EVALUATION OF A DIGITAL COMMUNICATION DEVICE FOR RAILROAD WORKER SAFETY

by

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Submitted to the Department of Aeronautics and Astronautics and to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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ABSTRACT

This thesis documents the testing of a prototype of a smartphone to be used by roadway workers and dispatchers that was based in a wireless data link service. The main purpose of using a smartphone in railroad communications is to eliminate errors due to radio and pronunciation deficiencies. Previous studies analyzed the communication environment of the dispatcher in order to address questions based upon data link becoming a means for sending and receiving information in railroad operations. These studies have examined what kind of information is appropriate for each medium (voice and visual), and by what criteria a dispatcher will select which communication medium. Building on these studies, this work presents a comparison between a radio and data link mediums for a long communication of a characteristic type: assignment of a form D.

This thesis reports on the on site testing of the data link system which proved to be useful and efficient in certain aspects of railroad applications. The new system was faster and more effective than the radio communication when used to convey long messages such as filling out Form Ds. The radio communication was faster than the datalink for confirmation communications that only require yes/no answers. One reason for this difference appears to be the users’ unfamiliarity with the device. The time to convey short messages could also be reduced after the users become more proficient with the new system. The document also includes an analysis of the regulatory challenges that the new system would bring. A list or recommendations for the new regulations are presented at the end of the report.

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1 INTRODUCTION

1.1 THE RAILROAD ENVIRONMENT TODAY

Railroad operations mainly rely on voice communications between the railroad dispatchers, locomotive engineers, and roadway workers. The roadway workers contact the dispatcher to get permission to work on a track, referred to as *fouling* a track. To obtain track occupancy, railroad workers need special forms or instructions dictated by the railroad dispatcher. These forms, referred to as form D or foul time, are completed via radio or telephone communications on a readback/hearback basis (an example of a form D can be found in Appendix-A). These forms are completed through the radio or the phone on a readback/hearback basis. The information given by the dispatcher is repeated by the roadway worker and confirmed by the dispatcher. The conductors contact the dispatcher to ask for special instructions or to notify the dispatcher about their position. This communication also takes place on the radio or the phone. The interaction between the dispatcher and the train crews and roadway workers to manage track use causes congestion on the radio channels and the phone lines. The voice radio communication has bandwidth limitations that make this medium questionable for the future railroad operations. Currently digital or automated communication only exists between the central dispatching station and the tracks. Dispatchers now track the trains through a schematic track layout wall display at the dispatcher. The approximate positions of the trains, signals and switches are displayed on computer screens.

An alternative to the voice radio communication is the use of data link technology: this new technology is more and more used in other applications such as air traffic and commercial highway vehicle control. In a rail application this technology involves a handheld device such as a Personal Digital Assistant (PDA) to create the information transfer between the foreman and the dispatcher. The dispatcher accesses the information through a desktop computer where he gets the permission request visually. Data link technology provides the means to transmit
information digitally thereby reducing radio frequency congestion. The advantage of using data link technology to transmit information far exceeds its promise to reduce frequency congestion. In addition, it may potentially eliminate some errors due to poor radio communications.

Previous studies analyzed the communication environment of the dispatcher in order to address questions based upon data link becoming a means for sending and receiving information in railroad operations. These studies have examined what kind of information is appropriate for each medium (voice and visual), and by what criteria a dispatcher will select which communication medium. Building on these studies, this work presents a comparison between a radio and data link mediums for a long communication of a characteristic type: assignment of a form D.

1.2 CURRENT RADIO SYSTEM

The Commuter Rail Operations Control Center “Syseca” controls the operations and the management of Massachusetts Bay Transportation Authority (MBTA)’s North Side commuter rail system. The Centralized Dispatching System (CDS) enables the train dispatchers to fulfill their responsibilities through improved train monitoring and control. The PC based system empowers the dispatchers to enhance service and revenue generation through improved train monitoring and control. The territory controlled by Syseca is divided into four branches and a terminal area. Each branch is controlled by a different dispatcher and a fifth dispatcher, called the terminal dispatcher, monitors the starting point of all branches. These branches are the North Station branches shown in the Figure 1.
As shown in Figure 2, each dispatcher has his/hers own cubicle and own display. The cubicles are located in a large room and the dispatchers can interact with people around them. 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.
The dispatchers monitor the trains and the maintenance operations through a schematic track layout editor (see Figure2). This is a color wall mount display of the tracks. The physical characteristics of the track such as curves, grade crossings, roads in the neighborhood, etc are not shown. The display consists of several video display screens. A photo of these screens is shown in Figure 3. Six screens display the tracks, four screens display the train schedules and one screen is used to fill out the movement authorization forms, to view information or to manage other control tasks. The color code used for the track display is:

White: the track segment is available for routing trains or other uses
Green: the track segment has been cleared for train routing.
Red: the track segment is being occupied by a train or track vehicle
Blue: the track segment is blocked for maintenance.
When a train occupies a track, its ID number and its movement direction are indicated on the schematic display as well. The delays are also coded in red, below the train’s ID number indicating how long the delay will be. The delay is updated as the train passes by the interlockings.

Each dispatching work station is equipped with track display screens, a telephone, a radio and a computer. Dispatchers also keep paper records of the train schedules/timetables in case the system crashes. Communications with train conductors and work crews are held through radio or telephone. They receive multiple requests at the same time over the radio. The inevitable consequence is that some requests are replied to with a delay. When the radio fails, they then use the phone for one-to-one conversations with people in the field. The telephone and radio
communications are combined in a single intercom system to help the dispatchers. Dispatchers can switch between the radio and the telephone using a pedal connected to the system. All such conversations are digitally recorded and kept in an archive for 90 days.

The computer is used to get print-outs of the movement authorization forms for backup purposes, to access the updated train schedules, to view the passenger number on board and train consist\(^1\) information. Through their computers dispatchers have internet access which is generally used to get real-time weather information and to notify the trains in case of unexpected bad weather that can cause delays or accidents.

Dispatchers are in almost constant interaction with the roadway workers. When the dispatcher receives a work permit request, he/she has to decide whether it can be granted depending on the train schedules. To give permission, the dispatcher should first block the track where the work will be performed. This will show up on the display when a track segment turns blue. This is the same as putting a blocking device on the switches and signals that control the access to the track. During this time, the dispatcher does not have authority on the track. If the maintenance crew needs the switched to be reversed, they have to do it themselves or give the track back to the dispatcher and wait until he reverses the switch. Once the job is complete, the crew gives the track back to the dispatcher. At this time, they also mention any necessary information such as speed restrictions.

1.3 PREVIOUS WORK

The main project was conducted by Volpe National Transportation Systems Center and sponsored by Federal Railroad Administration’s Office of Research and Development. The goal of the project was:

\(^1\) Consist: makeup or composition (as of coal sizes or a railroad train) by classes, types, or grades and arrangement
"To explore the information flow in railroad operations and look for potential uses of new information technologies in order to enhance safety in railroad operations. In particular, the use of data link has been proposed as an alternative communication medium to supplement voice radio."

Earlier studies covered the dispatcher's side (Malsch, 1999 and Basu, 1999) and the roadway worker's side (Oriol, 2000 and Masquelier, 2001) of the issue separately. Malsch and Basu's work tested the potential use of data link technologies from the point of view of dispatchers. Their findings and suggestions include:

- Dispatchers like the idea of data link technologies. They liked the fact that they could receive requests from trains or work crews in an e-mail like fashion instead of radio calls that had to be answered in a first-come first-served basis. With this architecture, they could assign priorities to incoming messages and deal first with the most important ones.
- They did not see how the work crews in the field would send them digital messages. Not only did they not have the appropriate tool but also some of them were not familiar with computers.
- They found interesting the fact that with data link they did not have to repeat a message many times due to low quality radio transmissions.
- They welcomed a system that helped to solve the congestion problem that affected radio communications.

Oriol's work identified the use of information technologies in order to fulfill the requirements of the railroad operations from the perspective of roadway workers. A first prototype of Personal Information Device (PID) was designed to establish direct communication with the dispatching center in order to retrieve vital information, previously not available, without distracting the dispatcher with radio calls. The testing for his work has been done in a simulation center with three roadway workers and one PID. 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 work attempts. 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 seems to be slower but more accurate using the data link device. The workload remains the same.

Masquelier again conducted a laboratory experiment. He could not do a field test due to the difficulty that he had to gain access to MBTA commuter rail’s real-time train database and track profiles in time. Using the MIT/Volpe Railroad Dispatching Simulator, he studied the dispatcher’s perspective. His work also showed that work permission processes were slower but more accurate with the device than with the radio. His experiment caught 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 subjects with the system. Masquelier also suggested to reduce the territory that each dispatcher is in charge of, in order to compensate for the increase in mental workload due to the tracking display.

The prototype communications system based in wireless data link device is intended to increase the safety of roadway workers and at the same time to reduce the radio congestion, thus improving overall efficiency of railroad operations. GPS option has already been used to localize track cars. The data link device consisted in a hand-held information appliance with wireless access to the internet, connected to a GPS receiver.
Given the previous studies, this study intends to prove with in-situ testing that using data link for communications would require fewer messages, diminish the error rate, decrease the communication time, eliminate the communication delay found in the radiotelephone mode, increase accuracy of the information flow, increase efficiency of the workers, and increase worker’s safety. The intention is to look at the findings in actual field situations and compare them with the previous simulation experiments.

1.4 DATA LINK SYSTEM

The data link communication uses digitally coded information. The device used in this experiment is a Kyocera smartphone which is a combination of a cell phone and a PDA. The information is transmitted through a network connection.

The dispatcher communicates with the maintenance of way (MOW) crew member using a desktop computer. A secure connection provides the updated train information to the worker in the field. The same connection enables the information flow between the dispatcher and the crew member. The form D’s are filled out using the drop down menus on the smartphone. The updated display of the forms requires a minimum amount of typing by the crew member. Once filled, the form is sent to the dispatcher who confirms the information by reentering the same data and sends it back to the worker. The last step is asking and granting “time effective”. When the time effective is assigned, the form D becomes active and the tracks are blocked.

The main purpose of using a smartphone in railroad communications is to eliminate errors due to radio and pronunciation deficiencies. By relying on the visual display of the information, the data link enables the dispatcher to double check the information entered by the railroad workers.

Furthermore, data link intends to reduce the radio congestion problem. By shifting specific types of communications from the radio environment to the data link environment, the radio channels will be used more efficiently. Studies of the
dispatcher environment showed that the dispatchers constantly receive calls. If they can take care of some of this work online, the radio channels will be freed up.

Another benefit is to give the railroad workers real-time train information. The real-time information is intended to improve the worker's decision about requesting work permission on the tracks. Being aware of the current status of the trains, the MOW crew would be able to request better time arrays to work on the tracks. This will also decrease the dispatcher's warnings about the scheduled trains that would occupy the tracks requested by the foreman.

The interface used for the smartphone can be custom designed according to the requirements of railroad operations. The current design reflects only the information that had already been tested. A more detailed form D design can be created, enabling the dispatcher and the foreman to use the same format.

1.5 RAILROAD WORKER SAFETY

The freight railroad industry was deregulated in 1980 by the Staggers Act and, as a result, provided the incentive to make substantial capital investments to improve the quality of its rolling stock and physical plant over the past 24 years. Nevertheless, train collisions and over-speed accidents continue to occur, and the National Transportation Safety Board (NTSB) has, for over a decade, been recommending that railroads install new communications-based Positive Train Control (PTC) systems. They have also recommended that the Federal Roadway Administration (FRA) issue regulations requiring that PTC be installed on the nation's railroads. PTC systems are made up of digital data links connecting locomotives, maintenance-of-way equipment, wayside base radios, and control centers; onboard computers, positioning systems, data radios, and display screens on locomotives and maintenance-of-way equipment; and control center computers. Positioning systems on the vehicles inform the control centers of their location via the data link. The dispatcher and the control center computer issue movement authorities to the vehicles via the data link. On-board
computers compare actual location with the movement authority, and if there is a violation of the authority, the on-board computer stops the train.

The need for this new technology is illustrated in the following figures. FRA reported that there had been an increase in the roadway worker fatalities during the last half of 2001 and the first half of 2002. During this period, six railroad engineering employees were killed by trains or roadway maintenance machines or other track equipments.

The reported accidents by FRA concerning Massachusetts within the past four years are as follows:

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cnt</td>
<td>%</td>
<td>Cnt</td>
<td>%</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>18</td>
<td>0.7</td>
<td>23</td>
<td>0.8</td>
</tr>
<tr>
<td>All states</td>
<td>2,768</td>
<td>100</td>
<td>2,983</td>
<td>100</td>
</tr>
<tr>
<td>Amtrak</td>
<td>85</td>
<td>2.35</td>
<td>148</td>
<td>4.1</td>
</tr>
<tr>
<td>Mass Bay Transit Auth.</td>
<td>2</td>
<td>0.55</td>
<td>1</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Table 1-1: Massachusetts Accidents Report

On January 30, 1997 about 9:42 a.m., Eastern Standard Time, a MBTA system track repairman was fatally injured when northbound MBTA subway train No. 1285, north of the Ruggles Street Station, struck him. The radio tapes between the trains and the Operations Control Center (OCC) revealed that the track repairman did not arrange or request protection from OCC.

One reason for this kind of accident is the misuse of the shared party line feature of the voice radio communications. The party line effect can be explained as one track worker overhearing the radio communication intended for another. For example, when crew A contacts the OCC to request permission, crew B hears about it over the radio. Then crew B might mistakenly start working on the tracks issued to
crew A. When crew A cancels the permission and gives the tracks back to the dispatcher over the phone, crew B may continue to work without their being notified about the cancellation and without anyone being notified about their presence on the tracks. Fatalities have occurred in the past when crew members got hit by trains because of these miscommunication situations.

Another reason for railroad accidents is the lack of situation awareness of the worker. Geographic disorientation is the main cause in this context. A worker may have asked protection for the correct track but he might be in a train’s route because of working on the wrong track, due to his disorientation. He might also be on the wrong track because the dispatcher misheard the request and granted permission on the wrong track. This type of situation occurs as the result of readback/hearback errors. Railroad personnel are required to read back all instructions verbatim (readback) and the dispatcher is required to acknowledge the accuracy of the readback (hearback). A readback error occurs when railroad personnel erroneously read back the dispatcher’s instruction. A hearback error occurs if the dispatcher fails to catch the employees’ error in the read back (Hearback Error Type I) or if he/she fails to detect an error in the readback resulting from his/her own error in the original instruction (Hearback Error Type II).

Such accidents can be avoided using real-time information. It is believed that a device providing the current position of the trains to the workers and the current position of the workers to the dispatchers would be effective in these situations. Our hypothesis is that use of digital datalink communications to update the train schedules on a PDA would fulfill the need. By adding earth coordinates from a GPS system on the railroad worker’s PDA, a dispatcher might easily locate the crews.

1.6 RESEARCH GOALS

The goal of this project is 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. The aim is to show which medium
is preferable for railroad communications. As previous studies already proved that the voice communication is better for short conversations, this study mainly focuses on the most time consuming communication type in railroad operations: form D assignments.

A PDA was earlier tested in an experiment, using simulators and scenarios for daily railroad operations. One group of roadway workers carried out assigned tasks using the PDA and the other group used the radio in the conventional way. The PDA proved to be more efficient in the test. The current project is aimed at testing the device in situ, with active dispatchers and track workers on the real routes.

In this study, a Kyocera smartphone 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 is to determine whether communication using data link:

- requires fewer messages
- requires less time
- reduces or eliminates certain types of messages, shifting the focus onto the control activities
- combines the communicator and the dispatcher center systems in a single medium
- eliminates or reduces imprecision and errors
- eliminates communication delays

and also

-cannot replace the radio communications even if it has significant advantages over the radio.
2 METHODOLOGY

2.1 CURRENT RADIO SYSTEM

2.1.1 DATA GATHERING

In order to have a better idea of the dispatcher interactions with the field personnel, ninety three hours of voice communications, a total of 973 transmissions, in the railroad environment were sampled. This data corresponds to five day-long communications. After the data collection, each conversation was labeled according to a categorization system.

First, the conversations were recorded using a digital audio tape (DAT) recorder, a videocassette recorder (VCR), both desktop units, 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 shows the time and the date of the recorded material. Also, four hours of audio was recorded on the DAT machine which duplicated the first four hours on the video tape. After the recordings proved to be useful and ready to analyze, five consecutive days of conversations were recorded.

Then, the tape recordings were transferred to the digital mode using the software Sound Forge 5.0. This is a two-track digital audio editor with wide-ranging audio processing capabilities. The file sampling rates are up to 192 kHz. 24-bit, and 32-bit floating point can be read and recorded. For ease of data storage and processing speed, each audio file was limited to 2-hour a period. The conversation time on the recordings was longer than the labeled messages because of the personal conversations that had been discarded in the analysis.
2.1.2 OBSERVATIONS

The dispatcher environment was observed by the author several times to get a better understanding of the daily work and issues. At the end of an observation period, five consecutive days of communication data were gathered for further analysis. The communications included all interactions of one dispatcher: the communications with other dispatchers, train conductors and MOW crews. During the observation time the following remarks were noted:

- Radio communication is subject to interference, background noise, fadeout and sound distortion. The noise level in a locomotive cab makes 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 operates 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 is a common occurrence when train traffic and maintenance activity are heavy.
- In addition to the limitations imposed by the congestion, the voice radio link is open to human error: acoustic confusions, alphanumeric transpositions, and misinterpretation due to poor pronunciation are some of the human induced errors.

All these inconveniences affect the performance of the train control system by causing delays in the issuance of the movement authorizations and track occupancy permits, or by contributing to collisions and accidents, sometimes including fatalities.

2.2 DATA LINK SYSTEM

The data link communications were observed with a pilot study 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. The software used by Massachusetts Bay commuter railroad Company (MBCR) was provided by ARINC, who helped to set up the network communication according to their requirements. The main issue was to establish a secure connection where there would be a one-way data feed from ARINC’s system to Volpe’s server and a one way access from the smartphone to Volpe’s server. The data that would be fed to Volpe’s server is the real-time update of the train locations. Setting up the connection was the most time consuming part of the project due to security reasons and the change in the operations of MBTA. MBTA’s commuter rail has been operated by AMTRAK since July 1, 2003. Starting on that date, commuter rail service was prioritized and the operations shifted to MBCR.

In order to have a secure network, MBCR requested to use encrypted data. The major problem was how the data would be transferred to the Volpe server after being provided by ARINC. The IT department of MBCR offered the following setup for the equipment:

![Network Setup at the Testing Facility](image)

Figure 2-1: Network Setup at the Testing Facility
All connections were secured with firewalls. The MBCR Network is connected to the internet via Virtual Private Network (VPN) which provides a secure connection through public domain. VPN enables a secure connection without using a private modem or phone line. The experiment server can only connect to one IP address, the site to access smartphone. This connection was set up such that the server cannot be used to surf on the internet.

The data that was transmitted to the system were: the train ID, milepost name, milepost ID, the direction in which trains operated, and the updated schedule. This information exists in the MBCR system as shown in the Figure 6. The uploaded data was accessed using a Kyocera QCP6035 smartphone, shown in Figure 5. This is a combination of a Palm handheld and cell phone that includes a built-in web browser and can share data with a PC. Its dimensions are larger than a cell phone but smaller than its predecessor Qualcomm Public Data Query (PDQ). It weighs 7 ounces and it is nearly an inch thick. It has 8MB of memory.
Figure 2-3: Train Schedule Sheet

The data gathering process started with a demonstration of the system to the dispatcher and the foreman. During usability testing of the initial system, the users identified potential problems with the interface. These issues were reconciled prior to field testing; a description of these issues is described below:

- The original time format on the smartphone was 24 hour military time and the one on the dispatcher screen was AM/PM format. The time format on the smartphone was changed to AM/PM so that both users would have the same layout.
- 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:
- Speed restriction
- Crossing protection restored
- Signs removed

- An additional information box was added to the dispatcher layout where he/she can enter messages in text form.
- When a request was denied by the dispatcher, the response was not visible on the smartphone screen. The information is now displayed with bold characters.

After refining the system according to the first feedback the testing started. The experimental equipment was placed next to the Boston East dispatcher and the smartphone was given to a foreman who was in charge of a MOW in this territory. While the Boston East dispatcher was doing his daily job, another dispatcher was imitating 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. These delays were identified in the data as “waiting for the dispatcher in charge”.

The experiment was repeated for 13 days according to the railroad employees’ schedules. The data were collected between 8am and 3pm, during the regular shifts of the experiment crew. The work was completed in a month and a half. The measurements were all done at the dispatcher center. As the program did not have a built-in chronometer, the time was recorded externally. First the dispatcher received the form D request. Upon receipt the time started, and after reviewing the information the dispatcher filled out the necessary fields and sent the form back to the foreman. Upon clicking on “send”, the time stopped. The next step was the request for “time effective” where the foreman asked for validation of the form. The dispatcher only entered the time and sent the form back. The length of this process was measured using the same method. Due to limited space in the MOW, it was not feasible to monitor the crew on the tracks.
3 DATA ANALYSIS AND SUMMARY OF RESULTS

3.1 CURRENT RADIO SYSTEM

3.1.1 CLASSIFICATION OF DATA

The data gathered using the current radio system is divided into messages where each message corresponds 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. 21.1.0). The first number indicates the order of the message within a two-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 used are as follows:

I: information request, notification communications between the roadway workers and the dispatchers
T: coordination communications between the dispatchers
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
E: communications about an emergency
U: unidentified communications

The main purpose of the categorization was to identify human errors. One type of communication error is poor phraseology, which is defined as non-compliance with the standardized wording or phrasing of railroad communications. When a dispatcher issues a Form D for track occupancy, the receiver is required to read back all instructions verbatim. Following the readback, the dispatcher is required to state the effective time of the instruction and the receiver is also required to read back the effective time. A specific example of a communication error is when a dispatcher
fails to state the effective time of a Form D following the readback (see NORAC operating rules). The numbers used for error identification are as follows:

0: clear conversation
1: inaudible conversation
2: congestion over the radio
3: alphanumeric transposition
4: other errors

Above described categorization system allows the assignment of the same identification letter to different conversations that can be grouped together. For example announcing schedule changes, explanation of delays and passing information about other trains, all fall under the information request category, namely the “I” category.

A brief list of the types of information that the dispatcher passes to the other railroad workers can be categorized as follows:

<table>
<thead>
<tr>
<th></th>
<th>Information Sent</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Any schedule changes</td>
</tr>
<tr>
<td>I</td>
<td>Explanations for the delays</td>
</tr>
<tr>
<td>I</td>
<td>Information about other trains</td>
</tr>
<tr>
<td>D</td>
<td>Issuing form D</td>
</tr>
<tr>
<td>D</td>
<td>Issuing foul time</td>
</tr>
<tr>
<td>T</td>
<td>Coordinate identifying tracks on which to put trains</td>
</tr>
<tr>
<td>T</td>
<td>Train delays</td>
</tr>
<tr>
<td>T</td>
<td>On what track to expect a train</td>
</tr>
<tr>
<td>T</td>
<td>What trains are coming in and on what track</td>
</tr>
<tr>
<td>T</td>
<td>Coordinate train movements in and out of yard</td>
</tr>
<tr>
<td>E</td>
<td>Location of / direction to emergencies</td>
</tr>
<tr>
<td>E</td>
<td>Contacting a passenger for emergency calls</td>
</tr>
</tbody>
</table>

Table 3-1: Information Sent by the Dispatcher.
A brief list of the information that the roadway workers and train crews passes to the dispatcher can be categorized as follows:

<table>
<thead>
<tr>
<th></th>
<th>Information Sent to the Dispatcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Report track, train, signal or equipment malfunction</td>
</tr>
<tr>
<td>I</td>
<td>Report location</td>
</tr>
<tr>
<td>I</td>
<td>Check whether there are any messages</td>
</tr>
<tr>
<td>I</td>
<td>Report the crew and time on duty</td>
</tr>
<tr>
<td>E</td>
<td>Report trespassers</td>
</tr>
<tr>
<td>E</td>
<td>Report harassment to passing trains</td>
</tr>
<tr>
<td>D</td>
<td>Request form D</td>
</tr>
<tr>
<td>D</td>
<td>Request foul time</td>
</tr>
<tr>
<td>D</td>
<td>Clear a track: cancel form D / foul time</td>
</tr>
</tbody>
</table>

Table 3-2: Information Sent to the Dispatcher

Each message within a conversation is labeled separately in order 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.

### 3.1.2 SUMMARY OF RESULTS

Using the above described labeling system, the data have been used to create different charts to reflect the error trends on daily communications. The data were also used to plot the communication length and the communication types versus the time of the day. These charts are based on an average of 200 communications per day. Approximately 5% of the data were excluded from the analyses because the transmissions were inaudible to the analyst. To have a general idea about the data, the frequency of each communication type in the sample is shown in Table 4. About 38% of the communications involved information requests. One type of information request was from the train crew who asked the dispatcher if there are any new instructions prior to moving from point A to point B. It is possible that this could be
automated so that the train crew personnel could downlink this information from a remote source (e.g., hand held PDA).

<table>
<thead>
<tr>
<th>Type</th>
<th>Transmissions #</th>
<th>% of Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Requests</td>
<td>536</td>
<td>58.2%</td>
</tr>
<tr>
<td>Form D Request/Issuance</td>
<td>202</td>
<td>21.9%</td>
</tr>
<tr>
<td>Coordination</td>
<td>141</td>
<td>15.3%</td>
</tr>
<tr>
<td>Emergency</td>
<td>34</td>
<td>3.7%</td>
</tr>
<tr>
<td>Unidentified</td>
<td>9</td>
<td>1.0%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>922</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3-3: Types of Railroad Communications

These data were then aggregated into summary graphs based on the salient parameters. The emphasis is given to the time analysis as well as to the quantitative analysis of the communications and the errors. The erroneous interactions are analyzed to reveal the type of the errors and the possible reasons, such as fatigue due to the late working hours.

Figure 7 represents the counts of different types of communications. As can be seen from the figure, 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 are usually short since giving additional information is not a routine task. This type of communication can be eliminated by providing real-time information to the railroad workers.
Figure 8 represents the average time that each type of communication required. 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 much time and is prone to human errors, so the information is repeated one or more times. The analysis shows that filling out form D’s with the current method takes twice as much time as the other communications. Generally a dispatcher is able to complete his/her communications in less than 1min. 26sec. But when filling out form D’s, the dispatcher requires up to 3min. 22 sec. to finish the task.
The count of each type of error is shown in Figure 9. Analysis shows that the errors are mainly caused by the noisy radio communication. As mentioned earlier, the environment where the radios were used was noisy due to loud train machinery. The presence of the dead spots where the radio communication was inaudible complicated the dispatcher’s work. Based on their expertise, they tried to guess the missing parts of the conversations. Figure 9 shows that the second reason for errors was the alphanumeric transpositions. These were human errors resulting from fatigue or divided attention. Roadway workers committed 55% percent of the number transmission errors. One-third of the number transposition errors were committed by dispatchers with the train crew accounting for 11% of these errors. When errors of identification or incorrect information were committed, dispatchers accounted for more than 80% of these transgressions. Rail workers were involved in approximately 17% of these errors.
Of the errors committed by the dispatcher, 38% caught their own mistakes. Another dispatcher caught the mistakes 38% of the time, while a railroad worker was responsible for error recovery 23% 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>
<thead>
<tr>
<th>Worker Class</th>
<th># of Total Errors Committed</th>
<th>% of Communications</th>
<th>Error Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispatchers</td>
<td>13</td>
<td>100%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Railroad Worker</td>
<td>9</td>
<td>70%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Train Crew</td>
<td>1</td>
<td>8%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

Table 3-4: Error Rate by Class of Worker
The table above 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. Errors for railroad workers are 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% error rate across the board for all three parties.

Errors involving number transpositions were the largest category of errors accounting for almost 40% of the errors committed (see Table 3 for a frequency distribution of type of error). 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% of these errors.

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

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

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.
<table>
<thead>
<tr>
<th>Type</th>
<th># of Errors</th>
<th>% of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Transpositions</td>
<td>9</td>
<td>39%</td>
</tr>
<tr>
<td>Incorrect Information/Identification</td>
<td>6</td>
<td>26%</td>
</tr>
<tr>
<td>Incorrect Time of Day</td>
<td>3</td>
<td>13%</td>
</tr>
<tr>
<td>Memory Lapse</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td>Phraseology</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td>Directional Error</td>
<td>1</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>23</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Table 3-5: Percentage of Errors Committed

Four percent of the transmissions resulted in a breakdown in communication due to equipment-related failures. While this is not directly a human factors issue, it does speak to the issue of workload. If a transmission has to be repeated, or one or more parties have to switch to a different form of communicating (e.g., switching from radio to cell phone), workload increases. It is important to understand whether this happens often and interferes with not only communications but also with carrying out other important work-related tasks.

### 3.2 DATA LINK COMMUNICATIONS

#### 3.2.1 SUMMARY OF DATA

Each day the field test crew (consisting of roadway workers) filled out around ten form Ds. The times the dispatcher took to fill out the forms and to assign time effective were documented, and daily charts were plotted. Charts were created using
the daily average times, one including waiting time and one excluding that component. The charts also show the total time required to issue one form D.

Figure 10 thus shows all the data that has been gathered during testing. During the testing, the field test crew acted as the shadow of the crew in charge: the forms were not completed via data-link unless the conventional forms were effective and the tracks were cleared. This chart represents all the outliers where the field test crew had to wait for the crew in charge to complete their duties. In contrast, Figure 11 reflects the data without the delays. The second chart shows some oscillations, but when the scale is taken into account, the data change in the range of 10 sec. The increase in time corresponding to day 10 can be explained by a one-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.
One of the main issues with the smartphone was the visibility of the Liquid Crystal Display (LCD) screen in sunlight. According to the standards\(^2\), 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\(^3\) must be maintained at \(5:1\) or higher.

Although a display with less than 500 nits\(^4\) 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

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\(^2\) [http://www.littlepc.com/faq_lcd_technology.htm#outdoorreadable](http://www.littlepc.com/faq_lcd_technology.htm#outdoorreadable)

\(^3\) 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.

\(^4\) A NIT is a measurement of light in candelas per meter square (Cd/m\(^2\)). 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.
readable display is normally considered to be an LCD with at least 1000 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 major advantage of the new system is the decline in the number of errors. With the new device, as the cancellation of Form D’s are automated, the human error factor for this particular use is totally eliminated. Once the foreman finishes the job, he/she cancels the work permit without communicating the dispatcher. The dispatcher then sees the form on the “cancelled” window, acknowledging the termination of the work permit.

Most of the data obtained in the experiment are 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. 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 under daylight or at night.

- The form D number is generated by the system: the number must be assigned by the dispatcher according to a procedure. This number does not only serve to itemize the form D’s 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 as 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.
- When the dispatcher rejects an erroneous 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 work on the same form D format in order to be able 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 D’s 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 while a fulfilled form D indicates a completed work.
- The system does not allow additions to an existing form D. The classical format permits up to three additions to an existing form D.

The errors that occurred using the data link system were:

- Connection quality
- User ability to navigate within the menu
- Tapping on the wrong parts of the screen (resulting in selecting wrong mileposts from the dropdown menus)

The overall feedback on the experiment was that the dispatcher and the roadway workers liked to use the device. They expressed their interest in
implementing the system in the railroad applications once the updates are 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 engineer. The scorings that they provided are shown in table 7. 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>
<thead>
<tr>
<th>TASK</th>
<th>DISPATCHER</th>
<th>TRACK ENGINEER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental demand</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Physical demand</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Temporal demand</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>Effort</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Performance</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>Frustration</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Overall</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 3-6: NASA-TLX Scale Rating Results.

One major feature that was required by the superintendent 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 in case of smartphone stops working during duty. One of the main reasons for this request is the education level of the potential users. If implemented, the device will be used by roadway workers whose exposure to computer use has been limited. Most of the users are computer illiterate or have very limited ability to use devices like palm pilots, smartphones, laptops. Once they have a problem with the device, it is really hard for them to come up with different ways to access the main menu. In case they end up using a function that they are not familiar 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 versus DATA LINK SYSTEM

The data using the radio technology shows that form D’s are the most time consuming type of communication between the dispatcher and the crew on the tracks. On average, a dispatcher takes 3min. 13sec. to complete one form D. This study shows that data link technology can decrease this time significantly. Using a smartphone this completion time is reduced to 1min. 05sec. This result is different than Masquelier’s and Oriol’s 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 in real-time, showed that the work permission processes were more accurate and faster with the hand held device.

The study also shows that the new system, in providing the visual aid to users, is prone to alphanumeric transpositions. With the current technique, the dispatcher and the foreman check the information on a readback/hearback basis. 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 work on the same file which makes it easier to catch mistakes since both sides are checking the same document. In other words, the form is verified by both parties.

As it can be seen from the error lists for both systems, the errors that occurred with the data link system are mainly related to the poor design of the device. Meanwhile the errors that occurred with the conventional system are mainly related to the user confusion. If the device is redesigned according to the feedback of the railroad workers and the wireless signal coverage area is amplified, most of the errors would be eliminated in time.

The new system eliminates all errors due to poor radio communications. As shown above, with the current system, most of the errors occurred because of inaudible radio transmissions. By eliminating the voice communication the
smartphone system relied on the transmission of the data with the HyperText Transfer Protocol (HTTP) procedure. It also reduces human errors such as alphanumeric transpositions. The new type of errors that are introduced with the device are linked to the usability issues such as tapping on the wrong part of the screen or having navigation difficulties with the software. These errors would reduce with time when the user gets more and more accustomed to the device.

The dispatcher participating in the study stated that the new system considerably reduced the noise in the work environment (since the files were filled out digitally without any voice transmission). The radio was used for other types of conversations and emergency calls. The 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 and believed in the device’s potential.

Another important feature of the smartphone is 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, hence decreasing the dispatcher’s workload. The smartphone’s browser can be programmed to access only certain webpages in order to eliminate the possibility of surfing the internet during working hours.

Although it has not been tested in this study as there was only one user, the SMS feature of the smartphone gives the roadway workers the possibility to communicate directly. This aspect of the system provides a more confidential medium for communications between roadway workers, eliminates the party line effect of the radio communications, and thus potentially reduces the fatalities caused by misuse of the party line.
4 REGULATORY CHALLENGES

Implementing a new device to railroad operations requires conforming to the regulations of the Federal Railroad Administration (FRA) and Federal Communications Commission (FCC). FRA, an operating unit within the U.S. Department of Transportation, is the safety regulatory authority for the nation's freight, intercity passenger, and commuter railroads. Its regulations cover railroad operating practices, equipment, track, and train control. The current regulations describe how to initiate and end a radio communication. With the new system, these regulations will be modified in a way that describes how to use the hand held device appropriately. On the other hand, the FCC is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite and cable. The Wireless Telecommunication Bureau of FCC oversees cellular phones and smartphones, pagers and two-way radios. This Bureau also regulates the use of radio spectrum to fulfill the communications needs of businesses, local and state governments, public safety service providers, aircraft and ship operators, and individuals. The FCC is responsible of assigning spectrum blocks to geographic areas. Once the assignment is done, the operator should fully comply with the FCC regulations.

Radio communications for transportation, particularly railroads, is heavily regulated. Railroads face the same technology issues and spectrum-efficiency problems as the rest of wireless users, but their problems are more complex. Although most of the railroads are operated by private companies, their activities in providing public transportation make them subject to detailed industry standards and closer federal inspection. Complying with both regulations sometimes can be hard on the companies: according to the FCC regulations users should not exceed pre-described frequency limits, and the dead areas are the user’s problems. According to the FRA
According to the Code of Federal Regulations, FRA 49 C.F.R. Part 220, a working radio is defined as follows:

“A radio that can communicate with the control center of the railroad (through repeater stations, if necessary to reach the center) from any location within the rail system, except: (1) Tunnels or other localized places of extreme topography, and (2) Temporary lapses of coverage due to atmospheric or topographic conditions.”

In 1998, definition of a working wireless communication was added to the statute. According to FRA 49 C.F.R. Part 220, a working wireless communication is the capability to communicate with either a control center or the emergency responder of a railroad through such means as radio, portable radio, cellular telephone, or other means of two-way communication, from any location within the rail system with the same exceptions as the working radio definition.

Current regulations describe in detail how the messages should be conveyed through the radio. The code indicates that “if necessary for clarity, a phonetic alphabet shall be used to pronounce any letter used as an initial, except initial letters of railroads. A word which needs to be spelled for clarity, such as a station name, shall first be pronounced, and then spelled. If necessary, the word shall be spelled again, using a phonetic alphabet.” With the data link technology, these detailed descriptions will not be necessary. As the FRA already has its regulations for the Form D format, using the approved format for the new system will facilitate the regulations for the information transfer.

With the data link technology, as the data messages can be displayed by LCD, VDT or other means, the crew doesn't have to memorize the message, and the information can be saved on the train's onboard computer. This would eliminate the current FRA requirement to make a hard copy of all radio orders. (The hardcopy feature is also recommended by the superintendent at Cobble Hill)
This study concurs with the following regulation “All passenger trains, regardless of the size of the railroad, have to be equipped with a working radio in the occupied controlling locomotive and with redundant working wireless communications equipment.” If the data link system is implemented in the railroad operations, the radio should be kept in the vehicle until the system is fully tested and all the imperfections are corrected.
5 CONCLUSIONS AND FUTURE RESEARCH

The data link system proved to be useful and efficient in certain aspects of railroad applications. The new system was faster and more effective than the radio communication when used to convey long messages such as filling out Form Ds. The radio communication was faster than the datalink for confirmation communications that only require yes/no answers. One reason for this difference appears to be the users’ unfamiliarity with the device. The time to convey short messages could also be reduced after the users become more proficient with the new system.

The users expressed many concerns about smartphones. Most of these concerns were related to the design of the device. Users thought that the commercial smartphones are too small and delicate to be used in railroad operations. They expressed preference for a device that would withstand being dropped and being in a dusty environment. Another major issue was the resolution of the screen: ideally the screen should be modified so that it is visible under direct sunlight. Other concerns were related to the unfamiliarity of the users with the PDA technology generally. 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 of the incoming calls such as schedule updates and weather inquiries. The smartphone would receive updated data from the dispatcher center, so the train schedule would be updated as soon as any change is entered to the system server 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 data link system, the dispatcher could send the same amount of information currently contained in multiple messages with only one message.
Although it has many advantages over the radio communication, the new technology is not intended to replace the radio. The radio should always be in the MOW vehicles to be used in case of emergency. As mentioned above, the smartphone can sometimes lose connection, which would interrupt critical information transmission.

5.1 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, a feature which was not welcomed by the railroad operators who contributed to this study.

5.2 USE OF HANDHELD DEVICE PRINTERS

This feature 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.
5.3 CUSTOM MODIFICATIONS

The smartphone used on this study mostly proved to be an efficient device for railroad operations. The messages conveyed using the data link technology were easier to understand since they were free of congestion. However an important problem 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.

Technology is changing rapidly and it is a challenge to keep up with. 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. New, updated developments need to replace outdated ones. In the future, as this industry grows, there will be more opportunities for better devices and better communications. As the wireless industry grows, the coverage area expands. A future study might compare the radio coverage area to the wireless one. Even if nowadays the radio coverage is more elaborate than the wireless, with the evolution of the technology, the wireless technology is expected to cover more and more territory each day.
**APPENDIX A. NORAC MOVEMENT PERMIT FORM D**

**NORAC MOVEMENT PERMIT FORM D**

<table>
<thead>
<tr>
<th>FORM D NO.</th>
<th>DATE</th>
<th>TO</th>
<th>DELIVERED TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A307</td>
<td>05/03/2001</td>
<td>Fm Bly TCT 22568 at Winchester</td>
<td>Winchester</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LINE</th>
<th>TRACKS</th>
<th>BETWEEN</th>
<th>SPEED</th>
<th>SIGNS</th>
<th>DISPLAYED</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>OPERATE IN</td>
<td>North</td>
<td>DIRECTION ON</td>
<td>No. 1</td>
<td>TRACK BETWEEN</td>
<td>Winchester</td>
<td>AND</td>
</tr>
<tr>
<td></td>
<td>ON</td>
<td>BETWEEN</td>
<td>AND</td>
<td>AND</td>
<td>AND</td>
<td>DISPACHTER</td>
<td>TIME</td>
</tr>
</tbody>
</table>

| 3 | TRAINS OR TRACK CARS AHEAD | None |
|   | TC PROCEED PAST STOP SIGNAL(S) AT | None |

| 4 | TRACK OUT OF SERVICE BETWEEN/AT | None |
|   | TRACK OUT OF SERVICE BETWEEN/AT | None |

| 5 | LINE | TRACK OBSTRUCTED FOR MAINTENANCE BETWEEN | AND | | | | |
|   | IN CHARGE OF | | | | | | |

| 6 | NON-SIGNALLED DCS RULES IN EFFECT ON | TRACK(S) BETWEEN | AND | | | | |
|   | RULES IN EFFECT ON | TRACK(S) AT | TRACK UNTIL | ENGINE ARRIVES TO ASSIST | WHERE TRAIN IS DISABLE |

| 7 | INT AND CP SIGNALS OUT OF SERVICE ON | TRACK(S) BETWEEN | AND | | | | |
|   | REMAIN AT | TRACK TO | TRACK UNTIL | ENGINE ARRIVES TO ASSIST | WHERE TRAIN IS DISABLE |

| 8 | OPERATE ON RESTRICTED SPEED ON | TRACK TO | TRACK UNTIL | ENGINE ARRIVES TO ASSIST | WHERE TRAIN IS DISABLE |
|   | TBS IN SERVICE AT | TRACK TO | TRACK UNTIL | ENGINE ARRIVES TO ASSIST | WHERE TRAIN IS DISABLE |

| 9 | IN CHARGE OF | TRACK UNTIL | ENGINE ARRIVES TO ASSIST | WHERE TRAIN IS DISABLE |

| 10 | CSS RULES OUT OF SERVICE ON TRACK(S) BETWEEN | AND | | | | | |
| 11 | PROTECT CROSSING(S) | | | | | | |
| 12 | OTHER INSTRUCTIONS/INFORMATION | | | | | | |
| 13 | TRAIN DISPATCHER | Coughian | TIME EFFECTIVE | 11:50AM | | | |

**BLOCKING DEVICE APPLICATION AND REMOVAL RECORD**
APPENDIX B. SMARTPHONE SCREENSHOTS

1. **Main Menu**

   - Train and territory information
   - Train status

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

2. **Request Line 4**

   **Form D Line 4 Request**
   - Work site between/at
     - 00.0 Boston
   - Start Time: 
   - Duration: 10 min

   Send request

   Main Menu
3. **Request Foul Time**

**Foul Time Request**

- **Track #:**
- **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

Track #: 1
Direction: East

Send request  Main Menu
1. **Form D Request**

<table>
<thead>
<tr>
<th>Requested Form Ds</th>
<th>Active</th>
<th>Requested Foul Time</th>
<th>Rejected/Cancelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith, Fm Revere, Trk 1</td>
<td></td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

**Form D 0001 is Requested**

Foreman Smith would like to work in 1 track at/between Fm and Revere
Desired starting time: 2:00p
Expected duration of work: 1 hour

<table>
<thead>
<tr>
<th>Form D #</th>
<th>0001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivered to:</td>
<td>Smith</td>
</tr>
<tr>
<td>Date:</td>
<td>04 09 2004</td>
</tr>
</tbody>
</table>
| Line 4: | track out of service between/at
| | and
| | 00:0 Boston

Train: NorthEastCorridor
Dispatcher:

Please select 'Confirm' to grant permission to work or 'Deny' to disregard this form D request and then press 'Send Response'

- Confirm
- Deny Reason: 

Send Response
2. **Time Effective Request**

<table>
<thead>
<tr>
<th>Requested Form Ds</th>
<th>Requested Fuel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**Form D 0001 is Without Time Effective**

Foreman Smith accepts this Form D and is waiting for a time effective. The requested initial time was 2:00p and the work will last around 1 hour.

<table>
<thead>
<tr>
<th>Form D #</th>
<th>0001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivered to</td>
<td>Smith</td>
</tr>
<tr>
<td>Date</td>
<td>04/09/2004</td>
</tr>
<tr>
<td>Line 4</td>
<td>1 track out of service between/Fx and Revere in charge of Smith</td>
</tr>
<tr>
<td>Train</td>
<td>NorthEastCorridor</td>
</tr>
<tr>
<td>Dispatcher</td>
<td></td>
</tr>
<tr>
<td>Time Effective</td>
<td>2:45p</td>
</tr>
</tbody>
</table>

Assign Time Effective
3. **Active From D**

Form D 0001 is Effective

- **Form D**: 0001
- **Cancel time-date**: 04/09/2004
- **Delivered to**: Smith
- **Date**: 04/09/2004
- **Line 4**: 1 track out of service between Boston and Chelsea in charge of Smith
- **Train Dispatcher**: NorthEastCorridor
- **Time Effective**: 2:40p

[Web page snapshot showing details of active form D 0001]
### Cancelled From D

#### Form D 0003 is Cancelled

<table>
<thead>
<tr>
<th>Form D #</th>
<th>0003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancelled Date</td>
<td>Fri, 1:03p - 07/02/2004 - NorthEastCorridor</td>
</tr>
<tr>
<td>Delivered to</td>
<td>Smith</td>
</tr>
<tr>
<td>Date</td>
<td>07/02/2004</td>
</tr>
<tr>
<td>Line 2</td>
<td>Operate in East direction on Single track between Cp - Wilson and Cp - Loop</td>
</tr>
<tr>
<td>Line 3</td>
<td>Trains or track cars ahead none TC proceed past stop signal(s) at -</td>
</tr>
<tr>
<td>Train Dispatch</td>
<td>NorthEastCorridor</td>
</tr>
<tr>
<td>Time Effective</td>
<td>12:20p</td>
</tr>
<tr>
<td>Message</td>
<td>-</td>
</tr>
<tr>
<td>Speed Restriction</td>
<td>-</td>
</tr>
<tr>
<td>Job Status</td>
<td>-</td>
</tr>
<tr>
<td>Signs Removed</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cancelled Form Ds</th>
<th>Requested</th>
<th>Active</th>
<th>Cancelled/Cancelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith, Cp - Wilson, Cp - Loop, Tk Sglk</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Smith, Manchester-Cp - Wilson, Tk 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Smith, Beverly Irt-Cp - Wilson, Tk 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rejected Form Ds</th>
<th>Requested</th>
<th>Active</th>
<th>Rejected/Cancelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
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.)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>

PHYSICAL DEMAND (physical exertion/activity)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>

TEMPORAL DEMAND (time pressure)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>

EFFORT (how hard you worked)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>

PERFORMANCE (success in accomplishing the task)

<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
</table>

FRUSTRATION (irritation, discouraged)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>

OVERALL (your impression of overall workload the task entailed)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
</table>
# Rating Scale Definitions

<table>
<thead>
<tr>
<th>Title</th>
<th>Endpoints</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>Low/High</td>
<td>How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>Low/High</td>
<td>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?</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>Low/High</td>
<td>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?</td>
</tr>
<tr>
<td>Effort</td>
<td>Low/High</td>
<td>How hard did you have to work (mentally and physically) to accomplish your level of performance?</td>
</tr>
<tr>
<td>Performance</td>
<td>Good/Poor</td>
<td>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?</td>
</tr>
<tr>
<td>Frustration Level</td>
<td>Low/High</td>
<td>How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?</td>
</tr>
</tbody>
</table>
**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…]

<table>
<thead>
<tr>
<th>Type of Interaction</th>
<th>Number of times per week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Very unfamiliar</th>
<th>Unfamiliar</th>
<th>Somewhat familiar</th>
<th>Familiar</th>
<th>Very familiar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beeper / Pager</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell Phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palm Pilot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
USABILITY QUESTIONNAIRE

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

<table>
<thead>
<tr>
<th></th>
<th>Very ideal</th>
<th>Ideal</th>
<th>Needs some improvement</th>
<th>Change completely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Font size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Font style (bold, underline...)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 D’s? 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 signalled. 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 four feet 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 signals 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.

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.

---

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

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

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

**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.

---

6 Roth, E.M. and Malsch, N.1999
REFERENCES


U.S. Code of Federal Regulations Title 49, Volume 4, Parts 200 to 399


Web pages:


