involves a Qualcomm® pdQ™ Smart Phone connected via its serial port to an Axiom Smart Antenna GPS receiver, a dispatcher terminal and a web server (see Description of the current Prototype, Figure 6). The phone is able to connect to the Internet via an integrated wireless modem in order 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 Description of the current Prototype Figure 20. 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)

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

Our configuration
To connect the GPS to the phone, we needed a DB-9 Male/DB-9 Male null modem adapter (small connector that exchanges pins 2 and 3), and the pdQ data cable (ordered from Qualcomm® Inc.).

For the power we used a radio controlled car battery of 7.2V. We used some diodes to drop the voltage. The battery capacity is 2200mAh at 7.2V, which is enough to power the GPS for more than 10 hours.

Qualcomm® pdQ™ Smart Phone

Specifications
The pdQ™ functions just like a Palm Computing device with a wireless modem. There are two different models, the pdQ™ 800 and the pdQ™ 1900 that operate on two different networks. We
chose the pdQ™ 800 model, as the coverage was better in the Boston area. Below are the main characteristics:

- **OS**
  Palm OS ® 3.0

- **RAM**
  2 MB

- **Internet access**
  PPP connection within 3-5 seconds.

- **Rate**
  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)

Some more information can be found at [http://www.kyocera-wireless.com/pdq/pdq_doc.htm](http://www.kyocera-wireless.com/pdq/pdq_doc.htm)

**Html forms**

To handle the database queries and work permission requests and cancellations, we used html forms stored on the pdQ (see Description of the current Prototype for screen shots).

The pdQ is sold with a light web browser called pdQ Browser™, which can surf the web with some limitations (images and JavaScript are not supported). We stored the html forms used to query our web sever 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 our web server using a post method.

**Location report application**

We wrote a small Palm OS ® application to report location periodically. The period is a parameter that can be changed. We performed tests with 1 minute and 5 minutes periods.

The application has been written in a C-like language using Code Warrior® for the Palm OS® Platform as a development environment. We also use functions from 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 these 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 \( t = \text{now} + \text{period} \).
- Closes the serial port.

This application’s name is `GPS.prc` and it is currently in:

`/WINDOWS/Desktop/PalmProgramming/GPS on the PC “EXPERIMENTER2”`.
Mapping application

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

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

Cartographer is a Window application that enables you to create your own map database and to download it into your Palm OSTM device. Cartographer supports .bmp Windows bitmaps, gif, and JPG maps.

Web server

The web server is now running in a computer of the Volpe National Transportation Systems Center. Its address is raildatalink.volpe.dot.gov

Perl script

We wrote a CGI script in Perl to build an interface between the web server and the Java query servers. The Perl file is located at: /data/rail-datalink.volpe.dot.gov/cgi-bin/query.pl

It simply reads the HTML forms as sent by the handheld device, stores a file with the request description in /data/rail-datalink.volpe.dot.gov/cgi-data/ (where the Java query servers are looking for them) and finally reads and returns the requested information to the handset.

Java server

The Java server consists in 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 in the directory /data/rail-datalink.volpe.dot.gov/cgi-data/. In case a request has arrived to the system, the appropriate query server reads the request, processes it and writes the answer in /data/rail-datalink.volpe.dot.gov/cgi-data/ 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 request have been defined to handle the GPS location reports, and the track clearings (when a roadway worker clear the tracks).
### Table 10 – New types of request

<table>
<thead>
<tr>
<th>Type of request</th>
<th>Location Report</th>
<th>Track clearing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
<td>- tq = di</td>
<td>- tq = di</td>
</tr>
<tr>
<td></td>
<td>- op = GPS</td>
<td>- op = CT</td>
</tr>
<tr>
<td></td>
<td>- d = %phone_number%</td>
<td>- d = %phone_number%</td>
</tr>
<tr>
<td></td>
<td>- p1 = validity ('A' or 'V')</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- p2 = UTC time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- p3 = latitude</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- p4 = longitude</td>
<td></td>
</tr>
<tr>
<td><strong>Action</strong></td>
<td>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 the directory: /data/rail-datalink.volpe.dot.gov/docs/GPS/TrackingFiles/</td>
<td>Removes the GPS data text file %roadway_worker's_name%.txt in /data/rail-datalink.volpe.dot.gov/docs/GPS/TrackingFiles/ so that the roadway worker disappears from the tracking display.</td>
</tr>
<tr>
<td><strong>HTML Response</strong></td>
<td>Message for the roadway worker to let him/her know that his/her position has been successfully reported.</td>
<td>Message for the roadway worker to let him/her know that his/her tracking file has been cleared.</td>
</tr>
</tbody>
</table>

GPS data are written in tracking files (text files) on the server, which will be read by the tracking applet (see next paragraph). Those text files are named %roadway_worker’s_name%.txt and put in the directory: /data/rail-datalink.volpe.dot.gov/docs/GPS/TrackingFiles/

We used comma-separated values:

- Date, time, UTC, validity, latitude, longitude, mile post, branch

Example:

04/05/2001 Thu, 15.08.18, 18:23:11,A,4221.5381,-7105.64,8,1,A

Here is the meaning of each variable:

### Table 11 – Tracking files format

<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Date when the location was reported on the sever (mm/dd/yyyy ddd)</td>
</tr>
<tr>
<td>Time</td>
<td>Time when the location was reported on the server (hh:mm:ss)</td>
</tr>
<tr>
<td>UTC</td>
<td>UTC time: (hh:mm:ss)</td>
</tr>
<tr>
<td>Validity</td>
<td>Validity of the GPS data: ‘A’=normal, ‘V’=warning</td>
</tr>
<tr>
<td>Latitude</td>
<td>Latitude: -90&lt;Latitude&lt;90, 2 digits for the degrees and 4 for the minutes. For e.g. 4807.038 means 48 deg 07.038’ N</td>
</tr>
<tr>
<td>Longitude</td>
<td>Longitude: -180&lt;Longitude&lt;180, 3 digits for the degrees and 4 for the minutes. For e.g. -01131.324 means 11 deg 31.324’ W</td>
</tr>
</tbody>
</table>
Since so far we did not have access to Amtrak’s track profiles, the computation of the branch and the milepost has been simulated.

**Dispatcher terminal**

*Message console*

When the system is running, any web browser can be turned into a dispatcher message console. If a dispatcher wants to enter the system he/she will only have to hit the page

http://raildatalink.volpe.dot.gov/dispatcher/login.html and, after selecting a territory and entering the appropriate password he/she will be logged as the dispatcher in charge of that territory. The system will generate a message console for him/her and all the incoming messages that affect the selected territory will be shown to him/her.

The message console consists in 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 sever. It can also display, active, cancelled and rejected work permissions. The message console refreshes periodically. The period is currently 5 s.

*Tracking applet*

*Overview*

The tracking application consists in a Java applet that can run on any Java-enabled web browser. The applet uses extensively Java 2.0 Swing package for Graphical User Interface 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 address is http://raildatalink.volpe.dot.gov/GPS/TrackingApplet.html.

The applet periodically checks for new tracking files (or new lines in an existing tracking file) in http://raildatalink.volpe.dot.gov/GPS/TrackingFiles, and updates the roadway worker’s locations if needed. It can show 1D and 2D displays and pinpoint the worker’s positions. Both kinds of displays can show previous locations. By right clicking on a worker, you can

- Send him/her an SMS
- Get some more information about the point (roadway worker’s name, time, validity, latitude, longitude, mile post).
- Access the complete roadway worker’s location file where all the previous locations have been stored.
- Get a local 2D map from Mapblast.com® based on the latitude and longitude.
2D display

The 2D display has been designed to work with a set of maps (possibly of different scales). The maps should be in GIF or JPEG format and put in the http://raildatalink.volpe.dot.gov/GPS/Database/ directory. Some information about the maps must be given in the http://raildatalink.volpe.dot.gov/GPS/Database/maps.txt file. Here is the format we used:

<table>
<thead>
<tr>
<th>Map Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>MIT</td>
</tr>
</tbody>
</table>

Explanations about the format can be found in Table 12 below.

<table>
<thead>
<tr>
<th>Field</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Map name used in the applet</td>
</tr>
<tr>
<td>File</td>
<td>Name of the map file in <a href="http://raildatalink.volpe.dot.gov/GPS/Database/">http://raildatalink.volpe.dot.gov/GPS/Database/</a></td>
</tr>
<tr>
<td>Height</td>
<td>Map height in pixels</td>
</tr>
<tr>
<td>Width</td>
<td>Map width in pixel</td>
</tr>
<tr>
<td>LatTopL</td>
<td>Latitude at the top left corner (between $-90$ and $90$)</td>
</tr>
<tr>
<td>LongTopL</td>
<td>Longitude at the top left corner (between $-180$ and $180$)</td>
</tr>
<tr>
<td>LatBotR</td>
<td>Latitude at the bottom right corner (between $-90$ and $90$)</td>
</tr>
<tr>
<td>LongBotR</td>
<td>Longitude at the bottom right corner (between $-180$ and $180$)</td>
</tr>
</tbody>
</table>

1D display

The 1D 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 PID are used (see Oriol, N. 2000). Nevertheless, only the location’s names and mileposts are read.
APPENDIX B. SIMULATION SOFTWARE

Overview
We developed some java software to assist us in the dispatcher experiment (see Evaluation part). The application essentially emulates a set of handheld devices that belong to virtual roadway workers. These emulated handheld devices send queries to the web server (Table 13) accordingly to a scenario. The code is actually in the directory:

/Kawa/Projects/Simulation/ on the PC “EXPERIMENTER2”.

Virtual roadway workers
Each one has a list of events (see next paragraph) that are read from the scenario file. Each one has its own Java thread that checks periodically if an event must be realized.

A window is displayed for each roadway worker. This window shows the following information:

- Roadway worker’s name
- Date and time
- Status (running or blocked)
- On tracks (yes or no)

And this window has to button:

- “Block”: to block a roadway worker (i.e. to stop his Java thread).
- “Next Event”: to skip an event (for e.g. if a work permission is refused).

Events
Events are essentially Java objects with a variable date (the date when the event should be realized), and a method action() (action to be performed), that are read from the scenario file. There are three main subclasses:

- Message events: display messages for the experimenter
- Blocking events: block the involved worker and start his timer (used when waiting for a work permission). Display a blocking window with a “Resume” button on which the experimenter clicks when the work permission has been processed.
- URL event: send a query to the web server. Here are the different queries used in the simulation (see Appendix A and Oriol, 2000 for explanations about the server’s type of queries):
### Table 13 – Server queries used in the simulation

<table>
<thead>
<tr>
<th>Type of query</th>
<th>Clearing tracks</th>
<th>GPS location report</th>
<th>Request Form D Line 2,3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>- tq = di</td>
<td>- tq = di</td>
<td>- tq = di</td>
</tr>
<tr>
<td></td>
<td>- op = CT</td>
<td>- op = GPS</td>
<td>- op = FD23</td>
</tr>
<tr>
<td></td>
<td>- d = %phone_number%</td>
<td>- d = %phone_number%</td>
<td>- d = %phone_number%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p1 = validity (‘A’ or ‘V’)</td>
<td>- p1 = site1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p2 = UTC time</td>
<td>- p2 = site2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p3 = latitude</td>
<td>- p3 = track #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p4 = longitude</td>
<td>- p4 = direction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p6 = milepost</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p5 = branch</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of query</th>
<th>Cancel Form D</th>
<th>Request Foul Time</th>
<th>Cancel Foul Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>- tq = di</td>
<td>- tq = di</td>
<td>- tq = di</td>
</tr>
<tr>
<td></td>
<td>- op = FDCR</td>
<td>- op = FT</td>
<td>- op = FTCR</td>
</tr>
<tr>
<td></td>
<td>- d = %phone_number%</td>
<td>- d = %phone_number%</td>
<td>- d = %phone_number%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p1 = site1</td>
<td>- p1 = site1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p2 = site2</td>
<td>- p2 = site2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p3 = track #</td>
<td>- p3 = track #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p4 = start time</td>
<td>- p4 = start time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- p5 = end time</td>
<td>- p5 = end time</td>
</tr>
</tbody>
</table>

---

**Scenarios**

**Format**

The scenarios are written in a tab separated text file. We wrote 3 scenarios: scenario1.txt, scenario2.txt, and scenario3.txt (used only for the training) currently in the directory:

/Kawa/Projects/Simulation/Scenarios/ on the PC “EXPERIMENTER2”.

Each line represents an event with using the following:

foreman<tab>ID<tab>A/R<new_loc<tab>time/start<tab>time/event<tab>fires_event<tab>display

and then eventually parameters to describe the query:

op<tab>tq<tab>d<tab>p1<tab>p2<tab>p3<tab>p4<tab>p5<tab>p6

Table 14 provides explanations about those fields.
Table 14 – Scenario file format

<table>
<thead>
<tr>
<th>Field</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>foreman</td>
<td>Name of the worker involved</td>
</tr>
<tr>
<td>ID</td>
<td>Event ID: unique number to refer to the event</td>
</tr>
<tr>
<td>A/R</td>
<td>A = “absolute event” (i.e. its date is fixed)</td>
</tr>
<tr>
<td></td>
<td>B = “relative event” (i.e. its date depends on other events)</td>
</tr>
<tr>
<td>new_loc</td>
<td>Boolean. True if the event is a new GPS location report, false if it is</td>
</tr>
<tr>
<td></td>
<td>another kind of event (this Boolean is used in the java code to prevent a</td>
</tr>
<tr>
<td></td>
<td>worker to be at two different places at the same time).</td>
</tr>
<tr>
<td>time/start</td>
<td>(only for “absolute event”) delay in second between the simulation start</td>
</tr>
<tr>
<td></td>
<td>time and the event’s date.</td>
</tr>
<tr>
<td>time/event</td>
<td>(only for “relative event”) delay in second between the time the event is</td>
</tr>
<tr>
<td></td>
<td>fired (by another event), and the event’s date.</td>
</tr>
<tr>
<td>fires_event</td>
<td>If the event fires other events, this field contains a semi colon separated</td>
</tr>
<tr>
<td></td>
<td>list of the events’ Ids.</td>
</tr>
<tr>
<td>display</td>
<td>This field can be 0 or 1 for URL events (0 means don’t display the URL in a</td>
</tr>
<tr>
<td></td>
<td>browser, 1 means display it), or a message in the case of a message event.</td>
</tr>
<tr>
<td>op, tq, d, p1, p2, p3, p4, p5, p6</td>
<td>(only for URL events) query’s parameters (see Table 13).</td>
</tr>
</tbody>
</table>

Typically, a work permission request (and cancellation) would look like:

Volpe3 3001 A Y 20 -1 3002 1 0 GPS di
(202)841-2896 A 0:00:00 4221.5381 7105.64 8.1 A
Volpe3 3002 R N -1 0 3003 1 1 FT di
(202)841-2896 2 3 1 now+00 now+10
Volpe3 3003 R N -1 0 3004 3 "WP #20, Wait for Volpe3’s Foul Time on track 1 between A2 and A3 from now+00 to now+10"
Volpe3 3004 R N -1 5 3005 1 0 GPS di
(202)841-2896 A 0:00:00 4221.5381 7105.64 8.1 A
Volpe3 3005 R N -1 500 3006 2 "WP #20, Cancel Volpe3’s Foul Time on track 1 between A2 and A3"
Volpe3 3006 R N -1 0 3007 1 1 FTCR di
(202)841-2896
Volpe3 3007 R N -1 0 -1 1 0 CT di
(202)841-2896

Explanations:

- Event 3001 is a new GPS location report (the roadway worker reaches his working site) that fires event 3002.
- Event 3002 is a Foul Time request that fires event 3003.
- Event 3003 is a blocking event that starts a timer that will run until the Foul Time is granted or refused, and fires event 3004.
**Scenario 1**

Below are the scenario1 and scenario2 files used in our experiment (the two scenarios focus on the branch A of the dispatcher simulator).

---

**Event 3004 is a GPS location report that fires event 3005.**

**Event 3005, once fired, wait for 500s (work time), then displays a cancellation message for the experimenter, and fires event 3006.**

**Event 3006 sends the “Cancel Foul Time” query and fires event 3007.**

**Event 3007 sends the “Clearing tracks” query so that the roadway worker disappears from the tracking display.**

The lines that begin with // are not read.

If the string now is used in a time field, the Java code will replace it by the simulation time at when realizing the event.

Below are the scenario1 and scenario2 files used in our experiment (the two scenarios focus on the branch A of the dispatcher simulator).
Volpel, 40007, R, N, -1, 0, 40008, 2, "ER #03, Volpel is between A2 and A3 Mile Post 5.9 without Work Permission"

Volpel, 40008, R, N, -1, 0, 40009, 2, "#03, Volpel is between A2 and A3 Mile Post 5.9 without Work Permission"

Volpel, 40009, R, N, -1, 0, 40010, 1, 0, 40011, 1, 1, FT, di, (617) 549-4842, A, 0:00:00, 4221.5381, 7105.64, 32.5, A

Volpel, 40011, R, N, -1, 0, 40012, 3, "WP #25, Error: Volpel is asking for FT on Track T23 at A6 instead of A7"

Volpel, 40012, R, N, -1, 0, 40013, 1, 1, FTPC, di, (617) 549-4842

Volpel, 40013, R, N, -1, 0, 40014, 1, 1, FT, di, (617) 549-4842

Volpel, 40014, R, N, -1, 0, 40015, 2, "ER #04, Volpel is in A7 without Work Permission"

Volpel, 40015, R, N, -1, 0, 40016, 1, 1, FT, di, (617) 549-4842

Volpel, 40016, R, N, -1, 0, 40017, 2, "WP #26, Error: Volpel is asking for FT on Track 1 between A2 and A3 instead of between A3 and A4"

Volpel, 40017, R, N, -1, 0, 40018, 2, "WP #26, Cancel Volpel's Foul Time on Track 1 between A2 and A3"

Volpel, 40018, R, N, -1, 0, 40019, 1, 1, FT, di, (617) 549-4842

Volpel, 40019, R, N, -1, 0, 40020, 1, 1, FT, di, (617) 549-4840, A, 0:00:00, 4221.5381, 7105.64, 32.5, A

Volpel, 40020, R, N, -1, 0, 40021, 3, "WP #26, Cancel Volpel's Foul Time on Track 1 between A2 and A3"

Volpel, 40021, R, N, -1, 0, 40022, 1, 1, FT, di, (617) 549-4840

Volpel, 40022, R, N, -1, 0, 40023, 1, 1, FT, di, (617) 549-4840

Volpel, 40023, R, N, -1, 0, 40024, 2, "WP #26, Cancel Volpel's Foul Time on Track 1 between A2 and A3"

Volpel, 40024, R, N, -1, 0, 40025, 1, 1, FT, di, (617) 549-4840

Volpel, 40025, R, N, -1, 0, 40026, 1, 1, FT, di, (617) 549-4840

Volpel, 40026, R, N, -1, 0, 40027, 1, 1, FT, di, (617) 549-4840

Volpel, 40027, R, N, -1, 0, 40028, 2, "ER #06, Volpel is between A2 and A3 Mile Post 5.9 without Work Permission"

Volpel, 40028, R, N, -1, 0, 40029, 1, 1, FT, di, (617) 549-4840

//train departure
//foreman ID useless, N

HMSL2, 5000, A, N, 1560, -1, -1, 2, Train 115 is ready to leave the Station

HMSL2, 5001, A, N, 1980, -1, -1, 2, Train 117 is ready to leave the Station

HMSL2, 5002, A, N, 1950, -1, -1, 2, Train 104 is arriving in A7

//check for train delays
//foreman ID useless

HMSL2, 5003, A, N, 1560, -1, -1, 2, Train 115 should be in A7

HMSL2, 5004, A, N, 1560, -1, -1, 2, Train 100 should be at Terminal

HMSL2, 5005, A, N, 2280, -1, -1, 2, Train 113 should be in A7

HMSL2, 5006, A, N, 2760, -1, -1, 2, Train 102 should be at Terminal

HMSL2, 5007, A, N, 3040, -1, -1, 2, Train 117 should be at Station A

HMSL2, 5008, A, N, 3900, -1, -1, 2, Train 115 should be in A7

HMSL2, 5009, A, N, 3500, -1, -1, 2, Train 104 should be in A3

Output

Each time a roadway worker is blocked (usually because he/she is waiting for work permission), the number of second he/she was blocked is saved in a comma separated text file named:

%roadway worker’s name%_scenario%#%radio%Y or N%_%date%_%time%csv

For e.g.: Volpel1_scenario1_radioN_4-5-2001_15.08.csv

Currently, those files are put in the directory:

/Kawa/Projects/Simulation/Output/ on the PC “EXPERIMENTER2”.

Here is the format:

time, message, delay

For e.g.: 13:01:16, WP#12 Wait for Volpel2’s Foul Time on Track T12 from 13:01:16 to 13:06:16, 167

Table 15 provides explanations about these fields.

<table>
<thead>
<tr>
<th>Field</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>Time when the blocking event is triggered (very often a blocking event is a work permission request).</td>
</tr>
<tr>
<td>message</td>
<td>Message attached to the blocking event (very often gives the work permission parameters).</td>
</tr>
<tr>
<td>delay</td>
<td>Delay between the blocking event and the resume time.</td>
</tr>
</tbody>
</table>
# APPENDIX C. 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:

<table>
<thead>
<tr>
<th>Device</th>
<th>Very Unfamiliar</th>
<th>Unfamiliar</th>
<th>Familiar</th>
<th>Very Familiar</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>World Wide Web</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Netscape</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>E-mails</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

### GPS background

10. Are you familiar with GPS technology?

<table>
<thead>
<tr>
<th>Device</th>
<th>Very Unfamiliar</th>
<th>Unfamiliar</th>
<th>Familiar</th>
<th>Very Familiar</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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

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

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**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 D. 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).

<table>
<thead>
<tr>
<th>Title</th>
<th>End Points</th>
<th>Description</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>MENTAL DEMAND</td>
<td>Low / High</td>
<td>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?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>PHYSICAL DEMAND</td>
<td>Low / High</td>
<td>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?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>TEMPORAL DEMAND</td>
<td>Low / High</td>
<td>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?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>PERFORMANCE</td>
<td>Poor / Good</td>
<td>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?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>EFFORT</td>
<td>Low / High</td>
<td>How hard did you have to work (mentally and physically) to accomplish your level of performance?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>FRUSTRATION LEVEL</td>
<td>Low / High</td>
<td>How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
</tr>
</tbody>
</table>
FORM D

1. TEMPORARY SPEED RESTRICTIONS

<table>
<thead>
<tr>
<th>LINE</th>
<th>TRK(S)</th>
<th>BETWEEN/AT</th>
<th>SPEED</th>
<th>SPEED SIGNS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. OPERATE IN __________________ DIRECTION(S) ON ________ TRK BETWEEN ________ AND ________.

<table>
<thead>
<tr>
<th>ON TRK BETWEEN</th>
<th>AND</th>
<th>DSPPR TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. TRAINS OR TRACK CARS AHEAD

TO PROCEED PAST STOP SIGNAL(S) AT ________.

4. ________ TRK OUT OF SERVICE BETWEEN/AT ________ IN CHARGE OF ________

<table>
<thead>
<tr>
<th>TRK OUT OF SERVICE BETWEEN/AT</th>
<th>IN CHARGE OF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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. TTS IN SERVICE AT ________.

11. CSS RULES OUT OF SERVICE ON ________ TRK(S) BETWEEN ________ AND ________.

12. PROTECT CROSSING(S) ________.

13. OTHER INSTRUCTIONS/INFORMATION ________.

<table>
<thead>
<tr>
<th>TRAIN DISPATCHER</th>
<th>TIME EFFECTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M.</td>
</tr>
</tbody>
</table>
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 employee (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 ________________________

We wrote this Foul Time sheet ourselves for our experiment, but it is very similar to the NORAC one.
APPENDIX F. 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, I work as a contractor for the Volpe transportation Center.

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

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

As part of this work we are conducting focus groups to obtain input from dispatchers as to help in developing the new tools. We’ll 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 we should consider in designing new tools;
- feedback on a prototype hand-held communication device that we are going to be demonstrating to you;
- 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’re 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’re 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, 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’re interested in hearing from each of you. So if you’re talking a lot, I may ask you to give others a chance. And, if you aren’t saying much, I may call on you. We just want to make sure we hear from all of you.

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 also phone.

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

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

Probes: Get a sense of frequency and duration

Transition Questions

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

Probes: Get a sense of priority level of these communications

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

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

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’ aspects? Are there situations where it helps to overhear others or have others overhear you? [10]

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

GPS

Global positioning 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]

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]

DEMO

Part II - Focus on hand-held device:

KEY Questions:

Which features of the ones we have demonstrated or described seem most useful? [10]
Do you think this device will the need for communication between roadway workers and dispatchers? In what way? [5]

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

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

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

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

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

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]

  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 2D map? [5]

Ending Questions

All things considered, do you think that a hand-held device like the one we demo'd to you is a good idea? [5]

Is there anything that we should have asked about but didn’t? Anything that you came wanting to say that you didn’t get a chance to say? [5]
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 restrict the operation of a switch or a signal. ²

**Cab signal**: A signal that is located in the engine control compartment and 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.

**FRA**: Federal Railroad Administration.

**Gang 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.
GPS: (Global Positioning System) Satellite based positioning system.

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.

JPEG: (Joint Photographic Experts Group) “lossy” 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.

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.

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.

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

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.

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.

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

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1 NORAC operating rules
2 Roadway Worker Protection Manual (RWP manual)
3 Roth, E.M. and Malsch, N.1999
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.

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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