Field Evaluation of a Wireless Handheld Computer for Railroad Roadway Workers

U.S. Department
of Transportation

**Federal Railroad
Administration**

Office of Research
and Development
Washington, DC 20590
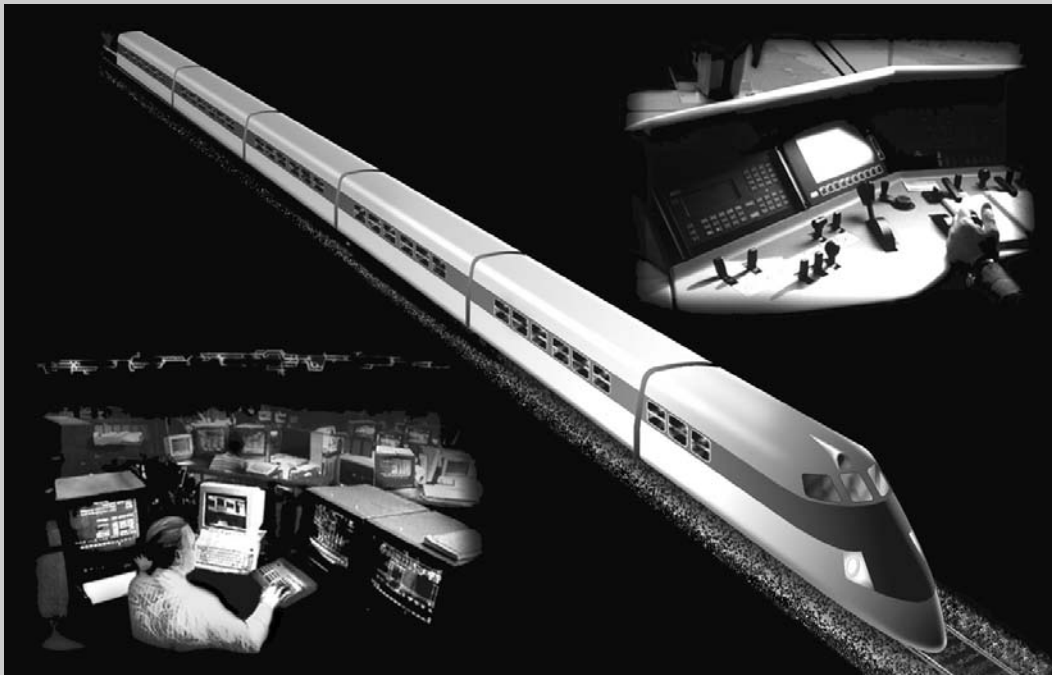
Human Factors in Railroad Operations

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE January 2009	3. REPORT TYPE AND DATES COVERED Final Report September 2003-February 2005

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Field Evaluation of a Wireless Handheld Computer for Railroad Roadway Workers	EB101/RR04
6. AUTHOR(S) Neslihan Doran and Jordan Multer	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center Cambridge, MA 02142-1093	DOT-VNTSC-FRA-08-05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1200 New Jersey Ave. SE, MS 20 Washington, DC. 20590	DOT/FRA/ORD-09/02

11. SUPPLEMENTARY NOTES

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

13. ABSTRACT

This report is the third in a series describing the development and evaluation of a software application to facilitate communications for railroad roadway workers using a wireless handheld computer. The current prototype operated on a cell phone integrated with a personal digital assistant (PDA). The roadway worker can perform two types of communication related tasks with the application: request information about train status and territory without assistance from the dispatcher and request track authority.

This study documents a field evaluation of the application to identify the safety implications of digital wireless communications on roadway worker safety and performance. It compares performance using traditional voice radio and telephone communications to the use of an application that can display this information in a visual form.

The software application was faster and more effective than the voice radio communication when used to convey long messages such as filling out Form Ds. Radio communication was faster than the visually based software application for simple communications that did not tax the operator's memory.

14. SUBJECT TERMS cognitive task analysis, data link, digital communications, decision-making, intelligent railroad systems, personal remote terminal, railroad dispatcher, roadway worker, track allocation, train routing, usability	15. NUMBER OF PAGES 58
	16. PRICE CODE

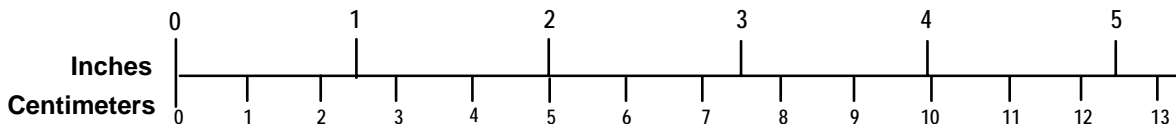| 17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC
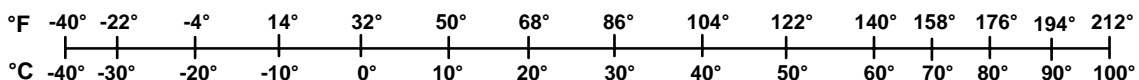
LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)

1 foot (ft) = 30 centimeters (cm)

1 yard (yd) = 0.9 meter (m)

1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)

1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)

1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)

1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)

1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)

1 pound (lb) = 0.45 kilogram (kg)

1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)

1 tablespoon (tbsp) = 15 milliliters (ml)

1 fluid ounce (fl oz) = 30 milliliters (ml)

1 cup (c) = 0.24 liter (l)

1 pint (pt) = 0.47 liter (l)

1 quart (qt) = 0.96 liter (l)

1 gallon (gal) = 3.8 liters (l)

1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)

1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

$[(x-32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)

1 centimeter (cm) = 0.4 inch (in)

1 meter (m) = 3.3 feet (ft)

1 meter (m) = 1.1 yards (yd)

1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)

1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)

1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)

10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)

1 kilogram (kg) = 2.2 pounds (lb)

1 tonne (t) = 1,000 kilograms (kg)

= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)

1 liter (l) = 2.1 pints (pt)

1 liter (l) = 1.06 quarts (qt)

1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)

1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

$[(9/5) y + 32]$ °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches: 0 1 2 3 4 5

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

QUICK FAHRENHEIT - CELSIUS TEMPERATURE 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

Acknowledgments

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Executive Summary

Overview/Introduction

Railroad operations rely on railroad dispatchers, train crews, and roadway workers to coordinate their activities. Railroad dispatchers allocate track for the safe movement of trains and maintenance. Train crews consisting of locomotive engineers and conductors operate trains, while roadway workers maintain the track infrastructure. Railroads depend upon communications technology to enable these employees to coordinate their activities and operate safely and productively. Analog communications technology as exemplified by voice radio while still the primary method for communications time critical information limit the ability to improve safety and productivity.

The voice radio system presents two major problems. First, the available radio bandwidth is inadequate to support current communication needs (Federal Railroad Administration, 1994; Roth, Malsch, and Multer, 2001). Second, the information communicated using voice radio imposes a significant burden on operator's memory when sending complex messages.

The development of digital communication technology offers the potential to improve railroad safety and productivity. The use of digital communications has been proposed as a communication medium to supplement voice radio. Digital communications uses this bandwidth more efficiently than voice radio. Information transmitted digitally can be presented aurally or visually. Displaying messages visually can reduce radio frequency congestion by decreasing the number of messages communication by voice radio. These characteristics offer opportunities to address the limitations posed by voice radio.

For digital communications to achieve their proposed benefits, all three parties, dispatchers, train crews, and roadway workers must have access to this technology. For the dispatcher working in an office environment and the train crew working in the protected space of a locomotive cab sufficient space exists to locate this equipment. However, adapting this technology for use by roadway workers represents a special challenge. Except for workers who operate equipment on the track, such as track inspectors, many roadway workers require a portable communication device with a sufficiently small form factor so that they can carry it along with other equipment needed to perform their job.

A proposed railroad application of this technology involves a wireless handheld device such as a cell phone with integrated Personal Digital Assistant (PDA) to enable the information transfer between the roadway worker and the dispatcher.

Oriol et al. (2004) identified the use of information technologies needed to fulfill the requirements of the railroad operations from the perspective of roadway workers. A prototype was designed to establish direct communication with the dispatching center to retrieve information, previously unavailable, without contacting the dispatcher by voice radio or cell phone. The testing for his work was done in a laboratory environment with three roadway workers and one smartphone. Oriol found that a data link device, able to receive real time information about train location, greatly improves situation awareness of roadway workers by letting them know about many of the potential hazards. Better knowledge of train location or higher situation awareness resulted in fewer requests for track authorization.

1

Research Goals

The goal of this project was to compare voice radio communications with a proposed data link communication system for the purpose of contrasting error rates and usability of these two communication media. As previous studies demonstrated that voice communication was better for short conversations, this study mainly focuses on the most time consuming communication type in railroad operations: authorizing train and equipment movements (i.e., Form D authorizations).

The current project was aimed at testing the device in situ, with active dispatchers and track workers on the real routes. In this study, a handheld communication device combining a PDA and a cell phone was used for data link communications. Throughout the report the device is referred as a smartphone. This work presents the statistics related to both communication media, voice radio and data link, in the real-time field tests. The objective was to determine whether communication using data link improved compared to voice radio.

Method

The performance differences between data link and voice radio were measured separately at the Massachusetts Bay Transportation Authority's (MBTA) north side commuter rail system dispatching center. In the voice radio condition, radio communications between the dispatcher and the train crews, roadway workers were recorded and then analyzed.

Using the radio system, dispatcher receives many calls at the same time. The dispatcher decides which call to take based on the importance of the message. The communications between one dispatcher and the roadway workers in his territory were recorded for 5 consecutive days then coded to identify message content and error types. The average time required to complete a Form D (movement authorization) and/or a foul time was used as a measure to compare the radio system with the data link system.

The dispatcher interacted with the roadway workers with the data link system using a computer monitor, keyboard and mouse. The experiment was conducted with one dispatcher and one roadway worker. The roadway worker contacted dispatcher using the smartphone. The device was used to request, fill out, and cancel Form D's and to check the train status of the scheduled trains. Due to time restrictions and the security concerns of the dispatcher center supervisor, other features of the device such as territory information and detailed train location information were not available for testing.

Results

Voice Radio System

The dispatcher environment was observed several times to get a better understanding of the daily work and issues. The communications included all interactions of one dispatcher: the communications with other dispatchers, train conductors and MOW crews. During the data collection period, the following remarks were observed:

- Radio communication was subject to interference, background noise, fadeout, and sound distortion. The noise level in a locomotive cab made it difficult for the dispatcher and the train crew to hear each other.

- From their experience, the dispatchers generally figure out the crew's request.

- As the voice radio link operated in a broadcast mode between a single dispatcher and all the trains and maintenance-of-way crews operating within the range of the radio under the dispatcher's control, radio congestion is was a common occurrence when train traffic and maintenance activity were heavy.

- In addition to the limitations imposed by the congestion, the radio communications have inherent human error issues: acoustic confusions, alphanumeric transpositions, and misinterpretation due to poor pronunciation are just some examples of the human induced errors.

All these factors affected the dispatchers' performance as well as the train crews and maintenance crews by causing delays in the issuance of the movement authorizations and track occupancy permits.

Approximately 5 percent of the data were excluded from the analyses because the voice radio transmissions were inaudible to the analyst. More than half (58 percent) of the communications involved information requests. Movement authorizations (Form D) requests were the second most frequent type of communication activity followed by coordination activities and emergency activities.

The analysis of five consecutive days of communications showed that the dispatchers were spending more time with Form D's than with any other communications. The readback/hearback routine takes took the longest amount of time compared to the other types of communications. The analysis shows that filling out Form D's via voice radio took twice as much time as the other types of communication.

Analysis shows that the errors were mainly caused by the noisy radio communications. As mentioned earlier, the field environment, where the radios were used, was noisy because of loud train equipment. The presence of the dead spots, where the radio communication was inaudible, complicated the dispatcher's work. On the basis of their experience, dispatchers frequently tried to guess the missing parts of the conversations. A common error took place when one of the parties transposed alphanumeric information such as train ID. Roadway workers committed 55 percent of the transmission errors. Dispatchers accounted for one-third of transposition errors while train crews accounted for 11 percent of these errors. When identification errors or incorrect information occurred, dispatchers accounted for more than 80 percent. Rail workers were involved in approximately 17 percent.

Comparison between voice radio and data link

During each day of the test period, the field test crew (consisting of roadway workers) completed around 10 Form Ds. The study documented how long the maintenance employee took to request a Form D and for the dispatcher to fill out the form and to assign time effective.

The major advantage of the new system was the decline in the number of communication errors. Since the cancellation of Form D's was automated, the error for this particular task was eliminated. Once the foreman finished the job, he/she canceled the work permit without communicating by voice with the dispatcher. The dispatcher saw the form on the "cancelled" display window and acknowledged the termination of the work permit.

The data, using the voice radio technology, shows that Form D's were the most time consuming type of communication between the dispatcher and the crew on the tracks. On average, a dispatcher took 3 minutes 13 seconds to complete one Form D. This study shows that data link technology can decrease this time significantly. Using a smartphone this completion time was reduced to an average of 65 seconds. This result was different from Masquelier's (2004) and Oriol's (2004) laboratory experiment results. Their findings showed that the work permission processes were slower but more accurate with the device than with the radio. This study, conducted under conditions more closely approximating real world, showed that the work authorization processes were more accurate and faster with the handheld device. The study also shows that the new system, in providing the visual aid to users, eliminated alphanumeric transposition errors when requesting and issuing Form D movement authorities.

The new system reduced errors attributable to auditory communications. As shown earlier, with the voice radio, some of the errors occurred because the radio transmissions were difficult to hear. They also minimized errors associated with memory lapses and numeric transpositions that are common with auditory-based communications.

New error types emerged that were linked to the visual modality and usability issues such as tapping on the wrong part of the screen or navigation difficulties with the software. Usability errors should decrease with time as designers adapt the application to meet the needs of the users and the user adapts to the new user interface.

Conclusions

The current study supported the results of Malsch et al. (2001), Oriol et al., 2004, and Masquelier et al (2004) showing data link communications reduce voice radio-related errors and improve efficiency when communicating long and complex messages. The new system was faster and more effective than radio communication when used to convey long messages such as filling out Form Ds. Radio communication was faster than the data link for confirmation communications that only require yes/no answers. One reason for this difference appears to be the users' lack of familiarity with the device. The time to convey short messages should improve as the users become more proficient with the new system.

The users expressed many concerns about smartphones. Most of these concerns were related to its design. Users thought that the commercial smartphone used in this study was too small and delicate to be used in railroad operations. They expressed preference for a rugged device that would withstand being dropped and operating in a dusty environment. Another major issue was the screen resolution: the screen should be modified so that it is visible in direct sunlight. Other concerns were related to the unfamiliarity of the users with the PDA technology in general. Some users were unable to navigate within the menu and unable to go to the main menu once they were on a page that was not familiar to them.

The data link system would reduce the dispatcher's communication load by eliminating some incoming calls related to information requests like schedule updates and weather inquiries. The smartphone would receive updated data from the dispatch center, so the train schedule would be updated as soon as any change is entered at the control center. As the smartphone has access to the internet, the weather information could be checked by the roadway workers without contacting the dispatcher. The data link would also reduce the dispatcher's workload by transferring long conversations to the digital medium. During long conversations, the dispatcher

both receives and sends many messages. With the data link system, the dispatcher could send the same amount of information currently contained in multiple voice messages with only one digital message.

1. Introduction

1.1 Adapting Digital Communications Technology for Roadway Workers

Railroad operations rely on railroad dispatchers, train crews, and roadway workers to coordinate their activities. Railroad dispatchers allocate track for the safe movement of trains and maintenance. Train crews, consisting of locomotive engineers and conductors, operate trains, while roadway workers maintain the track infrastructure. Railroads depend on communications technology to enable these employees to coordinate their activities and operate safely and productively. Analog communications technology, exemplified by voice radio while still the primary method for communications and time critical information, limits the ability to improve safety and productivity.

The voice radio system presents two major problems. First, the available radio bandwidth is inadequate to support current communication needs (Federal Railroad Administration (FRA), 1994; Roth, Malsch, and Multer, 2001). Within any geographic region, a much smaller number of radio channels are available for railroad operations than what the Federal Communications Commission has allocated. As each channel can only have a single user, other workers who want to use the same channel must wait until it is clear. Due to bandwidth limitations and high communication workload, voice radio communication channels are congested.

Second, the information communicated using voice radio imposes a significant burden on operator's memory when sending complex messages. To minimize the potential for errors on safety critical communications, railroad workers and dispatcher record important information on paper. They also engage in a readback/hearback procedure in which the receiver reads back the message from the sender, while the original sender listens to the message read back by the receiver to check that it was heard correctly. Although this process reduces the potential for error, it increases the time required to complete a transaction. This procedure also reduces the bandwidth available for communication.

The development of digital communication technology offers the potential to improve railroad safety and productivity. The use of digital communications has been proposed as a communication medium to supplement voice radio. Digital communications uses this bandwidth more efficiently than voice radio. Information transmitted digitally can be presented aurally or visually. Displaying messages visually can reduce radio frequency congestion by lowering the number of messages communication by voice radio. These characteristics offer opportunities to address the limitations posed by voice radio.

However, if the needs and limitations of operators are not clearly understood, new technology may adversely impact safety and productivity. Simply providing additional bandwidth could adversely impact the dispatcher's performance, if the design of the system does not consider the communication load the dispatcher can handle safely.

For digital communications to achieve their proposed benefits, all three parties, dispatchers, train crews, and roadway workers must have access to this technology. For the dispatcher working in an office environment and the train crew working in the protected space of a locomotive cab sufficient space exists to locate this equipment. However, adapting this technology for use by roadway workers represents a special challenge. Except for workers who operate equipment on the track such as track inspectors, many roadway workers require a portable communication

device with a sufficiently small form factor so that they can carry it along with other equipment needed to perform their job.

A proposed railroad application of this technology involves a wireless handheld device, such as a cell phone with integrated Personal Digital Assistant (PDA), to enable the information transfer between the roadway worker and the dispatcher.

Previous studies (Malsch, Sheridan, and Multer, 2001; Basu, 1999; Oriol, Sheridan, and Multer, 2004; and Masquelier, Sheridan, and Multer, 2004) analyzed the communication environment of the dispatcher to address questions based upon digital communications technology (also referred to as data link) as a means for sharing information in railroad operations. These studies examined what kind of information is appropriate for each medium (voice and visual), and by what criteria a dispatcher will select which communication medium.

Earlier studies covered the dispatcher's side (Malsch et al., 2001 and Basu, 1999) and the roadway worker's side (Oriol et al., 2004 and Masquelier et al., 2004) of the issue separately. Malsch and Basu's study evaluates the impact of using digital communication in place of the radio, on the dispatcher. Their findings and suggestions indicate:

- Dispatchers like the idea of data link technologies. They liked the fact that they could receive requests from trains or work crews in an email-like fashion instead of radio calls that had to be answered in a first-come first-served basis. With this architecture, they could assign priorities to incoming messages and deal first with the most important ones.

- They did not understand how the work crews in the field would send them digital messages. Not only did they not have the appropriate tool but some of them were unfamiliar with computers.

- They found it valuable that they did not have to repeat a message many times with data link.

- They welcomed a system that helped to solve the congestion problem affecting radio communications.

Oriol et al. (2004) identified the use of information technologies needed to fulfill the requirements of the railroad operations from the perspective of roadway workers. A prototype was designed to establish direct communication with the dispatching center to retrieve information, previously unavailable, without contacting the dispatcher by voice radio or cell phone. The testing for his work was done in a laboratory environment with three roadway workers and one smartphone. Oriol found that a data link device able to receive real time information about train location greatly improves situation awareness of roadway workers by letting them know about many of the potential hazards. Better knowledge of train location or higher situation awareness resulted in fewer requests for track authorization. The experiment showed that roadway workers tended to remember slightly more information when they used the data link device. His work highlighted the following differences between radio and data link communications:

- Data link device results in safer operations.

- Data link device results in better knowledge of potential risks but in a reduced number of jobs completed.

- Communication was slower but more accurate using the data link device. The workload remained the same.

Masquelier et al. (2004) also conducted a laboratory study. Using the Massachusetts Institute of Technology (MIT)/Volpe National Transportation Center (Volpe) Railroad Dispatching Simulator, he studied the dispatcher's perspective. Their work also showed that track authorization processes were slower but more accurate with the device than with the radio. His experiment found no error in location because of the Global Positioning Satellite (GPS) system, but trains tend to be more delayed with the device mainly due to the unfamiliarity of the participants with the system. Masquelier et al. (2004) suggested reducing the territory that each dispatcher controlled to compensate for the increase in workload due to the tracking display.

The prototype communications system-based wireless data link device was intended to increase the safety of roadway workers while reducing the radio congestion. GPS has already been used to locate track cars. The data link device consisted of a handheld information appliance with wireless access to the internet, which is connected to a GPS receiver.

Given that the previous studies were conducted in a laboratory setting, this study evaluated data link technology for railroad operations in a field environment. The intention is to assess the impact of this application on safety and productivity in actual field situations and compare them to the previous simulation-based studies.

1.2 Research Goals

The goal of this project was to compare voice radio communications with a proposed data link communication system for the purpose of contrasting error rates and usability of these two communication media. As previous studies demonstrated that voice communication was better for short conversations, this study mainly focuses on the most time consuming communication type in railroad operations: authorizing train and equipment movements (i.e., Form D authorizations).

A wireless handheld device was tested earlier in an experiment, using simulators and scenarios for daily railroad operations. One group of roadway workers carried out assigned tasks using the smartphone and the other group used the radio in the conventional way. The laboratory research proved that the data link system represents a potential solution to supplement voice data. Previous results suggest that data link can improve communication efficiency, safety, and situation awareness. During the experiments, by providing information in a visual format, data link eliminated readback errors and hearback errors associated with the auditory modality. Previous experiments also suggest that data link is better suited for communications whose length or complexity impose a significant burden on memory. The current project was aimed at testing the device in situ, with active dispatchers and track workers on the real routes.

In this study, a handheld communication device combining a PDA and a cell phone was used for data link communications. Throughout the report the device is referred as a smartphone. This work presents the statistics related to both communication media, voice radio and data link, in the real-time field tests. The objective was to determine if communication using data link improved compared to voice radio by:

- Requiring fewer messages,

- Requiring less time,

- Reducing or eliminates certain types of messages,

- Reducing or reduces imprecision and errors, and

- Reducing communication delays.

2. Methodology

2.1 Overview

The performance differences between data link and voice radio were measured separately at the Massachusetts Bay Transportation Authority (MBTA)'s north side commuter rail system dispatching center. In the voice radio condition, radio communications among the dispatcher, train crews, and roadway workers were recorded and then analyzed.

Using the radio system, the dispatcher receives many calls at the same time. The dispatcher decides which call to take based on the importance of the message. The communications between one dispatcher and the roadway workers in his territory were recorded for 5 consecutive days then coded to identify message content and error types. The average time required to complete a Form D (movement authorization) and/or a foul time was used as a measure to compare the radio system with the data link system.

The dispatcher interacted with the roadway workers with the data link system using a computer monitor, keyboard, and mouse. The experiment was conducted with one dispatcher and one roadway worker. The roadway worker contacted dispatcher using the smartphone. The device was used to request, fill out, and cancel Form Ds and to check the train status of the scheduled trains. Due to time restrictions and the security concerns of the dispatcher center supervisor, other features of the device such as territory information and detailed train location information were not available for testing.

2.2 Current Radio System

2.2.1 System Description

The Commuter Rail Operations Control Center controlled the operations and the management of MBTA's north side commuter rail system. The system was operated by employees from The Massachusetts Bay Commuter Railroad Company (MBCR). Dispatchers used the Centralized Dispatching System (CDS) to monitor and control train movements and maintenance activities. The dispatcher controlled train movements and maintenance within a defined geographic area called a territory. The area controlled by the PC based dispatching system was divided into five territories, represented by four branch lines and a terminal area. The top half of Figure 1 shows the four branches lines and Boston's North Station terminal.
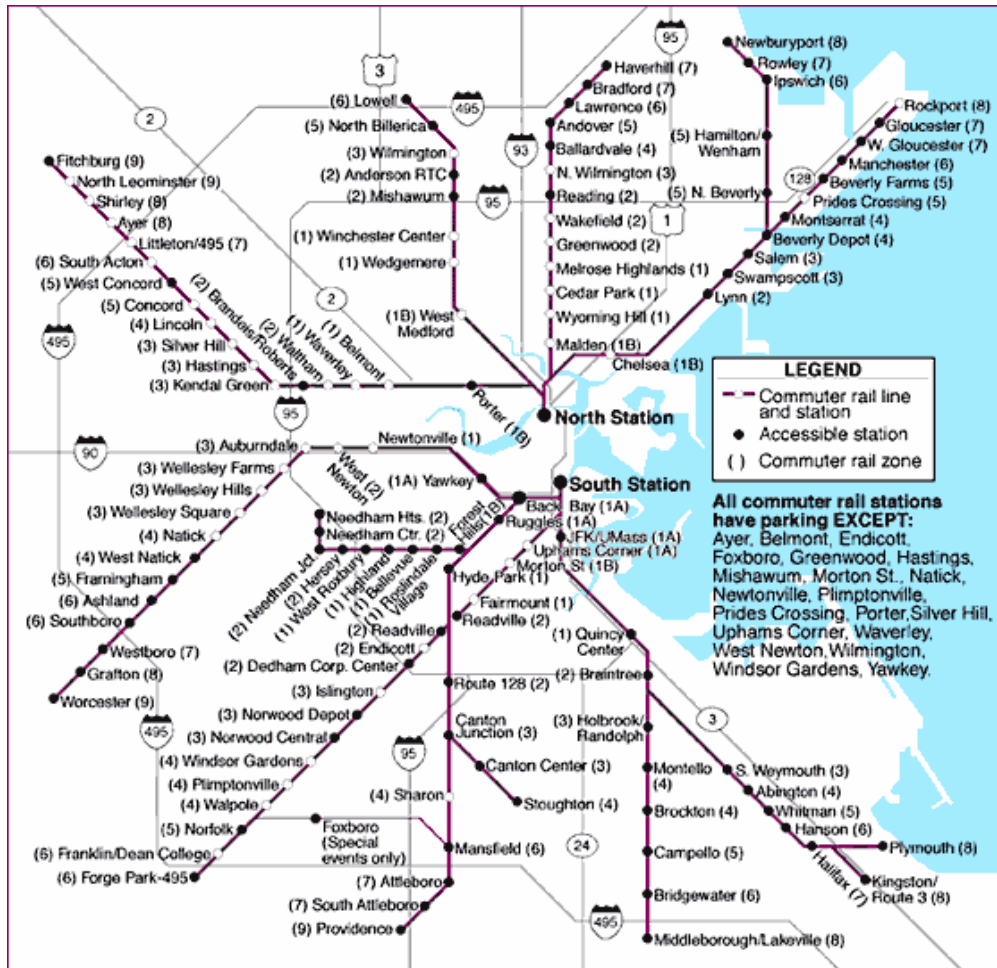
Figure 1. Commuter Rail Map

Figure 2, shows the layout of a typical dispatcher workstation. The workstations are located in a large room and the dispatchers can interact with each other. They can inform each other about the train delays, extra trains, and any malfunctions or ask whether a dispatcher is ready to receive a train.
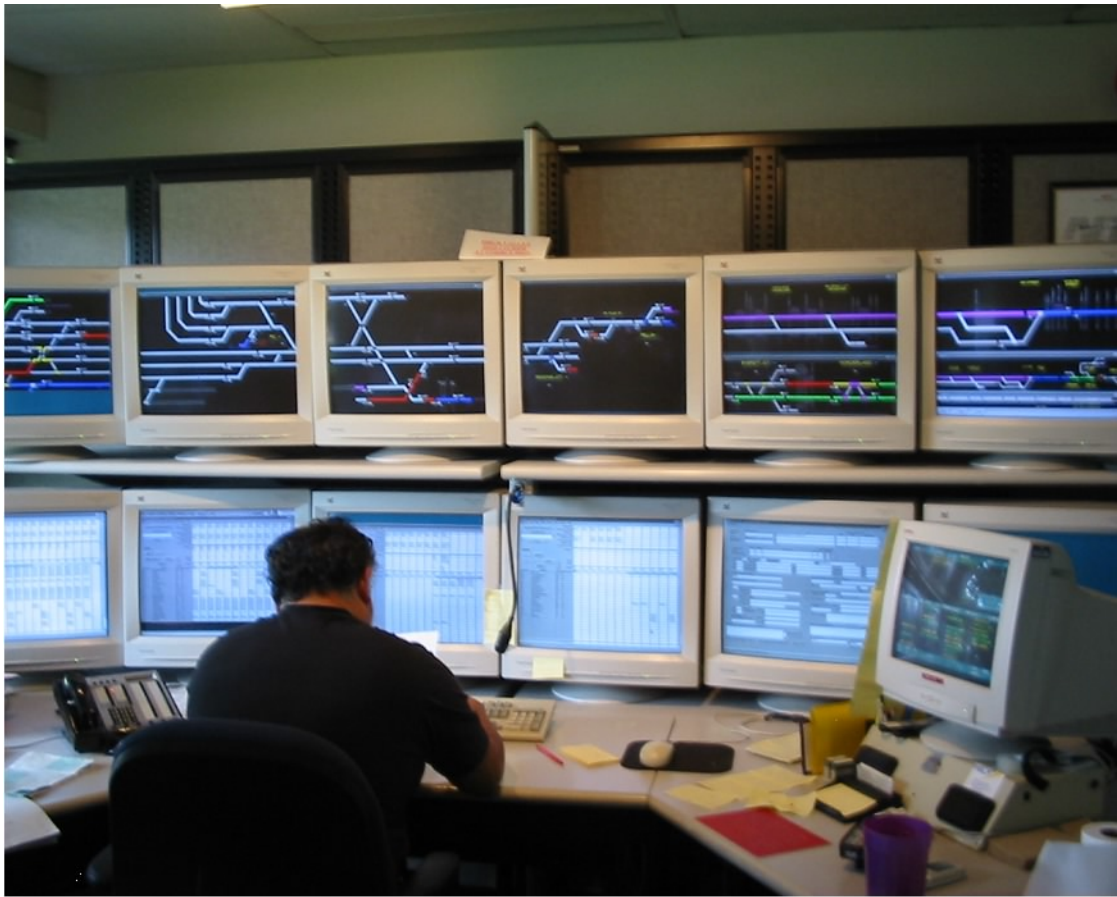
Figure 2. Dispatcher's Work Environment

Dispatchers monitor train movement and maintenance operations through several track displays, (see Figure 2). The physical characteristics of the track such as curves, grade crossings, and roads in the neighborhood are not shown. Figure 3 shows a close-up one of these screens. In Figure 2, six screens display the tracks, four screens display train timetables, one screen shows the movement authorization forms, and one screen shows other information related to control tasks. The track display used the following color coding scheme as shown in Table 1.

Table 1. Track Display Color Coding Scheme

White	Track segment is available for routing trains or other uses
Green	Track segment has been cleared for train routing.
Red	Train or track vehicle occupies the track segment
Blue	Track segment is blocked for maintenance.
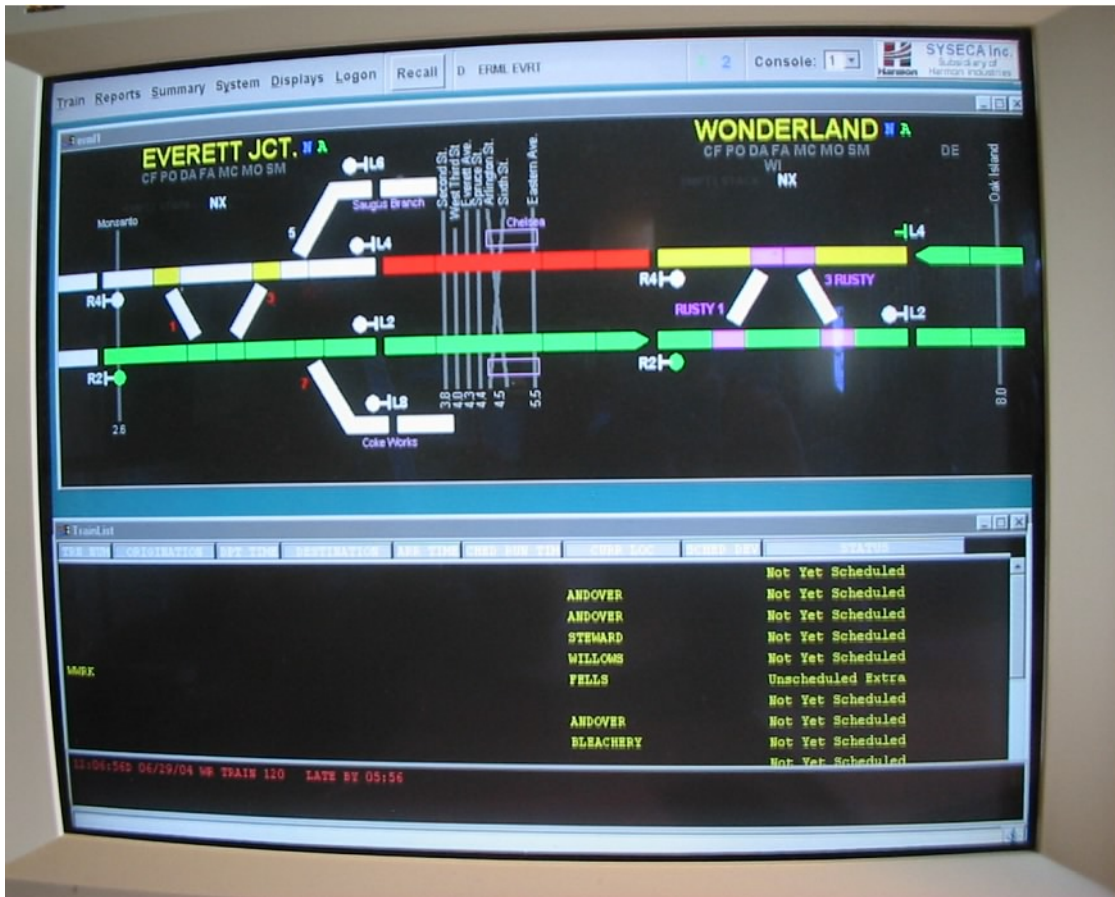
Figure 3. Train Location Display Screen

When a train occupied a track, its ID number and its movement direction were indicated on the track display. Train delays were also coded in red, below the train's ID number indicating the length of the delay. The delay was updated as the train passed an interlocking.

Each workstation was equipped with track display screens, a telephone, a radio and a computer. Dispatchers also kept paper records of the train schedules/timetables in case of system failure. Train conductors, locomotive engineers, and work crews conducted communications via radio or telephone. They received multiple requests at the same time over the radio. As a consequence, the dispatcher delayed responding to some requests. When the radio failed, they used the cell phone for one-to-one conversations with people in the field. Telephone and radio communications were integrated into a single communication system in the dispatch center to make it easier for dispatchers to handle all the communications. Dispatchers switched between radio and telephone using a foot pedal connected to the system. All such conversations were digitally recorded and archived for 90 days.

Dispatchers used a computer to print the movement authorization forms for backup purposes to access the updated train schedules to view the passenger counts and train consist[1] information. Through their computers dispatchers obtained real-time weather information through the Internet and notified trains when delays were anticipated.

2.2.2 Baseline Measurements

Ninety three hr of voice communications, in the railroad environment were sampled over a 5-day period. Following data collection, each conversation was coded according to information content, error type, and duration.

First, the conversations were recorded using a digital audio tape (DAT) recorder, a videocassette recorder (VCR), a lipstick video camera mounted on a microphone stand with a gooseneck, headphones, and a small monitor. Twenty-four hours of audio was captured on the VCR with low frame rate video of the display that showed the time and the date of the recorded material. Also, four hours of audio was recorded on the DAT machine which duplicated the first 4 hr on the video tape. Five consecutive days of conversations were recorded.

The analog tape recordings were transferred to a digital medium using the software application: Sound Forge 5.0. This was a two-track digital audio editor with wide-ranging audio processing capabilities. For ease of data storage and processing speed, each audio file was limited to 2-hour period. The conversation time on the recordings was longer than the labeled messages because of the personal conversations that were discarded in the analysis.

During the 5 days of data collection, dispatchers were observed several times to obtain an understanding of the work issues related to communication.

2.3 Data Link System

2.3.1 System Description

Digital communications took place with the dispatcher using a desktop computer to send and receive communications while the roadway worker used a cell phone with an integrated PDA[2]. A Kyocera Smartphone, Model 6035 was used in this study as shown in Figure 4. The information was transmitted through a wireless internet connection. A screen shot of the smartphone showing the main menu for the roadway worker communication application is illustrated in Figure 5. The device weighed 7 ounces and was nearly an inch thick. It contained 8 megabytes of memory.

The dispatcher communicated with the roadway worker using a desktop computer. A secure connection provided the updated train information to the worker in the field. The same connection enabled the information flow between the dispatcher and the crew member. The roadway worker filled out the Form D's using the drop down menus on the smartphone. The updated display of the forms minimized the need to select individual alphanumeric characters to write messages. The crewmember interacted with the display using a stylus to select options

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[1] Consist: makeup or composition (as of coal sizes or a railroad train) by classes, types, or grades and arrangement

[2] Since the completion of this research the railroad industry has begun evaluating the use of this technology. They refer to this application as a Personal Remote Terminal (PRT).

from dropdown menus on each screen. Appendix B shows all the display screens for each of the possible menu selections. Upon completion, the crewmember sent the form to the dispatcher who confirmed the information by re-entering the same data and sent it back to the worker. The last step involved granting "time effective." When the time effective was assigned, the Form D became active and the tracks were blocked.

Figure 4. Kyocera Smartphone QCP6035

The data link communications were observed at MBTA's North Station Commuter Rail Center in Somerville, MA. The study required an internet interface that acted as a portal to send tabular train operations specialist (OS) data through a secured internet connection, located at MBTA control center. Figure 6 shows the tabular information displayed in the Train Schedule Sheet (Train OS). At the request of the MBTA, Aeronautical Radio, Inc. (known as ARINC), the software vendor for their computer dispatching system (CDS) provided the communication link

to obtain real-time information from the CDS. The main challenge was to provide a secure one-way data feed from the CDS to Volpe's server and a secure one way access from the smartphone to Volpe's server.
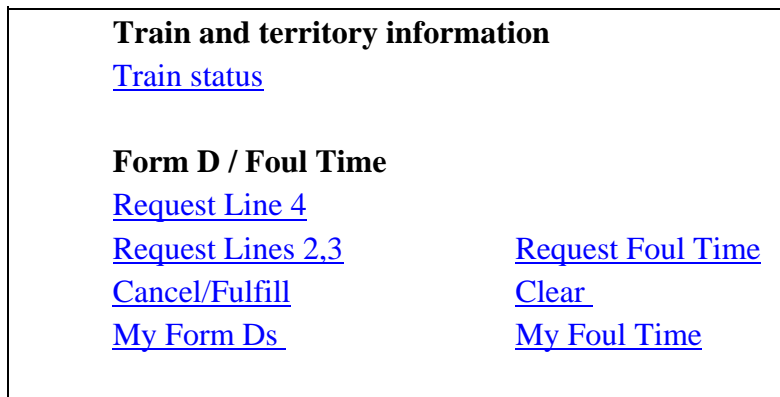
Train and territory information
Train status

Form D / Foul Time
Request Line 4
Request Lines 2,3   Request Foul Time
Cancel/Fulfill   Clear
My Form Ds   My Foul Time

Figure 5. Smartphone Menu

To maintain a secure network, MBCR requested that ARINC use encrypted data. The major problem was how the CDS data would be transferred to the Volpe server. The IT department of MBCR offered the following setup for the equipment.

Action Edit Query Block Record Field Window Help

ENGINEER:	tanberry,R	FOSTER	Lipp,P.A.	Greeley, V.	Allen, D.P.	Grundstro	Davidson,	Lipp,P.A.	Stanberry,R	McNall, D.	Greeley, V.	MacMillan,
Engine Crew on Duty:	0423am	0422am	0455am	0520am	0525am	0555am	0535am	0455am	0423am	0435am	0520am	0558am
CONDUCTOR:	Francis,D.L	Carbone,	Beckman,	Church,K.C	PIETREFE	Murphy, T.	McHugh,P.	Beckman,	Francis,D.L	CADOGA	Church,K.C	Frisch, E.M
Train Crew on Duty:	0423am	0422am	0455am	0520am	0525am	0555am	0535am	0455am	0423am	0435am	0520am	0558am
ENGINE:	1126	1125	1136	1017	1118	11061	1124	1075	1129	1131	1118	1123
	1633	1630	1647	1645	1635	1632	1643	1649	1642	1628	1635	1627
CARS:	5	5	5	5	6	6	7	5	6	5	6	5
TRAIN	151	191	61	103	153	63	109	161	113	165	117	169

View/Edit RULES/NOTES/ETC.
Print Rules/Notes
Retrieve
ERE
EDIT UPDATE
PRINT SCHED. CLOSE

Distance	Stations	Office Designations	Dist. Bet. Sta.											
0	BOSTON	IN	0	0635am	0644am	0718am	0739am	0807am	0821am	0830am	0946am	1016am	1116am	1217pm	0115pm
1.4	FX	FX	1.4	0639am	0648am	0722am	0743am	0811am	0826am	0835am	0951am	1023am	1120am	1222pm	0119pm
1.8	READING JCT.	RJ	.4	0640am	0650am	0724am	0745am	0813am	0828am	0837am	0953am	1025am	1122am	1224pm	0121pm
2.8	EVERETT JCT.	EVJ	1	0642am	0651am	0725am	0746am	0815am	0829am	0838am	0954am	1026am	1123am	1225pm	0122pm
6.2	REVERE	REV	3.4												
7	WONDERLAND	WL	.8	0647am	0658am	0732am	0753am	0821am	0835am	0846am	1001am	1033am	1130am	1232pm	0129pm
9.6	SAUGUS DRAW	SDW	2.6												
10.6	WEST LYNN	WLY	1												
10.8	BRICKYARD	BY	.1	0651am	0703am	0737am	0758am	0827am	0839am	0849am	1004am	1037am	1134am	1236pm	0133pm
15.1	CASTLE HILL	JC	4.3	0655am	0708am	0744am	0806am	0834am	0843am	0858am	1012am	1044am	1141am	1244pm	0141pm
16.3	MCNALL	MC	1.2	0657am	0709am	0745am	0809am	0835am	0844am	0859am	1014am	1046am	1145am	1246pm	0142pm
17	NORTHEY PT.	NP	.7	0658am	0712am	0749am	0812am	0838am	0848am	0902am	1017am	1049am	1149am	1249pm	0145pm
18.7	BEVERLY JCT.	BJ	1.7	0700am	0716am	0752am	0816am	0841am	0852am	0906am	1021am	1053am	1153am	1253pm	0149pm
25.6	MANCHESTER	MC	6.9												
31.3	CP - WILSON	WSN	5.7				0839am			0933am		1117am		0116pm	
35	CP - LOOP	LOO	3.7				0848am			0943am		1126am			
35.3	ROCKPORT	RKP	.3												
21.5	CHESLEY	EDT	2.8	0704am	0723am			0846am			1026am		1157am		0154pm
26.9	IPSWICH WEST	IE	5.4	0710am				0853am			1032am		1204pm		0201pm
27.4	BAGLEY	IE	.5	0715am				0854am			1033am		1204pm		0202pm
27.7	STEEVES	STV	.3												

Record: 1/?

Figure 6. Train Schedule Sheet

All connections were secured with firewalls. The CDS was connected to the internet via virtual private network (VPN), which provided a secure internet connection. VPN enabled a secure

connection without using a private modem or phone line. The Volpe server only connected to one IP address, the site to access the smartphone. As a final security measure, the Volpe server was set up to prevent the use of web browsers on the server, itself. Table 2 shows the CDS data transmitted to the Volpe server and the smartphone. Figure 7 shows the path by which information flows between the CDS and the smartphone.

Table 2. Real-Time CDS Information Displayed On Smartphone

Train ID
Milepost name
Milepost ID
Direction of train movement
Updated schedule

Prior to the data collection task, the software portion of the application was evaluated for usability by a track foreman and a dispatcher. During usability testing of the initial system, the users identified several problems with the interface. These problems described below were corrected prior to field testing:

- The original time format on the smartphone was a 24-hour format and the one on the dispatcher screen was a 12-hour format. The time format on the smartphone was changed to a 12-hour format so that both users used the same time format.

- The train schedule did not show the direction. East/West directions were added to the configuration.

- The dispatcher requested three additional lines on the Form D where the foreman can enter necessary text information:

    o speed restriction,

    o crossing protection restored, and

    o signs removed.

- An additional information box was added to the dispatcher's computer screen to enter messages in text form.

- When a request was denied by the dispatcher, the response was not visible on the smartphone screen. The display was changed to make this information clearly visible.
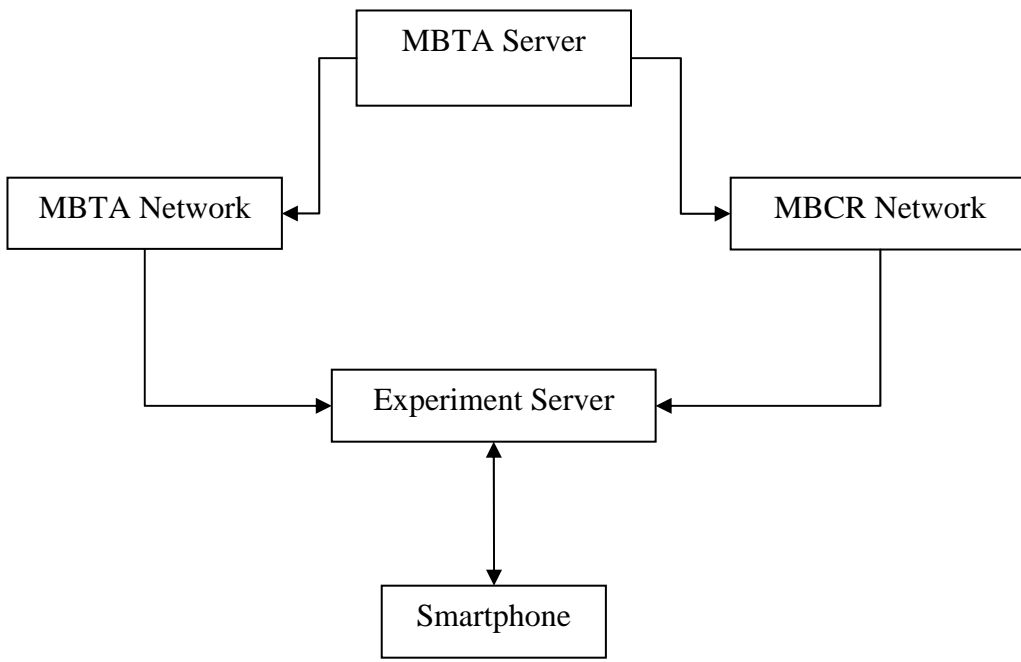
Figure 7. Network Setup at the Testing Facility

2.3.2 Experimental Measurements

The experimental equipment was placed next to the territory for the Boston East dispatcher and the smartphone was given to a track inspector. While the Boston East dispatcher was doing his daily job, another dispatcher employed the same procedures with the experimental devices. The procedures were first completed by the crew in charge, and once the blocking devices were in place, the procedures were repeated by the experiment crew. In some instances, the experiment crew had to wait until the crew in charge finished their job. The redundant procedures were implemented to maintain safety.

Data was collected for 13 days according to the railroad employees' availability. The data were collected between 8 a.m. and 3 p.m., during the regular shifts of the experiment crew. The data collection effort took place over 45 days. All measurements were collected at the dispatcher center. Since the program lacked a built-in chronometer, time measurements for Form D requests were recorded using a stopwatch. Due to limited space in the track inspection vehicle, it was not feasible to monitor the crew on the tracks.

3. Results

3.1 Current Voice Radio System

3.1.1 Observations

The dispatcher environment was observed several times to get a better understanding of the daily work and issues. The communications included all interactions of one dispatcher: the communications with other dispatchers, train conductors and maintenance-of-way (MOW) crews. During the data collection period the following remarks were observed:

- Radio communication was subject to interference, background noise, fadeout and sound distortion. The noise level in a locomotive cab made it difficult for the dispatcher and the train crew to hear each other.

- From their experience, the dispatchers generally figure out the crew's request.

- As the voice radio link operated in a broadcast mode between a single dispatcher and all the trains and MOW crews operating within the range of the radio under the dispatcher's control, radio congestion was a common occurrence when train traffic and maintenance activity were heavy.

- In addition to the limitations imposed by the congestion, the radio communications have inherent human error issues: acoustic confusions, alphanumeric transpositions, and misinterpretation due to poor pronunciation are just some examples of the human-induced errors.

All these factors affected the dispatchers' performance as well as the train crews and maintenance crews by causing delays in the issuance of the movement authorizations and track occupancy permits.

3.1.2 Data Classification

The data gathered using the current radio system was divided into messages where each message corresponded to one communication initiated by any party. Generally, more than one message constitutes a whole conversation between the roadway worker and the dispatcher. Each message was labeled with the following alphanumeric pattern: number-letter number (e.g. 21.I.0). The first number indicates the order of the message within a 2-hour section of the day. The letter stands for the categorization abbreviation, the last number indicates the error (if any) of the message. The categorizations and the abbreviations are shown in Table 3.

The purpose of the categorization was to identify human errors, frequency of trains, message content and complexity of the interaction. One type of communication error was nonstandard phraseology, which was defined as noncompliance with the standardized wording or phrasing of railroad communications. When a dispatcher issued a Form D for track occupancy, the receiver was required to read back all instructions verbatim. After the readback, the dispatcher was required to state the effective time of the instruction and the receiver was also required to read back the effective time.

Table 3. Voice Radio Classification Codes

Symbol	Definition	Examples
I	Information request: Notification communications between the roadway workers and the dispatchers.	Any schedule changes Explanations for the delays Information about other trains Report track, train, signal or equipment malfunction Report location Check whether there are any messages Report the crew and time on duty
T	Coordination: Communications between the dispatchers.	Coordinate identifying tracks on which to put trains Train delays On what track to expect a train What trains are coming in and on what track Coordinate train movements in and out of yard
D	Request track occupancy such as Form D requests/issuance of Form D/foul time requests/issuance of foul time/cleared tracks, cancelled Form D, cancelled foul time	Issuing Form D Issuing foul time Request Form D Request foul time Clear a track: cancel Form D/foul time
E	Emergency related communications	Location of/direction to emergencies Contacting a passenger for emergency calls Report trespassers Report harassment to passing trains
U	Unidentified communications	Inaudible messages due to the background noise or bad radio reception.

For example, a communication error occurred when a dispatcher failed to state the effective time of a Form D following the readback (see Northeast Operating Rules Advisory Committee (NORAC) operating rules). Table 4 shows the numbers used for error identification.

Table 4. Error Identification Codes

Code	Error Description
0	Clear conversation
1	Inaudible conversation
2	Congestion over the radio
3	Alphanumeric transposition
4	Other errors

Each message within a conversation was coded separately to eliminate the time spent before answering the calls. That means usually more than just one message correspond to a complete conversation. As mentioned earlier, the dispatcher receives multiple calls at the same time so he/she answers them on a priority basis.

3.1.3 Summary of Results

Approximately 5 percent of the data were excluded from the analyses because the voice radio transmissions were inaudible to the analyst. Table 5 shows the frequency of each voice radio communication type. More than half (58 percent) of the communications have involved information requests. One type of information request was from the train crew who asked the dispatcher if there were any new instructions before moving from point A to point B. Movement authorizations (Form D) requests were the second most frequent type of communication activity followed by coordination activities and emergency activities.

Table 5. Frequency of Voice Radio Railroad Communication

Type	Transmission Frequency	Percent of Communications
Information Requests	536	58.2
Form D Request/Issuance	202	21.9
Coordination	141	15.3
Emergency	34	3.7
Unidentified	9	1.0
Total	922	100.0

Figure 8 represents the counts of different types of communications. Each vertical line represents the minimum and maximum number of communication transmissions for each communication type per day. The points on the vertical lines represent the average (mean) values. The track workers and train crews are mostly calling the dispatchers to ask for new information. These information requests include schedule updates and speed restrictions. These conversations were usually of short duration. It is hypothesized that many of these information requests can be reduced or eliminated by providing real-time information directly to the train crews and MOW crews in the field.
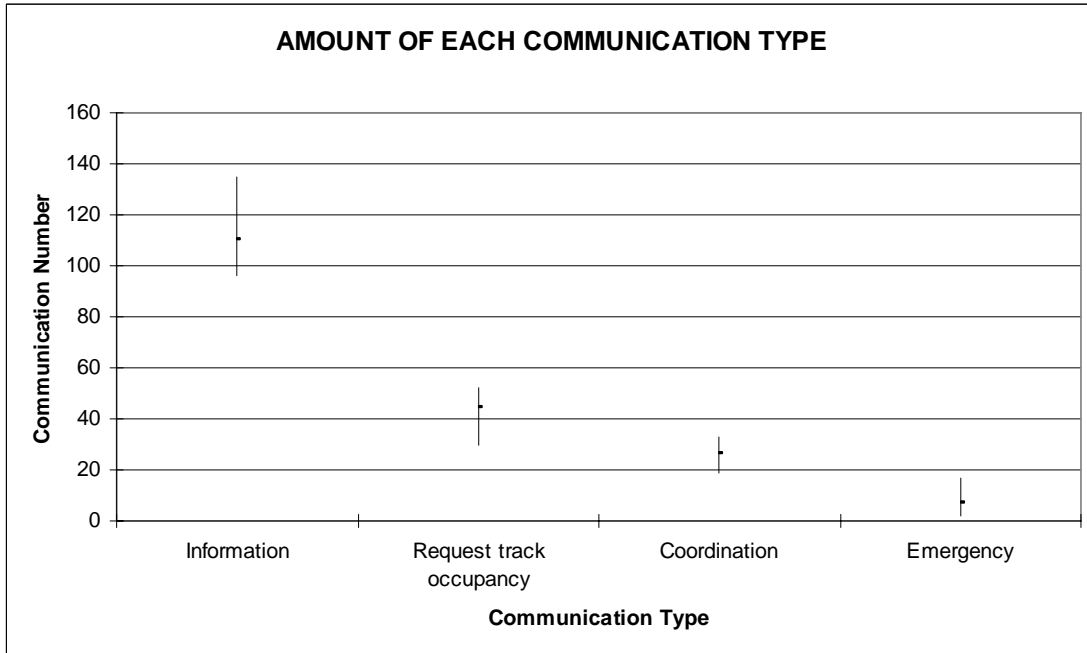
Figure 8. Communication Content by Day

Table 6 represents the average time that each type of communication required and the associated standard error. The analysis of five consecutive days of communications showed that the dispatchers were spending more time with Form D's than with any other communications. The readback/hearback routine took the longest amount of time compared to the other types of communications. The analysis shows that filling out Form D's via voice radio took twice as much time as the other types of communication. Generally, a dispatcher completed his/her communications in less than 1 min. 26 seconds (s). When filling out Form D's, the dispatcher required up to 3 min. 22 s to complete the task.

Analysis shows that the errors were mainly caused by the noisy radio communications. As mentioned earlier, the field environment where the radios were used was noisy due to loud train equipment. The presence of the dead spots where the radio communication was inaudible complicated the dispatcher's work. On the basis of their experience, dispatchers frequently tried to guess the missing parts of the conversations. A common error took place when one of the parties transposed alphanumeric information such as train ID. Roadway workers committed 55 percent of the transmission errors. Dispatchers accounted for one-third of transposition errors while train crews accounted for 11 percent of these errors. When identification errors or incorrect information occurred, dispatchers accounted for more than 80 percent. Rail workers were involved in approximately 17 percent.

Table 6. Communication Duration by Type

Communication Type	Mean (s)	Std Error (s)
Request Track Occupancy	120	8.9
Coordination	71	6.8
Emergency	53	9.4
Information	26	1.3

Of the errors committed by the dispatcher, 38 percent caught their own mistakes. Another dispatcher caught the mistakes 38 percent of the time, while a railroad worker was responsible for error recovery 23 percent of the time. With respect to the errors committed by a railroad worker, two-thirds caught their own mistakes and the dispatcher corrected them on one-third of the occasions. The dispatcher always corrected errors committed by the train crew.

Table 7 illustrates the following point. One would expect the train crew to account for a smaller portion of the total number of errors because they were involved in relatively fewer transmissions. The number of errors for maintenance workers is less than errors for dispatchers and they correspondingly are involved in fewer transmissions. Looking at the percentage of transmission of each party, one notices that there is a 1.4 percent error rate across the board for all three parties.

Table 7. Communication Errors by Occupation

Occupation	Communication Frequency	Errors
Dispatcher	922 (100%)	13 (1.4%)
Maintenance Crew	645 (70%)	9 (1.4%)
Train Crew	74 (8%)	1 (1.4%)
Total	922	23

Errors involving number transpositions were the largest category of errors accounting for almost 40 percent of the errors committed. Table 8 displays the frequency distribution for observed errors. Railroad workers committed 55 percent of number transmission errors. One-third of number transposition errors were committed by dispatchers with the train crew accounting for 11 percent of these errors.

When errors of identification or incorrect information were committed, dispatchers accounted for more than 80 percent. Rail workers were involved in approximately 17 percent of these errors.

Two-thirds of time discrepancy errors were committed by railroad workers with the remaining third committed by the dispatcher.

Table 8. **Errors Committed by Type**

Type	Error Frequency	Errors (%)
Number Transpositions	9	39
Incorrect Information/Identification	6	26
Incorrect Time of Day	3	13
Memory Lapse	2	9
Phraseology	2	9
Directional Error	1	4
Total	23	100

Of the errors analyzed involving a memory lapse, both instances involved the dispatcher. Of the errors involving poor phraseology, one was committed by the dispatcher and the other by a railroad worker. The one instance of a directional error was committed by a dispatcher.

Four percent of the transmissions resulted in a breakdown in communication due to equipment-related failures. Whereas this is not directly a human factors issue, it does speak to the issue of workload. If a party repeats a transmission or switches to a different communication mode (e.g., from radio to cell phone), workload increases.

3.2 Data Link Communications

3.2.1 Summary of Results

During each day of the test period, the field test crew (consisting of roadway workers) completed around 10 Form Ds. The study documented how long the maintenance employee took to request a Form D and for the dispatcher to fill out the form, and to assign time effective. Charts were created using the average daily times, one including waiting time and one excluding that component. The charts also show the total time required to issue one Form D movement authority.

Figure 9 shows the time to complete these activities by day. The chart shows some oscillations, but when the scale was taken into account, the data change is in the range of 10 s. The increase in time corresponding to day 10 can be explained by a 1-week interruption of the testing where the dispatcher working on the experiment went on vacation. On the first day after his time off, he needed some time to re-familiarize himself with the software.
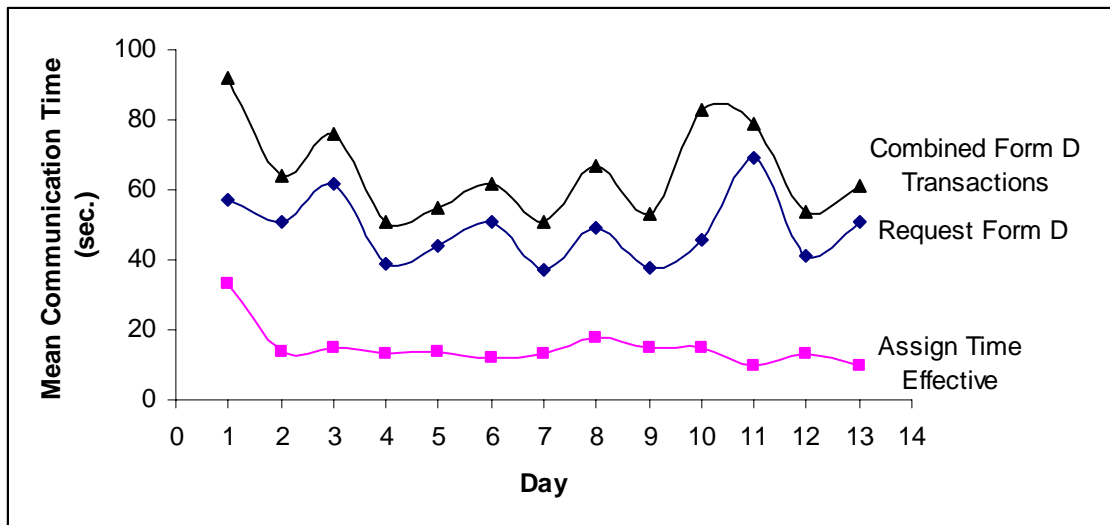
Figure 9. Time to Request and Receive Form D by Data link

The major advantage of the new system was the decline in the number of communication errors. Since the cancellation of Form D's was automated, the error for this particular task was eliminated. Once the foreman finished the job, he/she canceled the work permit without communicating by voice with the dispatcher. The dispatcher saw the form on the "cancelled" display window and acknowledged the termination of the work permit.

3.2.2 User Feedback

Most of the data obtained in the experiment was based on the feedback submitted by the field test crew. The railroad management also made comments about necessary modifications in the software so that the system would meet their needs. Based on these comments the following modifications need to be implemented before taking further steps:

- The smartphone must have a larger screen than the approximately 2-inch by 4-inch display. The commercial smartphones have small screens to accommodate the demand of the business people. A device used for railroad operations needs to have a slightly larger screen where the fonts and the displays will be larger for better reading.

- The screen should be visible in daylight and at night. One of the main issues with the smartphone was the visibility of the Liquid Crystal Display (LCD) screen in sunlight. According to the standards[3], the display screen on a sunlight readable/outdoor readable LCD should be bright enough so that the display is visible in direct or strong sunlight. Second, the display contrast ratio[4] must be maintained at 5 to 1 or higher.

  Although a display with less than 500 nits[5] screen brightness and a mere 2 to 1 contrast ratio can be read in outdoor environments, the quality of the display will be dreadfully poor and not get the desired information across effectively. A true sunlight readable display is normally considered to be an LCD with at least 1,000 nits of screen brightness and a contrast ratio greater than 5 to 1. In outdoor environments in the shade, such a display can provide an excellent image quality.

- The Form D number was generated by the system: the number must be assigned by the dispatcher according to railroad operating rules. This number not only serves to itemize the Form Ds but also to convey information about the dispatcher and the territory.

- When canceling a Form D, the foreman did not receive a confirmation message. There should be a confirmation page before the form is actually cancelled.

- Both ends of the system must have audio cues when a message is received. This way the user will be prompted of the incoming request preventing any delays that might occur if the user is not looking at the screen. For the Form D cancellation procedure, having an audio cue will notify the dispatcher immediately about the new status of tracks.

- The foreman should be able to send a short message, such a short message service (SMS) to the dispatcher instead of directly calling him on the phone or the radio. This feature supports the main purpose of the system, which is to decrease the congestion on the phone/radio lines.

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[3] http://www.littlepc.com/faq_lcd_technology.htm#outdoorreadable

[4] Contrast ratio (CR) is the ratio of luminance between the brightest "white" and the darkest "black" that can be produced on a display. A standard 200 nit LCD measured in a dark room has a 300 CR, but will have less than a 2.0 CR under intense direct sunlight.

[5] A NIT is a measurement of light in candelas per meter square (Cd/m2). For an LCD monitor it is brightness out of the front panel of the display. Most desktop LCD's or Notebook LCD's have a brightness of 200 to 250 Nits. The standard LCD's are not readable in sunlight.

- When the dispatcher rejects a request, the foreman should be able to go back to the incorrect form and make the necessary modifications instead of starting all over again.

- The dispatcher and the foreman should view information on a Form D in the same format to help each other in case of a misunderstanding. (With the current setup, the displays are slightly different than each other because of the limited display area of the smartphone.)

- The foreman should be able to enter his/her identification number when the smartphone is turned on: there should be a sign-in process.

- Form Ds must include the dispatcher's name, not just the territory name.

- The system should make the distinction between canceling a Form D and fulfilling it. A cancelled Form D represents an unfinished work, whereas a fulfilled Form D indicates a completed work.

- The current prototype did not allow additions to an existing Form D. The current procedures at the railroad where the testing took place permitted up to three additions to an existing Form D.

The problems that occurred using the data link system were associated with:

- Connection quality,

- User ability to navigate within the menu, and

- Tapping on the wrong parts of the screen (e.g., selecting wrong mileposts from the dropdown menus).

Overall, the dispatcher and the roadway workers liked to use the device. They expressed their interest in using the communication application once the updates were completed. They were impressed with the fast communication and the reduced number of errors. The workload ratings using the NASA-TLX scale showed that the workload perception was different for the dispatcher and the track foreman. The scorings that they provided are shown in Table 9. The maximum score for all tasks is 20. An example of the form and the explanation of its futures can be found in Appendix D.

Table 9. NASA-TLX Scale Rating Results

Task	Dispatcher	Track Foreman
Mental demand	15	10
Physical demand	3	2
Temporal demand	14	5
Effort	11	3
Performance	12	19
Frustration	15	2
Overall	19	13

One major feature that was requested by the superintendent of the dispatcher center was the use of handheld printers with the smartphone. This way, the roadway workers would also have a

hard copy of the Form Ds that they requested. This feature becomes very important if the device stops working. Another reason for this request revolves around the computer literacy of the potential users. If implemented, the device may be used by roadway workers whose exposure to computer use has been limited. Once they have a problem with the device, it may be hard for them to access the main menu. In case they end up using a function that they are unfamiliar with and cannot go back to the main menu, having a hard copy of the work permit would prevent potential accidents.

3.3 Current Radio System vs. Data Link System

The data using the voice radio technology shows that Form D's were the most time consuming type of communication between the dispatcher and the crew on the tracks. On average, a dispatcher took 3 minutes 13 seconds to complete one Form D. This study shows that data link technology can decrease this time significantly. Using a smartphone this completion time was reduced to an average of 65 seconds (see Table 10). This result was different from Masquelier et al's (2004) and Oriol et al's (2004) laboratory experiment results. Their findings showed that the work permission processes were slower but more accurate with the device than with the radio. This study, conducted under conditions more closely approximating real-world, showed that the work authorization processes were more accurate and faster with the handheld device.

Table 10. Form D Completion Time by Communication Mode

	Mode	
	Radio	Data Link
Form D Completion time (sec)	193	65

The study also shows that the new system, in providing the visual aid to users, eliminated alphanumeric transposition errors when requesting and issuing Form D movement authorities. With voice radio, the dispatcher and the foreman check the information using the readback/hearback procedure. They do not have access to each other's hard copy documents. If the dispatcher makes a mistake and the foreman does not realize it, there are no further checks. With the data link system, both users can see the same information which makes it easier to catch mistakes since both sides are checking the same source of information.

As described in section 3.2.2, the problems that occurred with the data link system were mainly related to the design of the device or the software (usability). Users reported problems associated with navigating to the appropriate screen, selecting desired information with the stylus, and difficulty seeing the display under certain ambient lighting conditions. As the device and the associated software are updated to address these problems, user acceptance should improve.

The new system reduced errors attributable to auditory communications. As shown earlier, with the voice radio, some of the errors occurred because of the radio transmissions that were difficult to hear. They also minimized errors, associated memory lapses, and numeric transpositions that are common with auditory-based communications. New errors types emerged that were linked to the visual modality and usability issues such as tapping on the wrong part of the screen or

navigation difficulties with the software. Usability errors should decrease with time as designers adapt the application to meet the needs of the users and the user adapts to the new user interface.

The dispatcher, participating in the study, stated that the new system considerably reduced the noise in the workplace (since the files were filled out digitally without any voice transmission). The radio was used for other types of conversations and emergency calls. Conversations that required less time than a Form D were still held over the radio. This practice decreases the radio use, hence the noise level in the dispatcher's work environment. In previous laboratory tests, the users also liked the new system for the same reason.

Another important feature of the smartphone was the ability to browse the internet. The dispatchers are required to check the weather information periodically during the day and immediately notify the roadway workers and the conductors of the changes. This information can be directly accessed using the smartphone, without contacting the dispatcher, decreasing the dispatcher's workload. The smartphone's browser can be programmed to access only certain Web pages to eliminate the possibility of surfing the internet during working hours. Combined with the efficiency gains from exchanging movement authorizations using the visual modality, this form of communication may enable dispatchers to operate more productively (e.g., handle more communications).

Although it has not been tested in this study as there was only one user in the field, the SMS feature of the smartphone gave the roadway workers the possibility to communicate directly with the dispatcher without sharing this information directly with others working on or near the tracks. This aspect of the system provides a more private medium for communications between roadway workers and dispatches and eliminates the party line effect of radio communications. The loss of the party line to keep track of movement authorities might normally be associated with a loss of safety. As Roth et al. (2001) discovered, the party line serves as an efficient method to inform railroad employees about the other track occupancies. However, the smartphone provides the same information with its territory status information feature. The users have constant access to the track information where they can see the updated information about each track.

4. Conclusion

The current study supported the results of Malsch et al. (2001), Oriol et al. (2004), and Masquelier et al. (2004) showing data link communications reduce voice radio-related errors and improve efficiency when communicating long and complex messages. The new system was faster and more effective than radio communication when used to convey long messages such as filling out Form Ds. Radio communication was faster than the data link for confirmation communications that only require yes/no answers. One reason for this difference appears to be the users' lack of familiarity with the device. The time to convey short messages should improve as the users become more proficient with the new system.

The users expressed many concerns about smartphones. Most of these concerns were related to its design. Users thought that the commercial smartphone used in this study was too small and delicate to be used in railroad operations. They expressed preference for a rugged device that would withstand being dropped and operating in a dusty environment. Another major issue was the screen resolution: the screen should be modified so that it is visible in direct sunlight. Other concerns were related to the unfamiliarity of the users with the PDA technology. Some users were unable to navigate within the menu and unable to go to the main menu once they were on a page that was not familiar to them.

The data link system would reduce the dispatcher's communication load by eliminating some incoming calls related to information requests like schedule updates and weather inquiries. The smartphone would receive updated data from the dispatch center, so the train schedule would be updated as soon as any change is entered at the control center. As the smartphone has access to the internet, the weather information could be checked by the roadway workers without contacting the dispatcher. The data link would also reduce the dispatcher's workload by transferring long conversations to the digital medium. During long conversations, the dispatcher both receives and sends many messages. With the data link system, the dispatcher could send the same amount of information currently contained in multiple voice messages with only one digital message.

4.1 Use of Positioning Technologies

In railroad operations, one of the main causes of fatality is the unknown location of the workers. Even though with the new and improved dispatcher centers, the dispatchers know that the work crew is between certain mileposts, but their exact location remains uncertain. Adding the GPS to the smartphone should solve this problem. GPS can be used to signal whenever the roadway workers leave the protected area. If they mistakenly start working on an unprotected track, the dispatcher can warn them and prevent fatalities. While adding safety precautions, this feature would also provide close supervision, which is a feature not welcomed by the railroad operators who contributed to this study.

4.2 Use of Handheld Device Printers

The use of handheld device printers was highly recommended by the superintendent at Cobble Hill. He was very excited about the idea that the work crew on the tracks could have a hard copy of the form that they fill out using the data link technology. He recommended this feature because he was concerned that the roadway worker might forget which permissions he/she has if

anything happens to the smartphone. Having hardcopies would let the roadway workers keep track of their work and prevent any accidents in case of a smartphone malfunction. Nowadays there are printers small enough to carry in the MOW vehicle and especially designed for PDAs, with printouts similar to cashier receipts. These printers usually work with batteries but they can easily be hooked up to the car's cigarette lighter with a power plug adaptor.

4.3 Custom Modifications

The smartphone used in this study mostly proved to be an efficient device for railroad operations. The messages conveyed using the data link technology was easier to understand since they were free of congestion. However an important issue was the size of the screen. The crews on the tracks would need a larger screen that they can easily see. When the screen is small, the font is too small and it gets harder to tap on necessary lines with the smartphone's plastic pen. The brightness of the screen was a second issue. As the device would be used mainly outside, the screen must be visible under sunshine, so either a brighter screen, or more likely a shading device, would be necessary. It also would need to have a screen light that can be used during night shifts.

Keeping up with rapidly changing technology is a challenge. Therefore, projects, using the latest technologies, are dealing with a moving target. By the time that this report was prepared, the smartphone used on the experiments was outdated and a larger selection of smartphones with more capabilities was on the market.

Appendix A.   NORAC Movement Permit Form D

NORAC Movement Permit Form D

FORM D No. _____

| FORM D |
| NO.(S)_____ |
| DELIVERED TO_____ |

DATE_____/_____/_____

TO   _____
            _____

1. TEMPORARY SPEED RESTRICTIONS

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

2. OPERATE IN _____ DIRECTION(S) ON _____ TRK BETWEEN _____ AND _____
    ON _____ TRK BETWEEN _____ AND _____ DSPR _____ TIME _____
    ON _____ TRK BETWEEN _____ AND _____ DSPR _____ TIME _____
    ON _____ TRK BETWEEN _____ AND _____ DSPR _____ TIME _____

3. TRAINS OR TRACK CARS AHEAD _____
    TC PROCEED PAST STOP SIGNAL(S) AT _____

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

5. ____ LINE ____ TRK OBSTRUCTED FOR MAINTENANCE BETWEEN _____
    AND _____

6. NON-SIGNALLED DCS RULES IN EFFECT ON _____ TRK(S) BETWEEN _____ AND _____

7. INT AND CP SIGNALS OUT OF SERVICE ON _____ TRK(S) AT _____

8. REMAIN AT _____ ON _____ TRK UNTIL ENGINE ARRIVES TO ASSIST

9. OPERATE AT RESTRICTED SPEED ON _____ TRK TO _____ WHERE TRAIN IS DISABLED

10. TBS IN SERVICE AT _____

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

12. PROTECT CROSSINGS(S) _____

13. OTHER INSTRUCTIONS/INFORMATION _____
    _____
    _____

    DISPATCHER_____   TIME EFFECTIVE _____

    FORM D CANCELLED, TIME _____, DATE __/__/__, DISPATCHER _____

Appendix B.   Smartphone Screenshot

1.   Main Menu

Train and territory information
Train status

Form D / Foul Time
Request Line 4
Request Lines 2,3   Request Foul Time
Cancel/Fulfill   Clear
My Form Ds   My Foul Time

---

2.   Request Line 4

Form D Line 4 Request

Work site between/at [00.0 Boston ▼]

[00.0 Boston ▼]

Track #: [1 ▼]

Start Time: [   ]

Duration: [10 min ▼] (estimated)

[Send request]   Main Menu

3.   Request Foul Time

Foul Time Request

Track #: [1 ▼]

Between/at:

[00.0 Boston ▼]

[00.0 Boston ▼]

Mile Post: [   ]

Start Time: [   ]

End Time: [   ]

[Send request]   Main Menu

---

4.   **Train Status**

Train Status Request

Select train number:

[0 ▼] [0 ▼] [0 ▼] [0 ▼]

[Get train status]

Find more train IDs   Main Menu

5.   **Request Lines 2,3**

Form D Lines 2,3 Request

Operate track-car between: `00.0 Boston ▼`

`00.0 Boston ▼`

Track #: `1 ▼`

Direction: `East ▼`

[Send request]   **Main Menu**

Appendix C.   Dispatcher Screenshots

Form D Request

Time Effective Request

Active Form D

Cancelled Form D

NorthEastCorridor Terminal - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back → Search Favorites History

Address C:\Documents and Settings\Administrator\Desktop\rww-2004-05-17\rww\data\rail-datalink.volpe.dot.gov\docs\dispatcher\terminalNE.html

Links Dispatcher Login

Requested   Active   Rejected/Cancelled

Cancelled Form Ds

- Smith , Cp - Wilson-Cp - Loop, Trk Single
- Smith , Manchester-Cp - Wilson, Trk 1
- Smith , Beverly Jct.-Cp - Wilson, Trk 1

Cancelled Foul Time

None

Rejected Form Ds

None

Rejected Foul Time

None

Form D 0003 is Cancelled

Form D # :	0003
Cancel time-date-dspr:	Fri, 1.03p - 07/02/2004 - NorthEastCorridor
Delivered to:	Smith
Date:	07/02/2004
Line 2:	Operate in East direction on Single track between Cp - Wilson and Cp - Loop
Line 3:	Trains or track cars ahead none TC proceed past stop signal(s) at -
Train Dispatcher:	NorthEastCorridor
Time Effective:	12:20p
Message:	
Speed Restriction:	-
Job Status:	-
Signs Removed:	-

Detecting proxy settings...   Unknown Zone (Mixed)

Appendix D.   NASA-TLX Scale Form

Workload Ratings using the NASA-TLX Scale

Job Title _____   Male/Female (please circle)

Age: _____   Years of Experience: _____

Please indicate your ratings for the contributions of each of the following dimensions to your task.

MENTAL DEMAND (thinking, deciding, remembering etc.)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|

    Low   **High**
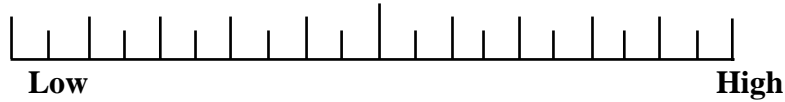
PHYSICAL DEMAND (physical exertion/activity)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|

    Low   **High**

TEMPORAL DEMAND (time pressure

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|

    Low   **High**

EFFORT (how hard you worked)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|

    Low   **High**

PERFORMANCE (success in accomplishing the task)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|

    Good   **Poor**
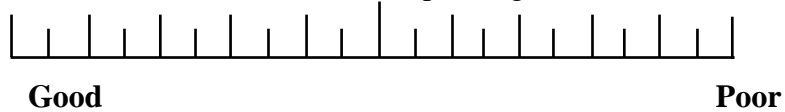
FRUSTRATION (irritation, discouraged)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|
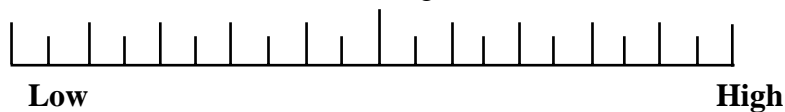
    Low   **High**

OVERALL (your impression of overall workload the task entailed)

|⌊_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_⌋|
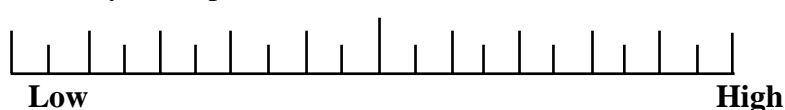
    Low   **High**

Rating Scale Definitions

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Appendix E.   Questionnaires

DEMOGRAPHIC QUESTIONNAIRE

1.   Job Title:

2.   Years of Experience:

3.   Please provide examples of your interaction with the dispatchers / work crews and an average number of these interactions per week. [such as Form D, foul time, train schedule update, message relay, other…]

Type of Interaction	Number of times per week

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

	Very unfamiliar	Unfamiliar	Somewhat familiar	Familiar	Very familiar
Radio					
Computer					
Beeper / Pager					
Cell Phone					
Internet					
Palm Pilot					

Usability Questionnaire

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

	Very ideal	Ideal	Needs some improvement	Change completely
Font size				
Font style (bold, underline…)				
Readability				
Organization				

6. Please provide feedback on the organization of the menu: was it easy to navigate through the main menu, were the menu names meaningful, what improvements can be made on the menu?

7. Please provide feedback on the PDA that you were using: general comments on its use, user friendliness, shape, brightness etc.

8. Can you compare the radio and the PDA: which one would you prefer for filling out Form Ds? Which one was faster and more efficient? Which one do you think is prone to errors?

9. Please indicate any safety concerns that you might have.

Thank you very much for your cooperation.

Glossary

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

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

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

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

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

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

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

Engineer: The person primarily responsible for operating the locomotive.

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

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.

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.

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 4 ft of the field side of the near running rail.

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

FRA: Federal Railroad Administration.

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

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

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

LCD: (Liquid Crystal Screen) Type of display used in digital watches and many portable computers. LCD displays utilize two sheets of polarizing material with a liquid crystal solution between them. An electric current passed through the liquid causes the crystals to align so that light cannot pass through them. Each crystal, therefore, is like a shutter, either allowing light to pass through or blocking the light.

Movement Permit Form D: A form containing written authorization(s), restriction(s), or instruction(s), issued by the dispatcher to specified individuals.[6]

NORAC: Northeast Operating Rules Advisory Committee.

Personal Digital Assistant (PDA): It is a handheld device with a large touch-screen, organizer and basic computing functions. Many have a stylus and support handwriting recognition. A typical PDA also has faster processor and more memory than a typical phone, and can run more complex software. Most PDA's run a standardized operating system (OS), such as Palm OS or Windows Mobile for Pocket PC. In the spectrum of mobile devices, PDA's fall in-between a laptop computer and a cell phone.

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

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

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

Smartphone: A category of mobile device that provides advanced capabilities beyond a typical mobile phone. Smartphones run complete operating system software that provides a standardized interface and platform for application developers.
Smartphones are distinct from PDA-based devices running operating systems such as Palm OS or Windows Mobile for Pocket PCs. While PDA-based devices usually have a touch-screen for pen input, smartphones usually have a standard phone keypad for input.

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

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

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

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[6] NORAC operating rules

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

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