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13. ABSTRACT (Maximum 200 words) This report describes the development and evaluation of a prototype real-time moving map display to support engineer situation awareness and safety performance for future U.S. high-speed rail applications. The development started with a hybrid Cognitive Task Analysis to develop Information and Functional Requirements for the display. Using basic design principles, the initial layout for an iPad-based display was created. The design was evaluated by 10 experienced engineers in a formal cognitive walk-through. After a brief training session, they answered questions about the display and performed typical actions such as entering track warrant information. Subjects completed most of these tasks successfully and provided feedback which was used to improve the display. The revised iPad display was then evaluated in a human-in-the-loop experiment. Eight experienced commuter rail engineers drove twice a 38-mile trip both with and without the display. The engineers demonstrated similar train handling performance and rule adherence in both operating conditions. They generally took 30 to 60 seconds more to enter track warrant information compared to using paper forms. Finally, the engineers thought that a similar display would be helpful for conductors and could replace paper rule books.				
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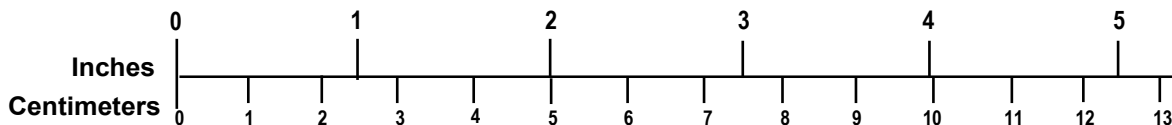
ENGLISH TO METRIC

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)
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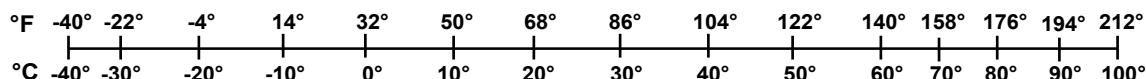
METRIC TO ENGLISH

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)
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QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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

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Executive Summary

This report describes the development and evaluation of a prototype real-time moving map display, by MIT researchers, sponsored by the FRA from September 2013 to January 2014, that would support situation awareness (SA) and safety performance of locomotive engineers for future U.S. high-speed rail applications. During the cognitive walk-through with the initial prototype, engineers were able to interact with the display and identify information correctly with only minimal training. Based on their feedback from the cognitive walk-through, the display was improved then tested in a human-in-the-loop simulation with another set of experienced locomotive engineers. The engineers drove equally safely in the two test conditions (i.e., with or without the moving map display) although they found the ability to add notes and traffic directives to the display to be very helpful. These would be especially helpful when driving on a relatively new route or one that had not been recently driven. Subjectively, the display reduced the workload of maintaining SA when compared to driving with paperwork since relevant operating information was in one location. Train handling performance was also similar between the two conditions. Data entry for en route slow orders took 30 to 60 seconds longer than using the paper forms.

The development process took a human-systems engineering approach, starting with a hybrid Cognitive Task Analysis (hCTA) of the Departure, Preparation and en route phases of the driving task. From the results of the hCTA, researchers generated a principled set of Information and Functional Requirements for the moving map display. These requirements were implemented in an initial layout using basic design principles. Once the iPad display was created, a formal cognitive walk-through was conducted using 10 experienced locomotive engineers recruited from the Massachusetts Bay Commuter Railroad (MBCR).

After a brief introduction to the main functions of the display, each subject was provided an iPad with the display and asked to answer questions and perform actions using the display. Typical actions included identifying information from the display such as current speed or track features, or entering track warrant information and verifying their entry. For seven of eight identification tasks, at least seven subjects correctly identified the requested information. Seven subjects were able to correctly enter a track warrant (temporary speed restriction) and verify that it was placed in the proper location. The other three subjects correctly entered the information, but needed a reminder on how to verify the location by panning the display. Feedback was solicited after each task and through a post-experiment debrief and a usability survey.

Based on the subject feedback from the walk-through, the display was revised then evaluated in a human-in-the-loop experiment using the Federal Railroad Administration (FRA) Cab Technology Integration Laboratory (CTIL) located at the U.S. Department of Transportation's Volpe Transportation Research Center (Cambridge, MA). Eight experienced MBCR commuter rail engineers were trained on a 38-mile route with scheduled station stops by driving the route twice during the morning training session, first without and then once with the moving map display. In the afternoon, subjects returned to drive two different scenarios over the same section of track. Each scenario had a slightly different schedule and set of track warrants.

The hypothesis was that the engineers would demonstrate equal, if not better, train handling performance and rule adherence when using the moving map display, which consolidated information about the run and provided a preview of upcoming terrain. Researchers found

similarly low numbers of rules violations (e.g., overspeeding, observance of quiet zones) in both conditions. Train handling performance when maintaining speed or initiating stops was comparable between conditions. The moving map display should provide better position information on when to begin stopping the train, especially for unfamiliar territory, but the unfamiliarity with the train dynamics and territory might have negated this potential advantage. The engineers generally required an additional 30 to 60 seconds to enter track warrant information into the iPad in comparison to completing the paper booklet. Based on user feedback, the additional entry time was largely due to the unfamiliarity with the layout of information for the electronic track warrant.

All subjects found the Route and Speed views to be the most helpful since they consolidated important information, like speed restrictions, grade crossings and station stops, onto a single display. The Grade display was useful for train handling in the simulation due to the engineers' unfamiliarity with the terrain while Curvature was deemed unnecessary. The note creation capability was very helpful, although the engineers had several suggestions on how to improve interaction. The subjects thought that a similar display for conductors would be helpful to support conductors' SA and communications with engineers.

1. Introduction

Locomotive cab design, a critical part of any rail system upgrade, is an identified area of improvement for the U.S. rail industry evidenced by various advisory groups and conferences on the future design of locomotive cabs. In such meetings, representatives of Class I railroads, original equipment manufacturers, Association of American Railroads and the Federal Railroad Administration (FRA) agree that a systematic approach is necessary for cab design, especially in an environment where technologies such as Positive Train Control (PTC) and energy management systems are being or will be incorporated into locomotives. Moving map displays, a representative futuristic cab technology for U.S. rail, are a case study that highlights the growing trend of incorporating new technologies in train management systems. This report explores both the design and development of this technology.

1.1 Background

This research was submitted to the Federal Railroad Administration (BAA-2010-1) for Research and Demonstration Projects Supporting the Development of High Speed and Intercity Passenger Rail Service. The overall objective of the project was to develop a real-time scheduling decision support display (moving-map) for high speed rail applications in the United States. The two-year effort took a human-systems engineering approach which included principled requirements generation, and display design to meet those requirements.

1.1.1 Rail Industry

The job of a locomotive engineer is becoming increasingly more complex as speeds are increased for high-speed rail corridors (Lowe and Tokuoka, 2010). Demand for freight services is expected to increase by 22 percent of its demand in 2010 by 2035 (U.S. Department of Transportation, 2013) and there are pressures for increased productivity and safety while minimizing environmental impact (Martins and Morgado, 2010) while also increasing levels of automation. Cab technologies are emerging to adapt to these changing conditions and to comply with regulations such as the mandate for Positive Train Control stated in the Rail Safety Improvement Act of 2008. For example, it was assessed that over 100 train collisions in the U.S. could have been avoided if “fully functioning” PTC systems were implemented, which explains why high-risk regions are first for PTC implementation (Bearman and Naweed, 2013).

As demands increase on the railroad and its locomotive engineers, technology solutions will be considered to meet these demands. Examples of technologies recently implemented in the U.S. include train management systems that can provide throttle and braking recommendations or automatic throttle and braking control. The progression of one such train management system can be seen with General Electric’s Trip Optimizer where capabilities were added over time. Auto throttle was released for production in 2008, advisement on throttle and dynamic braking was introduced in 2009, automatic dynamic braking was implemented in 2010, distributed power advisement was introduced in 2012, and automatic distributed power for selected modes was released in 2013 (Gitmez, 2013).

Sensor and detection technology enables higher levels of automation in rail; three levels of automation are identified for metro systems which include semi-automatic train operation (STO), driverless train operation (DTO), and unattended train operation (UTO) (Grogan, 2012). In STO, the locomotive engineer is in control of stopping the train, closing the doors, and

communicating with the passengers. In DTO, the locomotive is autonomously controlled but a train attendant is present to supervise. In UTO, there is no locomotive engineer or attendant. Cities that use DTO or UTO include Paris, Barcelona, Copenhagen, and London. Forty percent of “automated lines,” a mix of STO, DTO, and UTO, are in Asia.

1.1.2 Moving Maps

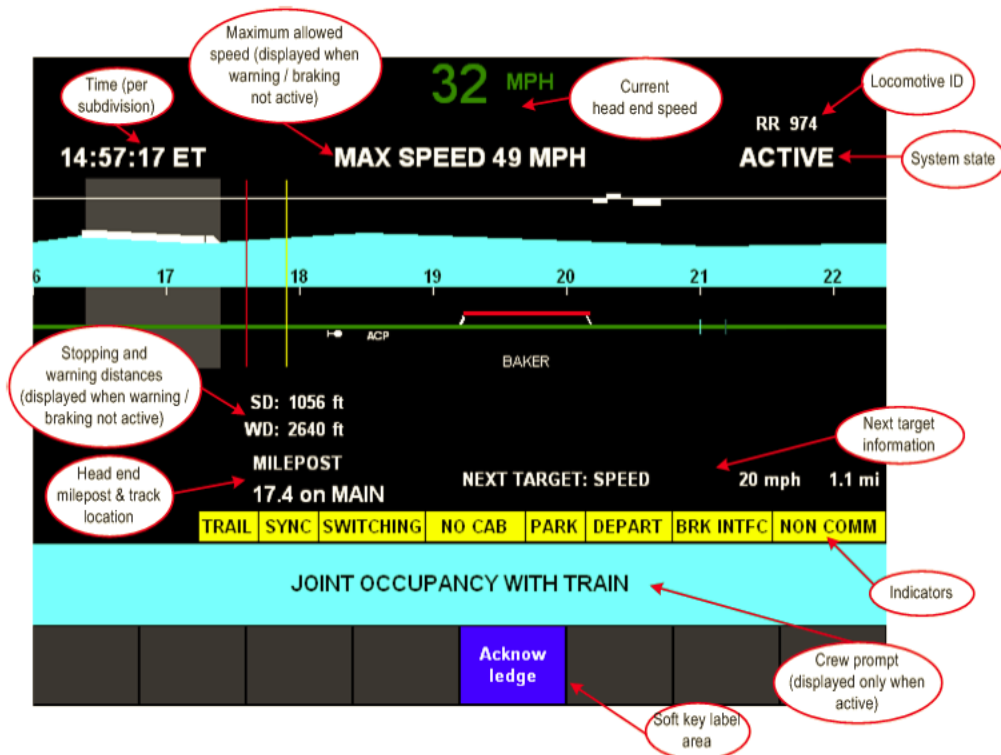


Figure 1. Annotated I-ETMS Display (Wabtec Railway Electronics, Union Pacific Railroad et al. 2011)

Moving maps and other preview displays are widely used in the commercial automotive industry and in airplane cockpits to provide graphical information about the surrounding environment to drivers and pilots, help with driving and flying functions, and improve situation awareness. Situation awareness (SA) is defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley and Jones, 2012).

Why is situation awareness a concern? Locomotive engineers are expected to memorize many details, both static and changing, regarding their routes in addition to considering variable external factors, such as weather, and internal factors, such as train weight and length. Concurrently, they must maintain awareness of other trains, track obstructions and the health of the equipment while operating between two points. To make matters more difficult, much of this information is dispersed across different mediums: rulebooks, track charts, track bulletins, track warrants issued via radio, multiple in-cab displays, etc. This dispersion of information sources draws the attention of the locomotive engineer away from outside the cab, resulting in decreased SA and potentially decreased safety performance. A single display that provides locomotive

engineers with a centralized source of the required information, currently scattered across various paper forms and displays, could improve situation awareness by providing the relevant information quickly and allowing the locomotive engineer to spend more of his or her time and attention looking outside the cab.



Figure 2. Transrail CATO Driver Machine Interface (Transrail Sweden AB, 2015)

Moving map displays have been considered for locomotive engineers as early as the 1970's, albeit for training or simulators (Wharton, 1994). Moving maps were used in early train simulators as the primary visual aid to the operator's location prior to the availability of modern graphics. Train management systems such as Wabtec's I-ETMS, New York Air Brake's (NYAB) LEADER, and GE's Trip Optimizer are new systems that have been implemented in a subset of freight locomotives which include a moving map as a part of their en route displays (see Figure 1 for a screen shot of I-ETMS). Approximately 6,000 of 8,391 Union Pacific locomotives and 800 of 4,178 CSX locomotives were at least partially implemented with I-ETMS in 2012, while other railroads such as BNSF and Norfolk Southern were in the process of testing I-ETMS for implementation (CSX Corporation, 2012; Union Pacific Corporation, 2012; Railway Gazette International, 2013). In 2013, roughly 1,500 of 4,074 Norfolk Southern locomotives were equipped with NYAB's LEADER (Norfolk Southern Corporation, 2012; Business Wire, 2013).

Currently moving maps for U.S. rail applications, also known as rolling maps or track profile displays, are not common in U.S. locomotives but are gaining use as a part of train management systems such as those mentioned above (Melnik and Rosenhand, 2011). A Swedish company, Transrail, has developed and deployed a "driver assistant system" called CATO whose driver-machine interface has a moving map component that provides "relevant and dynamic information about surrounding traffic and lines" (Figure 2) (Transrail Sweden AB).

While there have been studies on the effectiveness or the distraction of automobile moving maps as early as 1989 (Dingus and Antin, 1989; Antin and Dingus, 1990), similar human-in-the-loop studies have not been conducted for moving maps in locomotives. In 2005, Einhorn, Sheridan and Multer conducted a simulator-based human-in-the-loop study using a display to provide preview information to test subjects, both locomotive engineers and students, and found that subjects using the preview display had fewer speed violations, better signal adherence, less time between passing a signal indicating speed should be reduced and initiating braking, and worse station-stopping accuracy due to the insufficient resolution in the display.

1.2 Objectives

The overall objective of this project was to develop a prototype real-time moving map display that would support situation awareness and safety performance of locomotive engineers for future U.S. high-speed rail applications. A human-systems engineering approach was employed to generate principled information requirements that were implemented in the display. The implemented display was initially evaluated using a cognitive walk-through procedure before being evaluated by human-in-the-loop testing to assess human performance and possible safety issues. This report briefly describes the methodology used to develop the information requirements, outlines the resulting interface design, and presents the results of the cognitive walk-through and the human-in-the-loop evaluation tests. It concludes with a discussion of moving map implementation in future locomotives and the potential impact on future railroad operations.

1.3 Scope

The scope of this report is U.S. rail, both freight and passenger, with a focus on in-cab moving map displays for locomotive engineers. The moving map is intended to be a secondary display that provide a central location for critical information for the engineer to conduct the trip safely, while also providing additional capabilities for the engineer to annotate the display and further improve situation awareness. Since the evaluation of the display was performed only in a simulator, additional issues related to the operating environment such as readability due to locomotive vibration or ambient lighting cannot be addressed here.

1.4 Organization of the Report

Section 2 of this report describes the process used to design the moving map display, before going into a more detailed description of the elements and features of the display. Section 3 describes the two methods used to evaluate the display. Specifically, Section 3.1 describes the methods and results of the cognitive walk-through, while Section 3.2 describes the methods and results of the subsequent human-in-the-loop testing. Section 4 explains the conclusions drawn from the display evaluation, and also provides recommendations for future work and implementation.

2. Design of the Moving Map Display

The design process began with informal interviews and a hybrid Cognitive Task Analysis (hCTA) to systematically understand and document the processes and information required by the engineer to perform specific tasks. For each task, event flow diagrams were created that visually conveyed dependencies, order of events, decisions and processes. Decision ladders illustrate the decision-making process for each complex decision in the event flow diagram and are used to understand the information that is required to make these decisions. Situation awareness requirements are also derived from the event flow diagrams, but convey the information that contributes to three levels of situation awareness: perception, comprehension and projection (Rasmussen, 1983). The output of the hCTA was a set of Information and Functional Requirements that are necessary to perform the operational function that is analyzed. A complete description of the hCTA and the generation of the event flow diagrams, decision ladders, and situation awareness requirements can be found in Voelbel (2014).

2.1 Design Process

After reviewing the Information and Functional Requirements produced from the hCTA, it was determined that the requirements were heavily dependent upon the current location and upcoming information. A moving map was determined to be the best platform on which to display the necessary information: the graphical nature of the moving map allows for many track and terrain features to be intuitively displayed and it provides context-specific information that should enhance the locomotive engineer situation awareness. The interactive component of the moving map was introduced to permit changes to the normal route or reminders for the engineer. Route information includes requirements specifying train route with current location, next waypoint with scheduled arrival time, and trackside equipment indicators. Speed information requirements include temporary speed restrictions and the location of maintenance of way operations.

Some additional design features emerged from the discussions with subject matter experts that are directly related to the Information and Functional Requirements. For example, when rail experts noted that they would like to be able to review the entire route to refresh their memory before departure or even at station stops, the ability to pan across the entire route was added using a swipe gesture with the hand across the map portion of the display. When locomotive engineers mentioned that at times they need to see more detail, at switching yards for instance, or less detail, for stretches of track without many points of interests, the ability to zoom in and out on the map was added using a pinching and stretching gesture common to modern tablets. Notes or annotations to the map could be added by tapping a location on the display to bring up a template to populate. These notes could include track warrant information or reminders about upcoming track events like speed restrictions, quiet zones and work areas. This feature adds helpful location context for the types of notes engineers might typically write down on a piece of paper

2.2 Initial Prototype

An initial working prototype of the display was developed in Objective C and demonstrated on an iPad. (Figure 3) The main features of the display include:

- Visual display of upcoming track, adjacent track, speed, grade and curvature

- Ability to pan across the entire route
- Ability to zoom in or out for more or less detail
- Ability to add notes or annotations including track warrants and free-form notes

A brief description of the main sections of the display is provided below. Further details about the display are provided in Chapter 4 of Voelbel (2014).

The Route section near the top of the display contains the majority of the information requirements since it depicts track features that aid the locomotive engineer's determination of their location. In Figure 3, the intended route of travel is denoted by the bold line while the thinner horizontal lines depict parallel tracks or sidings. The black train icon represents the locomotive that is in operation and is drawn to scale so that the front and rear of the train is accurately depicted. The rear of the train is important because most operating rules apply until the end of the train has cleared a certain point. Additionally, if a train is required to enter a siding to allow the passage of other trains on the main track, it is vital to ensure that the rear of the train and thus the entire train is in the siding.

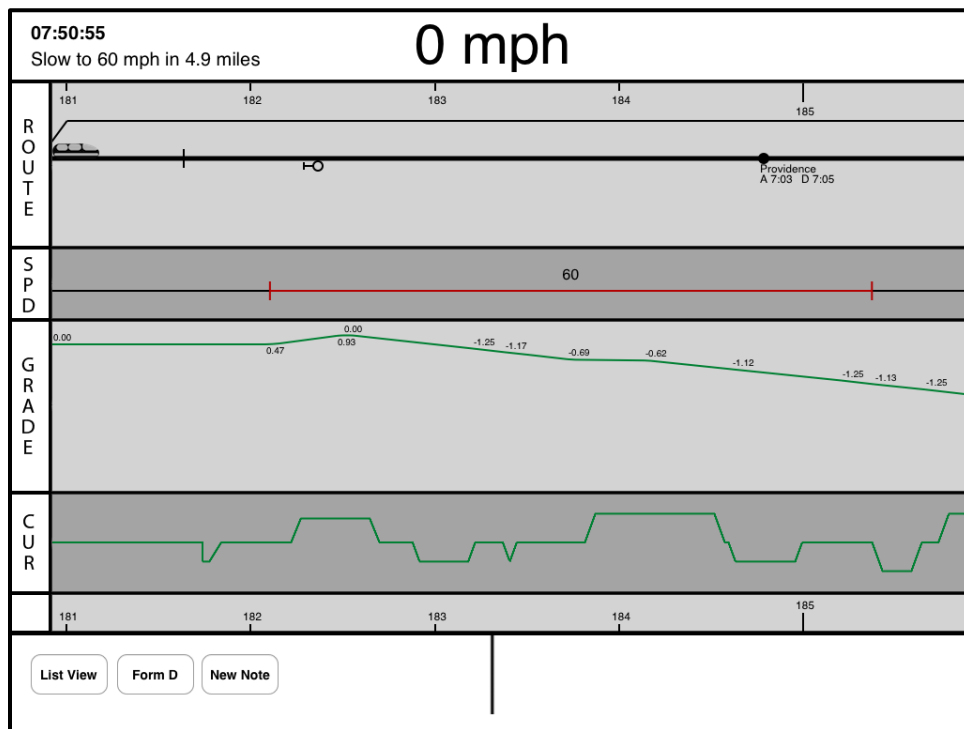


Figure 3. Format of the moving map display for the cognitive walk-through

Mileposts are numbered alongside train tracks but are not always visible at night or under certain weather conditions so they are displayed in the Route section for reference. Mileposts provide location information to the locomotive engineers during normal operations and also to communicate their location during an emergency or to report the location of failed equipment or other relevant information. Signal symbols are also depicted alongside the track so that locomotive engineers know when to keep an eye out for approaching signals to remain in compliance with the rules for the next block of track. Lastly, names of important landmarks such

as stations are labeled along the track. In the case of stations, the arrival and departure times are also indicated if the station is a required stop for the route.

The Speed section of the display, abbreviated “SPD,” is directly below the Route section and shows the corresponding speed restrictions for the sections of track shown above it. Figure 3 shows a permanent speed restriction of 60 mph in red with the remaining areas of track indicating normal track speed. Permanent speed restrictions are emplaced for sections of the track that have longstanding requirements for slower speeds such as sharp curves or road crossings. Temporary speed restrictions are not long-standing and are used, for example, for tracks that require maintenance before normal speeds are allowed.

The Grade and the Curvature sections of the display, abbreviated “CUR,” are directly below the Speed section. Directly below the Curvature section is another set of milepost labels. Percent grade is the elevation divided by horizontal distance where a value of 1 is equal to 1% grade. Negative values indicate negative elevation or downward sloping grade and positive values indicate positive elevation or upward sloping grade. Curvature is depicted by relative turn radius as indicated by the distance from the center of the curvature section. When the curvature line is in the upper or lower segments of the curvature segment this indicates right or left turns, respectively.

Notes take two forms, Form D notes or free-form. Form D notes follow the template for the paper form that locomotive engineers or conductors fill out when receiving a track warrant over the radio from the dispatcher. Track warrant forms vary across territories so the format and even the title for these notes would need to conform to the standards and rules in the territory in which the display would be used. Figure 4 shows the contents of the hardcopy Northeast Operating Rules Advisory Committee (NORAC) Form D. When using the form, the dispatcher indicates by line number which section will be dictated before relaying the remainder of the information. Figure 5 shows the corresponding screen to this action; after users select the “Form D” button, a pop-up window appears with the same header fields and choices (1-13) given on the paper Form D.

FORM D ILLUSTRATION

NORAC MOVEMENT PERMIT FORM D

Form D No. _____

Form D No.(s) _____
Delivered To _____

Date ____ / ____ / ____

To _____

1. TEMPORARY SPEED RESTRICTIONS

LINE	TPK(S)	BETWEEN OR 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-signalized DCS rules in effect on _____ trk(s) between _____ and _____

7. Int and CP signals out of service on _____ trk(s) at _____

8. Remain at _____ on _____ trk until engine arrives to assist

9. Operate at Restricted Speed on _____ trk to _____ where train is disabled.

10. TBS in service at _____

11. CSS rules out of service on _____ trk(s) between _____ and _____

12. Protect crossing(s) _____

13. Other instructions/information _____

Dispatcher _____ Time Effective _____
 Form D Canceled, Time _____, Date ____ / ____ / ____, Dispatcher _____

Figure 4. Sample of the NORAC Movement Permit Form D

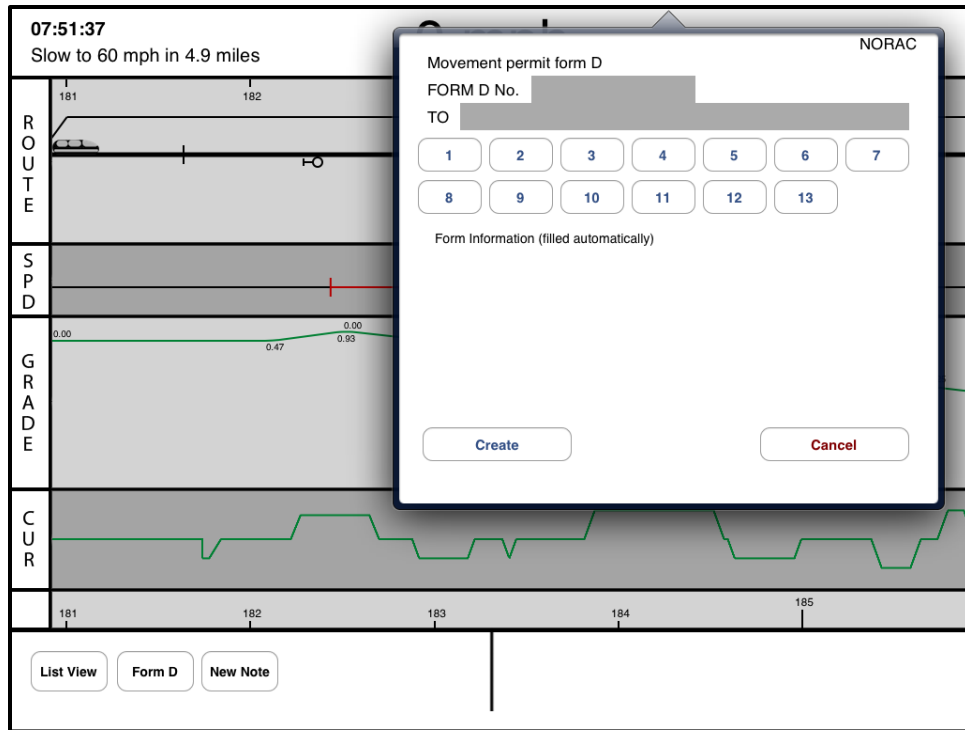


Figure 5. When the user selects the Form D button at the lower left of the display, this dialog box appears. The dispatcher will indicate which section number will be dictated and the user taps the corresponding button in the dialog.

Depending on the option selected, different pop-up windows appear requesting information specific to the selection. For example, for Line 1 - Temporary Speed Restrictions (Figure 6), users are prompted to enter the track number, starting, and ending mileposts, speeds for passenger and freight, and any additional information provided by the dispatcher. Once the information is input, it is consolidated into text that can be read back to the dispatcher for confirmation. At that point, the note is created and a symbol appears on the track in the location specified with the letter “D” in the middle of the symbol to indicate that it is a Form D note as opposed to a free-form note (Figure 7).

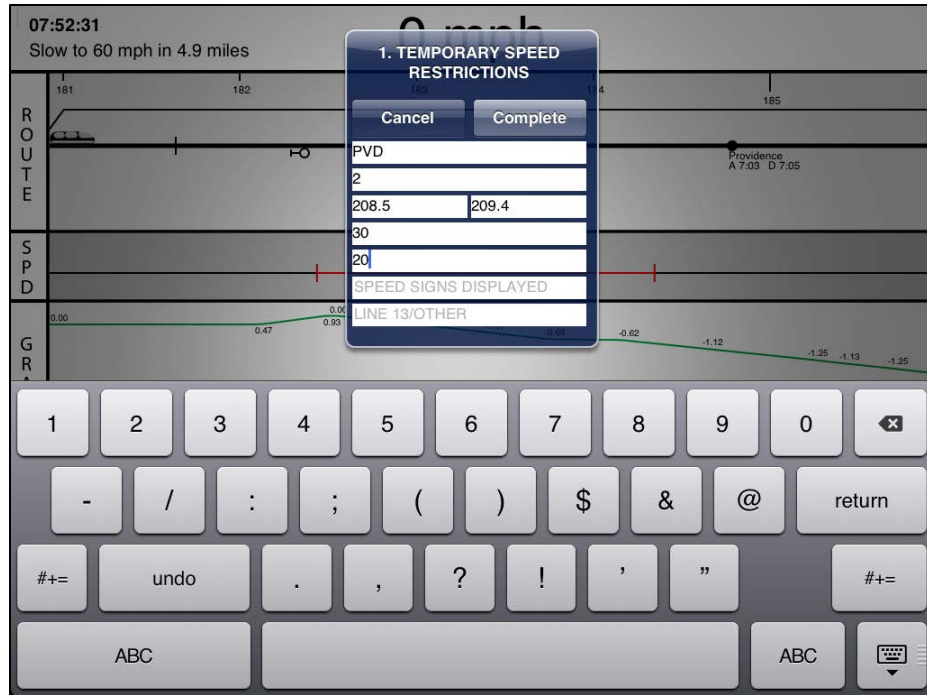


Figure 6. When the button for Line1 of the Form D information is entered, the following dialog appears so the user can enter relevant information for the directive

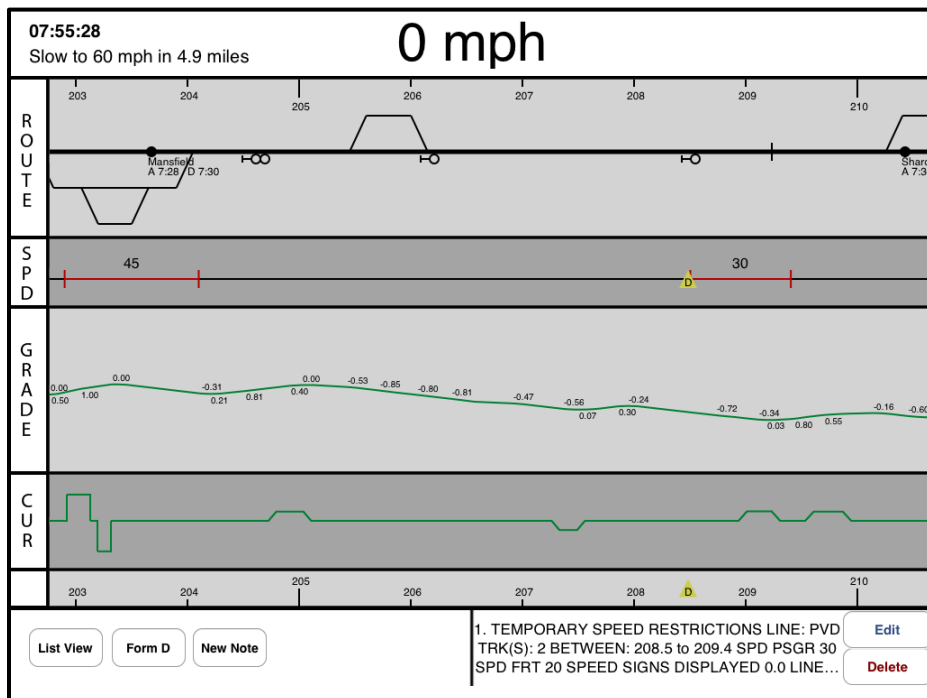


Figure 7. Once the Form D is selected, a yellow triangle icon with the letter “D” appears at the milepost location of the directive.

Free-form notes are customizable where the user can enter any text. There are also non-Form D templates that are available for speed restrictions or track workers. After the “New Note” button

is selected, a dialog box appears for creating a note (Figure 8, left) which allows the user to input his or her own text, choose a pre-defined template, and input the specific milepost location for the note (as indicated by the number “45.1”). If the user chooses a pre-defined template, then a dialog box appears with a list of options (Figure 8, right). If the user elects to enter his or her own text by clicking inside the box that says “Enter your text here”, then a keyboard for entry appears at the bottom of the display (Figure 9). Once the “Create” button is pressed, an icon for the note is placed at the designated milepost. Different icons indicate whether a pre-defined template or generic note was created.

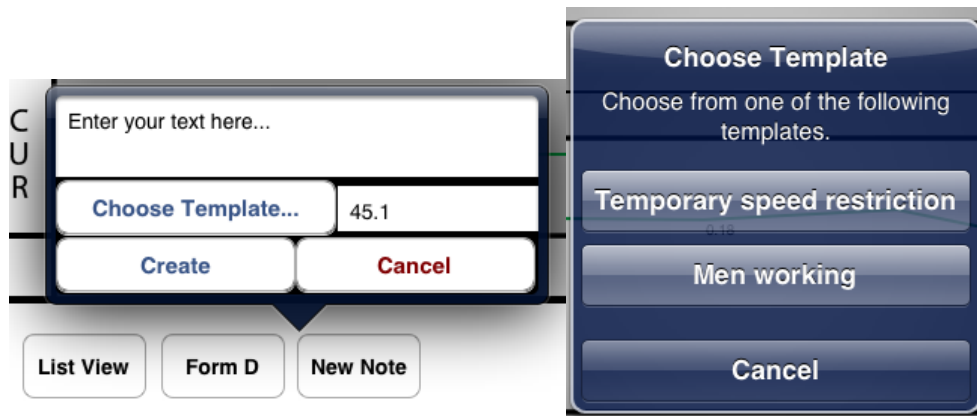


Figure 8. Left: Tapping on the “New Note” button brings up the free-form note dialog. Right: By pressing the “Choose template...” button, users can select one of two pre-defined messages that are placed into the text field of the note.

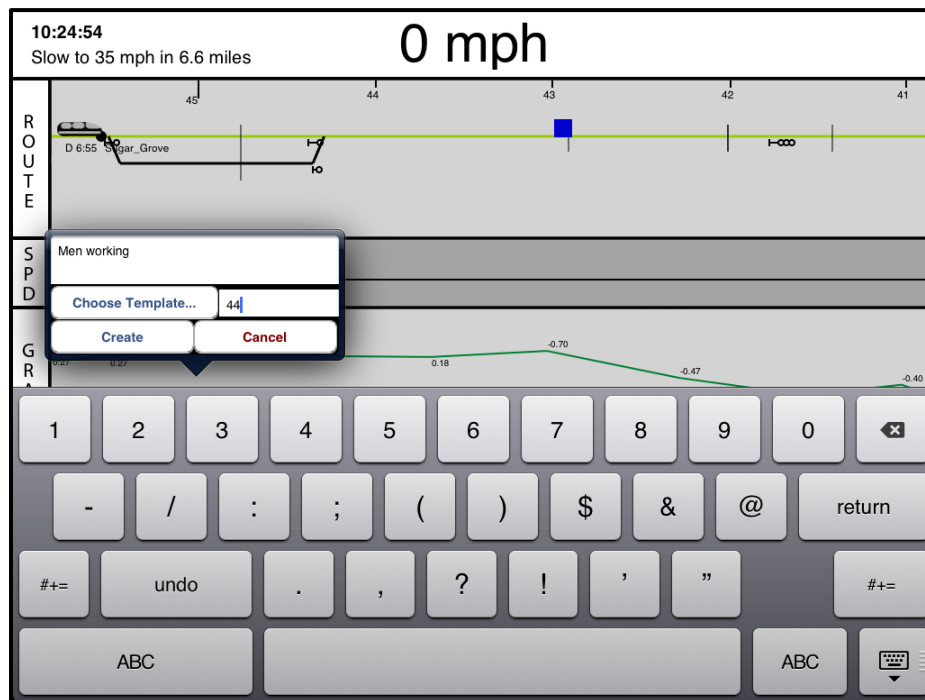


Figure 9. When the text or milepost field is selected, a keyboard appears for text entry

Figure 10 shows that a generic note (blue square) and a “Men Working” template note (red triangle) have been created.

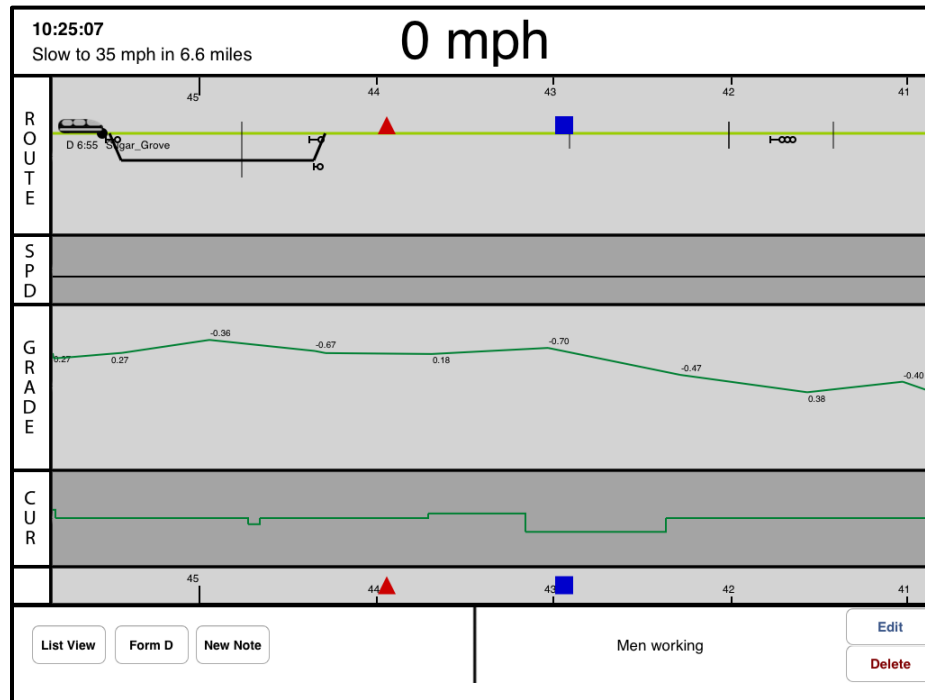


Figure 10. After the free-form notes have been created, icons are placed at the designated mileposts. Different icons are used to indicate whether a pre-defined template (red triangle for men working) or generic note (blue square) was created.

If a note icon is selected with a single tap, the associated text (“Men working”) appears in the message box at the bottom right of the display along with options to edit or delete the note. Tapping the “Edit” button opens the same edit dialog when creating the note, except with the current text included. Free-form notes can also be created by double-tapping directly on the map display within the Route Speed, Grade and Curvature areas. A free-form note dialog will appear but the milepost location corresponding to the location of the double-tap will already be entered. Furthermore, if the user presses then holds their finger on a note icon, the icon can be dragged to a new location within the four main fields of the map display. The milepost information is automatically updated.

List view is summoned by selecting the “List View” button in the lower left of the display. The action creates a list of upcoming points of interest in chronological order (Figure 11). In our implementation the list contains permanent speed restrictions, temporary speed restrictions entered through a Form D or station stops. Any of the points of interest can be selected from the list to make additional textual information appear in the message box in the lower right corner of the display. This list view feature allows users to preview important upcoming events that are beyond the preview scope of the graphical track display in the route section. As the location of the topmost event is passed, the entry is removed from the list.

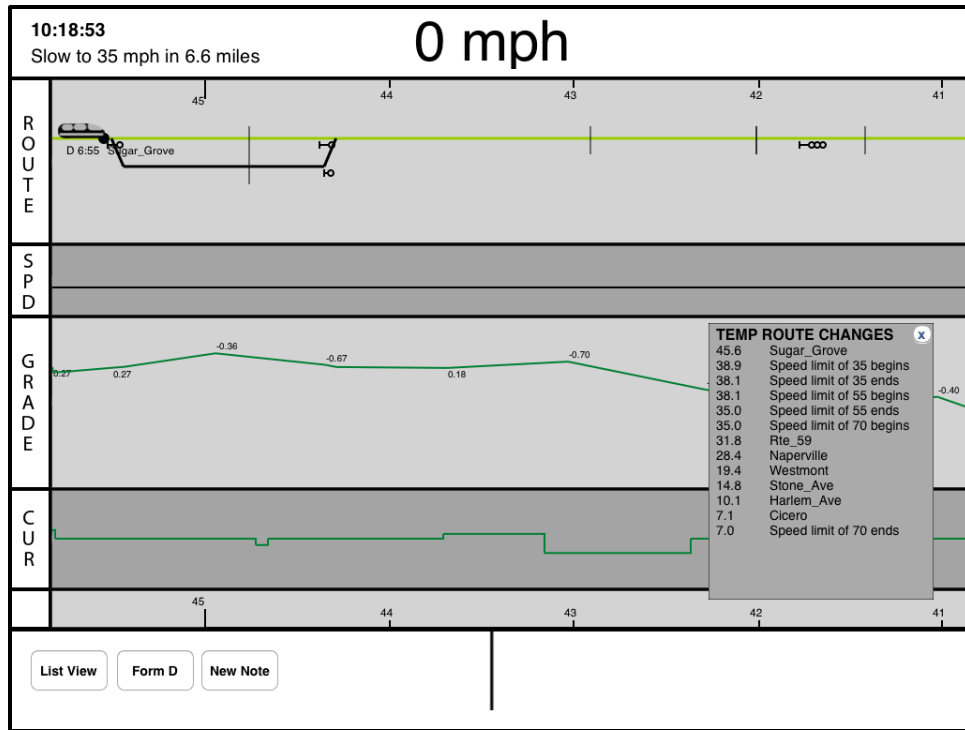


Figure 11. When the List View button is tapped, a pop-up window with a chronological list of events (e.g., speed restrictions, station stops) appears at the bottom left.

3. Evaluation of the Moving Map Display

3.1 Cognitive Walk-through

A cognitive walk-through is a method of assessing usability of a system by giving subject matter experts minimal training, asking them to complete tasks, and asking for their feedback (Wharton and Rieman, 1994). The experts are able to provide feedback about interacting with the interface elements within the context of the actual operational environment. The feedback is used to improve the interface and eliminate problems interacting with the system during the human-in-the-loop study.

3.1.1 Methods

The cognitive walk-through was conducted with ten current locomotive engineers with four to twenty-three years of experience driving locomotives. The average length of experience was roughly fourteen years with a standard deviation of seven years. Two of the participants spent their entire careers operating freight locomotives, seven spent their entire careers operating in passenger rail and one participant spent the majority of his career in passenger with some time in freight. Nine subjects were male and one subject was female. The experiment protocol was reviewed and approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES).

The participants were first shown a slide presentation outlining the purpose of the study and their requested involvement. After the consent forms were signed, the participants completed a demographic questionnaire and watched a short demonstration of some of the functions of the display. Subjects were then handed an Apple iPad and asked to use the display to perform certain tasks or determine certain information (i.e., the current speed). Subjects were also asked questions based on screen shots of enhanced future display features, i.e., features that were not yet implemented into the prototype. Example questions and tasks include describing track features around a landmark and inputting track warrants, which include additional information pertinent to the route for a given period. Feedback was solicited by a combination of questions administered immediately after performing a task, a five-point scale survey, and questions asked after the display interaction phase was complete. At the end of the cognitive walk-through, subjects were also asked questions about their experiences with the introduction of new technologies. The entire process lasted between one and two hours per subject.

Note that some elements from the display were later modified or not used in the human-in-the-loop tests, so these are not discussed in this report. Details about the results from these display elements can be found in the thesis (Voelbel, 2014).

3.1.2 Results

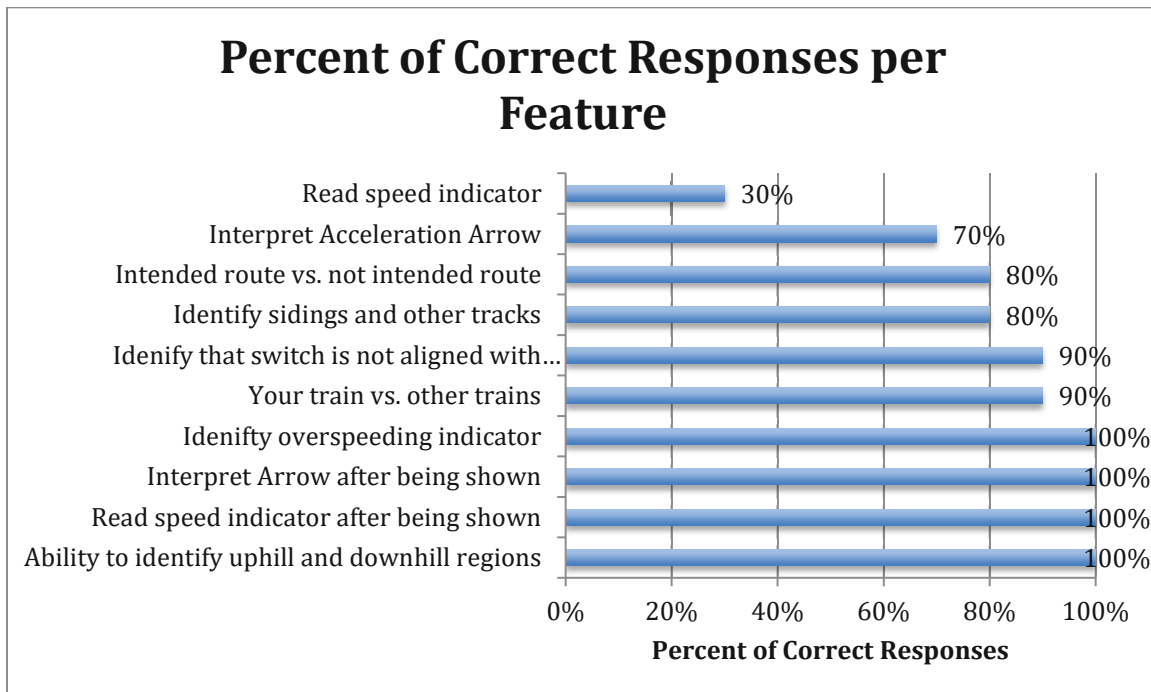


Figure 12. Percentage of correct responses assessing the subjects' comprehension of the display features.

Subjects were asked a number of questions regarding the track features shown on the display to assess their comprehension of those features (Figure 12). None of the tasks were explicitly trained in the tutorial. However, the tasks of “Read speed indicator after being shown” and “Interpret Arrow after being shown” were given after “Read speed indicator” and “Interpret Acceleration Arrow” which explains the 100% correct response result. The 30% correct response rate for reading the speed indicator is low, especially given the importance of the locomotive’s current speed for the locomotive engineer to maintain speed compliance and determine appropriate actions. Speeding through curves was a contributing factor to the fatal accident that occurred in New York in December of 2013 (Subramanian, 2013). Before this question, subjects were directed to look at the interior of the display, specifically the Speed section, to ascertain information about track speed restrictions. This may explain why subjects responded with the maximum allowable speed instead of the current speed when asked to provide the current speed of the locomotive according to the display (Figure 13).

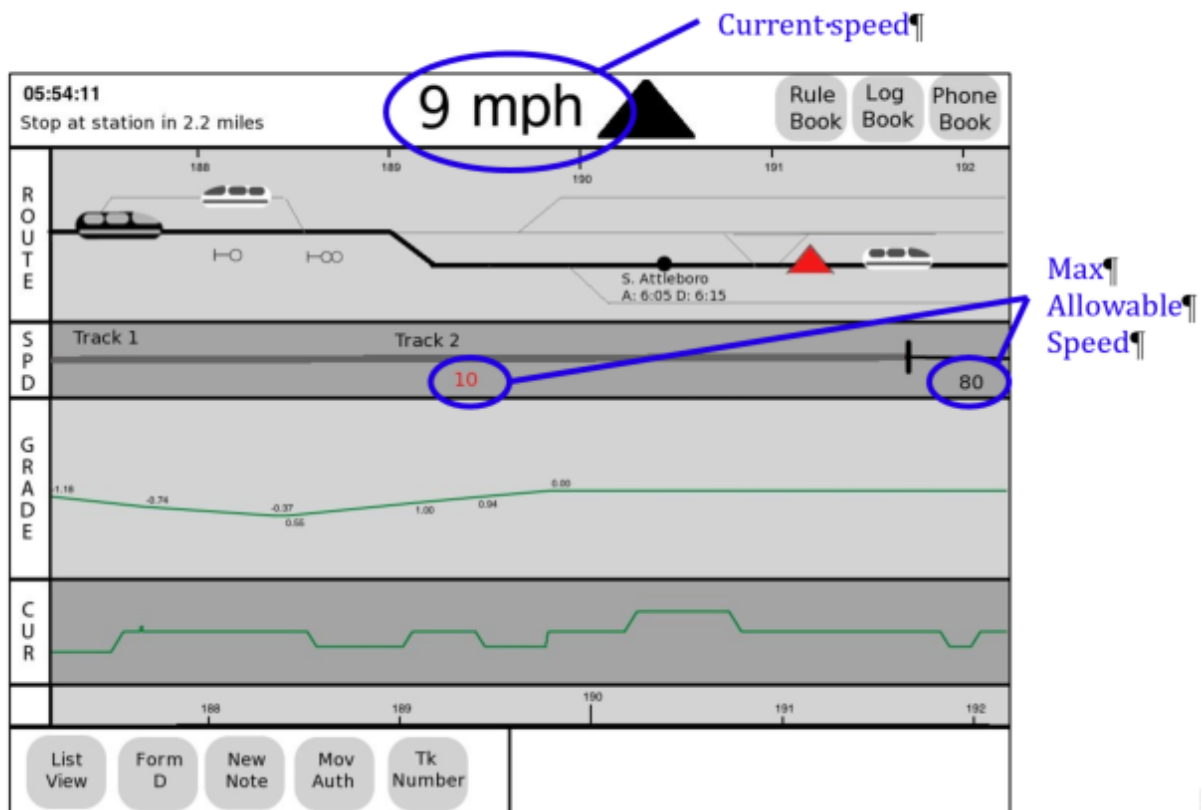


Figure 13. Some subjects mistakenly misinterpreted reported the current speed as 10 mph (instead of 9 mph), perhaps because they had been just asked questions about the temporary speed restrictions.

All ten subjects were able to correctly enter a track warrant or order for their train to operate under certain conditions such as speed restrictions when the experimenter played the role of a dispatcher calling over the radio to issue a track warrant. The track warrants were presented as a NORAC Form D because the majority of the subjects operate in NORAC compliant territory. The task of inputting Form D information and notes into the display was explicitly demonstrated in the tutorial. However, in the tutorial the notes were input on the default display screen that spans mileposts 181 to 186. For the experimental task subjects were asked to input a track warrant for a temporary speed restriction that was outside the default display screen and asked to verify that the reminder took effect on the display. Three out of ten subjects had to be told to pan to milepost 208.5 to check for the speed restriction indicated by the red line in the Speed section and yellow triangle with a "D" in the center. This may indicate that these subjects were not fully aware of the information they input into the display or not aware that the default screen did not contain the stretch of track where they input the data.

After performing tasks and answering questions using the display and screenshots, subjects completed the five-point scale usability survey composed of sixteen questions (see Appendix A). Subjects ranked their level of agreement with the first ten statements in the survey, where higher values indicated better agreement. The last five statements of the survey asked subjects to rank their level of agreement according to qualifiers such as difficult or easy, confusing or logical, very unclear, very clear and unsuited or suited.

The survey included a total of eleven positively worded statements and five negatively worded questions (marked by P and N in Appendix A respectively). Positively worded questions are those for which higher numeric responses (four or greater) indicate favorable ratings for the display. Negatively worded questions are those for which lower numeric responses (two or less) indicate favorable ratings for the display. A graph of the mean response values for each statement is depicted in Figure 14.

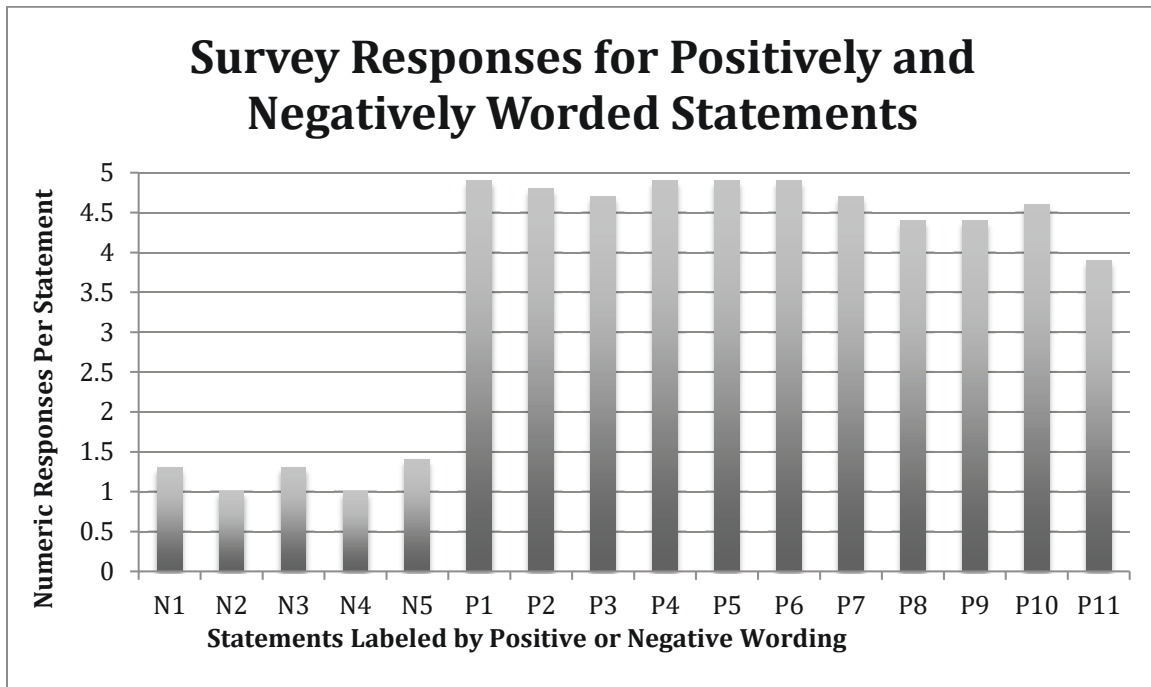


Figure 14. Survey responses for Positively and Negatively Worded Statements about the Moving Map Display. Statements are listed in Appendix A.

All positively framed questions except for one had a mean response of 4.4 or higher while all negatively framed questions had a mean response of 1.4 or lower. The question that deviated most from the most favorable score was the positively framed question, “How suited is this display for operating en route?” (P11) with an average score of 3.9 out of 5.0. In other parts of the interview, one of the subjects who provided an unfavorable response to this question (1=Unsuited) indicated that panning and zooming functions were “a little too sensitive” and would be “hard to do while moving.” Another subject in the same category stated concerns over how and where the display would be mounted as the experimenter provided no definitive answers and left it open-ended. The subject said the display should be in front of them so the engineer could quickly glance down to view the screen. The subject also remarked that when another system had been placed above him it was inconvenient and made interaction with the display difficult.

3.2 Human-in-the-loop Experiment

After the cognitive walk-through, a few minor modifications were made to the display (e.g., the color of the train route, changes to the dialogs used to enter notes or temporary speed restrictions) based on feedback from the subjects. The changes to the iPad moving map display was implemented in a human-in-the-loop study to examine whether train handling performance,

situation awareness, and rules compliance would be affected and to obtain feedback about the display's use during operations.

3.2.1 Methods

The experiments were conducted on the FRA Cab Technology Integration Laboratory platform housed at the U.S. Department of Transportation's Volpe Center in Cambridge, MA. The CTIL is built around a simulated locomotive cab with AAR 105 side stand controls and virtual displays through the four windows of the cab. The current simulation and track database was provided by Corys and covers a 200-mile section of BNSF track between La Crosse, WI, and Chicago, IL. For this experiment, researchers simulated an EMD F40 locomotive pulling six Kawasaki BTC-4 double-decker passenger cars, which is a typical consist for the Massachusetts Bay Commuter Railroad (MBCR) service. The subjects uniformly commented that the simulated locomotive seemed to accelerate more slowly than a typical locomotive they would drive while the braking power of the train set was somewhat better than usual. The subjects were not instructed where to place the iPad during the experiment session. All subjects eventually placed the iPad on the shelf in front of their seat where it would not interfere with their view of the main train gauges. (Figure 15) When the subjects entered information into the iPad, they would either lay the iPad flat on the shelf or place it in their lap.



Figure 15. Subjects placed the iPad on the shelf in front of their seat and in front of the main train gauges.

The track territory displayed on the moving map app differed from the territory shown in the cognitive walk-through. The new territory provided by Corys included a more complex track layout with several switches and multiple tracks (Figure 16). A few interactive features were enabled to operate even while the train was in motion, including zooming the display, tapping on an existing note or Form D to display the contents, or showing the list view. Other features such as creating and editing notes or panning the display remained disabled while the train was in motion. The iPad obtained train position, speed, and acceleration information from the simulation data server over a wireless connection at a 10Hz data rate.

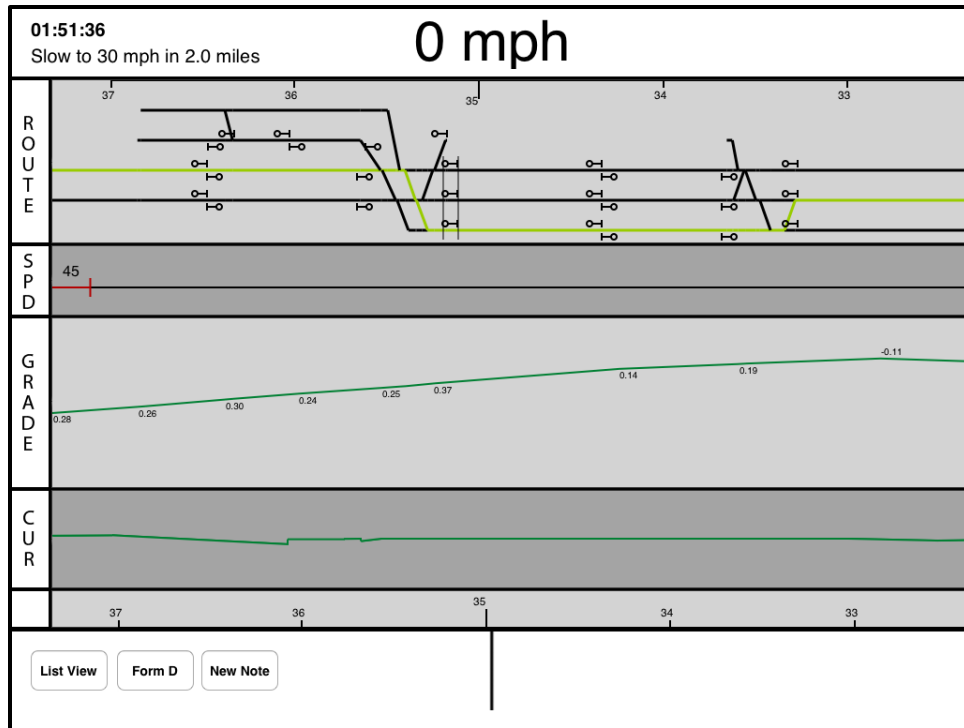


Figure 16. The track database used in the human-in-the-loop study was more complex than in the cognitive walk-through with multiple main tracks, more switchovers, and grade crossings. The green line indicated the current route.

Two scenarios were developed for the experiment simulating eastbound passenger service over a single 38 mile section of track to the west of Chicago. For both scenarios, subjects also had to observe three permanent speed restrictions (35mph, 55mph, 70mph and 79mph track speed) and two quiet zones where subjects were not supposed to blow the horn at grade crossings. Subjects were provided a timetable for station stops either on the iPad or on paper as well as a paper Operations Bulletin and a Temporary Speed Restriction Bulletin (TSRB). Scenario 1 included 5 station stops, 2 TSRBs, and one directive for a Work Area. En route, subjects were issued a Form D, Line 12 (Stop & Protect order) and a TSRB addition. Scenario 2 included six station stops, three TSRBs and one directive for a Work Area. En route, the subjects were issued a Form D, Line 12, a Form D, Line 5 (Work Area), and one TSRB Bridge Strike addition. The locations of the speed restrictions, work areas and other track warrants occurred at different locations in the two scenarios. Both scenarios took approximately 60-65 minutes to complete.

Eight engineers (six male, two female) between the ages of 27 and 50 years (avg: 40.4 ± 7.3 yrs) were recruited from the population of active MBCR engineers operating out of the Boston area. The engineers had between 4 and 22 years of experience (avg: 12.4 ± 7.0 yrs) as a passenger engineer. Three subjects were current road foremen, four others had previous experience as a conductor and one subject had 4 years of experience as a freight engineer. Three of the subjects had previously driven the CTIL simulation over the same terrain as part of a separate distraction study and two of the subjects had participated in the cognitive walk-through.

The one-day experiment protocol was approved by the MIT COUHES and subjects were paid \$350 for completing the entire protocol. Subjects arrived at the Volpe Center at 8:30a.m. and were given a consent briefing. After signing the consent form, subjects began the training phase

with a short 15 minute briefing about the simulation scenario which reviewed basic information such as type of locomotive and consist, operating rules, route characteristics. After the briefing, subjects stepped into the CTIL and operated the train from the starting point (Sugar Grove siding at Milepost 45.6) through its terminus at the Cicero Station (Milepost 7.0). The subjects were instructed to observe all operating procedures, including permanent speed restriction and to stop at the stations outlined in the Scenario 1 timetable. One of the experimenters was present in the cab to point out some train handling quirks and non-conforming signals that were present. The training run took approximately 1 hour and helped the subjects learn the handling characteristics of the simulated train, observe the roadside signals and establish some visual landmarks for braking at the stations.

After a 10-minute break, subjects began a second training session to learn to operate the iPad moving map display. The experimenter first described each of the views of the display then demonstrated the procedure to create, edit and delete notes and Form D entries. Subjects then were asked to enter a couple of notes (e.g., indicating the limits of a Quiet Zone) and Form Ds to demonstrate their understanding. These training procedures were similar to the procedures of the cognitive walk-through. Once the experimenter was satisfied that the subject understood the procedure, the subject returned to the CTIL and drove the route for a second time, but now using the iPad display. At the second station stop researchers simulated the procedure of recording a Form D on the iPad to familiarize the subjects with its use in operations. Again, at least one experimenter was in the cab during the training run to answer any questions about the scenario or using the iPad.

After a 30-minute lunch break, subjects began the experiment session in which they first drove Scenario 1 followed by Scenario 2 after a 10-minute break. Subject Group 1 drove Scenario 1 using the iPad followed by Scenario 2 without the iPad. Subject Group 2 drove Scenario 1 without using the iPad and Scenario 2 using the iPad. Subjects were given a 10-minute trip briefing before each scenario where the experimenters reviewed the timetable, operations bulletin and TSRBs with the subject engineer. After the briefing, subjects made notes about the scenario on the iPad or on paper, depending on the experimental condition. During the scenario, one of the experimenters would play the role of the dispatcher and conductor when communicating with the subject. After a final 10-minute break, subjects filled out the same usability questionnaire used in the cognitive walk-through then participated in a session debrief where they answered a series of questions regarding their likes and dislikes about the moving map display, what information they used, their feedback about the layout and its potential application to conductors.

3.2.2 Results

The objective train handling performance was examined for selected situations: (1) entering a speed restriction from a higher speed zone, (2) approaching a Stop & Protect directive at the specified grade crossing, and (3) approaching a bridge underpass for a Bridge Strike TSRB addition. When entering speed restrictions, the preview capability inherent in the Route display was expected to allow the engineers to smoothly decelerate the train and enter the restriction closer to the required speed. The data show that in the first scenario, there were 3 (out of 16) cases where trains entered a TSR at more than 4 mph above the designated speed when using the iPad but none when not using the iPad. In the second scenario, there was only one case (out of 12) of entering the TSR too fast when using the iPad compared with 3 cases when not using the

iPad. This seems to be a trait of the subject groups as the same three engineers were responsible for all six of the overspeed conditions.

Table 1. Individual subject and average braking behavior when approaching a grade crossing for a Stop & Protect directive. The scenarios marked with the gray background indicate trips using the iPad display.

Subjects	Scenario 1 – Avg Braking distance (ft)	Scenario 1 – Avg Time to stop (sec)	Scenario 2 – Avg Braking distance (ft)	Scenario 2 – Avg Time to stop (sec)
TH3217510	7914	254	2769	115
LP322255	2732	64	5460	110
SH3213910	3371	102	2676	73
AV319715	4653	104	4869	116
<i>Avg Group 1</i>	<i>4667 ft</i>	<i>131 sec</i>	<i>3944 ft</i>	<i>104 sec</i>
MU3216610	3860	62	3392	54
MC302145	6403	160	4981	110
EV311795	6633	112	3106	47
WH3210715	5254	104	4715	113
<i>Avg Group 2</i>	<i>5537 ft</i>	<i>110 sec</i>	<i>4049 ft</i>	<i>81 sec</i>

A similar trend is seen when examining the stopping distances and times as the engineers approached a Stop & Protect directive at a grade crossing (Table 1). In Scenario 1, the initial braking distance was slightly shorter when using the iPad whereas the time to come to a stop was about 20 seconds longer. However, the performance of a single subject in Group 1 (i.e., subjects who performed Scenario 1 with the iPad and Scenario 2 without the iPad) skewed the group averages, likely due to unfamiliarity with the simulated train's dynamics. In Scenario 2, the distance before braking was nearly equal although the stopping time was about 25% shorter when using the iPad. These results suggest possibly better situation awareness and train handling when approaching an unfamiliar landmark and using the iPad, although the effect could also be an artifact of learning of the train handling qualities.

Finally, researchers compared the subjects' train handling in response to the Bridge Strike addition to the TSR Bulletin in Scenario 2. For this directive, subjects had to reduce speed to 5 mph before crossing over the bridge and maintain the speed until the conductor notified the engineer that the train had completely crossed over. Subjects using the iPad first reached 5 mph at an average distance of 547 feet from the overpass compared to 635 feet for subjects not using

the iPad. This is about a 15 second difference in time before reaching the overpass. In both cases, subjects averaged similar speeds when crossing the bridge (iPad: 5.6 mph, no iPad: 5.9 mph).

Researchers also considered whether the subjects remembered not to sound their horn in the Quiet Zones as a final measure of rule compliance. In Scenario 1, two subjects using the iPad sounded their horn at a crossing in a quiet zone, whereas three subjects who didn't use the iPad sounded their horn. In Scenario 2, two subjects using the iPad sounded the horn in a quiet zone compared to only one subject who wasn't using the iPad. In all cases, subjects either sounded the horn at the beginning of the zone or near the end of the zone, suggesting possible confusion about the exact location of the limits of the quiet zones despite using notes to indicate the location on the moving map.

Subjective evaluation of the display was captured by the results from the usability questionnaire and user feedback. After driving both scenarios in this experiment, subjects completed the same usability survey used in the cognitive walk-through. The responses from our subjects were similar to those who participated in the walk-through. (Figure 17) The 5 negatively worded questions received responses with a score of 2 or less (avg 1.45), while the positively worded questions received scores of 4 or higher (avg 4.4). One of the eight subjects agreed with Question N3 that the software was inconsistent, while a different subject somewhat agreed with Question N4 that the software was cumbersome to use. All other scores were 3 or less for the negative questions. For the positive questions, one subject found the access to the information to be confusing (Question P7) and the organization of the display to be somewhat unclear (Question P8). All other responses to the positive questions were scored 3 or higher.

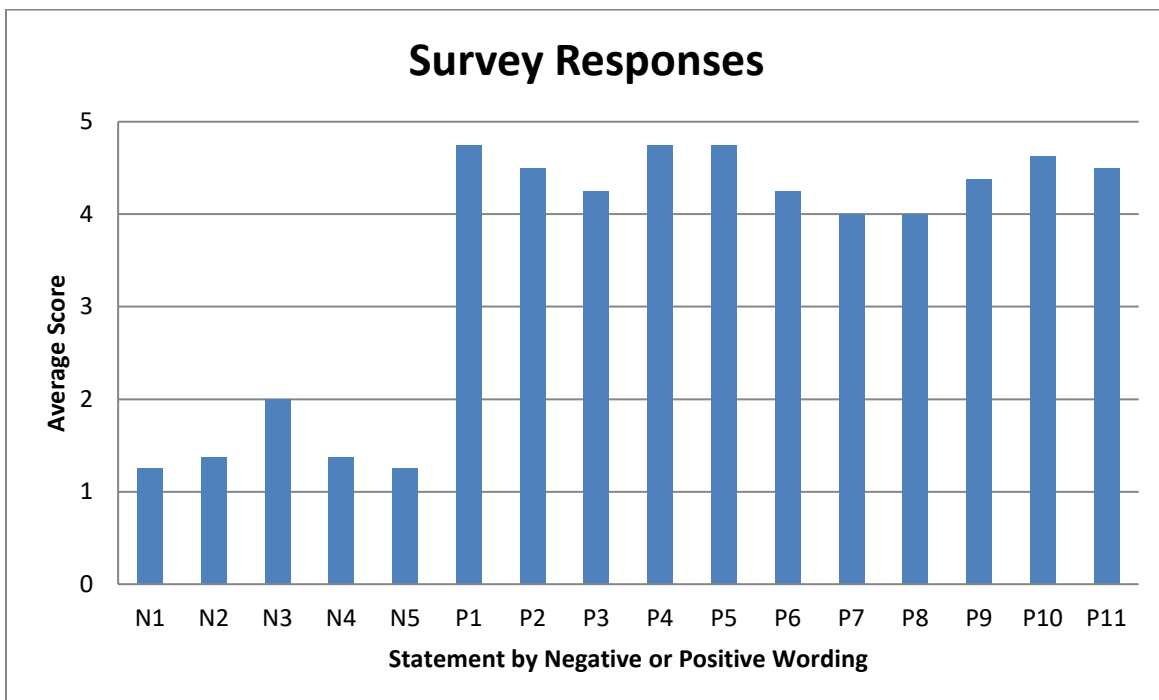


Figure 17. After using the display in simulated operations, the subjects responded similarly to the subjects in the cognitive walk-through.

The subjects' feedback largely corroborated the findings from the cognitive walk-through. The information in the Route and Speed windows was the most useful when driving the route. Those windows provided a preview of the upcoming sections of track, which enabled the engineer to maintain situation awareness of upcoming events such as TSRs. The display also consolidated the information that might be written or highlighted on several documents and thus lessened the memory workload while operating the train. These two windows were particularly useful in this experiment since the engineers were not familiar with this particular route to the same level of detail as routes they drove regularly.

Only three subjects explicitly mentioned the Grade window as being useful. The graphical representation was more useful than numerical values for these engineers when modulating the train speed, especially since there was no simulator cab motion to provide vestibular feedback to the engineer. One subject suggested that the window should be hidden by default, but be accessible via a button press from the main screen. Seven of the eight subjects stated that the curvature view was unnecessary since the information is generally implicit in the track speeds.

Four of the subjects made positive comments about the List View capability as it provided a chronological view of upcoming events on the route. These four subjects either reviewed the list at station stops, or kept it open on the main display while moving. In both cases, the list was used to update their location awareness as events disappeared from the list as they were passed.

The Form D capabilities were uniformly considered to be beneficial with the inclusion of the event location in the Speed window as the most helpful feature. The color-coded icon with the letter "D" made the events simple to recognize on the display, and being able to touch the icon and see the contents of the Form D was a convenient method to get a reminder of the event details, if needed. Form D speed restrictions also appeared in the List View, which was helpful to the subjects who used this view. By contrast, if subjects entered TSR additions as a generic note, the generic notes were not displayed on the Speed window or List View, so they were less effective as a memory aid. Two of the subjects entered all speed restrictions as a Form D in order to have them appear on the Speed window.

Overall, subjects spent, on average, 34 seconds longer to complete the Form D procedure (Line 12, Stop & Protect at Crossing) using the iPad than when using the paper form. There was no appreciable difference between subjects who used the iPad in Scenario 1 (33s longer to complete the procedure) and subjects who used the iPad in Scenario 2 (40s longer). There were large individual differences between subject entry times ranging from 4 to 84 seconds. In Scenario 2, a second Form D (Line 5, Work Area) was issued and subjects using the iPad averaged 189 seconds to complete the task compared with 180 seconds for subjects using the paper form. Several subjects noted that the Form D implementation was missing some essential fields, such as recording "time effective" or indicating whether the directive had been completed or cancelled.

Generic notes were used by most subjects to indicate the beginning and end of the quiet zones. One subject suggested that generic notes should also be able to indicate a range over which the note was applicable. This solution would have been useful for marking the quiet zones and may have eliminated the compliance lapses noted above.

Five of the subjects made specific suggestions to make the icons more readily identifiable, either by using icons that resembled the physical flags and markers and by color coding or matching the notes with entries in the List view. One missing feature was the ability to cancel a directive

or to indicate the engineer had complied with the directive. Only three of the eight subjects explicitly mentioned the desire for some type of alert to an upcoming note, which is different from the cognitive walk-through results where six of the ten subjects wanted an audible alert. Two of the human-in-the-loop subjects mentioned flashing alerts, such as an upcoming Form D while the third just mentioned alerts as useful addition.

Finally, none of the subjects felt that using this type of display would be more distracting than the current operating procedures. One subject commented that the consolidation of information on one display, rather than on multiple pieces of paper, would lessen the distraction. On the other hand, one of the road foremen suggested the potential for newer drivers, or students training on the road, to fixate their attention on the display rather than looking ahead in the real world.

3.2.3 Discussion

In examining train handling, researchers found that performance was largely comparable whether or not the engineer used the moving map display. Our hypothesis that performance, in terms of smoother braking or speed control, would be meaningfully enhanced by the use of the display was not supported. Since our subjects were unfamiliar with the route and consist, it is likely that their train handling would be more variable when applying the brake to stop the train at a specific point on the tracks (i.e., a Stop & Protect order at a grade crossing) or changing throttle notch to maintain speed through a slow speed restriction. The two training runs in the morning were probably not sufficient for the subjects to determine and remember appropriate braking points for the station stops to permit consistent performance.

The Form D orders and Bridge Strike directives involved locations at which subjects did not stop during training, but these locations were noted by the experimenters during training. These cases were thought to be the most likely situations where the moving map display could provide additional situation awareness by displaying the relative position of the train and stopping point. Perhaps by reducing the preview distance from 5 miles to 2-3 miles, engineers would have better discrimination of their relative location to impact train handling.

Only one subject actively used the zoom feature to change the preview length – the remaining subjects used the default distance and rarely changed the preview setting, even though the capability was available while the train was in motion. Testing the subjects in familiar territory (specifically the Boston-Providence section of Amtrak rail) would improve training efficiency and reduce variability in the train handling performance data in CTIL future experiments.

Other functions for the display were suggested by the subjects after the test sessions. Both the Grade and Curvature windows of the display were deemed unnecessary or not helpful by most of the subjects. Two subjects suggested that these windows could be collapsed by default but could be opened as needed. This functionality might be useful for student engineers during a training ride to display information that they wished to quickly remind themselves about upcoming track characteristics.

Several tasks required stopping or slowing near grade crossings or overpasses. Being unfamiliar with the territory, several subjects suggested that the names for the crossings and bridges could be added to the display or shown when the user tapped the particular landmark. For a congested urban area such as our test route, the former suggestion would clutter the display and the latter might be difficult to implement effectively if the crossings are very close together. One subject

alternatively suggested that crossings, overpasses and underpasses could be displayed in the List View format. This latter suggestion could also serve as an alternative method to add new directives or edit existing directives.

Finally, several subjects would tap on the icon for an upcoming note (either free-form or Form D) to display the note text in the lower right information panel and refresh their memory. However, once the location referenced to the note was passed, the text would remain displayed, rather than disappearing from view when passed. Removing the note would help avoid any confusion as to the current location of the train and any upcoming directives during a quick glance at the display.

Several subjects inquired whether the tablet platform would be suitable for other reference materials such as rule books. As was the case with the cognitive walk-through, our subjects said it would be desirable to have the rule books in electronic form since the actual books are quite bulky and heavy. Since trips can pass over track owned by several companies, engineers may have to carry additional rule books and documents for the other companies creating additional bulk and weight.

Major airlines have adopted “electronic flight bags” (EFBs) that contain electronic versions of airport approach and landing charts that save weight and space. Digital formats allow the airlines to more easily update content and flag the new information as well as reduce cost of printing new paper documents. Several airlines also are now experimenting with company issued tablets for this purpose and others like en route strategic weather planning (Croft 2014).

The primary obstacle for adoption in rail would be the amendment of current rules about the use of such devices in the locomotive cab, since their use has led to previous accidents. Croft notes that United Airlines and Fedex are studying how a mobile device manager could provide control over the configuration and use of the devices and enforce security policies. Railroad companies would then have to decide on the appropriate technological implementation to provide any needed information in real-time.

In the user feedback questionnaire, the subjects were asked if other railroad personnel could make use of a similar display. As part of normal rail operations, engineers and conductors must cross-check the information for any directives that are given by the dispatcher over the radio. Conductors could use a similar display to check the engineer’s entry of new directives, ensure the accuracy of the information and to help maintain their shared situation awareness. This could be especially helpful for conductors in passenger service since they are rarely in the locomotive with the engineer and more often busy collecting revenue in the passenger cars. Conductors could enter general notes to set reminders of upcoming directives and alert themselves when to contact the engineer with a reminder. A potential drawback of the iPad was whether the size was appropriate for the conductor or if a smaller sized tablet would be better. Generally, the conductors would not have a place to store the display if not kept on their person.

One subject who is a road foreman suggested that the moving map display would also be quite helpful to student engineers learning a new route. After learning the physical characteristics of the route, the moving map display could be used as an external memory aid to reduce some of the mental workload of driving a new route. Similar to novice automobile drivers, the inexperienced locomotive engineer might be susceptible to attention tunneling or lapses in memory recall during high workload periods. A supplemental display where the novice engineer

could place reminders at critical junctures of a trip would provide a memory aid in those circumstances.

Finally, two important issues were raised regarding how this type of display could be fielded. Regarding the procedure of issuing a Form D, one subject suggested that the entire contents could be transmitted directly to the iPad even when the train is in motion. The display would need to inform the engineer of its arrival and indicate where next to stop to confirm the information with the dispatcher. At the next stop, the engineer could then confirm the contents of the directive with the dispatcher and complete the remaining fields indicating the effective time and date. NORAC rules state that all employees addressed in the Form D (typically engineer and conductor) must have a copy of the Form D. Thus the directive could also be transmitted directly to the conductor's display which the conductor would review as the engineer communicated with the dispatcher.

NORAC rules also require engineers to keep copies of all Form D directives for 7 days after they are fulfilled or cancelled. In current practice, engineers simply keep the paper forms for the required period of time. In digital format, the Form D information could also be stored on the iPad in a separate database from the moving map app or even synchronized to a central repository after each trip. Using a central repository would allow the Form D's to be accessed and searched independently off line. If kept on the device, users could be notified to delete the directive after the requisite retention time. NORAC would have to review its current rules to determine how other Form D procedures could be appropriately fulfilled if electronic forms were to be used.

4. Conclusion

A prototype moving map display was developed for an iPad tablet to support the situation awareness and safety performance for engineers when operating locomotives. The results of the cognitive walk-through and human-in-the-loop experiments with experienced engineers suggested that train handling and operational safety would not be compromised by using the display, and could be enhanced as engineers became familiar with it.

The major features of the display (e.g., notes) and the associated gestures were easy to learn and apply during the simulated trip. All test subjects generally felt comfortable with using the display during train operations and thought it provided important information in an integrated and intuitive manner.

The user feedback from the human-in-the-loop experiment suggested the display might be very useful supporting engineers in training or do not have recent familiarity with a territory. Subjects also pointed out that further refinement of the display and data entry methods was still needed, such as including missing fields from the Form D or providing alternate methods to data entry through the list view.

An evaluation of the display against its original goals revealed that further investigation is needed to quantitatively assess the impact of the display on improving locomotive engineers SA. Based on the evaluation of Information and Functional Requirements, two features that should be strongly considered for inclusion in the next iteration of the display are signal aspects and PTC information. Then, a second iteration of the moving map display should be developed followed by another round of human-in-the-loop testing that includes a study of engineer-eye movements and explicit measures of locomotive engineer SA.

Two notable future research opportunities were suggested by the test engineers. The first was whether the tablet format could be used as the railroad equivalent of the aviation electronic flight bag. Several engineers offered this suggestion as a way to help easily update operating bulletins and rule books, and to ease the physical burden of carrying several large books. Given the feedback received during the study, future work should focus on developing interface mock-ups for logbooks (maintenance log) and rulebooks, and evaluating their utility through additional user-in-the-loop experimentation.

In addition, engineers in this study suggested developing a similar display for conductors that would help conductors maintain SA and support their tasks, such as reminding engineers about upcoming speed restrictions or other track warrants. Such developments would further enhance safe operations by improving the individual and shared situation awareness of engineers and conductors.

Future work on the moving map display should quantitatively examine how workload, SA, and attention change when using the moving map display. It is possible that the display could draw attention into the cab and away from the forward view. This could be determined by collecting eye movement data during operation with and without the moving map display. In addition, the engineers made several suggestions to improve the interface and interaction techniques such as creating an alert capability when the train approaches a location which is tagged with a note. Additional research should focus on other operational issues such as how to implement record retention of en route directives, whether the iPad platform could be an effective substitute for the

paper rule books that the engineers must bring on each trip, or if conductors would benefit from having a similar display.

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Appendix A.

Cognitive Walk-through Questionnaire

		1 Disagree	2	3 Neither agree nor disagree	4	5 Agree
P1	I think I would use this software frequently					
N1	I find this software unnecessarily complex					
P2	I think this software is easy to use					
N2	I think I need the support of a technical person to use this software					
P3	I find the different functions of this software well integrated					
N3	I think there is too much inconsistency in the software					
P4	I think it will be easy for locomotive engineers to learn to use this software					
P5	I find the software cumbersome to use					
N5	I think I need to learn many things before using this software					
		1 Difficult to read	2	3 Neutral	4	5 Easy to read
P6	These characters are:					
		Confusing				Logical
P7	The accessing information is :					
		Very unclear				Very clear
P8	The organization of information is:					
		Difficult				Easy
P9	Recalling how to access display functions is:					
		Difficult				Easy
P10	Scrolling and zooming on the map is:					
		Unsuited				Suited
P11	How suited is this display for operating en route?					

Abbreviations and Acronyms

BNSF	Burlington Northern Santa Fe Railroad
CTIL	Cab Technology Integration Laboratory
COUHES	MIT Committee on the Use of Humans as Experimental Subjects
DTO	Driverless train operation
EFB	Electronic Flight Bag
FRA	Federal Railroad Administration
GE	General Electric
hCTA	Hybrid Cognitive Task Analysis
I-ETMS	Interoperable Electronic Train Management System
MBCR	Massachusetts Bay Commuter Rail
MIT	Massachusetts Institute of Technology
NORAC	Northeast Operating Rules Advisory Committee
NYAB	New York Air Brake
PTC	Positive Train Control
SA	Situation Awareness
STO	Semi-automatic train operation
TSR	Temporary Speed Restriction
TSRB	Temporary Speed Restriction Bulletin
UTO	Unattended train operation