U. S. Department
of Transportation
**Federal Railroad
Administration**

Supporting Railroad Roadway Worker Communications with a Wireless Handheld Computer: Volume 1: Usability for the Roadway Worker

Office of Research
and Development
Washington, DC 20590

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Human Factors in Railroad Operations

DOT/FRA/ORD-04/13.1

**Final Report
October 2004**

**This document is available to the
public through the National Technical
Information Service, Springfield, VA 22161.
This document is also available on the
FRA website at www.fra.dot.gov**

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2004	Final Report September 1998-October 1999

4. TITLE AND SUBTITLE
Supporting Railroad Roadway Worker Communications with a Wireless Handheld Computer: Volume 1: Usability for the Roadway Worker

5. FUNDING NUMBERS
R2103/RR204

6. AUTHOR(S)
Nicolas Oriol, Thomas Sheridan, and Jordan Multer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FRA-04-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
1120 Vermont Avenue, NW Mail Stop 20
Washington, DC. 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-04/13.1

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. This document is also available on the FRA website at www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Communications in current railroad operations rely heavily on voice communications. Radio congestion impairs roadway workers' ability to communicate effectively with dispatchers at the Central Traffic Control Center and has adverse consequences for the safety and efficiency of railroad operations.

A prototype communications device was developed for roadway workers to request train and territory information and to request track protection from the dispatcher. The device uses a wireless data link to send and receive information in digital form. The data link device was designed to obtain real-time information about train location without assistance from the dispatcher.

The report describes the development of this device and a usability evaluation to identify safety and productivity issues that must be addressed for successful implementation.

14. SUBJECT TERMS
cognitive task analysis, data link communications, decision-making, intelligent railroad systems, railroad dispatcher, roadway worker, track allocation, train routing, usability

15. NUMBER OF PAGES
76

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

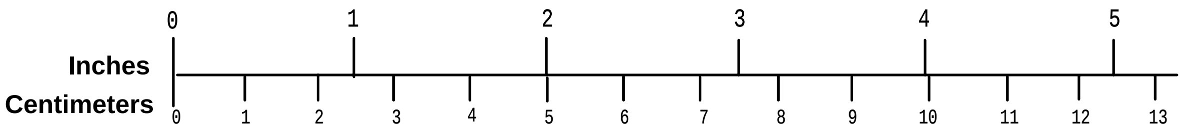
VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

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

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

Updated 6/17/98

PREFACE

Current communication technology offers the opportunity to improve productivity and safety in railroad operations compared to previous technology. This report documents the design and evaluation of a digital communication device intended to improve roadway worker safety and productivity. The goal of the study was to understand the safety implications of new communication devices and to identify usability issues associated with making them effective tools for their operators.

The prototype device was designed as a handheld information appliance with wireless access to the Internet. Roadway workers tested this data link device prototype as part of a usability evaluation. Their comments and the results of these tests are described in this report.

ACKNOWLEDGMENTS

The authors would like to acknowledge several people who helped in the development of this work. Nicolas Malsch and Santanu Basu, from MIT, developed the train dispatcher simulator that was the launch pad for this project.

John K Pollard, Mike Zuschlag, and Andrew Kendra from the Volpe National Transportation Systems Center and Emilie Roth, from Cognitive Engineering, provided help in their own field of expertise. David Lecumberri from MIT, helped in the early steps of the PDA application by envisioning feasible system architecture. Timothee Masquelier, from MIT, reviewed the appendix drafts.

Steve Jones, from Amtrak, provided the invaluable help of arranging visits to the Central Traffic Control Center at South Station in Boston, Massachusetts. Brian Radovich, from Amtrak, arranged the visits to work sites and volunteered to find test users for the experiment. All the test users, that were willing to test the device, provided excellent ideas to improve it and showed great enthusiasm.

The Federal Railroad Administration's Office of Research and Development sponsored the research, as part of its activities to develop Intelligent Railroad Systems (Federal Railroad Administration, 2002).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Communications between Roadway Workers and Dispatchers

The present study examined the use of data link (digital communications) from the roadway worker perspective. What communication problems does the roadway worker encounter? Does data link offer a solution to these communication problems? What are the requirements that must be addressed so that roadway workers can effectively use data link?

The use of current communication technologies to meet roadway worker information requirements was examined. An application was developed for use on a handheld computer with wireless communication capabilities that enabled the roadway worker to obtain information from the dispatcher only previously available by telephone or voice radio. This communication device was intended to supplement the use of voice radio and telephone.

The first goal of this study was to understand the communication link between roadway workers and train dispatchers. Communications between the two groups were observed at a Traffic Control Center as well as in the field. Dispatchers were interviewed regarding their conversations with roadway workers, and roadway workers were interviewed regarding their interactions with dispatchers.

Two types of messages between dispatchers and roadway workers were identified. The first type included those messages that followed a protocol governed by operating rules that everybody must follow. Examples of these messages were movement permits, authorization to foul the track, authority to pass a stop signal, and submission of speed restrictions. The second type included messages that did not follow a structured pattern. Examples of these unstructured messages were verbal permission for signal maintenance, detailed description of job being performed on the track, and updates about expected time to complete a given job.

Dispatchers and roadway workers were also questioned about potential tools aimed at improving their communication system. While dispatchers found benefits in shifting the structured messages to computer-based media, roadway workers did not see a significant benefit. In a previous study examining the use of data link (Malsch, Sheridan, and Multer, 2004), dispatchers preferred the idea of receiving work requests directly on their computer monitors rather than over the radio. They could see the queue of incoming messages and answer them according to their priorities, rather than on a first come first served basis. Dispatchers also saw potential in additional decision aids that could be implemented once the work requests had been electronically received, such as highlighting on their screens the section of track being requested.

While roadway workers saw benefits for the dispatchers, they also believed that sending just a few daily work requests electronically would be a burden and not an advantage. They were concerned about the ease with which they could send these work requests using a handheld computer. They were particularly worried about whether they would receive adequate training. Nevertheless, they saw benefits in using data link technology to obtain information about railroad operations that they normally would receive by voice radio from the dispatcher. The roadway workers saw great potential in retrieving important information in real time such as train location, or special rules that apply to specific sections of track.

Design and Evaluation of a Data Link Prototype

Based upon observations and interviews with dispatchers and roadway workers, a prototype communication application was developed to perform two types of tasks: request information related to operation conditions and request work authorizations. Despite the roadway workers' concerns for usability and training with respect to sending work requests by data link, this function was included because of its potential to assist dispatchers in reducing workload. The complexity of the application was reduced to improve roadway worker acceptance of the device.

The prototype device operated on a personal digital assistant (PDA) with wireless access to the Internet. Roadway workers volunteered to test the prototype in a series of laboratory experiments to evaluate its usability and to compare it with the voice radio environment.

In terms of usability, the participants indicated that all the features included in the prototype were easy or very easy to use. At the same time, they agreed that if they had the opportunity to use such an information device in real railroad operations, they would use it to submit work requests and to retrieve information related to operating conditions such as updated schedule of trains.

In comparison to the voice radio environment, the data link device resulted in safer operations, improved knowledge of potential risks, and communications that were more accurate. At the same time, it resulted in a reduced number of work requests submitted to the dispatcher and slower communications.

1. INTRODUCTION

1.1 Communications Play a Vital Role in Railroad Operations

Of the many employees working in railroad operations, three groups play a key role: railroad dispatchers, train crews, and roadway workers. Railroad dispatchers ensure the safe movement of trains, equipment, and personnel on the track. Each dispatcher manages a portion of the track network. Locomotive engineers and conductors operate and manage the train. They follow the instructions given by dispatchers through movement authorities and the signal system (wayside or in-cab). Roadway workers maintain and occasionally construct the railroad infrastructure, which includes: track, signals, switches, station platforms, electrification, bridges, tunnels, embankments, and culverts.

Communications are vital in making railroad operations safe and efficient. All three groups of railroad employees engage in a continuous exchange of information. Voice radio currently serves as the primary medium for sharing information. In addition to communications between operating staff, two-way communications also take place between operators and equipment along the right-of-way as well as at the dispatch center. In centralized traffic control territory, switches and signals receive commands from the dispatcher's computer. These commands determine the track over which the train will travel as well as any speed restrictions. Wayside signals communicate information about movement authorities to the train crews. Except in automatic block signal (ABS) territory and dark territory, remotely located equipment provides feedback to the dispatchers about the actual state of the switches and signals, as well as information about train location. In ABS and dark territory, voice radio serves as the only medium for communication among dispatchers, train crews, and roadway workers.

Voice radio communications are vital to the safe and efficient operation of the railroads. Voice radio supports two types of communication tasks. The first type includes safety-critical communications related to train movements and allocation of track between roadway workers and trains. The second type includes tasks that are important to the efficient operation of the railroad. For example, the dispatcher may forward information about train movements (i.e., current train delays) to roadway workers or train crews.

The characteristics of voice radio and the way railroad operations are conducted have contributed to several problems. First, the available voice radio bandwidth is inadequate to support current communication needs (Federal Railroad Administration, 1994; Roth and Malsch, 1999). The Federal Communications Commission has allocated 208 channels (182 in the VHF band and 26 in the UHF band) for railroad operations (Code of Federal Regulations, 2000). However, within a geographic region a much smaller number of channels are available (e.g., 3 or 4). Voice communications for main line operations are typically restricted to a single channel. In addition, only one person can communicate on a channel at a time. Other workers who want to use the same channel must wait until the channel is clear. As a result, voice radio channels are congested.

The inadequate communication bandwidth is also partly due to the changing nature of how dispatchers and roadway workers perform their jobs. As new technology in the form of voice radio and train control systems have been implemented, block operator positions have been gradually eliminated. Block operators performed a job similar to that of dispatchers, but over a smaller geographic territory. They communicated with dispatchers over wire line telephones and with train crews using a hoop with a string. As block operator positions were eliminated, the dispatcher became responsible for managing a larger territory with a concomitant increase in communication workload. By contrast, the roadway worker has not experienced the same increase in communication workload.

Second, the temporal nature of auditory information imposes a significant burden on railroad employee's memory. Railroad workers adapted by recording important information on paper. However, the time it takes to record this information places a burden on the dispatcher's memory and increases workload.

Advances in communication technology have the potential to improve railroad safety and productivity. The use of data link (defined as discretely addressed digital telecommunications) has been proposed as a communication medium to supplement voice radio. Data link uses the communication bandwidth more efficiently than voice radio. Information transmitted digitally can be presented aurally or visually. These characteristics offer opportunities to address the limitations posed by voice radio. However, if the needs and limitations of operators are clearly understood, designers are more likely to use new technology in ways that positively impact safety and productivity. As mentioned earlier, new train control technology has increased the communication load for the dispatcher. Simply increasing bandwidth by adding channels could adversely impact the dispatcher's performance if the design of the system does not consider the communication load that the dispatcher can handle safely. For example, if data link technology enables many people to simultaneously send the dispatcher messages, the dispatcher may still be only able to attend to one message at a time. To avoid communication overload, the dispatcher will need a way to filter and organize the incoming messages. Similarly, roadway workers may be frustrated by a lack of response when their requests for information or work authorization go unanswered longer than they expect.

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

The first study in the program examined the use of data link by the dispatcher (Malsch, 1999 and Basu, 1999; Malsch, Sheridan, and Multer, 2004). This research compared dispatcher performance in the current voice radio environment to a data link environment, using a train dispatcher simulator with data link capabilities. In this system, a computer-simulated train operates while the experimenter simulates all other railroad agents, including roadway workers. When data link capabilities were enabled, dispatchers received information from all the trains in their territory, as well as from roadway worker crews in visual form using an e-mail-like application. When data link capabilities were unavailable, dispatchers communicated with trains and roadway worker crews by voice radio.

The results indicate that data link was an efficient tool for communicating complex messages, particularly where acknowledgement of messages was required. Data link improved train and roadway worker safety, and situation awareness while lowering the dispatcher's perceived workload compared to voice radio. Data link was less efficient for communicating simple or urgent messages.

During the first study, dispatchers made several comments that addressed the use of data link in the field as well as in the traffic management center. In particular, they made several comments relevant to the use of data link by roadway workers.

These comments are listed below:

- Since, roadway workers currently lack data link communication tools, they wondered how the work crews in the field would send and receive digital messages. They also raised concerns that some roadway workers might be unfamiliar with computers.
- Dispatchers liked the idea of data link. Data link enabled dispatchers to control the order in which messages were responded to. When using voice radio, dispatchers are more likely to answer messages on a first-come first-served basis because they often don't know the reason for the call. With data link, they could assign priorities to incoming messages and deal first with the most important ones. This finding was also supported by Vanderhorst's (1990) research comparing data link to voice radio.
- The dispatchers appreciated not having to repeat a message many times due to low quality voice radio transmissions. Eliminating the repetition of messages decreased workload and left more time for other activities.

1.2 Research Goals

The present study examined one form of data link from the perspective of the roadway worker.

- What communication problems does the roadway worker encounter?
- Does data link offer a solution to these communication problems?
- What are the requirements that must be addressed so that roadway workers can effectively use data link?

The use of current communication technologies was examined to meet roadway worker information requirements. An application was developed for use on a personal digital assistant (PDA) with wireless communication capabilities that enabled the roadway worker to obtain information without requiring assistance from the dispatcher. The information was previously available only from the dispatcher by telephone or voice radio.

The project was divided in three main parts:

- Cognitive Task Analysis
- Prototype Design
- Usability Testing

The cognitive task analysis (CTA) describes the process by which the information requirements of roadway workers were established for the development of the roadway worker communication tool. The prototype design section describes the development of the hardware and software to meet the roadway workers information requirements. The usability tests describe several methods and results of two types of tests to evaluate and improve the effectiveness of the communication device developed.

2. COGNITIVE TASK ANALYSIS

In previous work, a CTA (Roth Malsch and Multer, 2001) was conducted to learn how train dispatchers manage and control trains. This report was helpful during the development of the present project but did not specifically address the roadway worker's perspective.

A focused CTA was conducted to understand the requirements of a digital communication device that would facilitate roadway worker's communications with the dispatcher. The CTA consisted of observing communications between roadway workers and dispatchers and interviewing both groups. Communications between the groups were observed at a traffic management center as well as in the field. Dispatchers were questioned about their conversations with roadway workers, and roadway workers were interviewed regarding their conversations with dispatchers. Dispatchers and roadway workers were questioned about potential tools aimed at improving their communications.

2.1 Tasks Performed by Dispatchers and Roadway Workers

This section describes the interactions between roadway workers and dispatchers, and the tasks each group performs. Table 1 shows the variety of roadway workers and the types of transactions that take place between the roadway worker and the dispatcher.

Table 1. Roadway Workers Who Interact with Dispatchers

Operator	Type of Communication
Point conductor	Serves as a focal point for communications between several roadway workers and the dispatcher. Transactions typically concern track authorities (i.e., Form D and Foul Time). The presence of the point conductor simplifies the work of the dispatcher by reducing the number of people with whom the dispatcher must communicate.
Flagman/Conductor	Requests track authority to protect railroad roadway workers or contractors.
Electrification worker	Conversations between electrification workers and dispatchers are rare due to the presence of the point conductor. However, when they do interact, the issues are similar to those for the point conductor.
Signal maintainer	Requests permission to shut down signals or to put them in local mode.
Track car foreman	As the operator in charge of a track car, the track car foreman asks permission to operate a track car and to pass stop signals.
Work extra train crew	Operate trains and track equipment to bring materials into the work area. Their communication with the dispatcher addresses the following information: equipment left on the track, new speed restrictions, and directions for routing the train, and requests for switch changes.

The operator labels represent terminology used by Amtrak along the Northeast Corridor.

2.1.1 Dispatcher Tasks Associated with Roadway Workers

When a dispatcher receives a request for roadway worker protection, the dispatcher decides whether to grant, modify, or deny the request. If the dispatcher grants permission to work, (under Foul Time, Form D, or verbal permission) the track is placed off-limits (blocked) for other uses. In Central Traffic Control (CTC) territory, blocking a track protects the roadway worker since it prevents the dispatcher from routing trains on that track. Switch operation is restricted, and the signals (wayside and in-cab) for the blocked track will display a stop signal at both ends to prevent movement by unauthorized track vehicles. In ABS and dark (unsignalized) territory, the roadway workers must block the switches manually.

Once authorization for track use is granted to a roadway crew and the track is blocked, the dispatcher has delegated authority over that track to the roadway crew. Roadway workers can change the state of a switch by manually using the local switch, or they may ask the dispatcher to make the change remotely.

While roadway workers perform their tasks, they continue to interact with the dispatcher. These interactions include making additional work authorizations, adding and removing speed restrictions, and fulfilling requests for updates on train location. When the job is completed, the responsible crew foreman releases the track back to the dispatcher. In CTC territory, the dispatcher unblocks the track making it available for other uses.

The dispatcher also communicates with other railroad employees in the field. Table 2 describes the communications associated with people other than roadway workers.

Table 2. Other Workers Who Interact with Dispatchers

Operator	Types of Communication
Bridge operator	The bridge operator calls the dispatcher when there are ships that require the bridge to be opened. The dispatcher unlocks the bridge (the display terminal displays the track section as occupied) and control is given to the bridge operator. After the bridge operator returns control of the track to the dispatcher, the bridge is locked and the track is available for routing and maintenance operations.
Train crew (freight conductor & locomotive engineer)	Reports tons carried, number of cars (loaded/empty), and engine number.

2.1.2 Roadway Worker Tasks

Roadway workers' tasks include inspection, construction, maintenance, and repair of the track infrastructure (i.e., track, bridges, signal, and communication systems, and electric traction systems) on or near the track.

When a roadway worker wants to perform a job on the track, several steps are followed, as shown below:

1. Collect information.

Examples of information needed by roadway workers include:

- Milepost number
- Track numbers
- Territory characteristics (i.e., rules that apply on each track, maximum train speed, signal system or dark territory)
- Name of dispatcher who controls the territory
- Train timetable schedule around working site

2. Request work authorization from the dispatcher (i.e., Foul Time or Form D) when necessary.
3. Conduct a job briefing with the crew.
4. Give control of the track back to the dispatcher.
5. Make sure work area is safe and secure.

The roadway worker obtains timetable schedule and territory information from the operating rulebook. For the roadway workers interviewed in this study, this rulebook contained only scheduled passenger train information. Unscheduled trains (i.e., freight, work extras), and commuter trains with higher frequency were not shown. The roadway worker requires updated information regarding the location of all the trains that could interfere with the job. The roadway worker calls the dispatcher for schedule updates and for unscheduled train information.

The crew foreman is responsible for the protection of other crewmembers and conducts the job briefing. The job briefing covers those activities each member will perform as well as safety issues. A major responsibility of the foreman includes obtaining work permission from the dispatcher.

Track inspection is another frequently performed activity that has a different set of communication requirements from those associated with tasks performed by maintenance of way crews. Track inspectors operate track cars through a territory examining the track for defects. Track cars pose a special challenge for the dispatcher. A track car is a piece of equipment other than a train, used for inspection or maintenance. In signalized territory, track cars do not usually shunt track circuits so the dispatcher cannot determine even their approximate location, as they can with trains. For this reason, track cars need movement authority (Form D, Lines 2 and 3) and authority to pass stop signals (Rule 241).

Other general-purpose trains, called work-extra trains carry equipment and work crews to job sites. These unscheduled trains shunt track circuits, but may remain on the track for a specified interval. Work-extra trains also need movement authority from the dispatcher (i.e., Form D, Line 4).

2.2 Information Shared between Roadway Workers and Dispatchers

Messages exchanged between dispatchers and roadway workers were divided into two types: structured and unstructured. Structured messages follow a protocol governed by operating rules that everybody must follow. Unstructured messages included all other messages. Examples of each message type are as follows:

Structured Messages

1. Movement Permit Form D

   According to the Amtrak operating rules (NORAC, 1999), the dispatcher issues Form Ds to restrict or authorize train movements. Form Ds are also issued to convey instructions not covered in the operating rules. Although Form Ds are intended primarily for trains, one interviewed dispatcher indicated they grant 90 percent of Form Ds to work crews and only 10 percent to trains. A roadway worker may receive a Form D, Line 4 "if the work involves on-track equipment or will disturb the track or catenary structure."[1]
   Once a dispatcher grants a Form D and puts it into effect, very limited changes may be made to the authorization. Changes include: cancellation, permission to continue to operate a track car in a given direction under new limits (Line 2), and "track is clear" information (Line 13) or 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 C.

2. Foul Time (track and time).

   A qualified roadway worker or contractor whose activities will <u>not</u> disturb the track or catenary may receive authorization from the dispatcher to foul the track. For example, a roadway worker under Foul Time protection may operate a crane over the track. Activities like replacing ties or leaving heavy equipment on the track require Form D authorization. Issuing Foul Time (also called *track and time* by some railroads) to roadway workers has become a time consuming part of a dispatcher's job. A dispatcher may easily have three to seven active authorities involving Foul Times within their territory.

3. Authority to Pass a Stop Signal (Rule 241).

   Normally, trains and track cars are prohibited from passing a stop signal. Rule 241 authorizes trains or track cars to pass a stop signal. Dispatchers grant this authority so track cars can enter an interlocking where inspection or maintenance work will take place. Normally, dispatchers grant permission to operate a track car (Form D, Line 2), accompanied by permission to proceed past a stop signal (rule 241 or Form D, Line 3). The choice of authority (Rule 241 or Form D, Line 3) depends on the dispatcher's preferences.

4. Speed Restrictions.

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

Unstructured Messages

In railroad operations, different situations arise 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 temporally shut it down.

[1] Disturbing the track requires the dispatcher to remove it from service while the authorization is in effect.

Another type of interaction between dispatchers and roadway workers occurs when the roadway workers are already working under protection. Dispatchers usually ask work crews for details on time restrictions. For example, a dispatcher may ask, "How long will it take to remove equipment from the track?" Dispatchers also ask for details about the job being performed. This information enables the dispatcher to better manage unanticipated events.

A roadway worker who has trouble communicating with another railroad employee may call the dispatcher to request that the message be relayed, or they may ask the dispatcher to make the telephone call.

2.3 Proposed Information Requirements

A goal of the interviews with both dispatchers and roadway workers was to elicit information requirements associated with their communications tasks. Their comments are summarized below.

1. Data link-based exchange of work authorization.

   Dispatchers liked the idea of receiving and granting data link transmitted work requests. They envisioned a visual interface with which they could browse through a list of work requests and answer each request in the order they considered appropriate. Other anticipated benefits were: saving time, improved legibility of Form Ds, and a verification system that prevented or minimized common human error such as blocking a track that does not match the one given in the work permission.

   For such a tool to be perceived as beneficial, it would need to minimize typing requirements. If much typing was necessary, little difference was perceived between written and electronic work authorizations. Confirmation that the message was received was also important to dispatchers. The dispatchers expressed concern about whether the currently well-established procedure of acknowledgments could be replicated electronically.

   Roadway workers saw little need for computer-generated issuance of work requests because they made few requests per day. If they did not use a handheld computer to send work requests, they would not use it to receive work authorizations.

   Roadway workers also expressed concerns about training and security related to issuing work requests. Some roadway workers were unfamiliar with computer devices so the question of training was raised. What kind of training would be needed to learn how to operate the device? The roadway workers also worried about unauthorized people using the device to make work requests. They did not understand how the system could tell if the worker sending the request was an authorized user.

2. Real time or near real time train location information.

   The roadway workers expressed interest in receiving train location information comparable to the information dispatchers currently receive. One instructor said, "Information about train location is already at the Traffic Control Center. Why don't we share it with the ones that will make good use of it?" Access to near real time or real time train locations would help them because they wanted more accurate information about train location than found in paper versions of the timetable schedules. It would help them plan their activities and when to request work authorization from the dispatcher. The information would be even more valuable if it included all trains on the track, not just the scheduled ones.

The roadway workers who were interviewed made several suggestions for features that embody the use of computer-based exchange of work authorizations and access to more timely information about train location. Some proposed features of this handheld device were:

- Show automatically generated schedule, including delays of the trains that are supposed to arrive at the roadway worker's location.
- Request information such as: where is a particular train or what is the next train at this interlocking?
- Warn of nearby trains. Whenever a train enters the same block as the roadway workers or an adjacent block, this device could send them a warning.
- Knowledge about the time they can ask for Foul Time or the time they have to wait before asking for Foul Time.

3. PROTOTYPE DESIGN

3.1 Task Requirements

Based upon the CTA, a software application was developed for use on a PDA with wireless communication capabilities. The application addressed the user requirements discussed in Section 2.3 and enabled the operator to perform two tasks: request information related to operating conditions, and request work authorization. The application was specifically designed for use on the railroad, and was intended to facilitate communication between roadway workers and dispatchers. Table 3 shows the type of information that may be requested, and the work authorizations allowed. Figure 1 shows the information flow using the PDA.

Table 3. Tasks Performed Using the PDA

Information Requests	Work Authorizations
Train Status	Form D
Train Schedule	Foul Time
Territory Information	Cancel Work Authorization
Track Out of Service Report	
Form D/Foul Time Under User Authority	
Other	

This prototype was designed to enable the roadway worker to request information or work authorization with minimal data entry. The ability to send work requests was included because it could potentially reduce dispatcher workload. It also had the potential to reduce communication errors between roadway workers and dispatchers.

Database requests were answered by a computer containing the train timetable schedule. The dispatcher handled requests for work authorities.

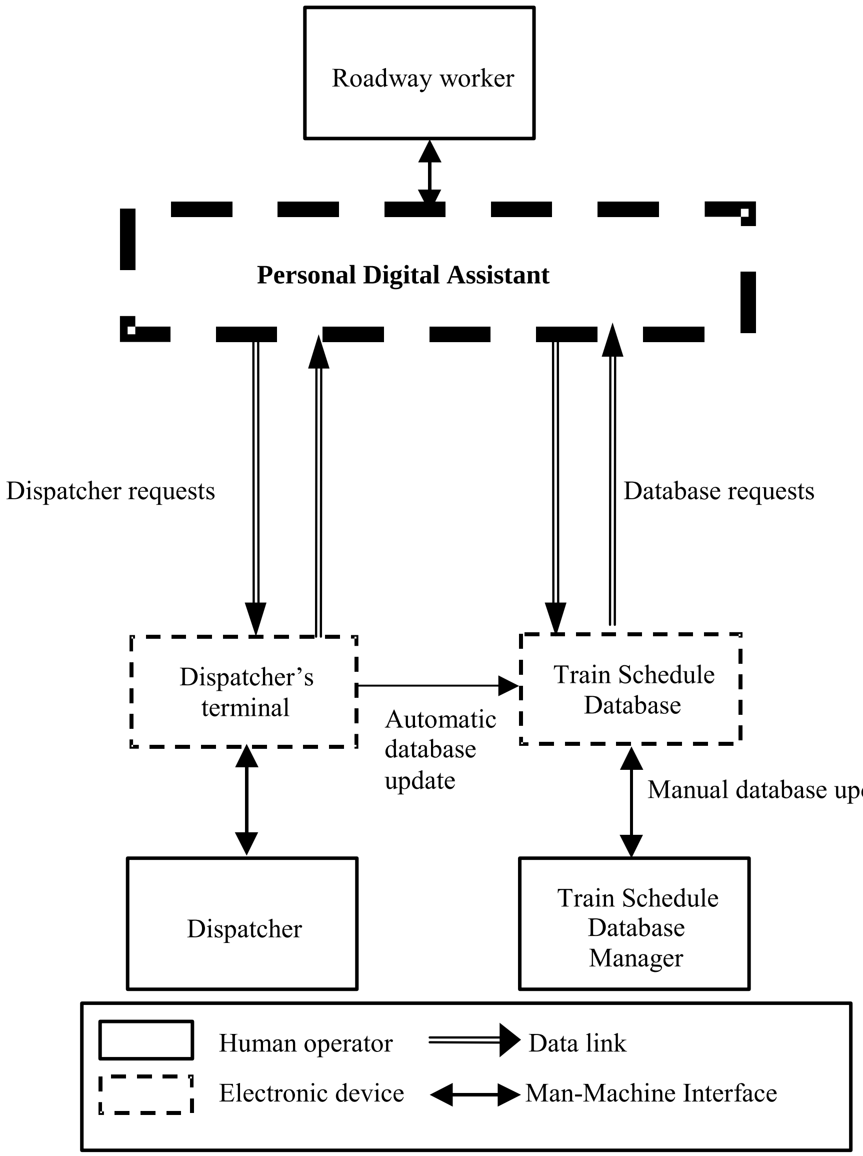


Figure 1. Information Flow Using PDA

3.2 Human-Machine Interface Requirements

The next step in the development of the prototype was to develop the user interface that roadway workers would use to communicate with dispatchers. Roadway Worker Protection (RWP) class instructors were interviewed to develop a set of conceptual specifications of a wireless handheld computer that could be used by roadway workers.

The instructors suggested the device should be smaller than a laptop computer and simpler to use. Roadway workers did not like the idea of carrying a laptop computer. They described a portable device like a pager, PDA, or mobile phone that could give updated train location information. The instructors also expressed concern about training issues. In particular, they were concerned about the fact that some roadway workers were not familiar with computers or security and authentication.

3.3 Hardware Selection

A device was selected that had wireless access to the Internet, and could be used anywhere along the track. A web site was used as the network interface for the prototype. The application also required a simple user interface to enable the roadway worker to operate the system with minimal training.

The following devices were considered:

- Laptop computer with wireless modem
- Pager
- Cellular phone
- Handheld computer with wireless modem

Although a laptop offered considerable flexibility in terms of available features, this option was rejected because it was too big to carry. Interacting with the device by using a keyboard was also considered unacceptable by the user population.

A pager or a cellular phone was considered because both had wireless coverage along the track and roadway workers were familiar with them. Although a pager or a cellular phone could receive information, at the time that the selection was made, data entry was difficult, limited, and the visual display was considered too small to display enough information.

The fourth option considered was a handheld computer referred to as a personal digital assistant or PDA. These devices are typically used as organizers for managing e-mail, as well as for storing contact and calendar-related information. They have visual displays larger than a cell phone, but are smaller than a laptop computer. The PDA can also be programmed to perform a variety of tasks, and it offers a range of options for manipulating information. The most common mode of interaction involves using a pointing device or stylus. Just prior to the beginning of this study in June 1999, versions became available with wireless modem technology and Internet access.

For the first prototype, a Palm™ VII Personal Digital Assistant was selected. It had built-in wireless Internet access, a simple user interface, was small, and had good technical support for developers.

3.4 System Architecture

Figure 2 shows the system architecture. Like a mobile phone, the PDA communicated with a base station that consisted of an antenna and a server. The antenna received the wireless message from the PDA. The message was sent to the server connected to the antenna and the server redirected the message to the appropriate destination via the Internet. Through this transaction, the PDA sent and received information to a web server. A number of servers look for requests sent by the PDA, the dispatchers, or a database manager. These servers represent the core of the system as they redirect the request to the appropriate recipient. A work authorization was sent to the dispatcher while an information request was answered by the system without interrupting the dispatcher by querying the database.

Dispatchers interacted with the system via web pages. Through this interface, they were able to receive work requests from roadway workers and send work authorities.

The database contained train timetable schedule, current delays, schedule of trains not part of the timetable schedule, track out of service under Form D or Foul Time, and territory information (maximum speed, dispatcher in charge, rules that apply). In the PDA prototype developed for this project, the database was modified manually by a database manager using another interface of simple web pages. For a more detailed description of the system architecture, see Appendix A.

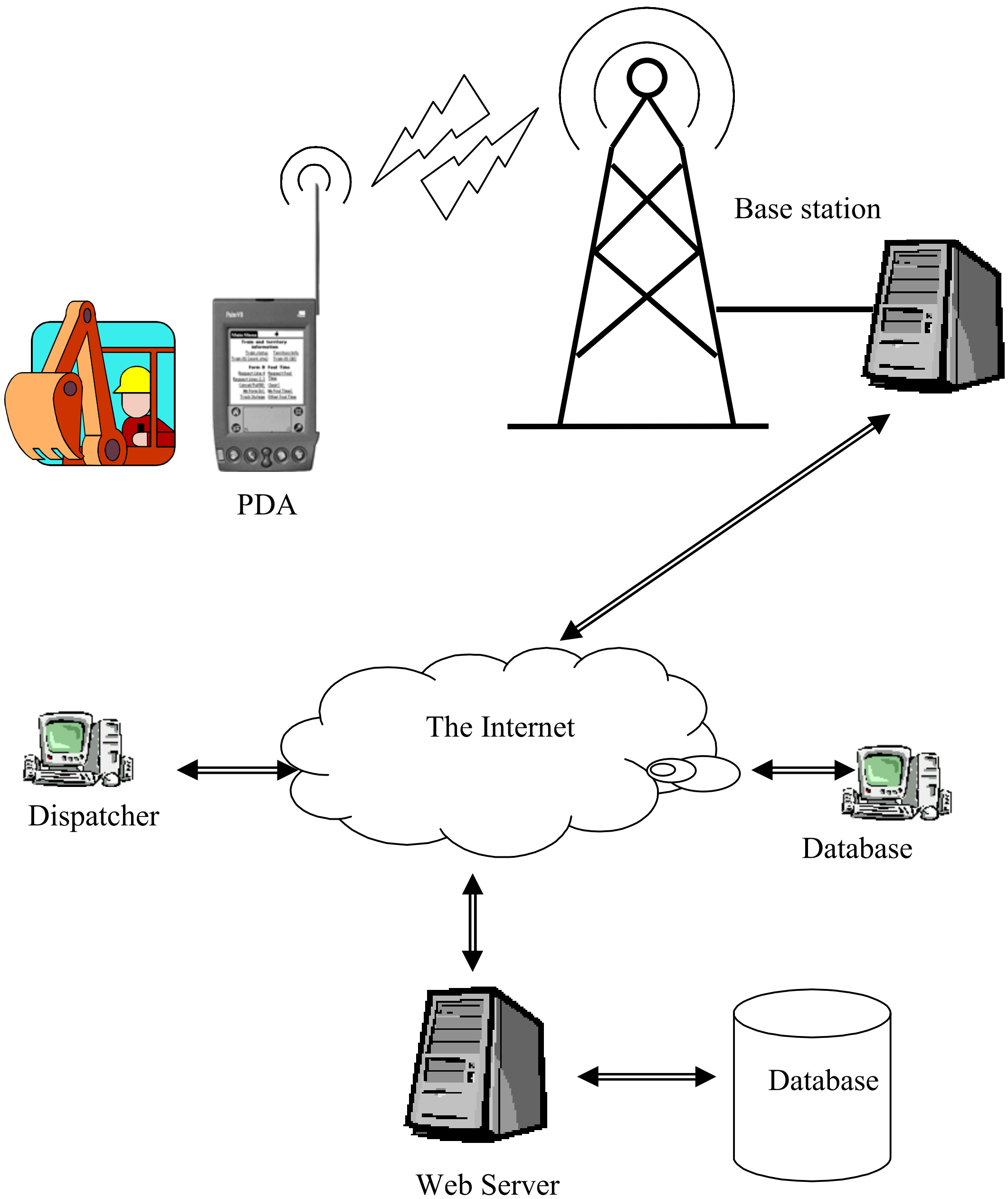


Figure 2. PDA System Architecture

4. USABILITY EVALUATION

4.1 Overview

The goal of the usability evaluation was to identify human factors issues that must be addressed for the device to be successfully implemented in the railroad environment. It was important to gauge user acceptance, and to identify human factors design issues that need to be considered as this device evolves toward a more mature design.

The design evolved through an iterative process in which user requirements were turned into an initial prototype and modified based on user feedback. The first round of usability testing focused on the information content that the tool should display, and tasks the user would perform. The same roadway workers were used (primarily conductor-flagmen), who made suggestions about the device during the CTA. When the first version of the PDA was completed, feedback was solicited from instructors of a Railroad Worker Safety class.

In the first prototype, train location and territory information was included and Form D requests were limited. It also included the ability to request Foul Time and submit speed restrictions. The main menu is shown in Figure 3.

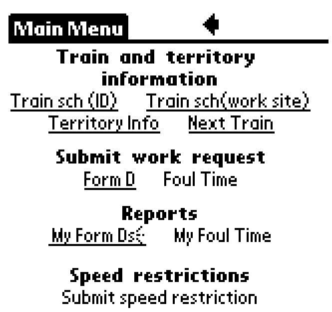


Figure 3. Main Menu (first version)

Useful comments were received concerning features that were missing from the first version of the prototype that would be helpful in revenue service. After carefully considering the comments and suggestions of the users, the following modifications were made:

- The *Next Train* (next train at a given interlocking[2]) option was removed since it was redundant of *Train Schedule at Working Site* (train schedule at a given portion of track during a given time period).
- A *Train Status* option (general information about a train: last interlocking, next interlocking, direction of travel and delays) was added.
- To simplify the user interaction and to better reflect actual railroad operations, modifications were made to the procedure for requesting a Form D and two options were

[2] Locating the train by interlocking is important to Amtrak operations and may not be typical of other railroads.

added. The first option enabled the worker to identify current track out of service and the second option facilitated the cancellation or fulfillment of a Form D.

- The Foul Time request was revised so that it was similar to requesting a Form D.
- After discussions with the user population, speed restriction requests were removed. This feature was removed to simplify the interface as the roadway workers who were interviewed indicated that they requested speed restrictions less often than requesting track use authorizations like Foul Time and Form Ds.

After revising the initial prototype, the main menu looked like the display shown in Figure 4.

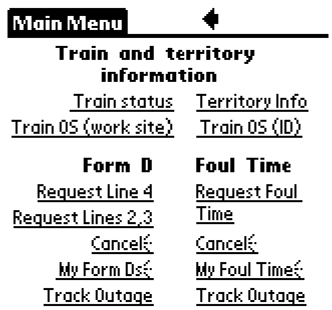


Figure 4. Main Menu (second version)

The revised prototype was shown to a train operations manager of an intercity passenger railroad. The manager commented that this tool could be useful to other railroad operating staff. This tool would enable the manager to monitor the state of the railroad network outside of the office environment where these information displays are traditionally located.

Following the preliminary informal tests, more formal usability tests were conducted in a laboratory environment. Two series of laboratory tests were performed. One test addressed readability and navigation. The second test compared the usability of the new device to communication by voice radio.

The readability and navigation test was performed first, after which the prototype was revised. Next, performance with the handheld PDA was compared to performance using the voice radio.

4.1.1 Participants

Nine conductor-flagmen employed by an intercity passenger railroad participated. Three conductor-flagmen participated in the readability and navigation test, while six others participated in the comparison with voice radio. Out of the nine participants, one was female and eight were male. The participants ranged in experience from 1 to 37 years, with an average railroad work experience of 16 years. Each participant received compensation equivalent to a full day of labor.

All participants were familiar with radios, PCs, pagers, cellular phones, the Internet, and e-mail. All participants except one were unfamiliar with handheld devices such as the one used in the study.

4.2 Readability and Navigation

4.2.1 Method

Three conductor-flagmen participated in the usability test. A thinking aloud protocol was used in which participants spoke aloud as they performed a variety of tasks. If the participant did not speak during the execution of a task, the experimenter prompted the participant with a series of questions.

Materials

A digital tape recorder was used to record the participants' comments during each task. The PDA was used to record the actions of the participant while using the device. A personal computer with a Pentium III processor was used to present the tasks to the participant. Paper worksheets were used to write down comments and answers to the tasks.

Procedure

Users were trained for 30 minutes on the use of the PDA, and then the steps to complete each task were explained. Participants interacted with a simulated train schedule modeled after an actual schedule with which they were familiar. The database included scheduled intercity passenger trains, commuter trains, and unscheduled trains. The user was given a list of tasks to complete. These tasks required the user to request information or obtain work authorization for a section of track using the PDA. While sitting in front of a personal computer, the participant received one task at a time and wrote the answer to each task in the worksheets. The participant used the PDA to execute each task while "thinking aloud." The experimenter did not answer questions unless the user was stuck and unable to continue. The experimenter asked the user questions, especially when the user was not saying anything. The experimenter asked usability questions about requesting information and work authorizations.

At the beginning of the test, demographic information was collected. This demographic information included years of experience and background knowledge of data link devices. At the end of the test, questions were asked about how the application could be improved, task realism, and how the information was presented to the user (i.e., font style, size, navigation procedures). It took approximately 3 hours to complete all the tasks and the questionnaires.

Observations and Measurements

From the recorded comments, difficulties with the user interface and errors made while using the device (i.e., selection of wrong menu) were identified.

From the questionnaires, subjective measures were collected regarding the usability of the device, as well as comments about improvements and potential changes in the way the work requests were handled.

From the log files, the number of times each feature was used was measured, as well as errors made, recovery from errors, and the task completion time.

4.2.2 Results and Discussion

From the readability and navigation test, several changes were identified to improve the user interface. The most important change was to the last steps of the Foul Time request, which was previously confusing for the participants. Roadway workers had to acknowledge Foul Time received from dispatchers. The process was designed so the incoming acknowledge request displayed the message “Foul Time not effective,” which led some participants to think that the Foul Time had not been accepted by the dispatcher. The header message “Foul Time not effective” was replaced by header “Please confirm Foul Time.”

In addition, the process of acknowledging Foul Time required selecting the desired action (“accept” or “do not accept”) and then tapping a “send response” button. These requirements were simplified by using two buttons labeled “accept” and “do not accept,” which automatically executed the intended operation without any further user action. Finally, the layout of the Foul Time message was modified to fit on one screen to eliminate the need for a vertical scroll bar. The same modifications were applied to the Form D request to maintain consistency.

Other changes included the following:

- Use of the a.m./p.m. time format.
- Reword menu titles and commands to be consistent with railroad operations vocabulary.
- Provide a link to the main menu from all submenus that previously lacked this capability.
- Add information sent with the train status report to include engine number and numbers of cars in the train consist.

It was also discovered that although the font size and the overall device size could be larger, the information was presented in a readable and organized way. The font used was Palm TD 9 (the default font for plain text in the Palm VII). The menu structure was rated as easy to navigate, however, the vertical scroll bar posed usability problems because it was only six pixels wide which made it hard to tap the correct location. This problem was solved by letting the participants use the built in scroll button. The screens used to generate and send requests were considered complete, easy to understand, and realistically reflected railroad operations needs. Response time was slow when sending and receiving information in the form of information requests or requesting work authorizations. Users did not get immediate response to their requests. This speed was limited by the slow transmission speed of current wireless data communications (7200 baud).

4.3 Comparison of PDA to Voice Radio

4.3.1 Method

Purpose

The purpose was to evaluate how the PDA affected roadway worker performance compared to the two-way radio. It was also important to identify usability issues that a handheld wireless communications device would need to address before roadway workers could use it as part of their job. The goal of this study was to identify the impact of the current user interface on task performance and user acceptance.

Participants

Six conductor-flagmen participated in this evaluation.

Materials

The materials used in the evaluation consisted of one Palm VII PDA and two VHF radios (Motorola-MT1000). The participant used one radio and the experimenter used the other. The participant was also given a book of operating rules, two trains schedules (one for inter-city trains and one for local commuter rail trains) for the territory on which the participant would be responsible for, as well as a worksheet to write down information.

Procedures

After welcoming the participant, the experimenter solicited demographic information. Each participant received 70 minutes of training on the features of the device, followed by practice on their own until he or she was comfortable with its operation.

Participants carried out a series of tasks with the Palm VII and the radio, which required knowledge of train timetable schedules. The train timetable schedule was modeled after a schedule with which the participants were familiar. The timetable included scheduled intercity passenger and commuter trains as well as unscheduled trains. After completing one set of tasks with the Palm VII, they carried out another set of tasks with the radio. The participant completed one task before beginning a new one. Each task was independent of the others, however, some tasks were designed so they could not be accomplished (because of train schedule conflict for example). In that situation, the user was instructed to report the problem to the experimenter. During each group of tasks, the experimenter paused the test several times to measure situation awareness. The participant completed a set of questions as shown in Appendix B, concerning events that recently occurred.

At the end of the evaluation, the participant answered questions about PDA usability, ways to improve the PDA, comfort level, task realism, workload, and implementation issues. The questions are listed in Appendix B. It took approximately 2½ hours to complete the tasks and the questionnaires.

Observations and Measurements

All tasks were presented to the participant on a computer monitor. The participants' use of the Palm VII was recorded and stored in a computer file. In the voice radio condition, all of the conversations were recorded on audiotape.

Time spent gathering information was measured as well as requesting and canceling work authorizations. Several kinds of errors were measured. These errors included work requests that should have been sent but were not, work requests that should not have been sent, communication errors, and safety errors.

From the questionnaires, situation awareness was measured in terms of the trains noticed by the roadway worker as potential hazards, as well as characteristics of the territory (i.e., maximum train speed). Subjective measures were collected relating to user acceptance and changes in workload, suggestions for PDA improvement, safety concerns, and other potential uses of the PDA.

To evaluate the overall efficiency of the application, several measures were taken. The specific measures that were taken are as follows:

Time measures

- Task completion time: included the time to complete a single task.
- Time to complete a work request or a work cancellation: included the time from the initiation of the request until it was completed and acknowledged. In the voice radio condition, these times were obtained from the tape recordings. When computing these times using the PDA, an estimate was made. Measuring the actual time when the roadway worker started to fill the request or when the answer arrived at the PDA could not be accomplished because the log files only stored request information when it arrived or was sent from the web server. For each work request, two estimated times were added to the ones stored in the log files. These times were an average time to complete a work request screen and twice the average time it took for a packet to arrive from the PDA to the web server (network latency). These average times were computed for each screen in the PDA. The average time to complete each work request screen and the network latency were measured prior to the current test. The timeline for completing a work request is shown in Figure 5.

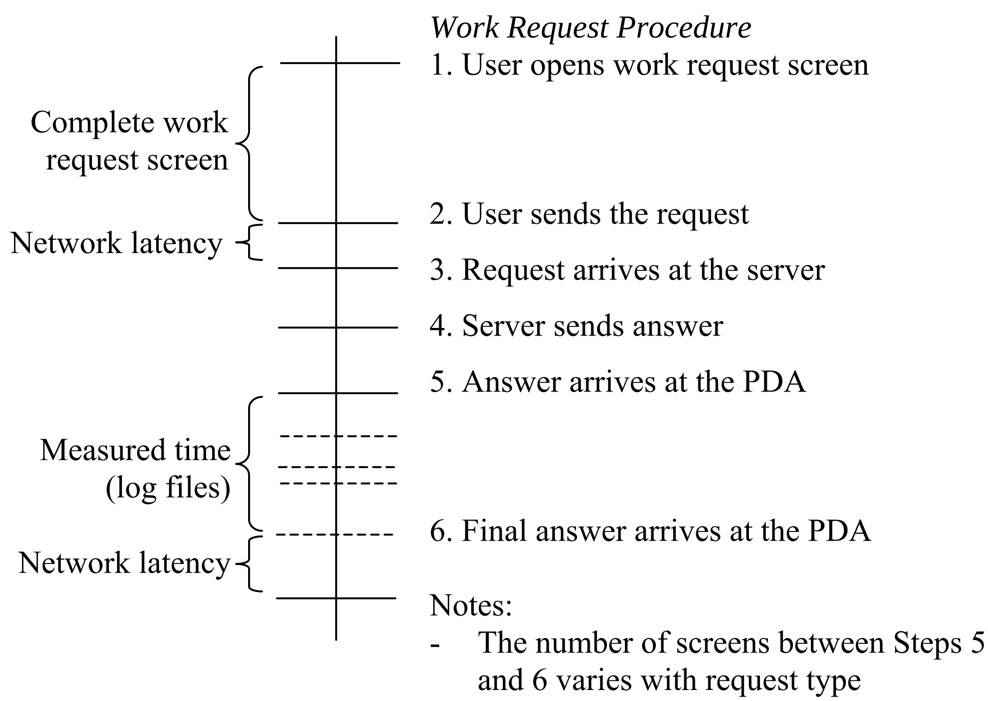


Figure 5. Timeline for Work Request Procedure

Error measures

- Communication errors: These errors represented work requests that had to be partially or fully repeated. For the PDA, they also included work requests sent more than once.
- Safety errors: These errors involved work authorizations accepted by the roadway worker without knowing the traffic pattern during the work period, work authorizations

that were not cancelled when it was required, or work authorizations accepted in a location that was not the one requested.

- Work requests that should have been sent but were not: The roadway worker had the opportunity to send the request, but for some reason he did not send it.
- Work requests that should not have been sent, but were: These were work requests that, because of traffic conflict, should not have been sent or work requests sent to the wrong dispatcher when using the radio.

Situation Awareness

A set of questions used to measure situation awareness were administered under two circumstances. Situation awareness was measured after the participant requested information by voice radio from the dispatcher or from the PDA. The first set was designed to measure the participant's ability to retrieve information. Situation awareness was also measured two times during each scenario when the participant had not requested information. The second set was designed to examine the participant's recall ability.

The questions assessed knowledge of the territory and train traffic at or near the hypothetical work site, and were based upon a specific time window. Territory information included dispatcher in charge, maximum train speed, and operating rules that applied to the section of track where the work took place. Train traffic patterns included the relevant trains that affected the roadway worker during the time when the work took place. For example, the roadway worker was queried about the train ID, updated schedule, whether or not the train was delayed, and track direction for trains that were supposed to pass through the work site while the job was being performed. Scores were computed according to the percentage of questions answered correctly. If the participant answered all the questions about the current train schedule correctly, a score of 100 percent was given.

4.3.2 Results and Discussion

Task Completion Time and Workload

Figure 6 shows the average time to complete each of the four communication tasks. Participants took longer to request Form Ds and Foul Time using the PDA compared to voice radio. The differences in both these comparisons were statistically significant ($t_{n=30} = 4.14$, $p < 0.0002$ for the Form D comparison; $t_{n=24} = 6.28$, $p < 0.0001$ for the Foul Time comparison). Form D requests averaged 3½ minutes with the PDA and 2½ minutes with voice radio. Foul Time requests averaged 3 minutes with the PDA and 1½ minutes with voice radio. In normal railroad operations, Foul Time is less structured than a Form D and therefore takes less time to request.

The device had limited two-way communications that resulted in longer transaction times. When the dispatcher answered a work request, there was no way to alert the roadway worker. The roadway worker had to periodically query the system for a response from the dispatcher the same way a person queries an e-mail server to obtain e-mail. If the roadway worker waited too long before he or she checked for a response, then the total work request time was also longer. With the next generation of handheld devices, the dispatcher can alert the roadway worker. These new devices will shorten transaction times.

The cancellation of work requests was shorter with the PDA than with voice radio, but comparable to a Foul Time cancellation over the radio. The Form D cancellation took longer over the radio because the formal acknowledgment steps required the participant to repeat the main fields of a Form D twice.

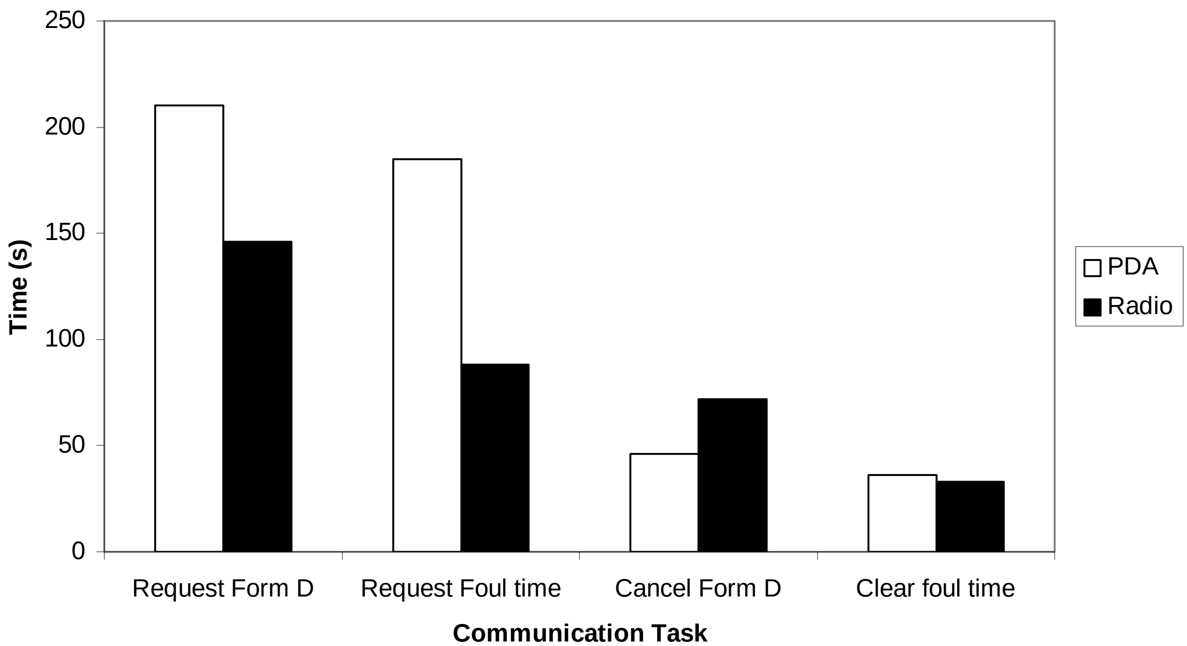


Figure 6. Average Task Completion Times

The transaction time comparisons measured between the two communication modes in this study may not apply to the typical railroad operating environment. In this study, the dispatcher played by the experimenter, answered work requests as quickly as possible. In normal operations, dispatcher response times vary. Dispatchers are often busy with other tasks and do not answer requests right away. Overall, the participants perceived the workload while using the PDA and the radio as being similar. Half the participants said that workload was lower with the PDA, while the other half said it was higher.

Error Analysis

Participants made fewer communications errors with the PDA compared to voice radio, as shown in Figure 7. Although these results were not statistically significant, the data suggests that presenting work authorization information on a handheld visual display can reduce communication errors associated with the acknowledgment process. This result can be attributed to the reduced memory load associated with information displayed visually. The participants filled in the same fields continuously, and it was easy to remember a field since it was displayed on the screen. A similar result occurred in an evaluation of a visually based data link display for dispatchers (Malsch, Sheridan, and Multer, 2004). In that study, fewer readback and hearback errors were made with data link than with voice radio. Communication errors with the PDA could have been reduced if the PDA had the ability to verify the request before sending it to the dispatcher.

Participants made more than five times the number of safety errors with voice radio than with the PDA. These differences were statistically significant (χ^2=6.87, df=1, $p < 0.01$). Figure 7 shows that there were 11 safety errors with voice radio and only 2 with the data link device.

Figure 7. Errors Associated with Communications, Safety, and Work Requests

There were no significant differences between voice radio and the PDA when submitting work requests that should not have been sent. Participants submitted four work requests in the radio condition compared to three in the PDA condition. While the average number of work requests was the same for both communication modes (six per scenario), participants made fewer requests than should have been sent with the PDA as compared to voice radio. Figure 7 shows the number of work requests that could have been sent, but were not. There were nine work requests that could have been sent in the PDA condition compared to four work requests in the voice radio condition. These differences were not statistically significant. Taken together, the two work request measures suggest that participants were more conservative in their willingness to submit work requests when using the PDA.

<u>Situation Awareness</u>

Overall, participants demonstrated better situation awareness scores with the PDA than with voice radio. Participants answered 78 percent of questions correctly in the PDA condition compared to 50 percent in the voice radio condition. These differences were statistically significant ($x = 39.87$, df=1, $p < 0.0001$).

The same set of questions used to measure situation awareness was administered under two circumstances. Situation awareness was measured after the participant requested information by voice radio from the dispatcher or from the PDA. The first set was designed to measure the participant's ability to retrieve information. Situation awareness was also measured two times during each scenario when the participant had not requested information. The second set was designed to examine the participant's recall ability.

In the first set of measures, participants exhibited better situation awareness scores in the PDA condition. Participants answered 78 percent of the questions correctly in the PDA condition, compared to 48 percent in the voice radio condition. These differences were statistically significant ($x = 41.03$, $df=1$, $p < 0.0001$). The second set of situation measures showed the same tendency. Participants answered 71 percent of questions correctly in the PDA condition, compared to 50 percent in the voice radio condition. However, the differences in the second set were not statistically significant.

Compared to voice radio, the data link device resulted in safer operations from two different points of view. First, situation awareness scores were higher using the PDA device compared to voice radio. Considering the train location and territory information that a roadway worker must collect before starting work on the right-of-way, the participants retrieved more information using the PDA device.

Figure 8 shows the five categories of information measured and Table 4 describes the categories of information collected. In four of the five information categories, participants retrieved more information when they used the data link device. The differences for three of these measures were statistically significant: relevant trains, updated train schedule, and train direction ($x = 21.00$, $df=1$, $p < .0001$; $x = 37.33$, $df=1$, $p < .0001$; $x = 21.00$, $df=1$, $p < .0001$ respectively).

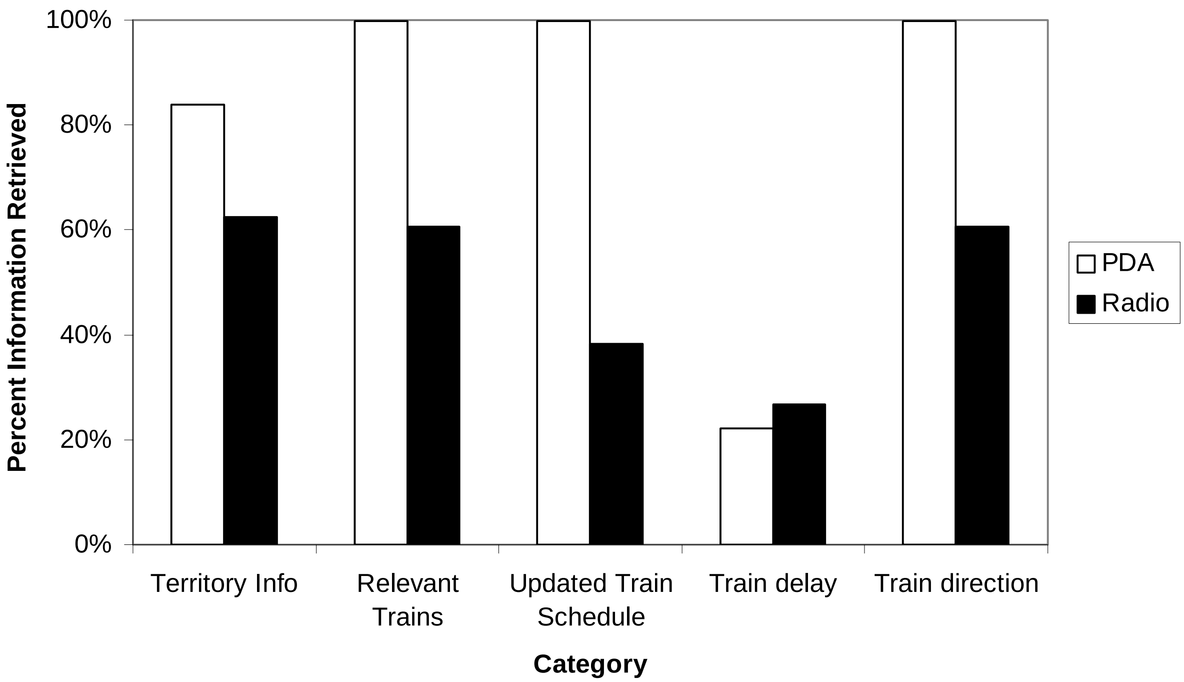


Figure 8. Information Retrieved

For all three measures, participants correctly answered the questions 100 percent of the time. With the voice radio, participants' answers were correct between 50 percent and 60 percent of the time. When the participants used the PDA, they identified almost all the trains that could represent a hazard, but only 61 percent of the participants could identify potential hazards when voice radio was used. Participants also demonstrated better understanding of the actual train schedule when the PDA was used.

When the roadway workers communicated by voice radio they could call the dispatcher for updates, but most did not take advantage of this opportunity. This behavior is consistent with their experience in revenue service as roadway workers avoid calling the dispatcher with this type of request. Roadway workers usually determine train status by calling station staff or other track crews. Participants indicated that the dispatcher was the last person they would call for train status because of the dispatcher's high communication workload. They also avoided calling dispatchers with simple requests.

Table 4. Situation Awareness Categories

Measure	Description
Territory Information	Includes dispatcher in charge of the territory, applicable operating rules, and the maximum train speed at the work site.
Relevant Trains	All trains that represented a potential hazard for the work crew.
Updated Train Schedule	Knowledge of the real time train schedule.
Train Delay	Is the train delayed or on-time?
Train Direction	Direction of the train: east or west.

Although the information for updated train schedules and train delay were similar, performance for these two categories differed considerably. Participants exhibited better situation awareness scores on the PDA for "updated train schedule" than for "train delay." This may be due to the implementation of these two types of information on separate screens. Knowledge of the train delay means the user also knows the updated train schedule, but not deviation from the schedule. When using the PDA, participants had no access to printed schedules that could be used for reference. The information found in the PDA contained updated times but the train delay had to be retrieved in a specific screen that was viewed infrequently. Several participants suggested that information about train status should be integrated with information about train schedule on the PDA. Had this integration been included in the PDA prototype, participants using the device might have performed similarly in the two conditions.

User Acceptance

Participants were asked if they would use the PDA in their jobs. Interest was high for both requesting information and work authorizations. The PDA application was rated on a scale from one to five with one being the maximum acceptance and five being the minimum acceptance. Participants gave the PDA a rating of 1.2 for retrieving train location information and a 1.5 for asking the dispatcher for protection. The participants' attitudes suggest roadway workers were eager to use a handheld device like the one tested in this study.

Participants liked the fact they learned to operate the device with minimal training. Three of the users asked if it would be used in railroad operations and whether they would get a PDA. Almost all of the participants saw other potential uses as discussed below. As one roadway worker said, "[The PDA] is an excellent tool for employees working both on the right-of-way and on trains."

Required Features

Despite the positive feedback for the use of a PDA in railroad operations, the participants mentioned several features the device must have before introducing it in revenue service. The criteria can be divided into two categories: hardware and software.

Hardware

- The device must be rugged enough to withstand the conditions typical of the railroad environment. In particular, it must be waterproof and shockproof. A clip for attaching it to the roadway worker's belt and a hardcover for protection would also be helpful.
- The screen should be larger (as much as twice the size of the current prototype) and the device should be able to do a self-diagnostic test to assure screen accuracy (i.e., to find malfunctioning pixels that may cause incorrect readings).
- The device must be able to withstand being dropped.
- The battery life should last at least one full day.[3]
- The wireless coverage should span the entire right-of-way and its surroundings. Participants were concerned about this issue because of their experience with inadequate coverage using cellular phones along the right-of-way.
- The wireless device should allow two-way communications so warnings could be received by the PDA.
- The PDA should also warn the user about approaching trains whenever they entered a block close to their working sites.

Software

- The system must keep a log of work permissions. NORAC rules require that fulfilled and canceled Form Ds must be kept for 7 days. Roadway workers usually keep a log of their Foul Time requests, and the PDA could benefit them by storing this log.
- The system should not allow the dispatcher to grant work permission with different information from that initially requested by the roadway worker since this may cause a safety hazard (i.e., the system should not let the dispatcher grant work permission on Track 1 if the roadway worker requested permission to work on Track 2).
- Security features are needed so that only authorized users can use the application. A mechanism is also needed to authenticate the identity of the sender.
- As a safety measure, the train schedule database must include all the trains (scheduled and unscheduled) under the control of the traffic center.

[3] The batteries of the Palm VII easily lasted a few days but the transmitter had to be recharged after prolonged wireless transactions. The transmitter was fed from an intermediate energy storage element that was, in turn, charged from the batteries. When the energy storage element was being charged, the transmitter could not be used. This limitation is unacceptable in revenue service.

- Information about train location should also be updated in real time.

One issue that spans both hardware and software is the need for security to ensure that only authorized employees are able to communicate using the application. Authentication procedures are also needed to ensure that users know with whom they are communicating.

Optional Features

Optional features for the device have been divided into three groups: improvements with respect to features that already exist in the prototype, new features to be added, and hardware improvements.

Improvements to Existing Features

- The software should be flexible enough to allow the roadway worker to ask for all types of work requests. The prototype only reflected three lines of a Form D when there were actually 13. Some of these lines were used often and should be included in an improved device. Work requests should be more flexible in terms of the ability to describe the desired work site. This includes the ability to ask for more than one track at a time (useful when requesting to foul an entire interlocking), and the ability to define work sites by mileposts as well as location names.
- Before giving any section of track back to the dispatcher, the system should prompt the roadway worker for confirmation. The PDA should provide confirmation that permission to work is no longer in effect. The confirmation process should also address the unlikely situation where two work authorizations are in effect, and only one is cancelled.
- The PDA could enhance the train status report by including the number of passengers or empty seats on passenger trains, the number of empty or loaded cars in freight trains from foreign railroads, and the reason for a train delay. Including this information offers the opportunity to speed up the movement of information for tracking business-related functions compared to paper-based methods.
- Another beneficial feature to the device would be a quick reference to rules and rule updates and a description of equipment changes (such as moved signals, energized sections, and signals out of service) linked to the territory information report.
- The PDA should also provide a visual alert screen to indicate if a train is late, or to indicate changes in train schedule. The updated and revised schedule could be shown on a separate screen. The PDA prototype always displayed updated times, but without the initial paper schedule it was not easy to tell whether a train was late or not. The PDA provided this information, but on a different screen (Train Status) and it was not merged with the updated times. Roadway workers commented that when the updated time was displayed, the time itself was not enough. The updated screen should also include a letter or a symbol indicating whether or not this time corresponded to the timetable schedule.
- The device parameters should allow the PDA user to view all work permissions in effect for each track section on screens indicating the track that is out of service. It would also be beneficial to include work permissions under the authority of other roadway workers.

- Finally, the device should allow easy access to information about special trains. The prototype design required that the user scroll through several different screens in order to reach the desired information. The existing PDA needs to be modified so that access to information is quick and easy.

New Features

- A valued addition to the PDA would be to include movement authorities such as Rule 241, as well as interactions with dispatchers for speed restrictions.
- Important information such as weather conditions in different sections of the track could also be incorporated.
- The device could be used to receive information concerning any situation that would affect the safe movement of trains or their time performance (i.e., train speed restriction bulletins, derailments, location of work crews or contractors on or fouling the track, blocks occupied, and over dimensioned cars).
- Roadway workers would benefit if communication capabilities were extended to enable PDA users to send and receive short messages among themselves.

Hardware Improvements

- Participants were asked about the need for a portable wireless printer to make paper copies of specific screens on the PDA. The original idea was to print train schedule reports and work permissions. Some participants were enthusiastic about the idea while others thought it would be a burden.

Additional Uses

- The participants in this study were conductors, so their duties often involved working on passenger trains. They mentioned the potential that a data link device might have while working on board trains. It would be useful as an alternative medium to communicate with management in stations or engineers while the conductor is on the train. It also could be used to give the passengers appropriate information about train connections or updated train schedule.
- While the roadway workers are in the right-of-way, the PDA could be a good tool to communicate with other staff at the dispatch center such as the Trouble Desk Manager, to report speed restrictions.
- During earlier tests, the PDA was demonstrated to the manager of operations for a passenger railroad. He observed great potential in real time train information and portable capabilities of the PDA to monitor the railroad network in and out of the office environment.

4.4 Conclusions

The communication tasks of one class of roadway workers (conductor-flagman) were evaluated as well as the information needed to support those activities. The conductor-flagman serves as a conduit for communications between roadway worker crews and dispatchers, and is responsible for the safety of the work crew. Two types of tasks were identified: acquiring information and requesting work authorizations. The task of acquiring information included train status and information related to the geographical territory (i.e., operating rules in effect). The second task of requesting work authorization from the dispatcher was classified according to whether the communications were structured or unstructured. Structured communications consisted of transactions defined by railroad operating rules. These include the exchange of movement authorities and track work authorization. Unstructured communications lack the formal procedures that make the structured transactions predictable and time consuming.

An application was developed to support these communications-related tasks on a wireless handheld computer. The key user information requirement consisted of timely information about the train status with respect to location and time. Work authorization procedures were included to address the dispatcher's task requirements. The work authorizations were representative of structured transactions between dispatchers and roadway workers. The PDA provided the roadway worker with current information about the status of the surrounding work area. The PDA also enabled the roadway worker to request a variety of work authorizations (Form D and Foul Time).

A text-based interface was developed on a wireless handheld computer. This tool was developed cooperatively with several conductor-flagmen and classroom instructors for roadway worker protection. Several user requirements were identified which drove the development of the user interface. The most important user requirements related to device size, data entry, and ease of learning. The device had to be small enough to be carried on the body, which also limited the available display space. A PDA was chosen, which was smaller than a laptop display, but larger than a cell phone display. Data entry had to be minimal, and the device simple to learn. Interaction with the PDA was accomplished using a stylus and a menu driven interface.

After developing an initial prototype, and conducting an informal usability test and revising it, a formal usability test was conducted to evaluate the device's readability and navigation. Overall, participants found the device easy to read and navigate. Several participants were looking forward to using such a device in their jobs. One drawback with the current prototype was the slow data transmission speed for wireless communications. This problem is a typical one for wireless applications being used in the field in the early 21st century, and it may impact the acceptance of the device in the workplace. Lack of consistent coverage in the field is another problem that may also affect usability and user acceptance in the short term. Slow transmission speeds will improve as better technology becomes available, and coverage will improve over time as wireless service providers widen their networks.

Following the usability tests, performance between the PDA and voice radio was compared for a variety of tasks. Task completion time, errors, and situation awareness were measured. When requesting Form Ds or Foul Time, completion times were longer for the PDA compared to voice radio. This performance can be partly attributed to the slow response time associated with wireless network and limitations of the user interface. The improved performance in the voice radio condition could be attributed to one specific artifact of this experiment. The dispatcher, who was being played by the experimenter, always responded to incoming messages as quickly as possible. In normal operations, the roadway worker may wait a considerable length of time (e.g., several minutes) before the dispatcher responds.

The prototype used in this study provided more accurate communications than voice radio. There were fewer communication and safety-related errors. A data link device capable of receiving time sensitive information about train location improved roadway workers' situation awareness scores and contributed to better decision-making processes in a laboratory setting. User requests for track protection were more consistent with the track availability. This benefits the dispatcher by reducing the communication load and lowering the number of errors associated with the acknowledgement procedures.

4.4.1 Future Directions for Research

The two groups of tasks supported by the PDA represent only the beginning in the evolution of digital communications and the development of information appliances for roadway workers. More work is needed to make the current prototype suitable for use in the field. A variety of user interface issues common to all wireless handheld devices need to be addressed. Two key issues include providing adequate display space and improving methods for interacting with the device. The current user interface is text based; however, roadway workers are comfortable viewing maps that spatially show information on the track. Presenting train status and territory information in a graphical format may enable workers to quickly and effectively retrieve information. Usability testing will be needed to answer this question.

The PDA addressed the roadway workers need to acquire information without contacting the dispatcher. However, the current prototype lacks the ability for true two-way communication in which the roadway, dispatcher, or computer system can initiate communications. The device relied upon the roadway worker to initiate communication. When a change in the system occurs, the dispatcher cannot alert the roadway worker to the change. Likewise, the dispatcher cannot send a signal to the roadway worker to indicate the status of a work authorization request. The roadway worker must initiate any action to request information or submit a work authorization. A digital communication system with true two-way communications could improve safety by enabling the dispatcher or computer system to send warnings to the appropriate work crew when relevant events occurred. A PDA with this capability is examined in the next phase of this research.

Roadway workers who were interviewed for the current study proposed making information currently found in paper form (an electronic briefcase) available on the PDA. While some roadway workers may find the current application useful, other tasks involving railroad operations may need to be supported by the PDA application as well. Track foremen and others who operate track equipment may have different or additional information requirements to complete their tasks than conductor-flagmen.

As new technology becomes available, there is potential for improvement in railroad operations. One technology that will improve safety and productivity is GPS (global positioning system). As part of a communications system, GPS can provide precise information concerning the location of trains, track crews, and other railroad equipment. The next study in this research program will evaluate the use of GPS to provide track crew location information to dispatchers.

APPENDIX A. PDA SYSTEM ARCHITECTURE

Components

As shown in Figure 2, the prototype developed in this project is based on the Internet, and has the following components:

1. **PDA device**. The prototype runs on a small information appliance called a Palm VII (Palm Inc, 1999; Palm Inc, 2001a, Palm Inc, 2001b). It stores the web pages that are used to send requests to the dispatcher or the dispatcher's terminal. These web pages are designed in such a way that user interaction is minimized and simplified.
2. **Web server**. This server hosts the master files that are used as templates to send information back to the PDA.
3. **Query servers**. Run on the same computer as the web server and they are continuously looking for requests sent by the PDA or the dispatchers. These servers are responsible for redirecting the request to the appropriate destination.
4. **Database**. The prototype version is a static database but it is ready to be dynamically updated with real time data. This database stores information about past train schedules, expected schedules in the future, current delay, train information (direction of travel, number of cars, engine number), out of service track under Form D, out of service track under Foul Time, and territory information (maximum speed, dispatcher in charge, rules that apply)
5. **Dispatcher interface**. A very schematic message console for the dispatcher. This is where the dispatcher receives and answers requests sent to him by the PDA.
6. **Database manager interface**. A simple web page that is used to update the database.

PDA Application

The prototype runs on a Palm VII, a device with wireless access to the Internet. For details about how this wireless access is implemented, refer to Palm VII white paper web page Palm, Inc. (1999). The Palm VII is only online when it sends data and it only waits for incoming data after the operator has sent a request. The Palm VII is limited by the fact that it will not receive data until it first requests it. Several design decisions were made because of this limitation. The application only hosts web pages that do not change over time, and are only used to submit requests to the server.

As shown in Figure A-1 to Figure A-4, the main menu is divided in three submenus. One of the figures refers to train location and territory information, and the other two refer to work requests (Form D or Foul Time).

From the train and territory information submenu, the operator can access train status information, territory information, and real time train schedule. Following the link "Train Status," a roadway worker can retrieve information for a given train which may include its current delay, last location and time at that location, next location and expected time at that location, destination, number of cars, and the engine number. Following the link "Territory

Information," for a given section of the track the roadway worker can learn about maximum train speed, dispatcher in charge of that territory, and rules that apply. The roadway worker can retrieve real time train schedule, or train out of service (OS) from two perspectives. Following the link "Train OS (ID)," for a given train ID the roadway worker can obtain the train OS from the beginning of its journey. Following the link "Train OS (work site)," for a given section of the track and window of time the roadway worker can obtain a list of trains that occupy or are expected to occupy the track during that period.

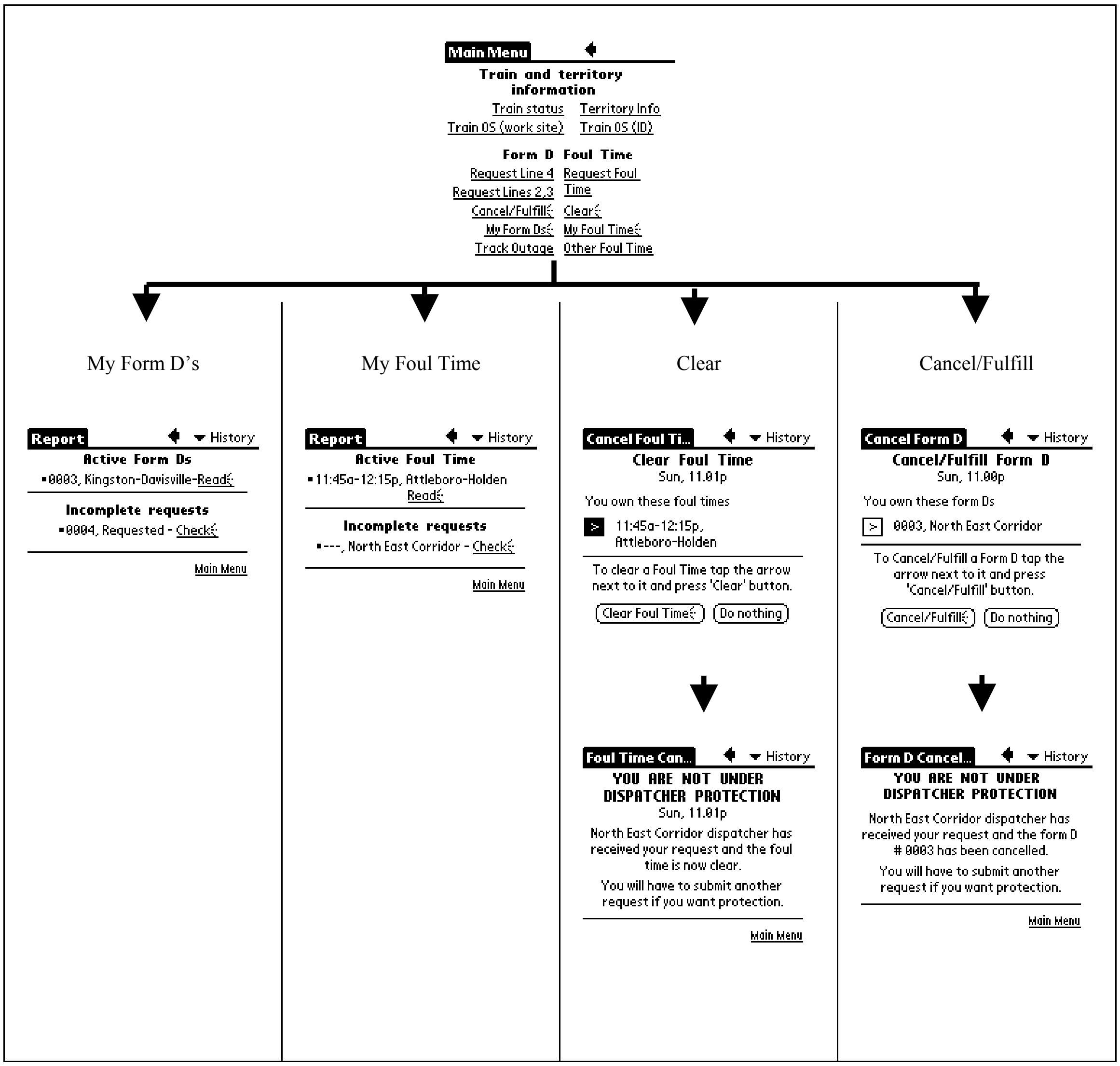


Figure A-1. PDA Screen Shots (1)

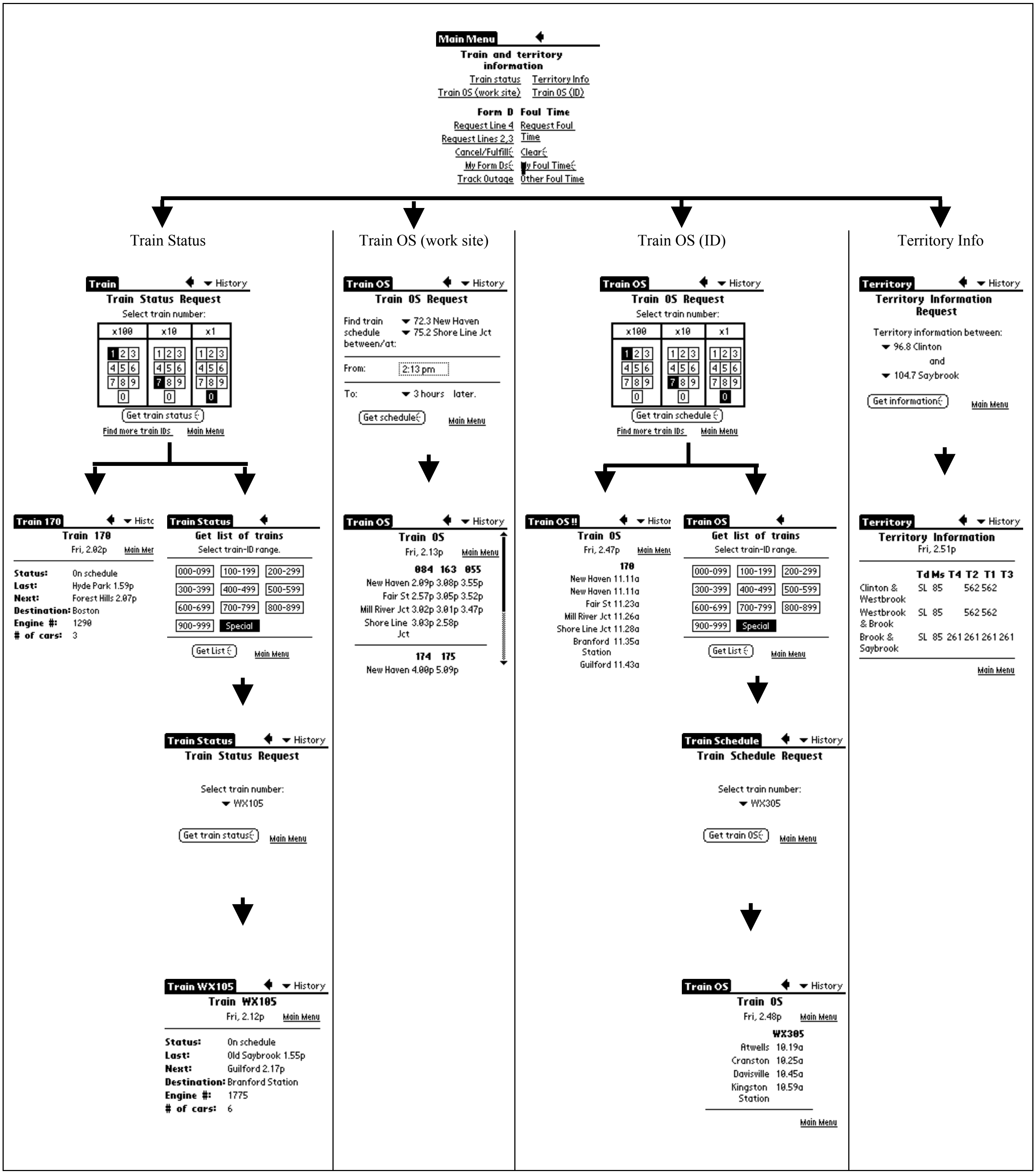


Figure A-2. PDA Screen Shots (2)

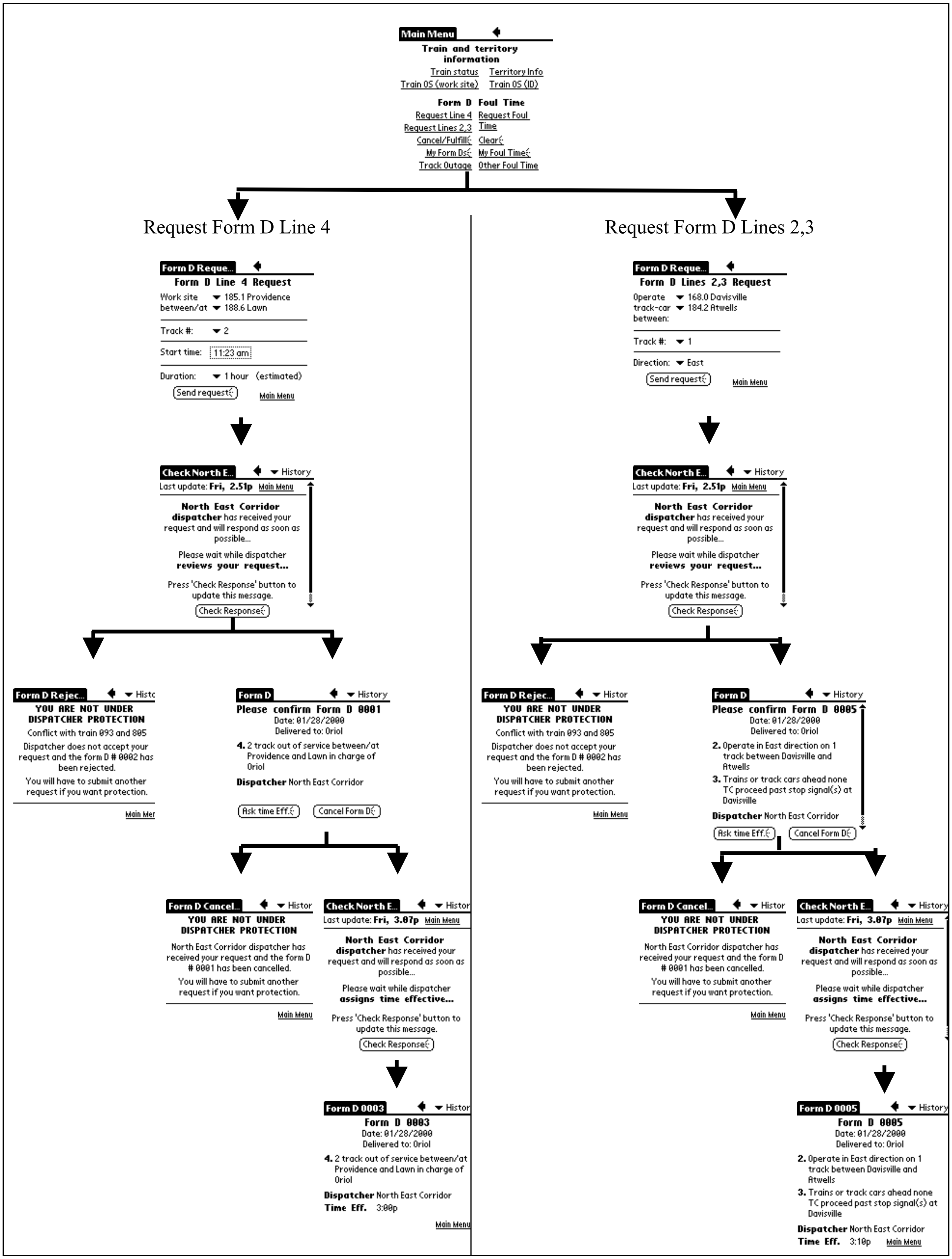


Figure A-3. PDA Screen Shots (3)

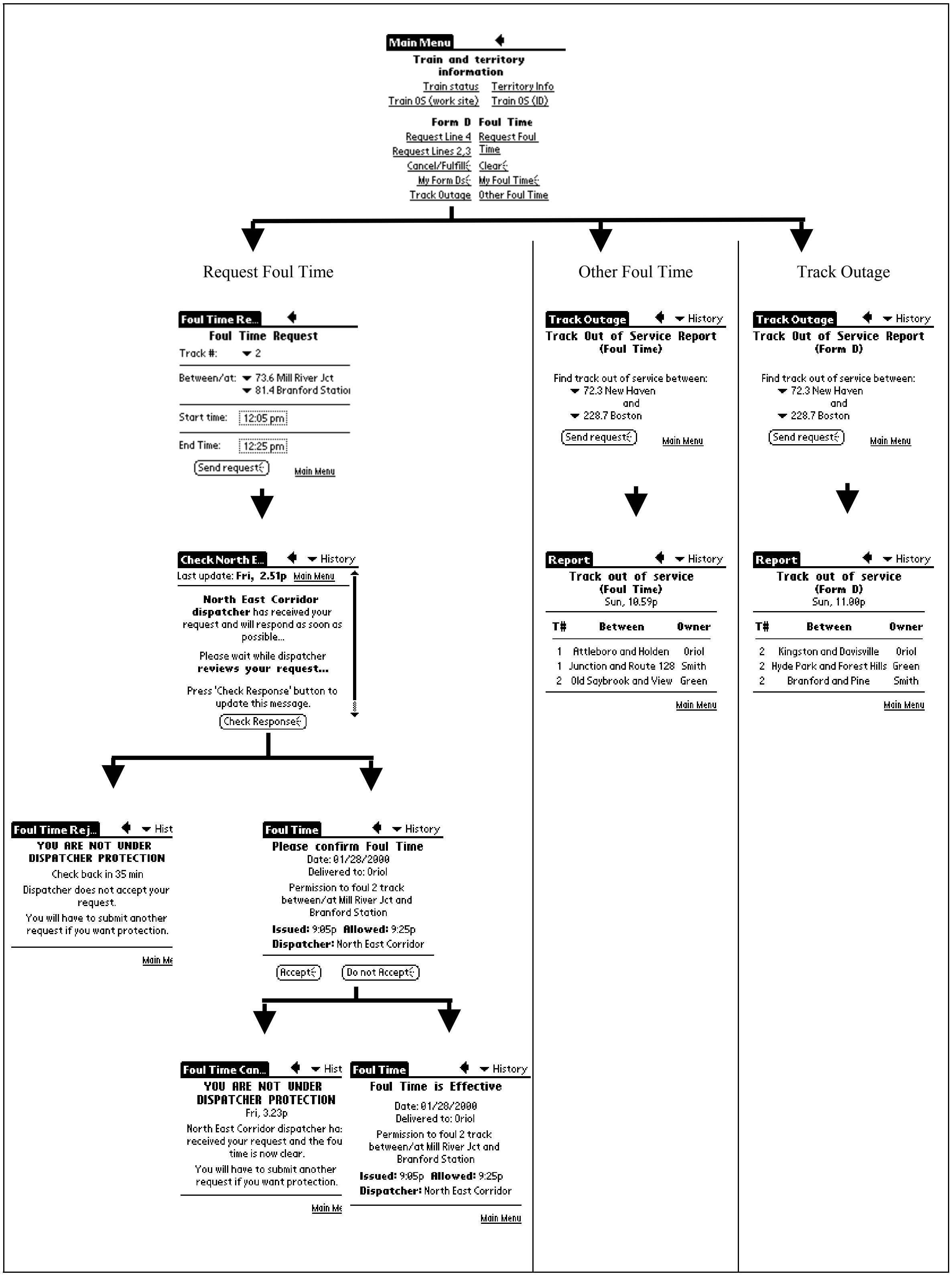


Figure A-4. PDA Screen Shots (4)

From the work request submenus, the roadway worker can request Form Ds (line 4 or lines 2 and 3) and Foul Time. Following the links "My Form D" or "My Foul Time," the roadway worker can retrieve a list of Form Ds or Foul Time under his/her authority, and continue an interrupted work request. Following the links "Cancel/Fulfill" or "Clear," the roadway worker is able to give some track under his authority back to the dispatcher. Following the links "Track Outage" or "Other Foul Time" the roadway worker is able to determine for a given section of track whether there is some track out of service under Form D or Foul Time.

Web Server

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

Query Servers

The query servers used in this study were mainly written in Java (Sun Microsystems, 2001), and only one file was written in Perl (Clay, 2001). The file used for this experiment is a Common Gateway Interface (CGI) script, which is used as an interface between the web server and the query servers. It reads the HTML forms as sent by the PDA, stores a file with the request description (where the query servers are looking for them), and finally reads and returns the requested information to the PDA.

There were five query servers: database, dispatcher, file, dispatcher terminal refresh, and simulation query servers. Every second, the servers would look for requests sent by the PDA or dispatcher. When a request arrived the appropriate query server read the request, processed it, and wrote the answer for the CGI script to be sent back to the original petitioner. A detailed description of the purpose of each server follows.

1. **Database Query Server**. Handles requests sent by the PDA that needs access to the train schedule database and the database updates sent from the database manager interface. These requests include:

    Train Status: Receives a train ID as input and returns the status of that train. The train status includes for all trains: current delay in minutes, last location, next location, time at these two locations, destination, number of cars, and engine number.

    Train OS (work site): Receives a time window and a portion of track as input, and returns the real time train OS of all the trains that occupy that portion of track in the given time window.

    Train OS (ID): Receives a train ID as input and returns its real time train OS from the beginning to the end of its journey.

    Territory Information: Receives a portion of track as input and returns the rules that apply in that territory as well as the dispatcher in charge, and the maximum train speed.

    Update database: The database manager uses this request to manually update the delay of any train in the system. This request can also be used to reset the schedule of the trains. At the end of the day the train schedule is automatically reset to reflect the next day schedule, but should the database manager want to do it manually this request provides the option for him/her.

Update database from file: Automatic update of the database. This request is supposed to be triggered automatically every given time. It was included as an interface between a potential real time database and the PDA database.

2. **Dispatcher Query Server**. Handles requests sent by the PDA that need dispatcher interaction such as requests that have to do with work permissions and answers sent by dispatcher to the PDA. These requests are:

Requests sent by PDA:

Request Form D line 4: Used to send a work site description to the dispatcher, track number, and desired window of time to perform a work that will require a Form D line 4 authorization.

Request Form D lines 2 and 3: Used whenever a roadway worker wants to operate a track car. This movement requires Form D lines 2 and 3 authorization. This request is used to send the dispatcher the portion of track, track number, and the direction of travel.

Ask for time effective or cancel Form D: A Form D is not active until the dispatcher assigns a time effective. Once the dispatcher has assigned a time effective, the Form D becomes a rule. Before this step, the roadway worker must acknowledge that the dispatcher has understood his/her request. The roadway worker then has to confirm the Form D by asking a time effective of the dispatcher.

This request receives just the acceptance or rejection of the Form D as input. If the roadway worker accepts the Form D, the dispatcher will assign a time effective and it will become rule until it is cancelled or fulfilled. If the roadway worker rejects the Form D, the entire Form D request procedure will have to be repeated.

Retrieve list of active Form Ds: Used whenever a roadway worker has finished their job or wants to cancel or fulfill a Form D and is giving the track back to the dispatcher. This request will send the dispatcher a list of their active Form Ds and will let them select the one they want.

Cancel/fulfill Form D: Works together with the previous request. This is the step to actually cancel or fulfill the Form D.

My Form Ds: Used to retrieve a list of current Form Ds or incomplete Form D requests under the authority of the roadway worker holding the PDA. Although it is not included in the first prototype of the PDA, this request should also comply with rule 176, which states, "Form Ds which have been fulfilled or cancelled […] must be retained and held available for inspection for a period of 7 days" (NORAC operating rules).

Track outage: This feature is used to retrieve a list of track that is currently out of service under Form D authorization. Receives a portion of track as input, and for every section of track out of service within those given limits, it returns a list of track numbers and track owners. This knowledge will let the PDA user know whom they should contact in case they want access to that portion of track.

Request Foul Time: This feature is used to send the dispatcher a work site description, track number, and desired window of time to perform work that will require Foul Time authorization.

Accept or do not accept Foul Time: This is a roadway worker acknowledgement. This request receives just the acceptance or rejection of the Foul Time as input. If the roadway worker accepts the Foul Time, it will become active. If the roadway worker rejects the Foul Time, the entire Foul Time request procedure will have to be repeated.

Retrieve list of active Foul Time: Used whenever a roadway worker has finished their job or wants to clear a Foul Time and is giving the track back to the dispatcher. This request will send the roadway worker a list of his active Foul Times and will let them select the one they want.

Clear Foul Time: Works together with the previous request. This step is required to clear the Foul Time.

My Foul Time: Used to retrieve a list of current Foul Times or incomplete Foul Time requests under the authority of the roadway worker holding the PDA.

Other Foul Time: This feature is used to retrieve a list of track currently out of service under Foul Time authorization. It receives a portion of track as input, and for every section of track out of service within those given limits; it returns a list of track numbers and track owners. This knowledge will let the PDA holder know whom they should contact in case they want access to that portion of track.

Requests sent by dispatchers:

New dispatcher (login): This feature is used whenever a new dispatcher enters the system. This request receives a territory description and a password as input and it returns a full dispatcher terminal that will receive any request that has to do with the given territory. Dispatchers have to log into the system before they are able to receive requests from the PDA.

Answer request for Form D lines 2 and 3: Used by a dispatcher to grant or deny the requested Form D lines 2 and 3. If the dispatcher grants the Form D, they will send the roadway worker who made the request the appropriate information. This information includes Form D number (automatically assigned by system), Form D recipient, date, direction of travel, track number, track location, and information about trains or track cars ahead. In case the dispatcher denies the requested Form D, it will be cancelled and the roadway worker will be notified.

Answer request for Form D line 4: Used by a dispatcher to grant or deny the requested Form D lines 4. If the dispatcher grants the Form D, the appropriate information will be sent to the roadway worker who requested it. This information includes Form D number (automatically assigned by system), Form D recipient, date, track number, track location, and foreman in charge of the track out of service. In case the dispatcher denies the requested Form D, it will be cancelled and the roadway worker will be notified.

Assign time effective for Form D: Once the roadway worker has received and acknowledged the previous information for any Form D, the dispatcher assigns a time effective. The time effective is sent to the roadway worker and the dispatcher is notified of its receipt.

Answer request for Foul Time: Used by a dispatcher to grant or deny the requested Foul Time. If the dispatcher grants the Foul Time, the appropriate information will be sent to the roadway worker who requested it. This information includes track number, time issued, time allowed, employee in charge, and track location. If the dispatcher denies the requested Foul Time, it will be cleared and the roadway worker will be notified.

3. **File Query Server**. Handles requests sent by the PDA or the dispatcher that only require reading a file or finding out whether a file exists.

These requests are:

Items in My Form Ds or My Foul Time reports: Form Ds and Foul Times are not stored in the PDA. They are stored in the machine running the web server. When a roadway worker wants to know about their own Form Ds or Foul Time, they use the PDA to retrieve it from the web server. The roadway worker will not look for the specific file name, they will only tell the PDA they want to retrieve a specific Form D number or a given Foul Time.

Wait screens: While the roadway worker or dispatcher are waiting for the other end to answer a request, a "please wait" screen lets the user know. Since the Palm VII has no way to receive information until it has asked for it, this "please wait" screen has a button the roadway worker will use to check whether the answer is available or not. If the answer is available, it will be sent. If it is not available, an updated "please wait" screen will be sent. On the other hand, the dispatcher terminal (running in a standard web browser) has the ability to periodically check for answers from the PDA.

4. **Dispatcher Terminal Refresh Query Server**. The dispatcher terminal must reflect in real time the current state of the work requests. This server is responsible for updating the information every 10 seconds.

5. **Simulation Query Server**. Used to conduct the experiment, this server is responsible for sending the proposed tasks to the participants.

Database

The database includes information about dispatchers, roadway workers, track (type of territory, dispatcher in charge, maximum train speed), and trains (ID, schedule, engine number, number of cars, direction of travel, and days run). For the purpose of the experiments, the database also includes information about tasks to be done by test users and initial delays for trains during the experiment.

Six types of text files are used to load the database. The data files are tab separated text files. Following is a description of their functionality and format.

Dispatchers (`dispatchers.txt`). Includes the name of the dispatcher, branch (not used), limits of the territory under his/her authority (initial mile post and final milepost), a territory ID, and the password needed during login.

Territory IDs are used internally by the query servers, and they must be unique.

1. Roadway workers (`MWForemen.txt`). Includes information about registered PDAs and their owner.
2. Track information (`Track Info.txt`). Includes information about all the locations along the track (milepost, dispatcher in charge, maximum train speed, interlocking or station), the maximum number of parallel tracks, the rules that apply in each track between every two

locations and whether each location is a control point or not. Control points or scheduled sites, will be the only locations sent to the PDA when a train OS is requested.

3. Schedule file (`Boston-New Haven.txt`) and (`New Haven-Boston.txt`). Includes information about scheduled trains (ID, schedule, engine number, number of cars, direction of travel, and days run)

Dispatcher Interface

Any web browser can serve as the dispatcher interface. After logging onto the home page and selecting a territory, the user will be logged as the dispatcher in charge of that territory. The system will show all the incoming messages that affect the selected territory. Figure A-5 shows the dispatcher interface.

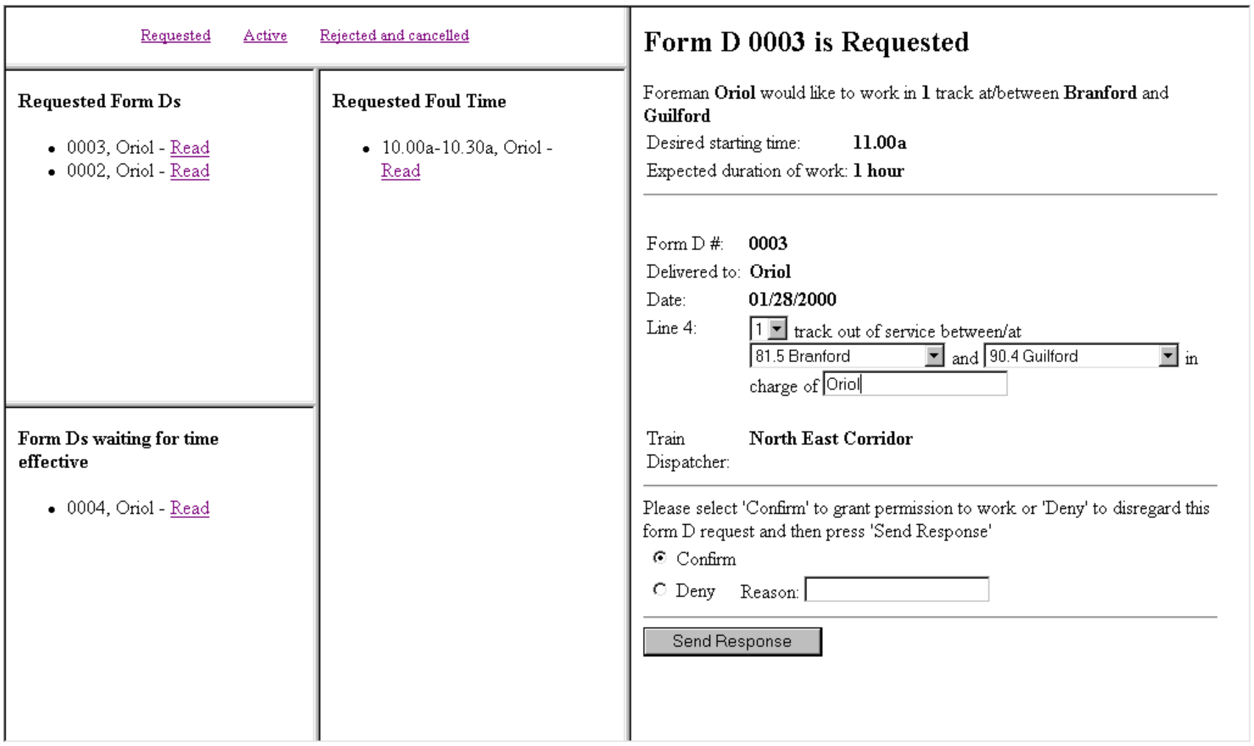
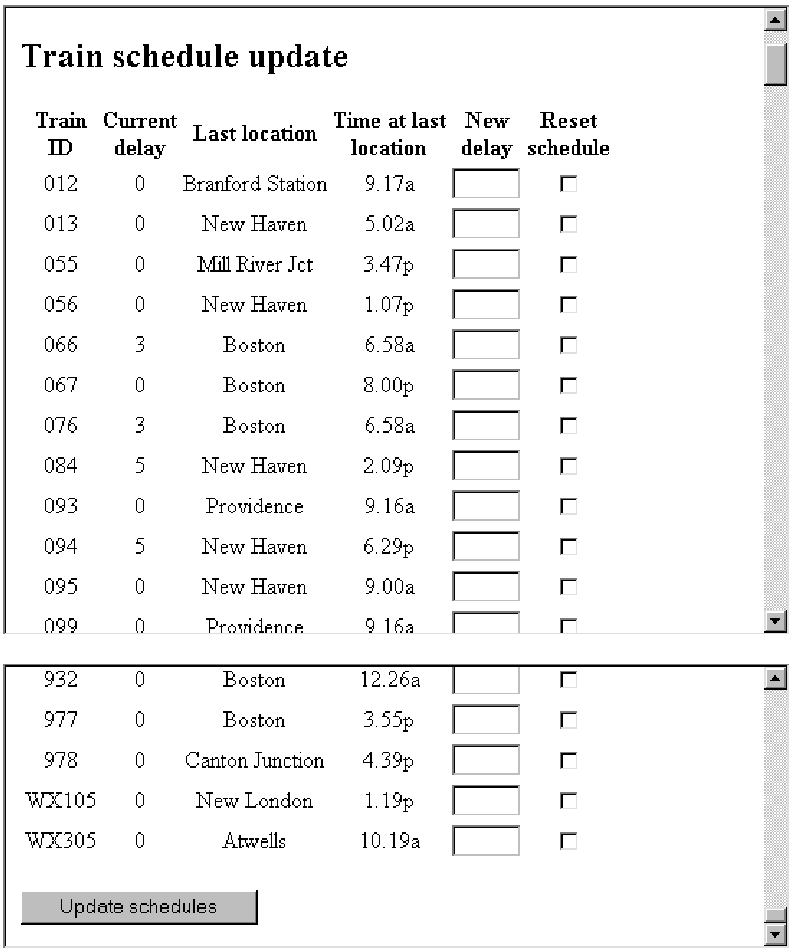


Figure A-5. Dispatcher Interface

Database Manager Interface

When the system is running, any web browser can serve as the database manager interface. From this page, a database manager can manually update delays of the trains in the system. Figure A-6 shows the database manager interface.



Train schedule update

Train ID	Current delay	Last location	Time at last location	New delay	Reset schedule
012	0	Branford Station	9.17a		
013	0	New Haven	5.02a		
055	0	Mill River Jct	3.47p		
056	0	New Haven	1.07p		
066	3	Boston	6.58a		
067	0	Boston	8.00p		
076	3	Boston	6.58a		
084	5	New Haven	2.09p		
093	0	Providence	9.16a		
094	5	New Haven	6.29p		
095	0	New Haven	9.00a		
099	0	Providence	9.16a		
932	0	Boston	12.26a		
977	0	Boston	3.55p		
978	0	Canton Junction	4.39p		
WX105	0	New London	1.19p		
WX305	0	Atwells	10.19a		

Update schedules

Figure A-6. Database Manager Interface

Type of Requests

Master Files

The system is designed to be highly configurable. To achieve this goal, not all the information that is displayed to the dispatcher or sent to the PDA is included in the source code of the servers. It is stored in what is called the master files. The master files are just templates of HTML files that are read by the servers and filled with the correct information every time they are used.

APPENDIX B. QUESTIONNAIRES

Following the ideas in Nielsen, (1994) and Kirwan, (1992) three sets of questionnaires were prepared. These questionnaires were given to the test users during the experiments.

The first set was a list of questions about background and demographics of the test user. The second set was used during the usability test to evaluate the last iterations of the PDA application design for specific major problems and to measure the user's ability to complete the tasks effectively. This questionnaire helped to identify points of confusion and difficulty. The third set of questions was used during the system evaluation test. It was used to validate the final PDA application design, to check if it met minimum performance levels and to understand its usefulness.

Demographic Questionnaire

Demographic

1. Job title ______________________

2. Years of experience ________

3. Please provide examples of your interaction with dispatchers and an average number of these interactions per week [form D (lines?), foul time, signal shutdown, train schedule update, bridge lock/unlock, message relay, rule 241, hazard report, TSRB, other...]

Type of interaction	Frequency (number of times per week)

4. Please rate your level of familiarity with the following devices or services

	Very Unfamiliar	Unfamiliar		Familiar	Very Familiar
4a. Radio	1	2	3	4	5
4b. Personal Computer	1	2	3	4	5
4c. Beeper or Pager	1	2	3	4	5
4d. Cellular phone	1	2	3	4	5
4e. World Wide Web	1	2	3	4	5
4f. E-mail	1	2	3	4	5
4g. Palm Pilot	1	2	3	4	5

Usability Questionnaires

Miscellaneous

Presentation

1. Please rate how the information is presented to you according to the following attributes.

	Very Small	Small		Big	Very big
1a. Font size	1	2	3	4	5
	Very confusing	Confusing		Clear	Very Clear
1b. Font style (bold, normal, underlined...)	1	2	3	4	5
	Very Unreadable	Moderately Unreadable		Moderately Readable	Very Readable
1c. Readability	1	2	3	4	5
	Very Disorganized	Moderately Disorganized		Moderately Organized	Very Organized
1d. Well organized information	1	2	3	4	5

2. Please write down any comments that you might have about how the information is presented to you. What would you change if you had the opportunity?

Navigation

3. Please circle your level of agreement with the following statements.

	Strongly Disagree	Disagree		Agree	Strongly Agree
3a. It is easy to navigate through the menu tree.	1	2	3	4	5
3b. I was always aware of my location within the menu.	1	2	3	4	5
3c. I knew how to navigate to the prior screen.	1	2	3	4	5
3d. The menu names are meaningful.	1	2	3	4	5
3e. The button labels are meaningful.	1	2	3	4	5
3f. The menu is organized according to railroad operations needs.	1	2	3	4	5

4. What menu names or button label would you change to clarify the meaning of the commands? Can you suggest an alternative name?

Current menu name or button label	Alternative

5. If you could change it, would you organize the menu in a different way? How?

6. Please write down any comments about a particular problem that you had while navigating.

Task realism

7. Please circle your level of agreement with the following statement.

	Strongly Disagree	Disagree		Agree	Strongly Agree
7a. The tasks proposed in the experiment are close to typical real interactions with dispatchers.	1	2	3	4	5

8. Would you include any other type of task in the experiment? What tasks?

PDA Improvement

9. Please write down any other general comments on how we should improve the PDA?

10. Please list and comment on any features that the PDA must have before even considering to use it in railroad operations.

11. What safety concerns need to be addressed before a similar device could be used in railroad operations?

12. Do you see any other potential uses for the PDA ?

Train location and territory information menu

Request Screens

1. Please rate the Request Screens on the following attributes

	Very Incomplete	Moderately Incomplete		Moderately Complete	Very Complete
1a. Completeness (whether you could ask for everything you needed or not)	1	2	3	4	5
	Very Uncooperative	Moderately Uncooperative		Cooperative	Very Cooperative
1b. Cooperation (whether the screens are designed to help you introduce the required information or not)	1	2	3	4	5
	Very Complex	Moderately Complex		Moderately Simple	Very Simple
1c. Complexity (whether the screens are puzzling or not)	1	2	3	4	5
	Very Slow	Slow		Fast	Very Fast
1d. Speed (whether there was a prompt answer to your request or not)	1	2	3	4	5
	Very Difficult to Understand	Difficult to understand		Easy to understand	Very easy to understand
1e. Understandability	1	2	3	4	5
	Very Difficult	Moderately Difficult		Moderately Easy	Very Easy
1f. Entering the information that is needed by the system	1	2	3	4	5
	Very Unrealistic	Moderately Unrealistic		Moderately Realistic	Very Realistic
1g. Realism (whether the screens reflect railroad operation needs or not)	1	2	3	4	5

2. Would you include any other information in the request screens? What information? In what screen? Information __________ Screen __________

____

____

3. If you could change it, would you present the requests in a different way? How? ____________________

____

4. What type of sites would you like to have in the drop down lists (interlockings, stations, platforms, bridges, other, all of them, some of them,...)? ____________________

5. How would you like the site names to be sorted by? (milepost, name, both, other criteria) ____________________

6. Please write down any comments that you might have about a particular request screen. ____________________

____

____

Report Screens

7. Please rate the Report Screens according to the following attributes

	Very Poor	Poor		Abundant	Very Abundant
7a. Amount of information.	1	2	3	4	5
	Very Unexpected	Unexpected		Expected	Very Expected
7b. Expected type of information.	1	2	3	4	5
	Very difficult to use	Difficult to use		Easy to use	Very easy to use
7c. Vertical scroll bar.	1	2	3	4	5

8. What other type of information would you like to receive? How accurate does this information need to be?

____

____

____

____

____

9. Write down any comments that you might have about a particular report screen.

____

____

____

____

____

10. Is information about train location in the past relevant to your work? Would you show this information in the train OS?

____

____

____

11. What other attributes, if any, would you like to include in the train status?

____

____

Form D and Foul Time menus

Request Screens

1. Please rate the Request Screens on the following attributes

	Very Incomplete	Moderately Incomplete		Moderately Complete	Very Complete
1a. Completeness (whether you could ask for everything you needed or not)	1	2	3	4	5
	Very Uncooperative	Moderately Uncooperative		Cooperative	Very Cooperative
1b. Cooperation (whether the screens are designed to help you introduce the required information or not)	1	2	3	4	5
	Very Complex	Moderately Complex		Moderately Simple	Very Simple
1c. Complexity (whether the screens are puzzling or not)	1	2	3	4	5
	Very Slow	Slow		Fast	Very Fast
1d. Speed (whether there was a prompt answer to your request or not)	1	2	3	4	5
	Very Difficult to Understand	Difficult to understand		Easy to understand	Very easy to understand
1e. Understandability	1	2	3	4	5
	Very Difficult	Moderately Difficult		Moderately Easy	Very Easy
1f. Entering the information that is needed by the system	1	2	3	4	5
	Very Unrealistic	Moderately Unrealistic		Moderately Realistic	Very Realistic
1g. Realism (whether the screens reflect railroad operation needs or not)	1	2	3	4	5

2. Would you include any other information in the request screens? What information? In what screen? Information ________________ Screen ________________

____

____

3. If you could change it, would you present the requests in a different way? How?

____

____

____

Report Screens

4. Would you change the way a Form D is displayed in the screen? How?

____

____

____

5. Would you change the way a foul time is displayed in the screen? How?

____

____

____

6. Do you have any comments about the screens that tell you to wait while the dispatcher reviews your request?

____

____

Work Request Procedure

7. For each task below, do you have any comments about the procedure that we have used? How could we improve it?

7a. Request Form D

7b. Cancel Form D

7c. View Form D report

7d. Request foul time

7e. Cancel foul time

7f. View foul time report

7g. View track out of service report

8. Is the form D request procedure close to current railroad operations? Do you have any comments about it?

9. Is the foul time request procedure close to current railroad operations? Do you have any comments about it?

10. Write down any comments about a particular problem that you had while navigating through the form D or foul time screens.

System Evaluation Questionnaire

Overall usability

1. Please rate the PDA's ease of use for the following tasks

	Very easy	Easy		Difficult	Very Difficult
a. Request train location	1	2	3	4	5
b. Request territory information	1	2	3	4	5
c. Request Form D	1	2	3	4	5
d. Cancel/Fulfill Form D	1	2	3	4	5
e. View Form Ds under your authority	1	2	3	4	5
f. Request foul time	1	2	3	4	5
g. Clear foul time	1	2	3	4	5
h. View foul time under your authority	1	2	3	4	5
i. View Track out of service report (under foul time or Form D)	1	2	3	4	5

2. What additional features or information would you like to include in this tool?

____

____

____

____

____

Task realism

3. Please circle your level of agreement with the following statement.

	Strongly Disagree	Disagree		Agree	Strongly Agree
a. The tasks proposed in the experiment are close to typical real interactions with dispatchers.	1	2	3	4	5

4. Would you include any other type of task in the experiment? What tasks?

____

____

____

Usefulness and PDA improvement

5. Please circle your level of agreement with the following statement.

	Strongly agree				Strongly disagree
a. If I had the opportunity, I would use the PDA to retreive train location information	1	2	3	4	5
b. If I had the opportunity and if it were permitted by operating rules, I would use the PDA to ask the dispatcher for protection	1	2	3	4	5

	Much lower	Lower	Same	Higher	Much Higher
6. Compared to current procedures using the radio or cell phone, the work load using the PDA was?	1	2	3	4	5

7. What safety concerns need to be addressed before this device could be used in railroad operations?

____

____

____

____

____

8. List and comment on any features or requirements that the PDA must have before even considering to use it in railroad operations.

____

____

____

____

9. Do you see any other potential uses for the PDA?

____

____

____

____

	Not at all important	Slightly Important	Moderately Important	Very Important	Extremely Important
10. How important is it to be able to have a wireless portable printer to print information received from the PDA?	1	2	3	4	5

11. Please write down any other general comments on how we should improve the PDA?

____

____

____

____

____

____

12. Can you suggest a better name for the Personal Digital Assistant (PDA)?

____

____

Situation Awareness Questionnaire

Situation awareness

1. Write down an available window of time to perform the assigned task. From: ____________ To: ____________

2. What is the next train at your location? Is it delayed? Train # ______ Delayed: yes / no

3. What is the maximum train speed allowed at your location? __________ mph

4. For the next two trains at your location indicate their direction of travel. Write the Train ID and circle the appropriate direction.
Train _______ Direction: East West
Train _______ Direction: East West

5. Name the dispatcher in charge of the territory you are in? ____

APPENDIX C. FORM D

NORAC MOVEMENT PERMIT FORM D 100

FORM D NO. ________

FORM D NO.(S) ________________
DELIVERED TO ________________

DATE ___ / ___ / ___

TO

FORM D CANCELLED

	TIME	DATE	DSPR
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	
		/ /	

1. TEMPORARY SPEED RESTRICTIONS

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

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

TRAIN DISPATCHER ________________ TIME EFFECTIVE ________ M.

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

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

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

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

4 [132-134]: Track goes out of service. Another railroad employee (i.e., flagman-conductor) is in charge of the track.

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.

APPENDIX D. PALM VII CHARACTERISTICS

The Palm VII device was a member of the Palm family of handheld organizers. Some of the features of the Palm VII included the following:

- Pocket size: 5.25" x 3.25" x 0.75" and lightweight: 6.7oz.
- Built in wireless Internet connection with the following security measures: data encryption, secure sockets layer, and network authentication
- Several weeks of battery life on two AAA batteries (depending on usage), and low battery indicator
- Able to send and receive e-mail
- No previous computer knowledge required. Works with a stylus that is used to tap on the screen and fill the requests without typing
- Infrared port that could be used with a portable printer

Its weight and dimensions together with the wireless Internet capability made this device ideal for data link communications with roadway workers.

The main disadvantages of the Palm VII device were its fragility and the fact that it couldn't receive information without first asking for it. It had two-way communication capabilities but the communication had to always start at the Palm VII side. Its fragility made the Palm VII useless in tough environments such as the railroad. It didn't resist rain or dust and it was hard to read under very sunny conditions. The fact that it couldn't receive information without first asking for it made the Palm VII device useless for receiving warnings (i.e. approaching trains).

Security and Authentication

Roadway workers expressed major concerns for adequate security to prevent unauthorized access. Roadway workers interviewed for this study indicated that it would also be important to positively identify the person communicating with the PDA by utilizing some form of password protection.

The Palm VII incorporated several levels of protection. During the wireless portion of the communication, the Palm VII used a cryptographic technology developed by Certicom. According to a product white paper (Palm Inc, 1999), "Certicom's advanced elliptic curve cryptosystem enables significantly shorter message sizes with the security strength of their 163-bit keys. These keys are equivalent in strength to RSA 1024-bit keys, thus minimizing message lengths without sacrificing security." During the server-to-server portion of the communication between the Palm Computing Web Clipping Proxy and other servers, 128 bits secure socket layer (SSL) could be used. There were also other levels of security such as network authentication and physical security of the Palm Computing Web Clipping Proxy server.

Regarding authentication, again two different levels could be provided. Each Palm VII device had a built in device ID that could be sent with every message. This device ID was used to identify which roadway worker was sending each request. In addition, messages from Palm VII devices that were not registered with the system were ignored. Unregistered users could retrieve train location information or submit a work request to a dispatcher. The second level, which was not incorporated in the prototype, was password-protected access to the system. A personal password could have been required to communicate with the Traffic Control Center.

GLOSSARY

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

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

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

Cab signal: A signal located in the engine control compartment that 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]

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 voice radio links to be transmitted over data lines. [3]

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]

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

Movement Permit Form D: A form containing written authorization(s), restriction(s), or instruction(s) issued by the dispatcher to specified individuals. [4]

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. [5]

[4] NORAC operating rules

[5] Roadway Worker Protection Manual (RWP manual)

Real time train OS: Dispatcher's term that refers to train schedule with time updates**.**

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

Shunt: Activate block or interlocking signals when present on track. [6]

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

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

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

REFERENCES

Basu, S. (1999). *Real Time Simulation of Rail Dispatcher Operations.* Unpublished master's thesis, Massachusetts Institute of Technology, Cambridge, MA.

Clay, I. (October 29, 2000). Perl Reference Documents [Online]. Available: www.perl.com/reference [March 12, 2001].

Code of Federal Regulations. (October 1998). Title 49--Transportation. Chapter II--Federal Railroad Administration, Part 214-Railroad Workplace Safety. [On-line]. Available: www.fra.dot.gov/o/counsel/regs/cfr/part/49CFR214v1.htm [March 12, 2001].

Code of Federal Regulations. (October 2000). Title 47--Telecommunication. Chapter I--Federal Communications Commission, Part 90.35- Private Land Mobile Radio Services, Subpart C: Industrial Business Radio Pool. [On-line]. Washington, DC: U.S. Government Printing Office, 280-316.

Developer Documentation and Books. (2000). Palm, Inc. [Online]. Available: www.palm.com/devzone/docs.html [March 12, 2001].

Ditmeyer, S.R. and Smith, M.E. (1993). Data Links and Planning Tools: Enhancing the Ability to Plan and Manage Train Operations. *Rail International*, pp 69-77.

Federal Railroad Administration. (2002). A Vision for the Future: Intelligent Railroad Systems *Five-Year Strategic Plan for Railroad Research, Development, and Demonstrations*. Report No. FRA/RDV-02/02 Washington, DC: U.S. Department of Transportation.

Federal Railroad Administration. (1999). Paper presented at the John A. Volpe National Transportation Systems Center.

Federal Railroad Administration. (1994). *Railroad Communications and Train Control: Report to Congress*. Washington, DC: U.S. Department of Transportation.

Kirwan, B. (1992) *A Guide to Task Analysis*. New York: Taylor & Francis.

Leveson, N. G. (1995) *Safeware*: *System Safety and Computers*. Reading MA: Addison-Wesley.

Malsch, N. (1999). *Design and Testing of a Railroad Dispatching Simulator Using Data-Link Technology*. Unpublished master's thesis, Massachusetts Institute of Technology, Cambridge, MA.

Malsch, N., Sheridan, T., and Multer, J. (2004). *Measuring the Impact of Data Link Technology on Railroad Dispatching Operations.* Report No. DOT/FRA/ORD-04/11. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

National Railroad Passenger Corporation. (1997). *Northeast Corridor Amtrak Roadway Worker Protection Manual.*

Nielsen, J. (1994). *Usability Engineering.* San Francisco: Morgan-Kaufmann.

Northeast Operating Rules Advisory Committee (1997). *NORAC Operating Rules* 6^{th} edition.

Palm VIIx Handheld Description. (2000). Palm, Inc. [Online]. Available: www.palm.com/products/palmvii [March 12, 2001].

Palm VII Handheld Technology:Wireless Internet Access Comes To The Palm Computing ® Platform. Palm, Inc. [Online]. Available: www.palm.com/pr/palmvii/7whitepaper.pdf [March 12, 2001].

Roth, E.M. Malsch, N. and Multer, J. (2001). *Understanding How Train Dispatchers Manage and Control Trains: Results of a Cognitive Task Analysis.* Report DOT/FRA/ORD-00/X. U.S. Washington, DC: Department of Transportation, Federal Railroad Administration.

Sheridan, T. (1992). *Telerobotics, Automation, and Human Supervisory Control.* Cambridge, MA: MIT Press.

Switching Operations and Fatality Analysis (SOFA) Working Group. *(1999) Findings and Recommendations of the SOFA Working Group.*

The Java Tutorial: A Practical Guide for Programmers. (February 3, 2001). Sun Microsystems [Online]. Available: http://java.sun.com/docs/books/tutorial/?frontpage-spotlight [March 12, 2001].

Vanderhorst, J. (January 1990). *ARES, for safety and service - A comparison of voice and data link communication in a railroad environment*. Burlington Northern Railroad Research and Development Department.