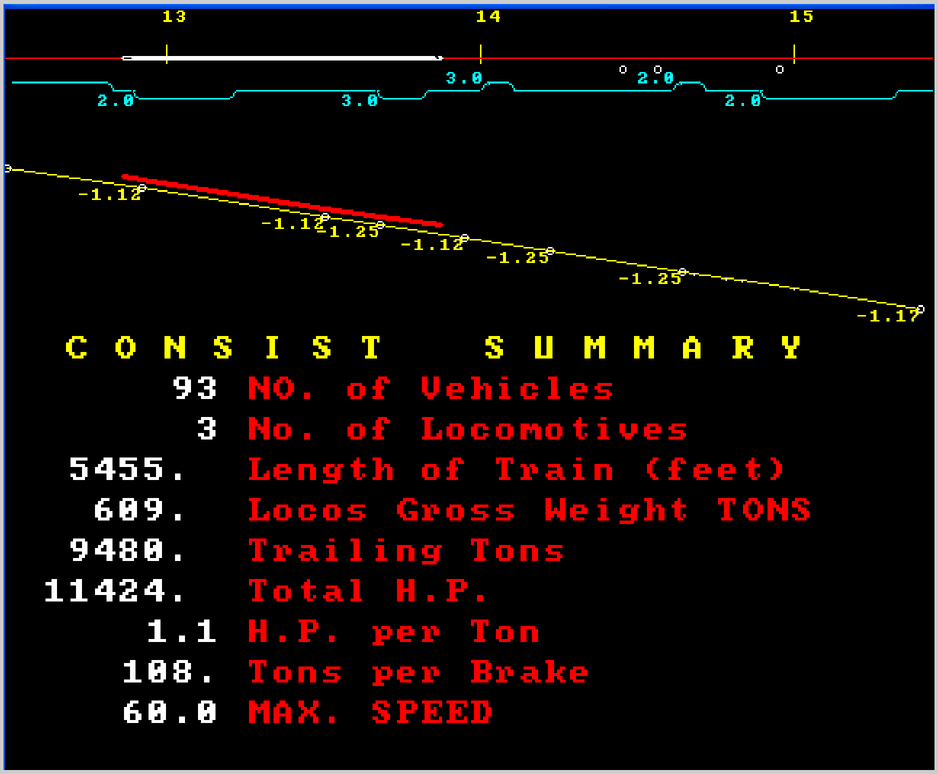
U.S. Department of
Transportation
**Federal Railroad
Administration**

Cab Technology Integration Laboratory Demonstration with Moving Map Technology

Office of Research
and Development
Washington, DC 20590

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093



CONSIST SUMMARY
93 NO. of Vehicles
3 No. of Locomotives
5455. Length of Train (feet)
609. Locos Gross Weight TONS
9480. Trailing Tons
11424. Total H.P.
1.1 H.P. per Ton
108. Tons per Brake
60.0 MAX. SPEED

Human Factors in Railroad Operations

DOT/FRA/ORD-13/14

Final Report
March 2013

NOTICE

NOTICE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*LEAVE BLANK*)

2. REPORT DATE
March 2013

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Cab Technology Integration Laboratory Demonstration with Moving Map Technology

5. FUNDING NUMBERS
RR04A4-KMD24

6. AUTHOR(S)
Gina Melnik, Hadar Rosenhand, and Matthew Isaacs

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

8. PERFORMING ORGANIZATION
DOT-VNTSC-FRA-

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-13/14

11. SUPPLEMENTARY NOTES
Program Manager: Michael Jones

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161, and on the FRA Web site at http://www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A human performance study was conducted at the John A. Volpe National Transportation Systems Center (Volpe Center) using a locomotive research simulator—the Cab Technology Integration Laboratory (CTIL)—that was acquired by the Federal Railroad Administration (FRA). The primary objective of the study was to conduct a hands-on simulator training exercise and system demonstration. A moving map experiment was chosen for the study because FRA is interested in determining the human performance and safety implications of this technology following prior FRA research on preview information in cab displays (Einhorn, Sheridan & Multer, 2005). However, because surrogate (novice) engineers were used for the experiment instead of experienced locomotive engineers, the results have limited applicability. Lessons learned and general best practices for designing and running future CTIL experiments are discussed in this report. Possibilities for future research regarding operator use of moving map displays are also considered.

14. SUBJECT TERMS
Cab Technology Integration Laboratory (CTIL), pilot experiment, moving map display, operator performance, safety, technology

15. NUMBER OF PAGES
35

16. PRICE CODE

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

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
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1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
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1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
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1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
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 meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE** (EXACT)	
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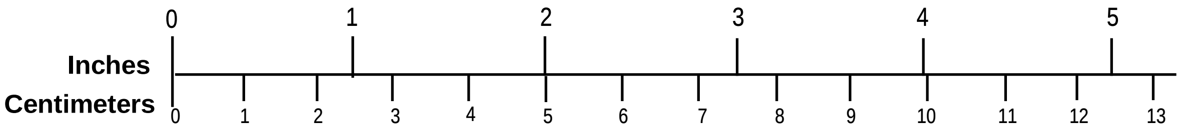

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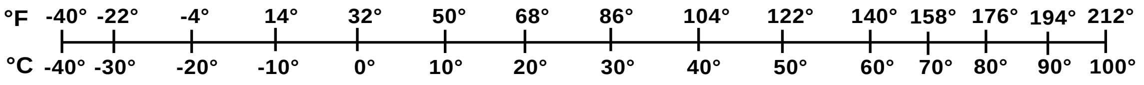

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SD Catalog No. C13 10286

Updated 6/17/98

PREFACE

This report was prepared by the Behavioral Safety Research and Demonstration Division of the Human Factors Research and Systems Applications Center of Innovation at the John A. Volpe National Transportation Systems Center (the Volpe Center). It was completed with funding from the Federal Railroad Administration's (FRA) Office of Research and Development as part of the Cab Technology Integration Lab (CTIL) program. We would like to thank our FRA sponsor, Michael Jones, as well as Dr. Thomas Raslear and Michael Coplen, for providing guidance and feedback throughout this project. Additional thanks to Les Fiorenzo, FRA Region 1 Administrator, and his staff for providing further guidance regarding scenario design.

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Executive Summary

This report documents the first human performance study that the John A. Volpe National Transportation Systems Center (Volpe Center) conducted using FRA's new locomotive research simulator—the Cab Technology Integration Laboratory (CTIL). The study had two objectives: (1) to exercise CTIL research capabilities and provide hands-on experience to Volpe researchers on CTIL functions by conducting a pilot experiment, and (2) to provide a basic example of the type of experiment and data analysis that can be conducted in the simulator for those seeking to conduct CTIL research. Given that CTIL experiments studying moving maps may be planned in the future, it seemed an appropriate choice for a pilot.

Moving map displays, sometimes also called rolling maps, or track-profile displays in the railroad industry, provide the locomotive engineer with a visual representation of the position of the train on the track, as well as terrestrial track features such as mileposts, signals, track curvature, and grade.

Moving map displays are currently not widely used in the railroad industry. It is unclear how they would affect freight locomotive engineer operation. It is assumed that they would aid locomotive crew situational awareness by providing route preview information such as signals, hills, and turns relative to the location of the full length of the train on the route. Because of their inclusion in new technologies such as Positive Train Control (PTC) and locomotive energy management systems, moving maps are increasingly being implemented in the railroad environment and so it is important to know more about the display's use and its possible impact on locomotive crew performance.

This first step of the research effort was a "pilot experiment" to help resolve minor CTIL issues associated with the system's use. Therefore, (a) the hypothesis is not based on previous research, (b) the moving-map display used is a new display generated specifically for CTIL by Alion Science & Technology rather than a standard moving map used in current cab technology, and (c) qualified locomotive engineers were not used in the study.

In the *Paper Chart plus Moving Map* condition, participants operated the train over 13 miles of simulated track with the CTIL moving map display visible. In the *Paper Chart Only* condition, participants completed the same 13-mile route without the use of the moving map display. In both conditions, participants were provided with a paper-based track profile that displayed vital information about the route. All participants were provided with the minimum training required in railroad signals and operations to run the route using CTIL.

Objective performance measures (e.g., fuel consumption, brake pipe pressure, buff and draft forces, and number of throttle changes) were chosen for analysis based on the knowledge that many performance measures may not be meaningful for those without extensive experience in train handling. Performance measures related to speed control (e.g., ability to maintain the permitted speed in reference to signal adherence, track warrants/terrain restrictions, and general operation) were also selected for examination.

There was no statistically significant difference between the *Paper Chart plus Moving Ma*p and *Paper Chart Only* conditions in the number, duration, or magnitude of overspeed events. We also looked at the mean durations and magnitudes considering only the nonzero data points. The average duration of overspeeds that occurred (greater than zero)—expressed in number of seconds the surrogate engineers were operating over the allowable speed limit—was less in the

Paper Chart plus Moving Map condition than in the *Paper Chart Only* condition. The average magnitude of the overspeeds that occurred (greater than zero)—expressed in mph over the speed limit—was very similar for the two conditions but slightly higher in the *Paper Chart plus Moving Map* condition.

Given that this work was intended to serve as a baseline pilot experiment and not a true moving map study, results must be interpreted within that context. The results do not address any specific research questions about moving maps, but they are fairly indicative of the analysis process and will likely help stimulate ideas for future moving map research projects.

1. INTRODUCTION

1.1 BACKGROUND

The Federal Railroad Administration (FRA) is interested in examining the effects on locomotive crew performance of implementing locomotive moving map displays. Moving map displays, sometimes also called rolling maps, or track-profile displays in the railroad industry, provide the locomotive engineer with a visual representation of the position of the train on the track, as well as topographic track features such as mileposts, signals, track curvature, and grade. Moving map displays are in use across transportation domains; for example, in cars using Global Positioning Systems (GPS) technology. Surface moving maps are also widely used in aviation to display aircraft position on the airport surface in relation to other airport elements; it is also useful for tasks such as taxiing to and from runways (Yeh & Eon, 2009).

FRA is interested in better understanding how moving map displays may affect freight locomotive engineers' operation of trains. A previous FRA-sponsored study on preview information in the control of high-speed trains indicates that locomotive engineers respond favorably to preview information (Einhorn, Sheridan & Multer, 2005). It is unclear how moving map displays will affect freight locomotive engineer operation, but it is assumed that they will aid locomotive crew situational awareness by providing route preview information. This can help the locomotive crew plan ahead to ensure they are maintaining the train's speed and schedule. The weight and dynamics of a train are such that it takes a long time for the train to speed up or slow down in response to what the engineer does at the controls, therefore an engineer may need to start braking two miles before a signal in order to reach the appropriate slower speed that is required by the time the train reaches it. This makes it critical that engineers have advance awareness of the location of things such as signals, hills, and turns relative to the location of the full length of the train on the route. Although engineers are required to be familiar with their territory, situational awareness might be enhanced by having a moving map that displays these important pieces of information.

Moving map displays are currently in limited railroad use. But because of their inclusion in new technologies such as Positive Train Control (PTC) and locomotive energy management systems, moving maps are increasingly being implemented in the railroad environment. In particular, PTC systems—and the moving maps these systems contain—will see more widespread use in future years since the Rail Safety Improvement Act of 2008 has mandated that PTC systems be implemented on all Class I railroads by December 2015. In light of these changes, it is important to know more about the display's anticipated use and its potential impact on locomotive crew performance.

At this stage of moving map integration, stakeholders and researchers can only speculate as to how moving maps will affect operator performance. For example, moving maps may improve operator performance by accelerating familiarization with the route and enabling operators to become experts more quickly. Future moving map research will help to determine more precisely how these displays affect operator performance and may suggest design changes or information enhancements that ensure maximum performance and safety.

1.2 OBJECTIVES

This was the first human performance study that the John A. Volpe National Transportation Systems Center (Volpe Center) conducted using FRA's new locomotive research simulator—the Cab Technology Integration Laboratory (CTIL). This research study has two objectives: (1) to exercise CTIL research capabilities and provide hands-on experience to Volpe researchers on CTIL functions by conducting a pilot experiment and (2) to provide a basic example of the type of experiment and data analysis that can be conducted in the simulator for those seeking to conduct CTIL research. This first effort was a "pilot experiment" in the sense that the goal was to help resolve minor CTIL issues associated with the system's use. Therefore, (a) the hypothesis is not based on previous research, (b) the moving-map display used is a new display generated specifically for CTIL rather than a standard moving map used in current cab technology, and (c) qualified locomotive engineers were not used in the study.

1.2.1 BENEFITS AND LIMITATIONS

A pilot experiment is an effective tool for exploring technological capabilities because it allows researchers to have a real-world context on which to base their exploration and information-gathering. In proceeding as though this were an actual experiment, the same steps and procedures were followed to ensure an effective test of the system.

Benefits of this work include the following:

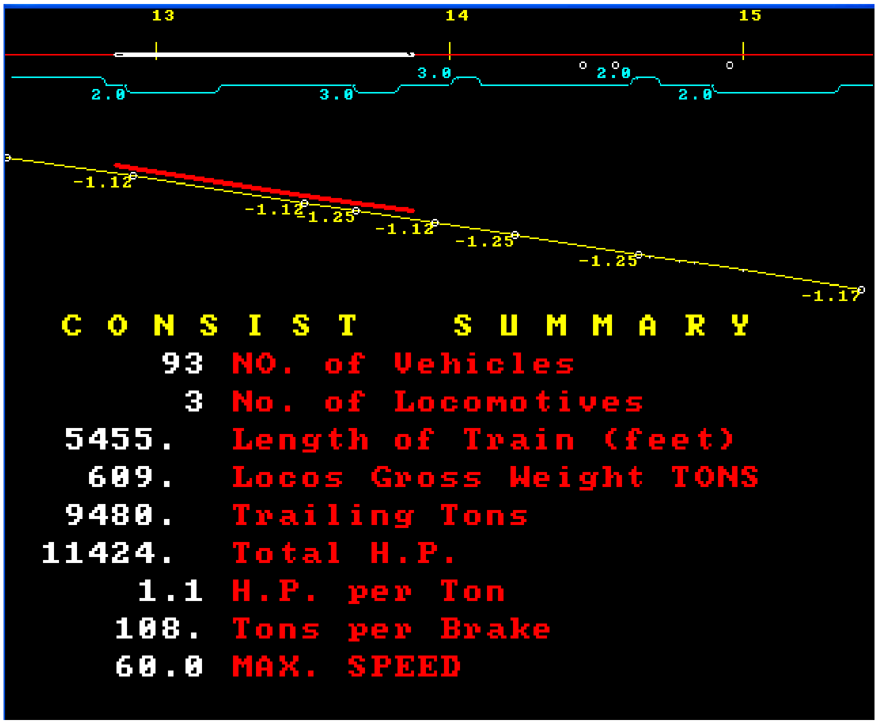
(a) Providing exploratory, hands-on training to Volpe staff;
(b) Allowing any technical issues with the system to be addressed early in the CTIL life cycle and before they impact any future research projects; and
(c) Refining the CTIL research process outside the context of an actual experiment, which will ultimately ensure better use of funding and less risk to CTIL projects and the CTIL program.

Given that CTIL experiments studying moving maps may be planned for the future, a moving map experiment seemed an appropriate choice for a pilot CTIL study. Volpe staff hope this study will supplement future research on how moving map displays affect operator performance in freight rail operations. It is important to remember, however, that there are limitations to the information this study can provide given the goals with which it was designed; it is being done within a moving map context, but is not a moving map study. Therefore, it will not result in data that can inform moving map design or use. Additionally, it is not designed to be an exhaustive exploration of the entire CTIL system.

2. METHOD

2.1 OVERVIEW

This preliminary research will help FRA understand how locomotive moving map displays can affect operator performance. The study was carried out in the CTIL using the imbedded moving map display designed by Alion Science and Technology Corporation (see Figure 1). Participants were novice train operators with no train operating experience.



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C O N S I S T     S U M M A R Y
       93  NO. of Vehicles
        3  No. of Locomotives
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    9480.  Trailing Tons
   11424.  Total H.P.
      1.1  H.P. per Ton
     108.  Tons per Brake
     60.0  MAX. SPEED
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Figure 1. Moving map display designed by Alion Science and Technology

Participants were given specified target speeds (e.g., 30–50 mph) to follow without exceeding as they operated over 13 miles of prebuilt track. In the *Paper Chart plus* Moving *Map* condition, participants operated the train over the 13 miles of track with the CTIL moving map display visible. In the *Paper Chart Only* condition, participants completed the same 13-mile route without the use of the moving map display. In both conditions, participants were provided with a paper-based track profile that displayed vital information about the route.

2.2 PARTICIPANTS

Because of the nature of the study—a pilot experiment—it was jointly determined by Volpe and FRA that trained locomotive engineers were not required for the project; the added cost and time required to retain experienced locomotive engineers would not be well spent in this particular case—especially in light of that fact that Boston, the city in which the experiment was conducted, does not have a freight rail hub, so no qualified locomotive engineers are in close proximity to the research facility. For these reasons, the moving map study utilized participants with no prior rail experience. In the current document, participants are referred to as *surrogate engineers*.

Seven participants (six males, one female) were recruited through email solicitation to serve as surrogate engineers at Volpe facilities in Cambridge, MA. All surrogate engineers were Federal employees who signed on voluntarily and had no train operating experience. The experiments were carried out during the workday (with the consent of the participants' supervisors) so no monetary compensation was provided.

2.3 EXPERIMENTAL DESIGN

The study employed a within-subjects design so that all surrogate engineers were run in both experimental conditions: *Paper Chart plus Moving Map* and *Paper Chart Only*. The number of surrogate engineers starting each condition first was counterbalanced using alternating assignment, with the first participant's order selected randomly.

Surrogate engineers were provided with the minimum training required in railroad signals and operations to run the route using CTIL. This involved two training runs followed by feedback after each run to familiarize surrogate engineers with operating CTIL and with the routes. Route familiarization was deemed important because engineers are certified on the routes over which they operate and so become intimately familiar with the territory. Providing at least some degree of familiarization was deemed more representative of a real-world scenario than having the surrogate engineers go into the experimental trials with training on different routes.

Objective performance measures for analysis were chosen based on the knowledge that study participants were surrogate engineers and many performance measures may not be meaningful for those without extensive experience in train handling (e.g., fuel consumption, brake pipe pressure, buff and draft forces, and number of throttle changes). Some of CTIL's other data capturing and analysis tools (e.g. the head-and-eye tracking device and human performance and behavioral modeling tool (LOCAT)) were not used for the same reasons. Consequently, performance measures related to speed control, that is, the ability to maintain the permitted speed (in reference to signal adherence, track warrants/terrain restrictions, and general operation), were selected for examination. The following criteria were monitored:

- Frequency of speed violations: number of times the engineer goes at least 1 MPH over the speed limit
- Magnitude of speed violations: severity of the violation—expressed by the number of mph over the speed limit
- Duration of speed violations: length of the speed violation—expressed by the number of seconds the violation lasted

It was expected that those in the *Paper Chart plus Moving Map* condition would have less frequent, less severe, and shorter speed violations than those in the *Paper Chart Only* condition.

2.4 ROUTE SIMULATION

Apparatus

All of the experiments were conducted in the CTIL simulator located at the Volpe Center (Figure 2). CTIL is a portable, full-sized locomotive simulator owned by FRA. It is the first and only locomotive simulator in the United States designed primarily for human factors research, rather than for training purposes. CTIL is managed on site by Volpe researchers and is available to industry, academic, and government researchers.

Figure 2. Exterior and interior view of CTIL

Scenario

Currently, there is no data to suggest that train consist and terrain affect moving map use. However, discussions with stakeholders, including a former locomotive engineer, did suggest that they might; therefore, experimental design guidance regarding these factors was provided. A short, heavy train operating over mountain grade territory (grades over 0.5 percent) was selected because it was thought that this type of scenario (which required the engineer to exert more control over the locomotive due to the increased tonnage and grade) would best showcase the performance of the moving map.

2.5 PROCEDURES

The surrogate engineers were run individually, with each data collection session lasting approximately 3 hours. The sessions included study discussion and informed consent, training, two practice runs, experimenter feedback on practice runs, experiment instructions, two experimental runs, debriefing questions, and intermittent breaks.

The procedure for each participant was as follows:

1. The surrogate engineers began by reading about the study and signing an informed consent sheet. Each participant was given an opportunity to ask the experimenter questions related to the study.

2. The surrogate engineers received approximately 15 minutes of training on train handling and driving the CTIL, including instructions on how to read the moving map display. The surrogate engineers were provided with an instruction sheet (see APPENDIX A) and asked to follow along while the experimenter read them out loud.

3. The surrogate engineers completed two practice runs over 13 miles of track (the same track used in the experimental runs). During the first practice run, the experimenter remained in the CTIL with the participant. The simulation was paused after 10 minutes to allow the experimenter to provide feedback to the participant and answer any questions. The simulation was then resumed and the participant finished the first practice run. Upon completion of the practice run, the experimenter again provided the participant with feedback on the run and answered participant questions. For the second practice run, the participant was left alone in the CTIL (without experimenter help) while the experimenter observed from the researcher station (equipped with a camera and voice input/output so the experimenter could see, hear, and speak to the participant, if necessary). Upon completion of the second practice run, the experimenter gave the participant feedback on the run and answered any additional questions. Each practice run took approximately 25–30 minutes, followed by 5–10 minutes of experimenter feedback and a 5–10 minute break.

4. The surrogate engineers were given verbal and written experiment instructions (See APPENDIX B) while in the CTIL and had the opportunity to ask the experimenter questions.

5. The surrogate engineers completed the first experimental run, followed by a 5–10 minute break.

6. The experimenter reiterated the instructions and the surrogate engineers conducted the second experimental run.

7. The surrogate engineers were debriefed on the experiment (APPENDIX C). This took no more than 15 minutes.

3. RESULTS

Given that this work was intended to serve as a pilot experiment and not a true moving map study, results must be interpreted within that context. The results do not address any specific research questions about moving maps, but they are fairly indicative of the analysis process and will likely help stimulate ideas for analysis in future moving map research projects. Data from the experiment were analyzed and the results are shown below. The lessons learned from this process will be addressed in the discussion section of the report.

Overspeeds

The number of overspeeds was one of the primary dependent measures of the study. Of particular interest was whether there would be fewer overspeeds in the moving map condition. The surrogate engineers did in fact have fewer overspeeds when the moving map was available (M = 1.71, SD = 1.80) than when they did not have the moving map available (M = 2.00, SD = 1.73). However, a Wilcoxon signed-rank test showed that the difference in overspeeds was not significant, Z = -.707, p = .24.[1]

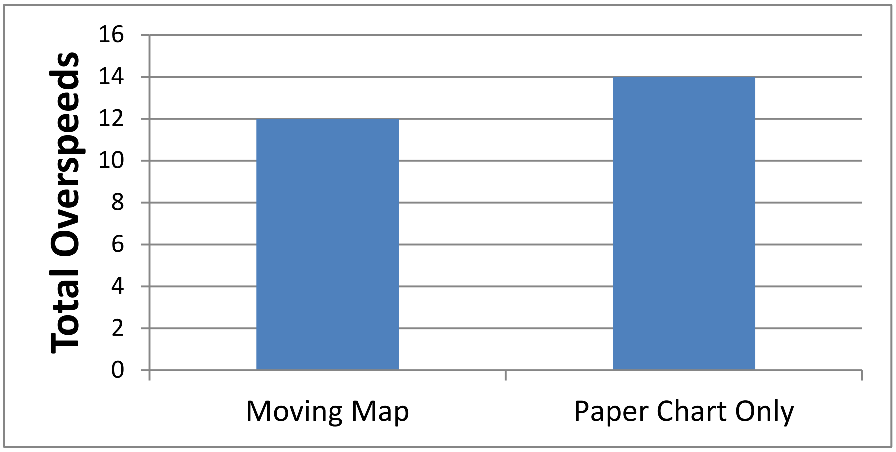

Figure 3. Total overspeeds for the Moving Map and Paper Chart Only conditions

The other aspects of speed control were the magnitude and duration of the overspeeds. The average duration of overspeeds, expressed by the number of seconds the surrogate engineers were operating over the allowable speed limit, was smaller in the *Paper Chart plus Moving Map* condition than in the *Paper Chart Only* condition (M = 7.90, SD = 8.18 versus M = 11.35, SD = 12.51, respectively). The average magnitude of the overspeeds, expressed in mph over the speed limit, was very similar for the two conditions but slightly higher in the *Paper Chart plus Moving Map* condition (M = 1.86, SD = 2.13 versus M = 1.56, SD = 1.25).

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[1] The Wilcoxon signed-ranks test was used because the data does not meet the assumptions required for a t-test to be performed. The Wilcoxon-signed ranks test is a nonparametric test so it does not compare means in the same way that a t-test would, but means and standard deviations are included in the report for further information.

There was no statistically significant difference in the duration of the overspeeds (Z = -.73, p = .23), nor in the magnitude of the overspeeds (Z = -.105, p = .46).[2]

It was also interesting to look at the mean durations and magnitudes considering only the nonzero data points. Where overspeeds did occur, how long were they on average? The average duration of overspeeds that occurred (greater than zero)—expressed in number of seconds the surrogate engineers were operating over the allowable speed limit—was smaller in the *Paper Chart plus Moving Map* condition than in the *Paper Chart Only* condition (M = 11.06, SD = 7.52 versus M = 15.89, SD = 12.02, respectively). Also, when overspeeds did occur, what was their average magnitude? The average magnitude of the overspeeds that occurred (greater than zero)—expressed in mph over the speed limit—was very similar for the two conditions but slightly higher in the *Paper Chart plus Moving Map* condition (M = 2.61, SD = 2.10 versus M = 2.18, SD = 0.81, respectively).

Consideration of Underspeeding

In analyzing the data set, the research staff considered whether some surrogate engineers may have run the route significantly slower than the speed limit in an effort to avoid any overspeeds. If this were the case, it could account for some of the differences observed in the number of overspeeds made by some surrogate engineers.

Table 1 shows the number of overspeeds by participant. The number of overspeeds ranges from zero for participant #1 to nine for participant #6. To determine if the surrogate engineers were actively employing a strategy of underspeeding to avoid overspeeds, experimenters examined run completion times and overspeeds for each participant—based on the premise that run completion time and number of overspeeds should be inversely related.

Participant	Paper Chart plus Moving Map	Paper Chart Only	Total
1	0	0	0
2	1	0	1
3	1	1	2
4	3	4	7
5	0	2	2
6	5	4	9
7	2	3	5

Table 1. Total overspeeds by participant and condition

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[2] In order to test the magnitude and duration data for significance, the average duration and magnitude were considered to be zero in cases where no overspeed ocurred. This allowed all surrogate engineers to be included in the Wilcoxon-signed ranks test instead of excluding those that did not overspeed in at least one of the two conditions (three of the seven surrogate engineers).

A square root transformation was done to normalize the count data. Figure 4 shows the relationship between number of overspeeds and total completion time. As expected, there is an inverse relationship between overspeeds and run time; although it is not statistically significant (r =.61, p >0.05), the relationship accounts for more than 38 percent of the variance in the data.

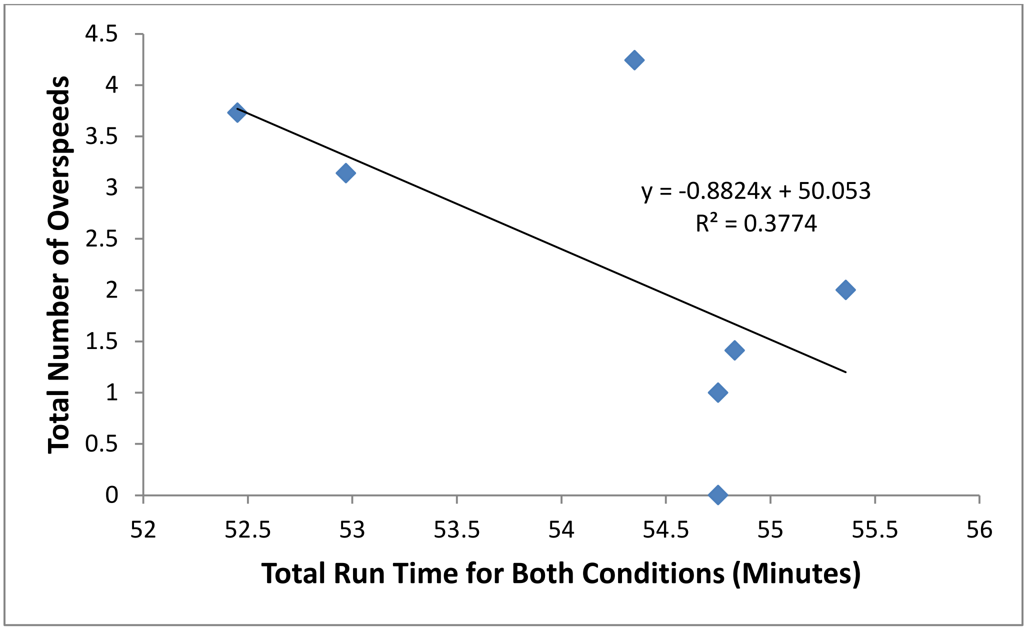


Figure 4. Relationship between overspeeds and run completion time

Further Options for Understanding and Visualizing Speed Data

Overspeeds were further separated into three different types of situations in which they might occur:

- Missed Signal Overspeeds: the surrogate engineers missed a signal indicating they needed to slow down;
- Early Acceleration Overspeeds: the surrogate engineers were headed into a section of track with a higher speed limit and sped up too early; and
- Control Overspeeds: the surrogate engineers demonstrated a general problem controlling the speed of the train; the problem was not directly attributable to a signal or changing speed authority.

Figure 5 shows the number of overspeeds in each category. With a greater number of data points, breaking down overspeeds into categories such as these might be useful for understanding the context behind the overspeeds that occur.

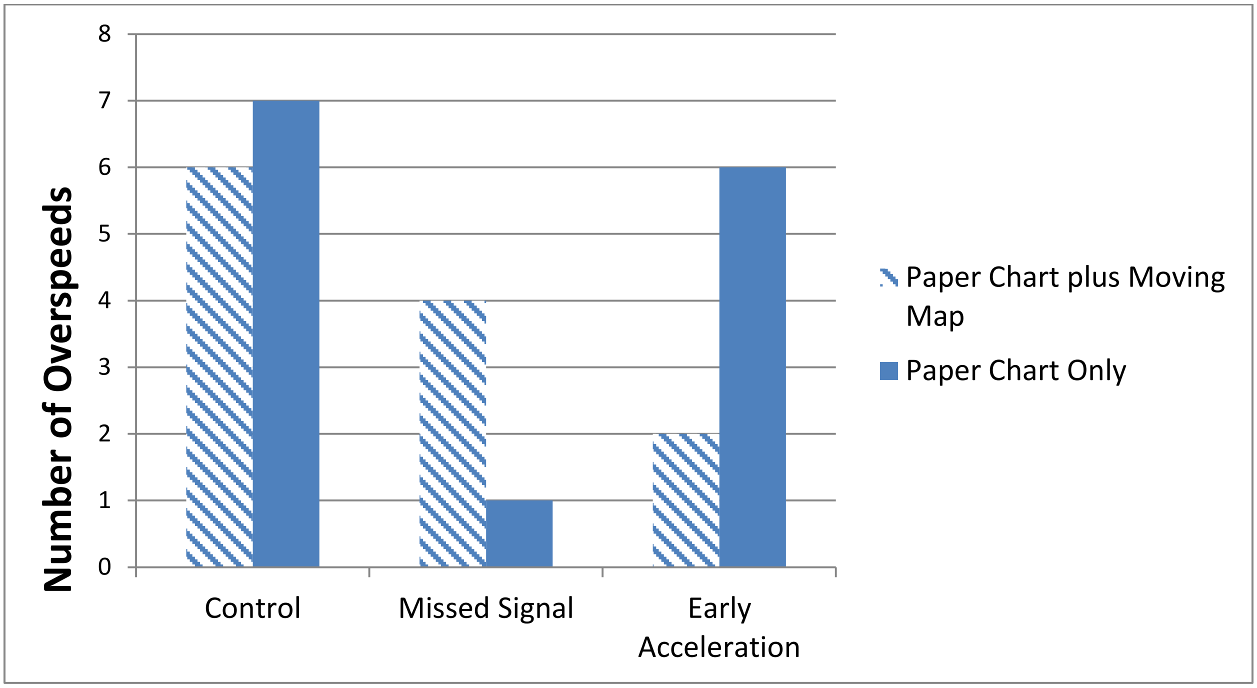


Figure 5. Comparison of overspeeds for missed signals, early acceleration, and control

For speed, the primary dependent measure, Figure 6 provides a visualization of the entire run as well as the speed changes that occur during the run. This example displays the run of participant #4 in the *Paper Chart Only* condition. The vertical lines delineate where speed limit changes (i.e., the engineer's maximum allowed speed) occurred. The numbers along the top show the maximum permitted speed in the section of track between the vertical lines. A chart such as this could be useful for examining participant speeds (or other dependent measures) at a particular area(s) of interest along the route; it would also enable researchers to gain a better understanding of participants' responses and behaviors.

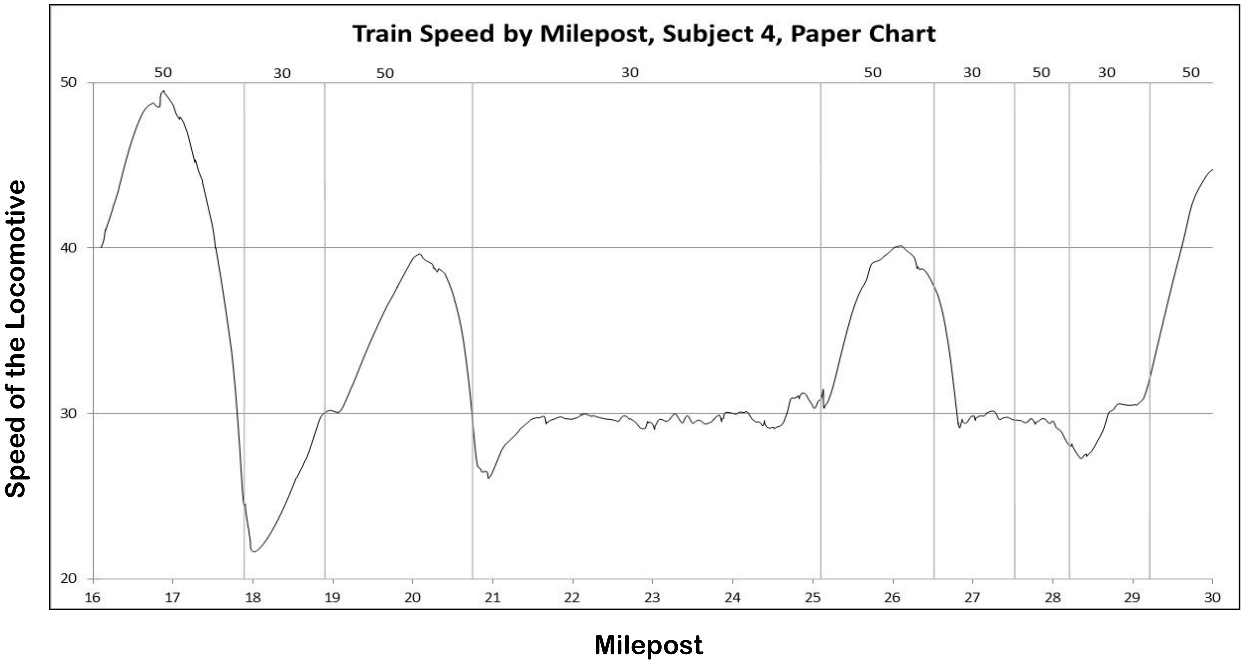


Figure 6. Example chart displaying train speed by milepost for participant #4

4. DISCUSSION

As previously mentioned, the current study was primarily intended to provide hands-on training experience to researchers and serve as a way to evaluate the CTIL simulator. Operator performance with and without a moving map display was the research focus of this pilot experiment; however, obtaining statistically significant and valid results was not the study's primary purpose. Rather, the objective was to demonstrate the capabilities of CTIL and to uncover and document lessons learned that may be useful in designing future CTIL experiments. This final section discusses lessons learned and suggestions for future research on moving map displays.

4.1 SURROGATE ENGINEERS VERSUS CERTIFIED LOCOMOTIVE ENGINEERS

Training and Train Operation

One of the questions raised by this pilot experiment is whether novices are acceptable substitutes for freight engineers in research studies. Because novices have little to no knowledge of railroad operating rules and locomotive operations, they will operate the simulator differently than experienced engineers, and this will limit the generalizability of the research findings. However, the exact limitations of using surrogate engineers are likely to be dependent on what is being studied.

Researchers sought to mitigate these effects by providing the novice surrogate engineers with both CTIL training and a brief railroad operating rules training, as well as allowing the participants to have practice runs in order to become familiar with the route. However, 15 minutes of training and the accompanying 50 minutes of practice runs do not equate to official engineer railroad training courses and years of experience operating a freight locomotive.

Surrogate engineers are also unlikely to succeed at tasks that center on accurate train handling, such as coming to a complete stop close to a red signal. Additionally, because of their limited understanding of how the locomotive will react to changes in the throttle, novices may spend more time monitoring displays in the cab for speed information instead of also observing the outside environment through the window. This can be dangerous because when the engineer spends more time "head down" (i.e., looking down at displays or other objects in the cab), the likelihood of missing important events outside the cab (e.g., signal changes, trespassers, objects on the track, etc.) increases. Several surrogate engineers noted during the debrief session that they spent most of their time monitoring the acceleration display in order to control their speed. Presumably, surrogate engineers relied heavily on the acceleration display to stay within the speed limit because they did not understand how the train's characteristics (i.e., train weight and length), coupled with the territory characteristics, would affect train handling. Experienced engineers understand these relationships and would likely need fewer throttle changes to stay within speed limits. Therefore, certain data measures such as buff and draft forces, number of throttle changes, brake pipe pressure, and fuel consumption may only be meaningful in experiments using experienced engineers.

Potential for Invalid Data

Compared with certified engineers, surrogate engineers are more likely to make different mistakes which may not be related to the research question. For example, during the moving map experiment, one participant accidently engaged the emergency brake during both experimental runs, which caused the train to come to a complete stop and resulted in no usable data from that participant. Another participant noted in his response to the debrief questions that because he knew the moving map would be removed eventually, he did not want to rely on it. As a result, he refrained from using the moving map in the practice runs and both of the experimental runs, even when it was available to him. This case conveys the importance of planning for the possibility of invalid data and the value of enlisting slightly more surrogate engineers than necessary.

Another point to consider regarding surrogate engineers is that they do not have the same sense of time pressure that would be felt in an actual railroad context. Although the experiment instructions explicitly stated that the surrogate engineers should operate the train as close to the maximum allowable speed as possible without going over, during practice runs and experimental runs, researchers noted that the surrogate engineers frequently did not accelerate to that maximum speed of 50 mph in the allowable zones.

Route Familiarization

Another area of concern identified by the researchers is related to the experience and route familiarity of the person running the train. If the surrogate engineers have no experience operating over the route used in the experiment, it may mean that their behavior is not representative of what would be seen in a real-world context where locomotive engineers are intimately familiar with their route. (And even in cases where certified locomotive engineers are used, this concern would still exist if they are running a route other than the one(s) on which they were certified.)

The researchers attempted to address this issue by using training runs to acquaint surrogate engineers with the routes. Surrogate engineers were given two practice runs over the entire 13 miles of track. The runs took approximately 25–30 minutes per practice route. With longer routes, practice runs will take significantly more time; this should be considered in future planning processes.

If full track practice runs are not possible for the experiment, one option is to use territory with which the engineers are already familiar. (However, the researcher may still want to include some practice time to ensure the participant is familiar with the simulator.) Because surrogate engineers have no prior rail knowledge, using territory with which they are already familiar is not a viable option. Therefore, when surrogate engineers are used, shorter routes may be the best solution to ensure that they experience several practice runs over the entire route.

4.2 RUNNING SIMULATOR STUDIES IN CTIL

In addition to providing a better understanding of the implications of using surrogates in place of experienced engineers, this study also served as practice in setting up CTIL experiments. By executing a study from start to finish using CTIL, researchers were able to compile lessons learned for future experiments. Note that these lessons learned relate specifically to the CTIL software designed by Alion Science and Technology and some may not apply to upgraded versions of the simulator that use different software.

CTIL Track Chart and Scenario Development

When scenarios are constructed, consideration must be given to developing a corresponding paper track chart. For experiments that require the use of real-world track, corresponding track charts that can be used with little editing are likely to already be available. Frequently, however, it may be more economical or more ideal to build a simulated track or use already built CTIL scenarios—in the following instances, for example:

> *Time and Cost Sensitive Projects.* Many railroads consider information contained in their track charts to be proprietary information. Therefore, if an experiment is not affiliated with a particular railroad, obtaining engineering information sufficient for recreating a desired existent track may require a monetary outlay. Additionally, the steps required to build an existent track require a long period of data collection, programming development, and testing. As a result, experimenters who intend to operate CTIL on a short schedule or small budget should consider using modified versions of scenarios that have already been built in CTIL, such as the default provided by Alion.
>
> *Designing for Research Needs.* If the research needs allow for it, experimenters may consider using track scenarios with fewer embellishments. Simplifying the track scenario can streamline the process of creating a track profile. For example, researchers may consider using zero-grade scenarios in fatigue studies (assuming operator performance on grade is not a data measure), as track profiles that do not need to accurately depict grade are easier to create.
>
> *Unrequired Realism.* In some cases, investing the time and money required to make an authentic track profile may not be necessary. For instance, if an experimenter were interested in developing a separate scenario to be used in a training run, it would be considerably simpler to use a scenario that has already been built rather than building one from engineering documents.

When simulated track is used (i.e., track designed specifically for the experiment and which is not representative of track in the real world) a procedure is needed for the reverse-engineering of accurate paper track charts based on the digital scenario. CTIL's scenario authoring environment does not allow automatic creation of paper track charts, so that needs to be done manually.

For the current pilot experiment, researchers decided to use an edited version of the Alion-provided scenario. Following scenario edits, the Alion-provided paper track chart was edited using Adobe Photoshop to match the track profile used in the experiment. Although this is a viable process, it is also potentially error-prone since any small changes on the digital route need to be identified manually. Without an internal version management system, the paper chart and automatically-generated moving map were frequently out of sync and required many iterations of testing and updating to ensure that they matched.

Additionally, during the experiment, a previously existing discrepancy between the moving map display and the paper track chart—a discrepancy not due to the edits made for the current work—was discovered. (A slight grade was depicted on the paper track chart along a section of track that the moving map displays as flat terrain; generally, in fact, the moving map display showed exaggerated grade compared with the paper track chart). This finding further highlights the need for a more automated and accurate procedure for creating track charts, particularly in studies where they are of central importance. Options for reverse engineering accurate paper track charts still need to be explored, but one possible way to facilitate this is through computerized evaluation of track definition files (tdf), which hold track scenario information in the software.

During the study, another technical issue relating to the alerter sounding during experimental runs was discovered. A previously noted idiosyncrasy of CTIL is that if the simulation freezes (either because it has ended or been paused) with the alerter sounding, the sound will continue until the simulator is restarted. During the moving map experiment, the simulation run ended two times while the alerter was sounding and necessitated a restart of the simulator. A solution for this is to place an event towards the end of the scenario that requires the participant to use the controls. For example, adding a whistlepost and grade crossing before the end of the scenario will require the participant to sound the horn and this will prevent the alerter from activating.

Data Collection and Analysis

Unlike some simulators which display information directly related to specific events, the CTIL data output is time-based. It records experimenter-specified simulator state variables at regular intervals of up to 20 Hz. Data collection frequency for the experiment should be determined ahead of time to ensure a consistent resolution in the data of all subjects. In this study, it was collected at 3 Hz because resolution of the data was not critical and the slower collection frequency yields an easily manageable data set. Below is a brief primer on time-based data collection and analysis.

> Because data is only collected at regular intervals, linear interpolation must be used to insert simulator state values for events that occur at specific locations such as signals and the beginnings and ends of permanent speed restrictions. For example, assume one subject was recorded at 31 mph (v_0) when he was 30 feet from a signal (p_0), and again at 29 mph (v_1) when he was 50 feet beyond it (p_1). Given this information, we can use the following formula to estimate his speed (v) when the head end of the train was passing the signal (p):
>
> $$\frac{v - v_0}{p - p_0} = \frac{v_1 - v_0}{p_1 - p_0}$$
>
> In this case we know the values for all of the above values except *v*, the speed of the train at the signal. Solving for *v* reveals that the train is travelling at 30.25 mph at that point.
>
> Of course, the values of these recorded continuous variables are not likely to be linear. As a result, it is clear that for experiments that seek to examine data at very precise locations, data collection frequency should be increased. Additionally, a very fast run will have data points that are spaced farther apart than a slower run that uses the same sampling rate. Therefore,

the higher the maximum expected speed of the train, the higher the sampling rate should be set.

4.3 IMPLICATIONS FOR FUTURE MOVING MAP RESEARCH

Further moving map research is needed to understand how the inclusion of a moving map display affects operator performance in freight rail operations. To obtain data that can be generalized to the freight rail industry, efforts should be made to design a study utilizing certified locomotive engineers operating over familiar territory, as this better simulates a real-world scenario. Additionally, when possible, experiments should be designed to encompass a multitude of real-life conditions. Focus groups with professional, experienced locomotive engineers may uncover situations in which the moving map displays may be more or less useful; for example, daytime versus nighttime conditions and/or when operators are fatigued.

For the current study, researchers purposely created an objectively difficult route that included a short, heavy train operating in territory with a host of hills and curves, and passing through sidings and grade crossings. Despite this, the surrogate engineers did not perform better when they had access to the moving map. The ability to simulate night conditions and adverse weather in future experiments may make the scenario more difficult and therefore require the participant to rely more heavily on the tools available (as opposed to looking out the window to assess the operating territory). Another interesting measure to study in moving map research is fatigue. Future studies using eye-tracking devices to measure fatigued engineers’ use of moving maps may shed light on how often engineers refer to moving maps and under what circumstances. Additional study options include adding dynamic objects to the scenario (such as a passing train or a car driving across a grade crossing), or stopping scenarios mid-run and checking operator situation awareness.

Finally, the current experiment tested the Alion-designed moving map display installed in CTIL. Future moving map research should test moving map displays already in use (or proposed to be in use) by the industry, as different moving maps may have varying effects on operator performance.

4.4 FUTURE RESEARCH

Questions remain regarding how moving map displays are actually used by engineers and conductors. Engineers are required to have detailed knowledge of their territory before they are permitted to run trains on it, so the “look ahead” functionality of a moving map may not appeal to experienced engineers who already know when to expect signals, curves, etc. Furthermore, some railroads may prefer that engineers use their knowledge of the route rather than relying on the moving map display to ensure that they retain their route knowledge and do not become dependent on the moving map. Given the engineers’ knowledge and the job expectations, questions remain as to what extent moving maps are used and under what situations.

Possibilities for future research regarding operator use of moving map displays are presented below for consideration.

Possible Uses

- Confirmation/Redundancy: If it's the case that engineers know their routes so well that they don't need the map, it's possible that in many cases (i.e. ideal conditions), the moving map may be used primarily as a redundancy check.
- Training: One potential use of moving maps in train operations that may deserve further consideration is in training new engineers, or training experienced engineers over new routes.
- Conditions of fatigue: Are moving maps used differently under conditions of fatigue? For instance, in the event that an engineer does become drowsy and loses situational awareness, is the moving map a useful tool in quickly verifying critical information?
- Poor weather or poor visibility conditions: Can moving maps be used to determine train position information in situations where it would be difficult to view out-the-window landmarks?

Possible Moderating Variables

- Experience level of the engineer: Do new engineers use the moving map more often (and in different ways) than more experienced engineers? What kind of experience plays a factor—overall train handing experience, experience with that particular route, or both?
- Territory/Run characteristics: Are moving maps likely to be more useful in certain territory (e.g., mountain grade territory rather than flat terrain), or during certain scheduled runs (e.g., night runs)?

As moving map displays become more commonplace in the rail operating environment, additional research is needed to discover how operators use moving map displays and under what conditions. Research findings may suggest design changes or enhancements that will ensure maximum performance and safety.

5. REFERENCES

Einhorn, J., Sheridan, T. B., and Multer, J. "Preview information in cab displays for high-speed locomotives." Rep. No. DOT/FRA/ORD-04/12. 2005. Washington, DC: U.S. Department of Transportation.

Yeh, M., and Eon, D. "Surface moving map industry survey." Rep. No. DOT-VNTTSC/FAA-09-15. 2009. Washington, DC: U.S. Department of Transportation.

APPENDIX A.
TRAINING DOCUMENTATION FOR MOVING MAP STUDY

Controls Related to Speed

Throttle:

- Increases the train's speed. *Think of this like the gas pedal in a car.*
- Pulling to the left (back) attempts to increase speed and pulling to the right (front) attempts to decrease speed.

There are 2 methods of braking. Which one you should use depends on how fast you are going when you need to break.

Dynamic brake:

- Use at slow speeds (30 mph or less).
- Pulling to the left attempts to increase speed and pulling to the right attempts to decreases speed. But…
- The handle for dynamic brake *will not move unless the throttle* is *disengaged*.
    - *Therefore,* using the dynamic brake requires two steps:
      (1) place the throttle in its left-most position (Idle)
      (2) move the dynamic break to the right.
- Dynamic brake only affects the locomotive (the front of the train)

Automatic brake (the red lever):

- Pull the red lever to the right and leave it in the position marked "minimum" for a few seconds before pulling it further.
- The maximum braking mode using this brake is an emergency mode. Do not pull the automatic brake past the area marked "full service" or the train will come to a full stop. (It takes a long time to start the train back up again, so that is why this is only for emergencies.)

Other Controls

Alerter:

- An automatic safety alarm designed to make sure you're awake in the cab.
- When the alerter sounds, press the large yellow button to acknowledge it. (Do this within 9 seconds or the train will automatically come to a full stop.)

Whistle:

- Use the whistle to warn any motorists that a train is coming.
- Pull the metal lever on top of the control stand between the whistle post sign and the crossing where the road intersects the tracks.

Environment

Mileposts indicate where you are along the route. They appear exactly every mile and they look like this:

Whistle posts are signs that indicate you should blow the whistle. They look like this:

As you approach road crossings, there will be a *W sign* on the side of the railway. When you pass the sign, pull the whistle lever and hold it until the head of your train passes through the roadway intersection.

Turnouts are portions of the railway where the tracks intersect. If you are to leave your current track via a turnout, you will follow a speed restriction as indicated by the signal.

Signals are akin to traffic lights. They tell you the speed at which you should operate the train for the near future. The descriptions of the different signal types are posted inside the train's cab.

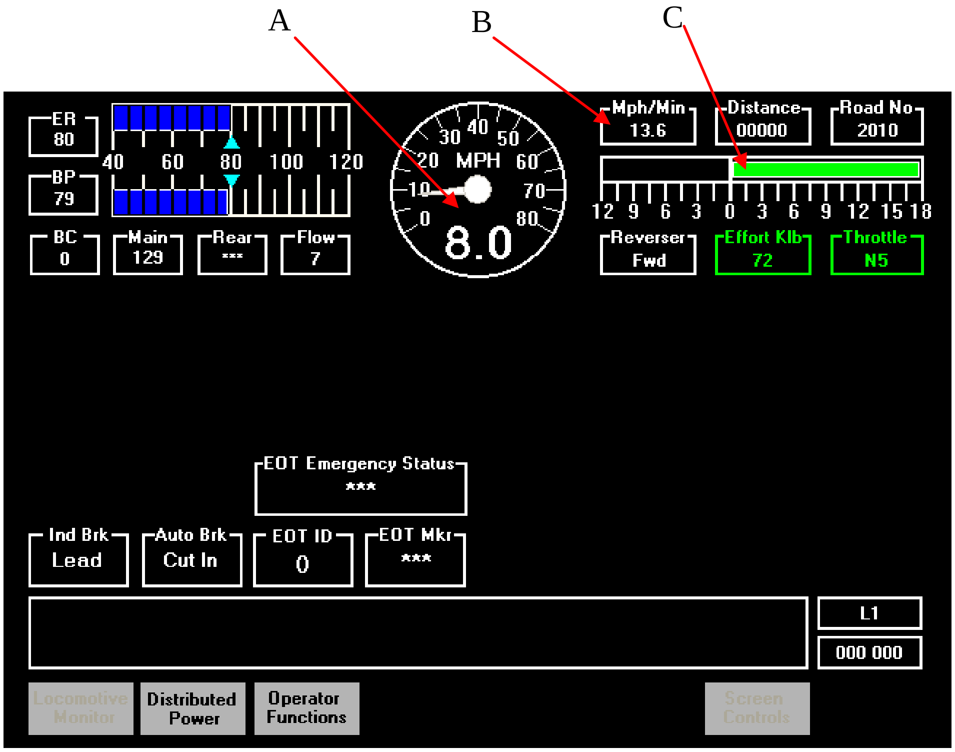
Track Warrants indicate speed restrictions in place for your route. It will contain data similar to the information below:

> Do not exceed 60 mph
>
> Between Milepost 15 and Milepost 16 make all movements at restricted speed (25 mph). Limits occupied by train or engine.
>
> Do not exceed 50 mph between Milepost 23 and Milepost 30.

Displays

Standard Display

Below is an image of the train’s standard display and a description its most important elements.



ER 80
BP 79
BC 0
Main 129
Rear ***
Flow 7
8.0
Mph/Min 13.6
Distance 00000
Road No 2010
Reverser Fwd
Effort Klb 72
Throttle N5
EOT Emergency Status ***
Ind Brk Lead
Auto Brk Cut In
EOT ID 0
EOT Mkr ***
L1
000 000

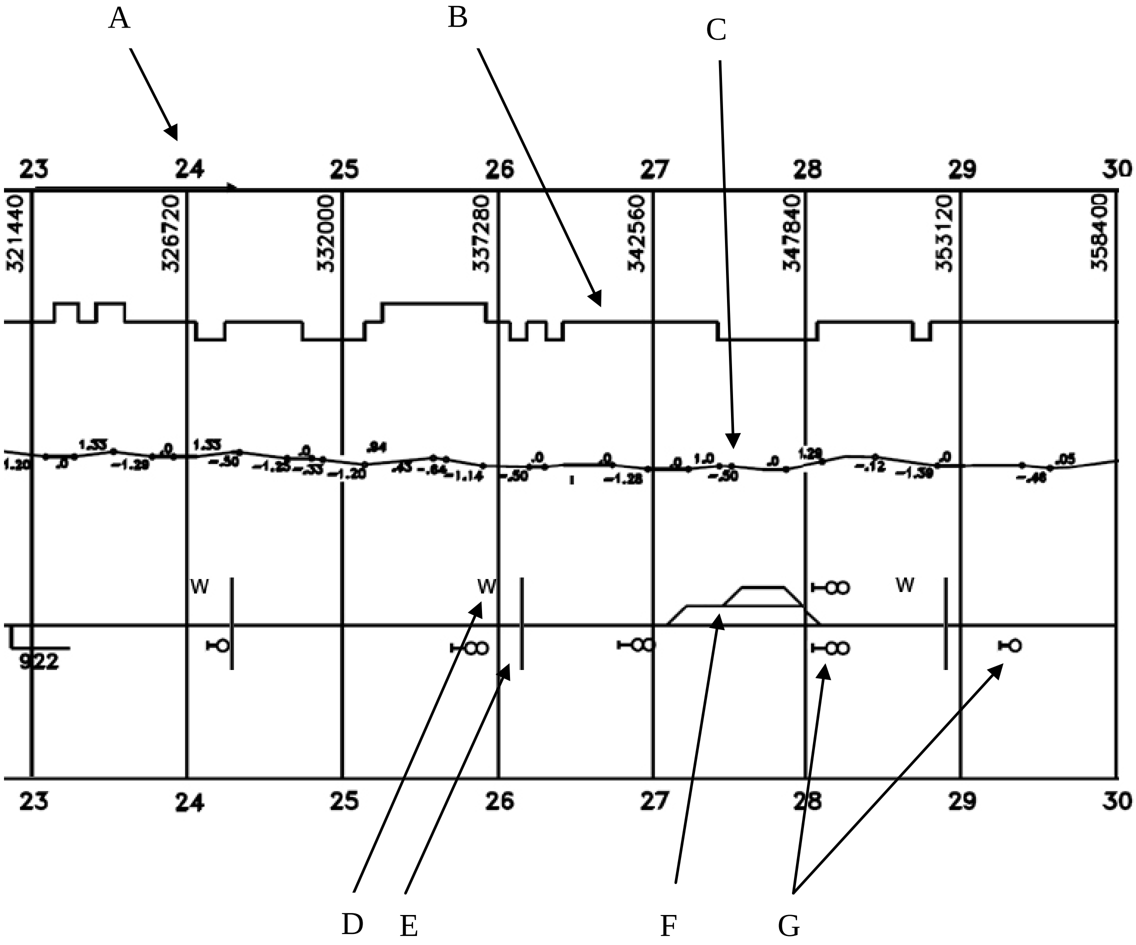
a) **Speedometer** indicates current speed in mph

b) This indicator shows your **acceleration** in mph/min. For example, if your current speed is 30mph and this indicator shows -5 mph/min, this means that in one minute your speed will be 25 mph.

c) **Energy Field Indicator** shows whether power is being applied to the train.

Paper Track Chart

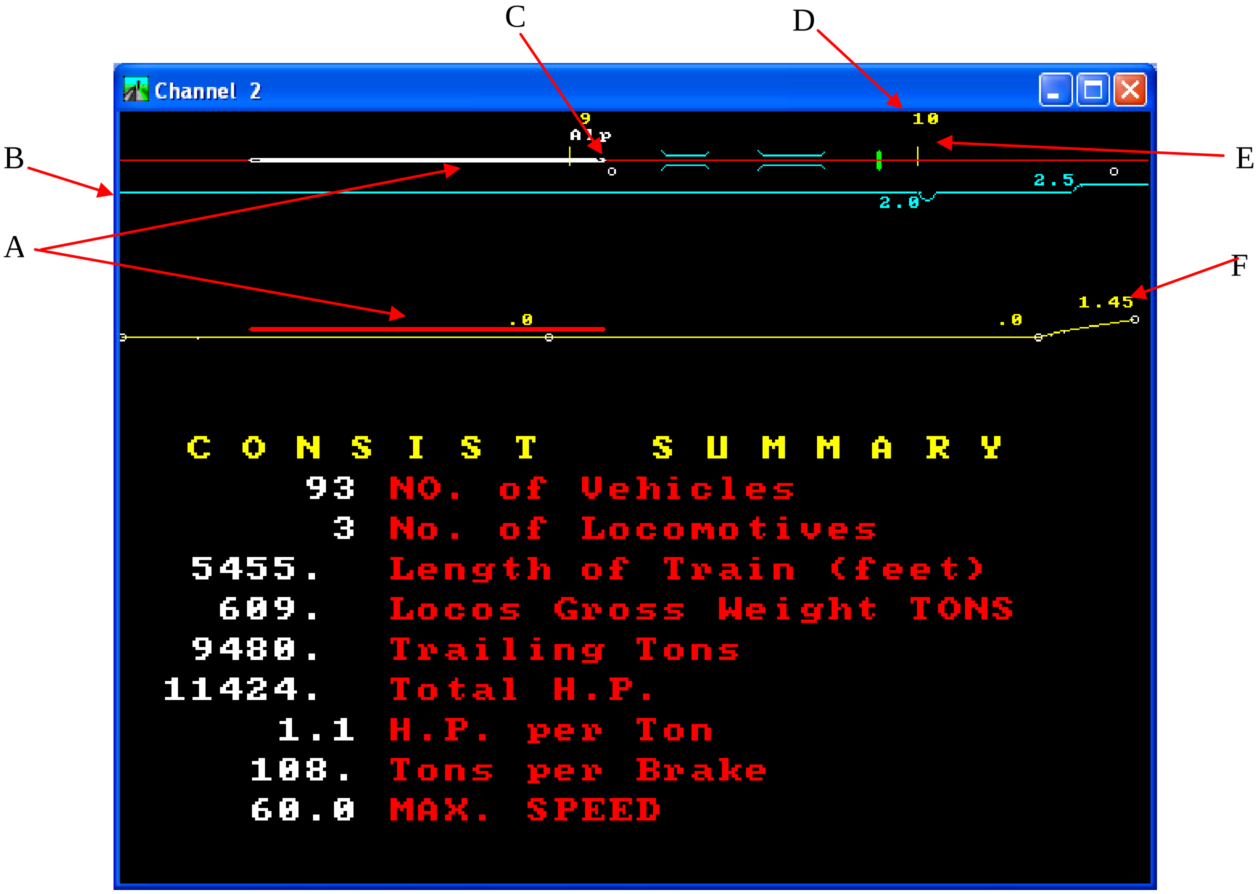
For both experiment runs you will be given a paper copy of the track chart to use. Below is a copy of the track chart, and descriptions of its features.



a) The numbered vertical lines indicate the **milepost** along the railway.
b) The top horizontal bar indicates the direction of upcoming **turns**
c) This line, along with annotations of positive or negative numbers, indicates the degree of incline or decline, known as **grade.** Positive numbers are inclines. Negative numbers are declines. A grade of greater than 1 is considered a steep grade.
    - The number shown is the number of vertical feet per 100 horizontal feet. Therefore, grade changes are difficult to perceive by looking out the window.
d) The W symbol indicates a **whistlepost** and will always precede a grade crossing.
e) The short, vertical line bisecting the horizontal track indicates a **grade crossing.**
f) These lines show upcoming **turnouts.**
g) This symbol indicates an upcoming **signal.** Signals can have two heads or one head (both shown here)

Moving Map Display

You will be asked to run the train through the route twice. One of these times you will have access to a *moving map display on the dashboard for additional help. (The other time the moving map* display will be covered up and unusable.) Below is an image of the moving map display and description of its most important features.



```
C O N S I S T     S U M M A R Y
       93  NO. of Vehicles
        3  No. of Locomotives
    5455.  Length of Train (feet)
     609.  Locos Gross Weight TONS
    9480.  Trailing Tons
   11424.  Total H.P.
      1.1  H.P. per Ton
     108.  Tons per Brake
     60.0  MAX. SPEED
```

a) The red or white bars here show the **position of your train.**
b) The middle bar shows upcoming **curves** on the track.
c) The white circles indicate the location of **upcoming signals**
d) **Mileposts**
e) This bar on top shows upcoming **turnouts**, and **bridges.**
f) This is the degree of incline or decline, called grade. Positive numbers are inclines and negative numbers are declines. A grade greater than 1 is considered a steep grade.

APPENDIX B.
TASK INSTRUCTIONS

Task A [disabled Moving Map]

You are an engineer hauling grain to a farm. There is a train behind yours, so it is important to keep the train on a tight schedule. In order to succeed at your objective you must:

- Adhere to required **speed restrictions**. Stay as close to the speed limit as possible *without going over it*. The following items indicate speed restrictions:
    - Information on you **track warrant** showing the speed to follow over portions of the track.
    - States of the **signal heads** that you pass along the way. To supplement the training you have undergone, the meaning of the signal heads will additionally be posted inside the train cab.
- Respond to **whistle post** signals by blowing the whistle to warn motorists, starting from the time when the cab passes the sign to the moment the cab passes through the grade crossing.
- Acknowledge the **alerter** by pushing the yellow button in the cab when it sounds. It must be acknowledged quickly, before the train applies its emergency brake.

For this route, **portions of the in-cab computer display will be disabled.**
Your track warrant and a copy of the signal head definitions are provided on the following pages.

Task B [enabled Moving Map]

You are an engineer hauling grain to a farm. There is a train behind yours, so it is important to keep the train on a tight schedule. In order to succeed at your objective you must:

- Adhere to required **speed restrictions**. Stay as close to the speed limit as possible *without going over it*. The following items indicate speed restrictions:
    - Information on you **track warrant** showing the speed to follow over portions of the track.
    - States of the **signal heads** that you pass along the way. To supplement the training you have undergone, the meaning of the signal heads will additionally be posted inside the train cab.
- Respond to **whistle post** signals by blowing the whistle to warn motorists, starting from the time when the cab passes the sign to the moment the cab passes through the grade crossing.
- Acknowledge the **alerter** by pushing the yellow button in the cab when it sounds. It must be acknowledged quickly, before the train applies its emergency brake.

Your track warrant and a copy of the signal head definitions are provided on the following pages.

APPENDIX C.
DEBRIEFING STATEMENT

This study is the first in a series of studies in the Cab Technology Integration Laboratory aimed at understanding how technology affects operator performance. The goal for this study is to understand how the inclusion of a moving maps display – a computer-based, track profile display that depicts the moving train along the route – can affect operator performance in freight rail. Specifically, we are interested in comparing how people run the train when provided with a moving map display versus when it is unavailable to them. Information such as speed and signal adherence will be compared for the routes when the moving map was available with when it was not available.

If you have any questions, comments or concerns about any aspect of this experiment, please feel free to discuss them now. Or, you can contact Hadar Rosenhand at hadar.rosenhand@dot.gov at a later time. Thank you for your participation!