A Systems Approach for Developing, Designing, and Transitioning Moving Map Technology in U.S. Rail Applications

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ABSTRACT

Safety, efficiency and productivity are top priorities for rail industries, but technology implementation faces many barriers. While the demands of locomotive engineers and railroads are increasing, the industry lacks a clear roadmap for technology development, design, and transition for in-cab display technologies. The needs and goals of the moving map, a representative in-cab display technology, are characterized via an analysis of the stakeholders and other sociotechnical influences. These activities are conducted in parallel with requirements generation, design, prototyping, and evaluation.

Through an analysis of sociotechnical influences, the main industry barriers to transition of in-cab display technologies are identified: a lack of a unified industry stance on the direction of in-cab technologies; ineffectiveness developing, implementing, and overseeing standards; and a need for a systems approach throughout the lifecycle of a technology. A strategic approach is needed for the industry to be able to successfully (efficiently, affordably, safely) transition these technologies across U.S. Rail. A committee chartered to identify and create roadmaps for significant technologies, such as moving maps, can facilitate these objectives and is recommended. The trend in transportation and in foreign rail service is shifting toward increased levels of automation and an Advanced Automation Roadmap is recommended.

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LIST OF ACRONYMS

AAR	Association of American Railroads
ABS	Automatic Block Signaling
ACSES	Advanced Civil Speed Enforcement Systems
CFR	Code of Federal Regulation
CLIOS	Complex, Large-scale, Integrated, Open Systems
CTA	Cognitive Task Analysis
DoD	Department of Defense
DTO	Driverless Train Operation
DL	Decision Ladder
EFB	Electronic Flight Bag
ERTMS	European Rail Train Management System
FELA	Federal Employers' Liability Act
FIR	Federal Railroad Administration Information and Functional Requirements
FRA	Federal Railroad Administration
GCOR	General Code of Operating Rules
hCTA	hybrid Cognitive Task Analysis
HSE	Human Systems Engineering
HSI	Human-System Integration
HSR	High Speed Rail
INCOSE	International Council on Systems Engineering
IR	Information and Functional Requirements
km	kilometers
kph	kilometers per hour
MIILO	Minimum Information Interface for Locomotive Operations
MIR	MIILO Information and Functional Requirements
mph	miles per hour
NEC	Northeast Corridor
NORAC	Northeast Operating Rules Advisory Committee
OEM	Original Equipment Manufacturer
REMSA	Railway Engineering-Maintenance Suppliers Association
RSI	Railway Supply Institute
RSSI	Railway Systems Suppliers, Inc.
SA	Situation Awareness
SAR	Situation Awareness Requirement
STO	Semi-automatic Train Operation
STO	Scenario Task Overview
TAG	Technical Advisory Group
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
UTO	Unattended Train Operation

1. INTRODUCTION

1.1. MOTIVATION

Safety, efficiency and productivity are top priorities for rail industries, but technology implementation faces many barriers. This can be seen by the challenges of implementing Positive Train Control (PTC) [1] or High Speed Rail (HSR) in the U.S. Rail transportation system where other countries have been operating with these systems for years. Positive Train Control, as defined by the Rail Safety Improvement Act of 2008 is "a system designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left in the wrong position"[1, 2]. According to international HSR rail operations in 2012, the U.S. had one of the lowest maximum operating speeds (240 kph) as compared to countries with maximum speeds at 300 kph or greater (France, Germany, Italy, The Netherlands, Spain, United Kingdom, South Korea) and fewer kilometers of HSR tracks (362 km) versus Spain (2056 km), France (1896 km), or Germany (1285 km) [3]. Thirty-four countries have implemented PTC in the form of European Railway Traffic Management System (ERTMS) [4], while the U.S. is struggling due, in part, to the fact that many of these countries deployed PTC systems much earlier than the U.S. [5].

Locomotive cab design, a critical part of any rail system upgrade including PTC, is an identified area of improvement for the U.S. Rail industry evidenced by Technical Advisory Groups (TAG) [6] and conferences [7] on the future design of locomotive cabs. In these meetings, representatives of Class I railroads, Original Equipment Manufacturers (OEMs), American Association of Railroads and the Federal Railroad Administration agree that a systematic approach is necessary for cab design, especially in an environment where technologies such as PTC and energy management systems are or will be incorporated into locomotives. Moving map displays, a representative futuristic cab technology for US Rail, are a case study specifically explored in this thesis, which highlights the growing trend of incorporation of new technologies in train management systems. This thesis will explore both the design and development of this representative technology, but also addresses the remaining question of how such designs can be transitioned to operational use/practice in an ecosystem that already has a track record for being behind the technology curve.

1.2. PROBLEM STATEMENT

The ecosystem of U.S. Rail is extremely heterogeneous. There are seven Class I railroads[1] and 560 Class II and Class III freight railroads [8], each with varying operating practices, signals, rules and equipment. In addition, passenger rail often shares track with freight railroads; 72% of Amtrak tracks leverage host railroads [9]. This creates multiple customers for the OEMs, who have to strike the balance between customizing products to please everyone or risk losing business to the next OEM in the highly fragmented U.S. market. For example, in passenger rail and intercity rail, there are twenty Tier 1[2] OEMs and 153 Tier 2[3] firms [10] both domestic and international that serve the U.S. market. A representative from one of the major U.S. OEMs lamented that two different Class I Railroads can request differ-

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[1] Class I Railroads are U.S.-owned and operated line haul railroads with revenues of over $433.2 million in 2011.

[2] Tier 1 OEMs produce assembled railcars or locomotives and also produce the body and design

[3] Tier 2 firms supply components or subsystems to Tier 1 firms

ent design changes on the same component, i.e., position of a switch, based on feedback on user preference [7]. Legacy equipment and decades of operating in the same manner play a large part in differences in user preference, familiarity, and constraints to changes in the cab. In addition to being highly segmented, the U.S. Rail industry is very capital intensive with many stakeholders, adding further complexity to developing and transitioning technologies in locomotive cabs. Moving map displays are chosen as a representative technology through which development and transition of in-cab technologies will be investigated, however, a number of in-cab informational aids such as scheduling, planning, fuel management, head-up displays, etc. could have been chosen for which the same methodology would apply.

In-cab displays will support increasing levels of automation and supervisory control, as are the trends globally in rail systems and in other industries. These technologies can allow for safer operations with increased throughput [11]. Take, for example, the train derailments that occurred in Spain and New York in July and December of 2013, when the trains approached curves too quickly resulting in multiple fatalities [12, 13]. Technologies to warn the train crew, stop the train, remotely control the train, or detect track defects could have prevented such events. From 2005 data, the Federal Railroad Administration determined that 72 percent of all U.S. train accidents are a result of human factors and track defects [14].

A holistic design, development and implementation approach to display technologies in the U.S. Railroad industry is needed that considers:

1. Human factors
2. Key stakeholders and their interactions
3. Upstream and downstream sociotechnical influences
4. Technology transition research

This thesis explores the issues of design and implementation for moving map displays in the context of cab redesign efforts in U.S. Rail through the lenses described above in order to provide recommendations for transitioning such technologies.

1.3. Research Methodology

The scope of this research is U.S. Rail, both freight and passenger, with a focus on in-cab moving map displays for locomotive engineers. Determining the boundaries of the problem is important first step in that this forces the researcher to stay within the problem-space, identify internal and external factors and determine the appropriate level of detail or abstractness instead of moving too quickly into the solution-space without the opportunity to explore options.

A requirements analysis can be considered a first step in analyzing stakeholder needs and is conducted in parallel with ecosystem characterization. The goal of the requirements analysis to understand the roles, tasks and cognitive functions involved with the operation of running a locomotive as well as external constraints such as safety, regulations, etc. Specifically, a hybrid Cognitive Task Analysis (hCTA) systematically determines requirements for an interface to a complex system and was conducted for the U.S. Rail leveraging earlier works [15]. In parallel with the human factors effort, research is conducted to understand the wider ecosystem of study. This involves understanding the stakeholders, stakeholder value proposition, stakeholder interactions and sociotechnical upstream and downstream influences. A prototype moving map display is developed using the requirements analysis and design principles after which informal and formal feedback is solicited.

With a prototype based on sound human factors principles and an understanding of the ecosystem, research is then conducted on how to transition such technology and a list of questions is developed in order to ask stakeholders, at varying levels, their perspective on technology transition issues. These questions are asked both informally through routine conversations with those in the industry and formally, as additional questions asked at the end of a usability study. Lastly, recommendations for moving technologies from concept to practice for moving maps displays are provided.

1.4. THESIS ORGANIZATION BY CHAPTER

This thesis is organized into 8 chapters:

- Chapter 1, *Introduction*, provides the motivation, problem statement and research methodology
- Chapter 2, *Background*, provides a brief history of locomotive cab technologies and specifically moving map technologies
- Chapter 3, *Human Systems Engineering*, covers the steps taken to understand the problem and the user to derive information and functional requirements
- Chapter 4, *Design of the Display*, details the process by which the display was designed and describes the resultant design
- Chapter 5, *Evaluation*, covers the informal and formal evaluation of the prototype moving map display
- Chapter 6, *Technology Transition in Rail*, discusses technology transition in U.S. Rail within the context of sociotechnical considerations such as stakeholders and influences
- Chapter 7, *Conclusion*, provides recommendations for developing, designing and transitioning moving map and other similar technologies in US rail applications based on the findings of the previous chapters

2. BACKGROUND

2.1. RAIL INDUSTRY

The job of a locomotive engineer is becoming increasingly more complex as speeds are increased for high-speed rail corridors [10]. Demand for freight services is expected to increase by 22 percent of its demand in 2010 by 2035 [16]; and there are pressures for increased productivity and safety while minimizing environmental impact [17], while increasing levels of automation. Cab technologies are emerging in order to adapt to these changing conditions and also to comply with regulations such as the mandate for Positive Train Control [2]. 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 targeted first [18].

As demands are increased on the railroad and its locomotive engineers, technology solutions will be considered in order to meet these demands. Examples of technologies recently implemented in the U.S. include train management systems and remote control locomotives. Train management systems 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 [19].

Remote control locomotives are trains where an operator that is not on the train controls train movement via a remote control device. Remote control locomotives were implemented in the U.S. starting in 2002 to improve safety and decrease time/effort spent assembling and disassembling locomotives in yard operations [20] [21].

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) [11]. 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 [11]. Forty percent of "automated lines," a mix of STO, DTO, and UTO, are in Asia [11].

2.2. Moving Maps

Moving maps and other preview displays are widely used in the commercial automotive industry and in airplane cockpits in order to graphically provide drivers and pilots information about the surrounding environment, help with driving/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" [22].

Why is situation awareness a concern? Locomotive engineers are expected to memorize many details, both static and changing, regarding their routes in addition to taking into account variable external factors, such as weather, and internal factors such as train weight and length, all while maintaining 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 out-the-cab, resulting in decreased SA and potentially decreased safety. A single display that provides locomotive engineers with a centralized source of much 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/her time and attention looking out the cab.

Moving map displays have been considered for locomotive engineers as early as the 1970's, albeit for training or simulators [23]. 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, NYAB's LEADER, and GE's Trip Optimizer are new systems that have been implemented in a subset of freight locomotives; these systems include a moving map as a part of their en route displays (see section 3.3 for screenshots of LEADER and Trip Optimizer and 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 [5, 24, 25]. In 2013, roughly 1500 of 4,074 Norfolk Southern locomotives were equipped with NYAB's LEADER [26, 27].

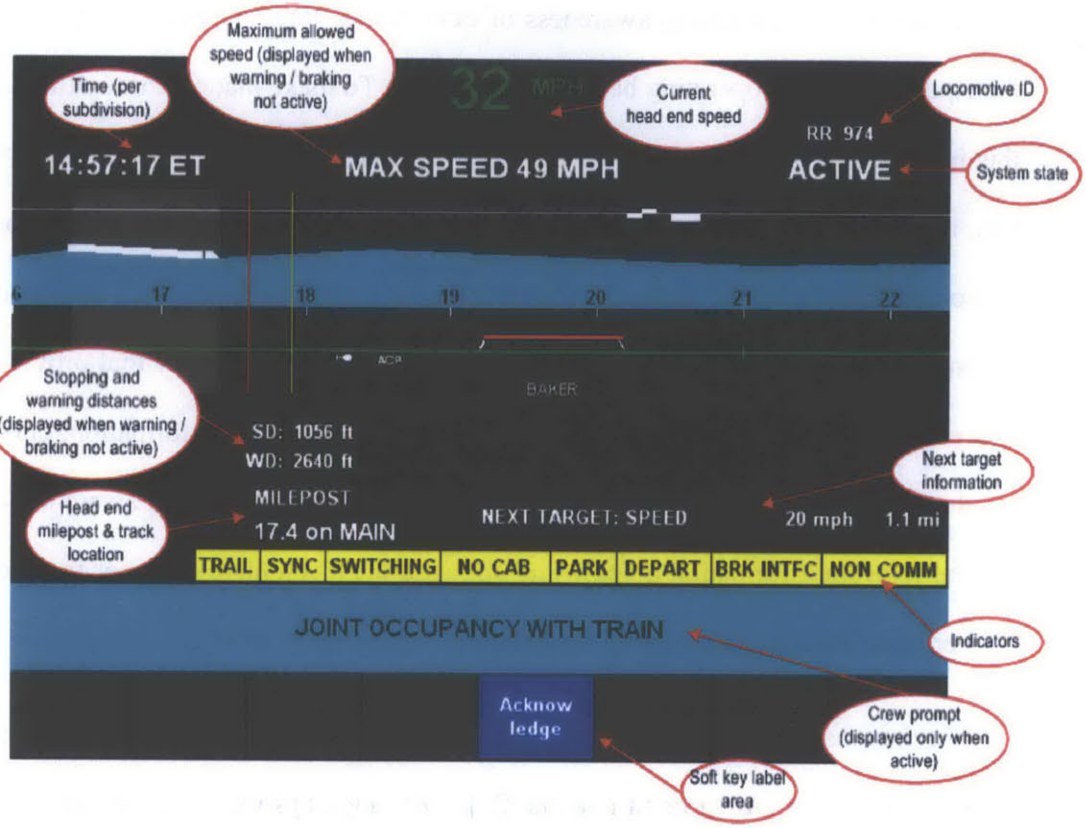

Figure 1: Annotated I-ETMS Display [28]

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 [29]. A "driver assistant system" developed by Swedish company Transrail has developed and deployed a 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) [30].

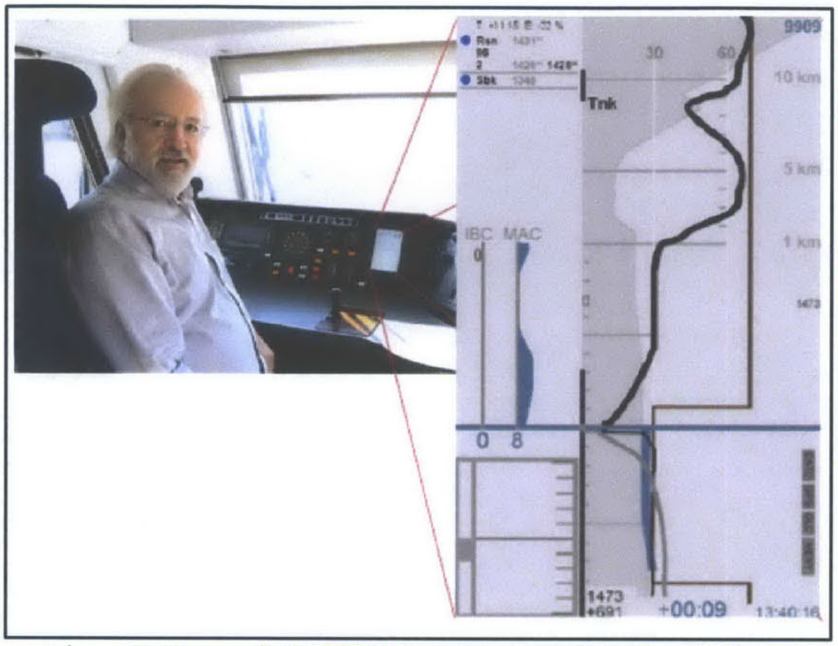

Figure 2: Transrail CATO Driver Machine Interface [30]

While there have been studies on the effectiveness or the distraction of automobile moving maps as early as 1989 [31, 32], similar human-in-the loop studies have not been conducted for moving maps in locomotives. 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 less speed violations; better signal adherence' less time between passing a signal indicating speed should be reduced and initiating braking; and worse at station-stopping accuracy due to the insufficient resolution in the display [33].

3. Human Systems Engineering

Human Systems Engineering is best described as a broad application of Human Factors Engineering to align with Systems Engineering and is also an approach of developing a system concept from function to form (section 3.1). Human Factors Engineering is defined as, "The discipline of engineering concerned with the analysis, design, and development of human-technological systems in which primary emphasis is on the human" [12]. The International Council on Systems Engineering (INCOSE), defines Systems Engineering below:

> Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Cost & Schedule, Performance, Training & Support, Test, Disposal, Manufacturing. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. [35]

Therefore, Human Systems Engineering is the practice of incorporating Human-System Integration[4] (HSI) while maintaining a holistic, systems engineering approach during the whole lifecycle of the system. Although the field of HSE is gaining traction in both academia and industry, it is still underrepresented as a formalized discipline. In systems with a high degree of human interaction, such as some locomotive engineer displays, processes and

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[4] Human-System Integration is "concerned with ensuring that the characteristics of people are considered throughout the system development process with regard to their selection and training, their participation in system operation, and their health and safety. It is also concerned with providing tools and methods meeting these same requirements to support the system development process itself [36].

methods from this field should be used to ensure that the system meets the needs of the user and functions within the overall system.

The first step in the HSE process involves understanding the problem as well as the needs of the stakeholders and goals of the system. In addition, the HSE process involves understanding the tasks and information required by operators to perform their job function, in this case via a hybrid Cognitive Task Analysis (hCTA). From the hCTA, display information requirements are derived and are an input to the design process. The design process for this display involves incorporating design principles, user feedback, and iteration. Once a viable prototype is developed, a formal usability assessment in the form of a cognitive walkthrough is conducted and the results of which can lead to redesign, additional/removal of features, or changes in how the user interacts with the existing functions.

Incorporating HSE practices into the design and development of a system is a necessary component in the successful transition of technology from concept to use. Not only does it ensure that the system aids rather than hinders the users, it also involves key stakeholders early in the process, which increases the likelihood of their buy-in when the system or product is at the level of maturity to be considered for implementation.

3.1. System Architecture Foundation for Display

The first step towards a solution is a clearly defined problem. While many sociotechnical issues were discussed above regarding varying conventions for cab design, track territory rules, acquisition processes, etc., the problem of increasing situation awareness of the locomotive engineers will be the focus of this effort. The sociotechnical and technology transition issues will be addressed within the context of the resultant display/system in order to provide concrete recommendations.

Based on this discussion of the problem and need, a concept and high-level goal is developed as the first step in the architecture of the display. According to Crawley and Cameron, System Architecture is, "the embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of relationships among the elements and with the surrounding context" [34]. A graphic of this mapping of function on to form via a concept is shown in Figure 3.

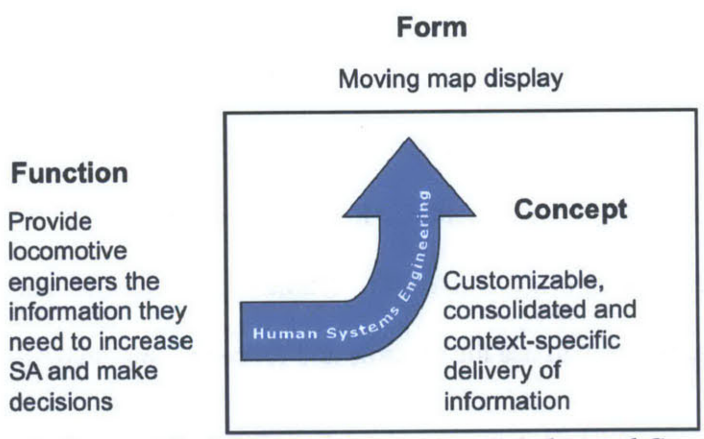

Figure 3: Concept for Display adapted from Crawley and Cameron

The high-level goal of the display is ***to provide railroads and their locomotive engineers with information that they need to increase SA and make decisions in a safe and efficient manner by allowing them to easily interact and access this information***. The high-level goal and concept described here will guide the requirements, design and evaluation. The process of going from function to form for a moving map display will include a Humans Systems Engineering (HSE) approach, which is discussed in the remainder of this chapter.

3.2. INFORMATION GATHERING

Before starting any analysis, a variety of resources were used in order to gain an understanding of the tasks involved in operating a locomotive. These resources are described in the following subsections.

3.2.1. Operational Experience

Often, the best way to learn is by doing. Although taking control of a locomotive was not feasible due to obvious safety concerns and policy restrictions, simulators can be informative substitutes [37].

The Volpe Center's Cab Technology Integration Laboratory (CTIL) contains realistic cab hardware and computer graphics that simulate running a locomotive. Volpe is a part of the U.S. Department of Transportation's Research and Innovative Technology Administration and is located in Cambridge, MA [38]. Numerous visits were made to the CTIL where researchers learned how to use the controls and proceed along preprogramed routes.

Researchers also had the opportunity to observe CTIL experimental runs for a study on distraction where participants traversed routes constructed to be similar to the Northeast Corridor. Trainz®, a Microsoft train simulator, was also used on a desktop computer early in the project for basic familiarization with operating locomotives.

Head-in rides, or trips where one is located in the locomotive cab and able to observe the locomotive engineer during his/her route, were valuable for seeing operational practices in action such as interactions with dispatch and going through paperwork. Additionally, tours of a freight dispatch center, commuter rail stations and a large switching yard provided context for the operating environment.

3.2.2. Interviews

Researchers had the opportunity to informally interview foremen, locomotive engineers and numerous individuals with varying levels of rail expertise to include:

- Volpe employees
- Conductors
- Maintenance Crews
- Dispatch Center Manager
- Retired engineers, active consultants
- Original Equipment Manufacturer (OEM) employees (past and present)
- 3rd Party Manufacturers
- Federal Railroad Administration (FRA) representatives
- Association of American Railroad (AAR) representatives
- Union representatives

3.2.3. Railroad Documentation

US Railroad specific material such as track charts, track warrant forms, timetables, rulebooks and training material were reviewed in order to understand operations and how locomotive engineers use the materials.

Jerry Freadman's Fog Charts (Figure 4) are an example of user-based strategies for learning a route and providing reference material while en route that were mentioned during interviews [39]. The website encourages users to create their own charts for their routes, laminate them and annotate them with information specific to certain time period, such as a temporary speed restriction that is only in effect for a few weeks.

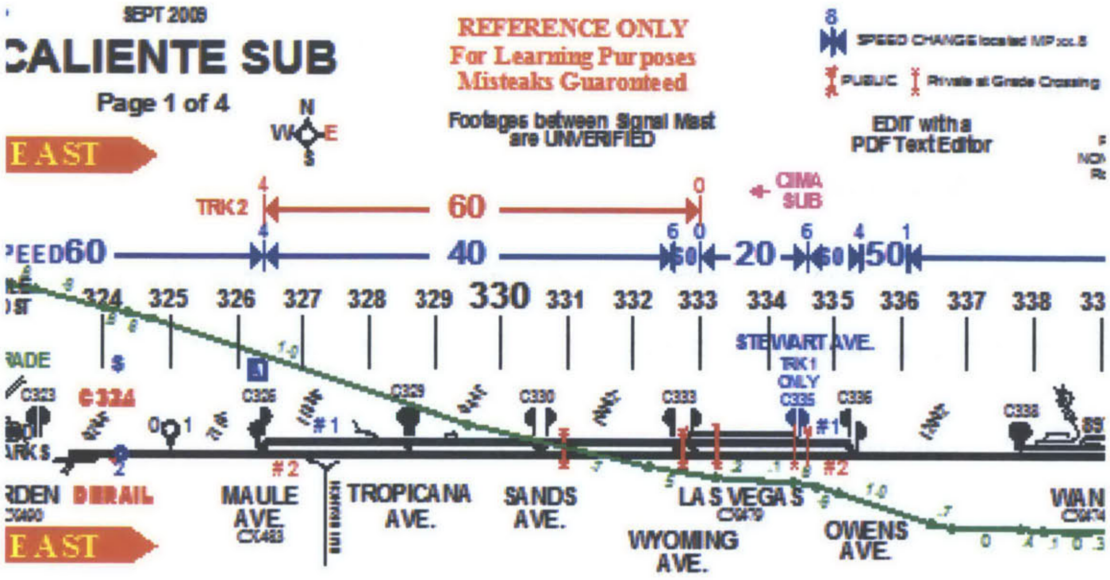

Figure 4: Jerry Freadman's Fog chart

Local track charts and timetables were examined to see how information is currently be portrayed to locomotive engineers. Figure 5 is an excerpt from a CSX timetable booklet showing a depiction of the main line, authorized speeds, mile posts, stations, sidings, authority for movement, etc. These documents are studied by locomotive engineers in order to qualify on their routes and also used to review routes, especially if he/she has not operated on a certain route and would like a refresher.

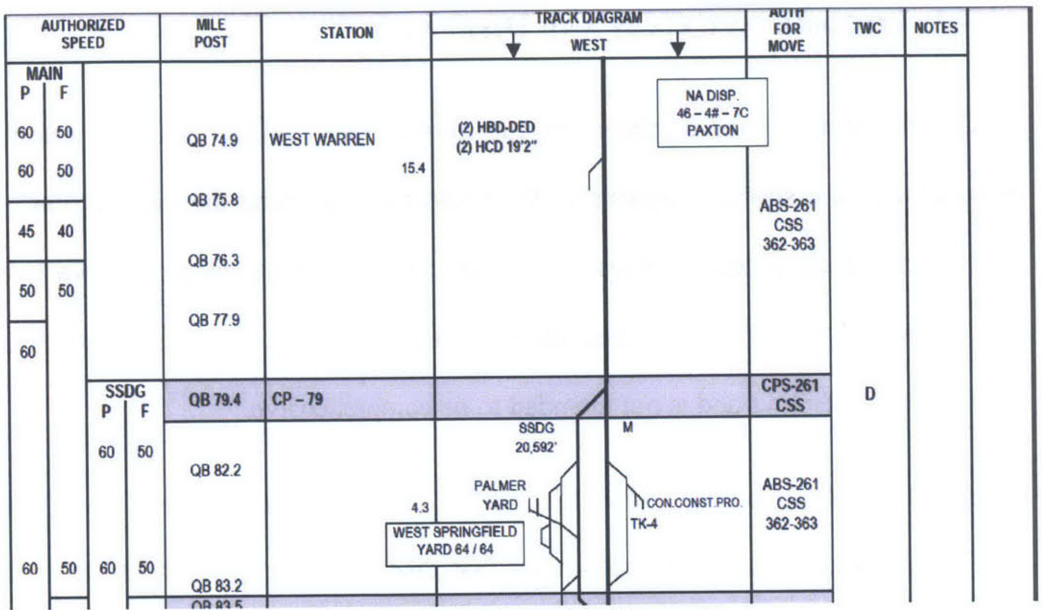

Figure 5: CSX Timetable Excerpt

In addition, documents from agencies such as the U.S. Department of Transportation [40] and Association of American Railroads (AAR) were also reviewed to better understand display constraints. Specifically, Title 49 Code of Federal Regulation (CFR) 229 Part 236 Subpart E does not prescribe requirements for the cab display other than they are plainly visible/audible and tested daily upon departure [41]. AAR Manual of Standards and Recommended Practices Section M Locomotive System Integration Operating Display Standard also describes a similar level of leeway in design:

> Exact graphical representation of the information on the locomotive operating display is not defined as a standard. The appearance of the display items will be determined by the individual railroad. [42]

3.3. LOCOMOTIVE CABS AND DISPLAYS

Existing and planned displays and cab designs vary across the U.S. depending on the manufacturer and specific requests of the company purchasing the locomotives. There are also varying levels of technologies in the trains from analog gauges to Positive Train Control (PTC) systems. A subset of current displays and/or cab control stands are selected to show the breadth of displays and is not intended to be comprehensive.

An Electro-Motive Diesel (EMD) SD60M Cab is shown in Figure 6 [43]. This locomotive control stand has one digital screen that displays speed and is the oldest of the displays/control stands shown in this section.

Figure 6: EMD SD60M Cab

The interior of an Acela cab used in the Northeast Corridor (NEC) is shown below in Figure 7 and a close up of the right screen is shown in Figure 8. The digital display depicts speed, alarms, and train status in addition to analog representations of gauges such as pressure for the braking systems.

Figure 7: Acela Cab

Figure 8: Acela Display

These cabs are equipped with Advanced Civil Speed Enforcement Systems (ACSES) that denote the current and upcoming signal aspects as well as the current speed restriction (See Figure 9 for the display that the locomotive engineers see in their cabs). These systems also have the ability to stop the locomotive when it exceeds the speed restriction.

Figure 9:
ACSES Display

Positive Train Control systems have been developed by a number of companies to include Interoperable Electronics Train Management System (I-ETMS) by Wabtec Railway Electronics (WRE), LEADER by New York Air Brake (NYAB), and Trip Optimizer (TO) by General Electric. Screen shots for Locomotive Engineer Assist Display/Event Recorder (LEADER) and Trip Optimizer modified from a Class I Railroad's training material are shown below in Figure 10 and Figure 11.

Figure 10: LEADER

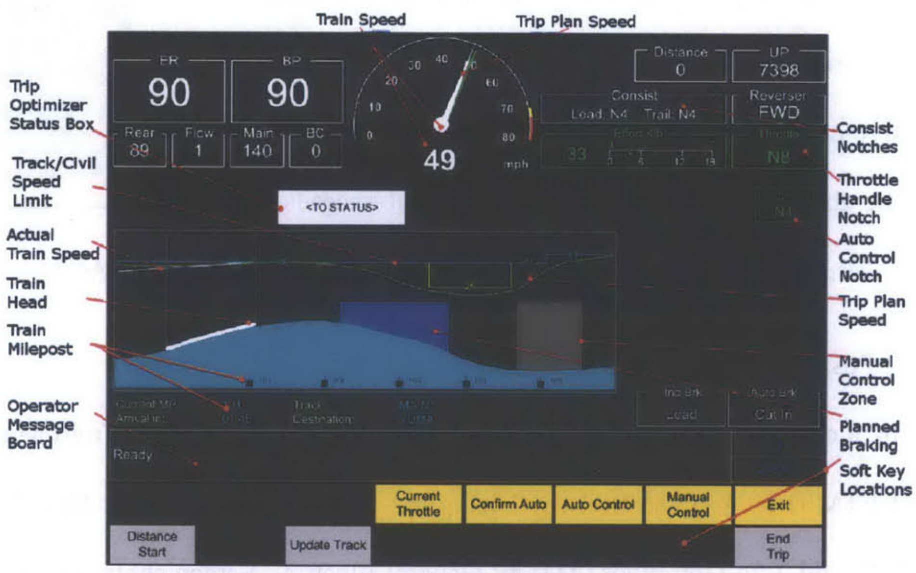

Figure 11: Trip Optimizer

Both LEADER and TO provide the following information as part of the en route displays: speed, system status, speed limit, train head, mileposts, brake pressures, curvature, grade profiles, speed restrictions and also have rolling map displays. Whereas TO provide some consist information en route, LEADER provides this information during initialization, when the latest back office data is transmitted to the system before starting a route.

3.4. Observations from Information Gathering

Understanding current operational practices is one way to identify current system gaps. During the information-gathering phase it became apparent that locomotive engineers develop individualized methods for remembering temporary route changes. Some examples of these methods are listed below:

- Write on sticky notes
- Write on the windshield with erasable markers
- Write on one's hand
- Rewrite list with information pertinent to current route
- Highlight, check or cross out changes that are applicable or ones that have been passed
- Affix paperwork with magnets so that is closer to eye level while gazing out the cab
- Review all paperwork frequently
- Laminate a track-chart like diagram and write directly on the map
- Use physical placement or orientation of objects to signify that an actions has been completed or needs to be completed such as
    - Turn bulletins upside-down
    - Place paperwork directly in front vs. off to the side
    - Place pen in hand vs. not in hand
    - Remove the reverser so that the train cannot move
    - Hang strings

The workarounds listed above point to an underlying need in the design of the system to assist locomotive engineers in remembering key events along their routes.

3.5. Hybrid Cognitive Task Analysis & Requirements

A hybrid Cognitive Task Analysis (hCTA) is a systematic approach to understanding and documenting the processes and information required to perform tasks for a specific operational function [15]. The first step of the hCTA is to divide the tasks into phases of operation, called the scenario task overview (STO). For each phase in the STO, event flow diagrams are created that visually convey dependencies, order of events, decisions and processes. Using the event flow diagrams, situation awareness requirements (SARs) and decision ladders are formulated concurrently. Decision ladders (DL) are created for each complex decision within the event flow diagram, that is, a decision that "involves many variables and uncertain environments" [44]. Decision ladders illustrate the decision-making process for the complex decision 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 [45]. The output of a hCTA is a set of information and functional requirements that are necessary to perform the operational function that is analyzed. The hCTA process is depicted in the Figure 12.

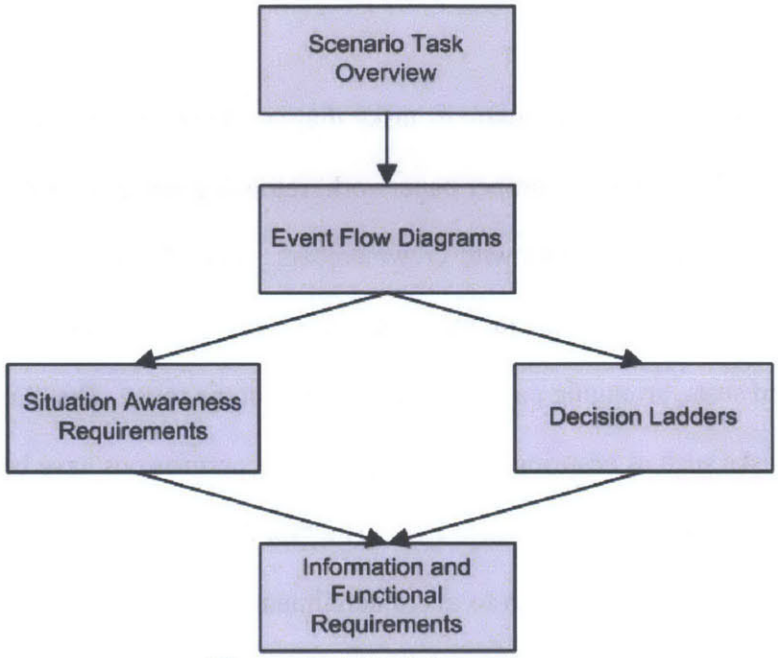

Figure 12: hCTA Process

A previous hCTA that shared many commonalities was extended and modified for this effort [46]. Key aspects of the hCTA are included in the following sub-sections to highlight unique requirements, i.e., information that is not currently provided to locomotive engineers via displays currently in use. A description of the hCTA process for this effort can be found in Appendix A.

3.5.1. Scenario Task Overview

The distinct phases developed for the Scenario Task Overview are listed below. The first five phases were maintained from the previous hCTA and the last phase, End of Trip, was added. The STO phases are listed below [46]:

(1) Departure Preparation
(2) Before Departure
(3) Leaving Station
(4) En Route

(5) Arrival at Station
(6) End of Trip

"Departure Preparation" involves tasks that are done before boarding the train such as gathering and checking the proper paperwork, retrieving personal protective equipment, and attending job/safety briefings with crewmembers. The "Before Departure" phase involves tasks that are done in the cab but before departing such as checking the equipment, adjusting mirrors and seats, arranging paperwork/reminders for the route. The "Leaving Station" phase includes tasks such as ensuring the doors are closed, permissions have been granted to depart, and that the track ahead is obstacle free. The "En Route" phase involves more complicated tasks such as handling the train to avoid derailment, maintaining a schedule and providing a smooth ride for passengers while complying with rules and speed restrictions. The "Arrival at Station" phase involves tasks such as slowing down at an appropriate distance away and stopping at the correct point on the platform. Finally, the "End of Trip" phase involves completing any paperwork regarding the trip and preparing the train for its next activity or crew.

3.5.2. Decision Ladder

Decision ladders convey the decision-making process across three levels of human behavior—knowledge-based, rule-based and skill-based behaviors—via the relationships that exist among states of processing information (represented by rectangles) and knowledge/information (represented by ovals) [47]. The decision ladder for the complex decision, "Is action required within the current mental track segment" is shown in Figure 13 with display requirements overlaid with call-out boxes. The complex decision, "Is action required within current mental track segment?" requires further explanation. Locomotive engineers are required to qualify on routes before they are permitted to run a route on their own. Route qualification involves demonstrating that the engineer has memorized grades, curvatures, speed restrictions and other key features along the route. In order to memorize routes that can be hundreds of miles in length, locomotive engineers divide the routes into segments for memorization. Through interviews with locomotive engineers it was determined that locomotive engineers use the segments that they used while learning a route in conjunction with en route experience to develop mental track segments that they use while running routes. Some engineers break up their routes from station to station; others will break up their mental segments according to the number of landmarks, signals or actions required. The development of these segments is specific to the route and the engineers' preference for decomposing the route.

Four locomotive engineers were given a description of the decision ladder and walked through the flow of a decision. All four subjects said that the diagram accurately captured their thought processes and did not have any suggested improvements.

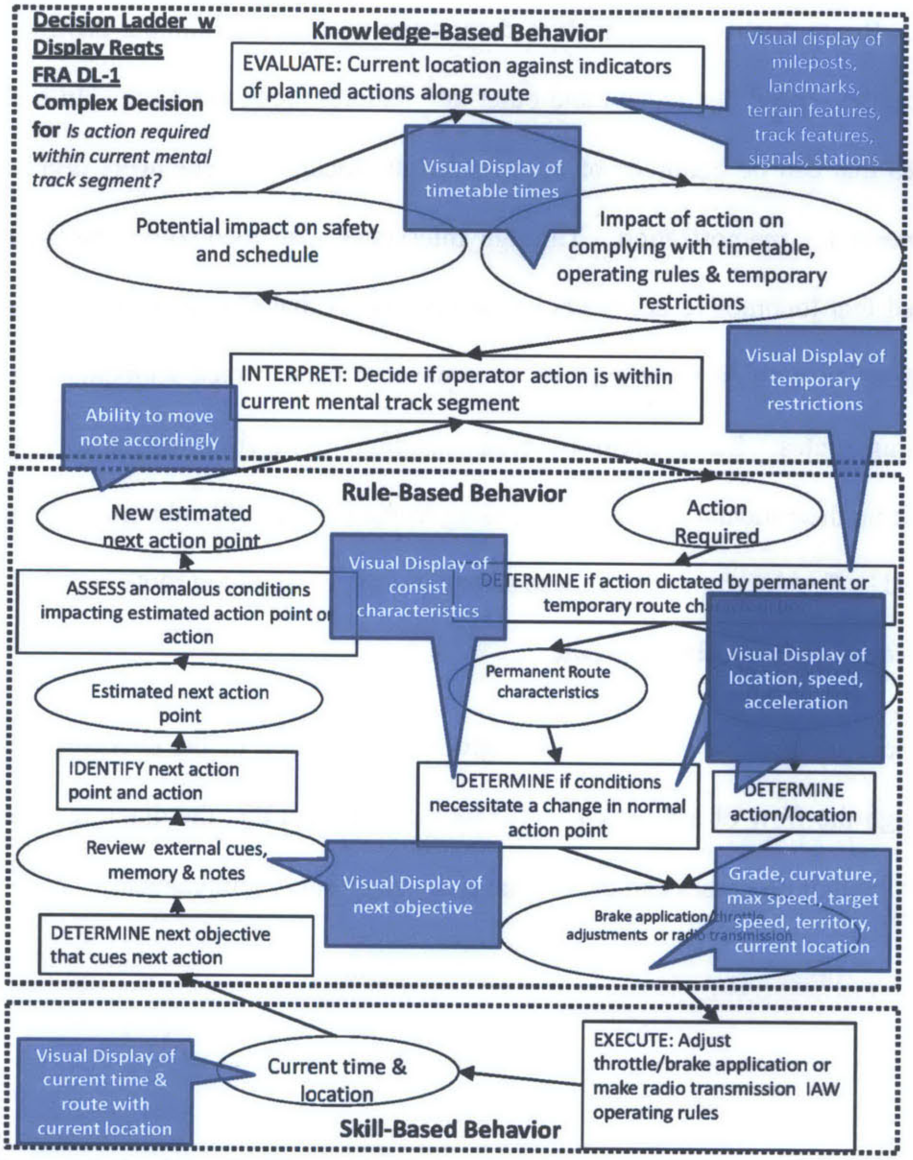

Figure 13: Decision Ladder with Display Requirements from Appendix A

3.5.1. Requirements

The resulting requirements, shown in Table 1, were derived from the event flow diagrams, Situation Awareness Requirements (SARs), and decision ladders. Situation Awareness Requirements are yielded after creating event flow diagrams and in parallel with creating decision ladders to reflect requirements derived from monitoring tasks that do not correspond to decisions. The "Source" column indicates the decision ladder or situation awareness requirement from which the requirement was derived. The "Item #" column is the requirement identification number. The Information and Functional Requirements from the original effort, Minimum Implementation Interface for Locomotive Operations, are identified by "MIR" and the Information and Functional Requirements added for this project are identified by "FIR" [46].

Table 1: Information and Functional Requirements extended from Tappan et al [46]

Item #	Information Requirement	Source[5]	Details
MIR5	Incoming radio transmission	DL1-FRA	A networked system could allow the dispatcher to push updated information to the display to complement dispatcher transmission and Form D annotations
MIR23	Location of security signals along train route	DL1-FRA SAR-11	A networked system could send signal states to display for last signal and upcoming signal (in-cab signaling)
MIR24	Current T/F lever position	DL1-FRA	Engineers will refer to "Operating Displays" or will know the position through touch and experience
MIR25	Current speed	DL1-FRA	One of the most frequent pieces of information read by locomotive engineers
MIR26	Goal speed	DL1-FRA	This is different that maximum allowable speed. Trains should not be excessively early to a station and may run at less than max speed to achieve this. Usually this is memorized, but may need to be calculated if delayed by an emergency or TSRB
MIR27	Speed differential	DL1-FRA	Difference between desired speed and actual speed (desired speed is either goal speed for the route or on a shorter level, desired speed curve to obtain objective speed for a circumstance)
MIR28	Current time	DL1-FRA	Engineers are required to have a functional watch, but time is referenced often.
MIR40	Departure time	DL1-FRA SAR-14	Usually memorized, but if route schedule has changed, timetable is referenced
MIR42	Current train	DL1-	More concerned with specific values when coming

[5] Situation Awareness Requirements are found in Appendix A, Table 10

Item #	Information Requirement	Source[5]	Details
	route rail grade	FRA	to/from a stop or around times where speed change is needed.
MIR43	Rail grade along train route	DL1-FRA	Memorized for route, but does play large part of train handling. Would be used most often when unfamiliar with route or has not run route in a while
MIR44	Potential impact of rail grade on speed	DL1-FRA	Notes can be inserted if there is a particular part of the route the engineer has trouble remembering, but otherwise the impact is learned with the route and through running trains
MIR45	Current track	DL1-FRA	Current track and current authority (rules in place)
MIR46	Track assignment	DL1-FRA	Track assignments can change en route and are controlled by the dispatcher
MIR48	Speed change indication	DL1-FRA	Speed refers to the maximum allowable speeds
MIR51	Train route with current location	DL1-FRA	Location context: mileposts, track features, bridges, control points, stations, grade crossings. Grade and curvature also provide contextual clues
MIR52	Next waypoint with scheduled arrival time	DL1-FRA SAR-14	Similar to Departure time IR
FIR1	Temporary Speed Restrictions-from train order/time table	DL1-FRA	Beginning and ending mileposts, reason for restriction and special instructions
FIR2	Temporary Speed Restrictions-from track warrant (en route)	DL1-FRA SAR-12	Track warrants are issued via the radio from the dispatcher. Engineers must enter information on a Form D and repeat back to the dispatcher. Form D's must be kept by the engineer for 7 days
FIR3	Consist Characteristics	DL1-FRA SAR-10 SAR-15	Consist information includes tonnage, weight distribution, number of cars, which cars are powered, etc. This effects train handling required to maintain smoothness and to obtain objective speeds and stopping points
FIR4	Territory Information	DL1-FRA SAR-13	Determines which operating rules must be followed; can vary from territory to territory
FIR5	Movement Authority	DL1-FRA SAR-13	Determines who is granting the train permission to move (dispatcher in dark territory, signals, timetable, etc)
FIR6	Positive Train Control infor-	SAR-16	Braking curves, target speeds and speed/location above/beyond which penalty brake application is

Item #	Information Requirement	Source[5]	Details
	mation		applied. Not included in display
FIR7	Trackside Equipment Indicators	SAR-11	Signals and corresponding interlocking states should be displayed as preview information so engineers can verify their intended route/actions at signals and interlocking in advance
FIR 8	Curvature	SAR-4	Memorized for route, but can play large part of train handling. Would be used most often when unfamiliar with route or has not run route in a while
FIR 9*	Location of Trains in the vicinity	SAR-3	Locomotive engineers indicated that they listen to radio traffic or memorize trains in their vicinity for a given route in the event that an anomaly with a surrounding train may impact his/her coarse of action

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* Not in initial hCTA, added after informal feedback

4. Design of the Display

In this chapter, the design process used to develop the interactive moving map display is explained. The process first starts with a grouping of the requirements and an initial layout using design principles. A working prototype was created and shown to domain experts and some of their comments were iteratively incorporated into the design/prototype.

4.1. From Requirements to Design

After reviewing the Information and Functional Requirements produced from the hCTA, it was determined that the Information and Functional 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 IRs; the graphical nature of the moving map allows for many track and terrain features to be displayed in an easy to understand format. Furthermore, a moving map provides context-specific information that should enhance the locomotive engineer situation awareness, assuming that that the information is presented clearly and the operator uses the display.

The interactive component of the moving map was introduced to address the IRs that dealt with changes to the normal route and the notes feature is similar to the sticky-note workaround discussed in Section 4.3.5 Notes.

The layout of the display features was determined by looking at the list of requirements (Table 1) and grouping them into the following categories: route, speed, grade, curvature, frequently accessed information and note-related information. Route information includes train route with current location (MIR51), next waypoint with scheduled arrival time

(MIR52), trackside equipment indicators (MIR 23, FIR7). Speed information includes temporary speed restrictions (FIR1, FIR2). Grade and curvature includes the grade and curvature of the track (MIR42, MIR43, FIR8). Frequently accessed information was determined by interviews and includes current speed (MIR25), current time (MIR28), and next waypoint with scheduled arrival time (MIR52). Note-related information was defined as textual information contained in track warrants or user-generated content (e.g., an engineer said he would put in a self-generated note if there was excessive slack time built into the schedule between two stations to remind himself to go slower to avoid arriving early). The first design of the display is shown below in Figure 14 and was created on a whiteboard so that elements could easily be added, removed and rearranged.

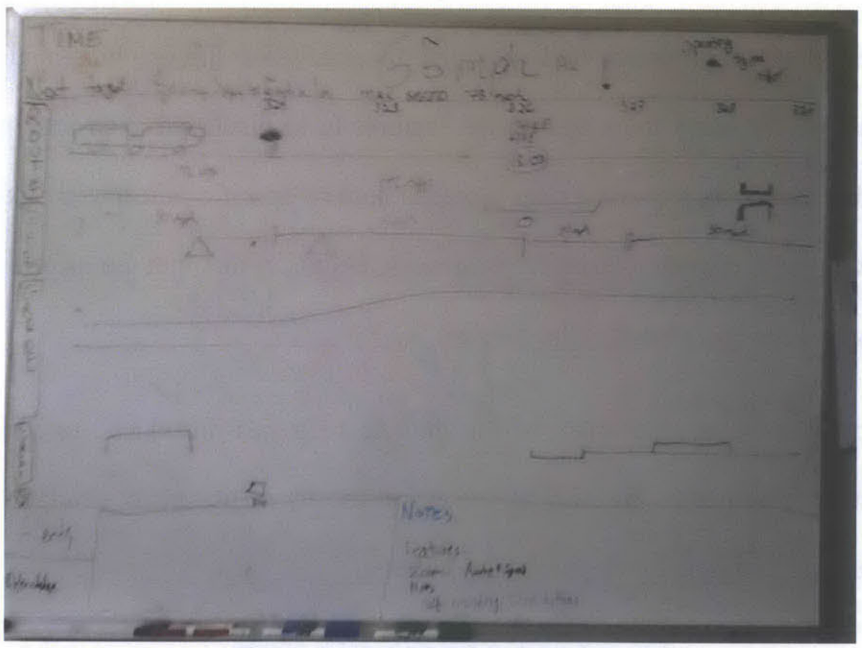


Figure 14: Initial Whiteboard design

After the end of the whiteboard design iteration, the design was transposed into a graphic so that it could be easily shared and also to more closely represent the intended design with colors, fonts, etc. This version of the design is shown in Figure 15 and Figure 16.

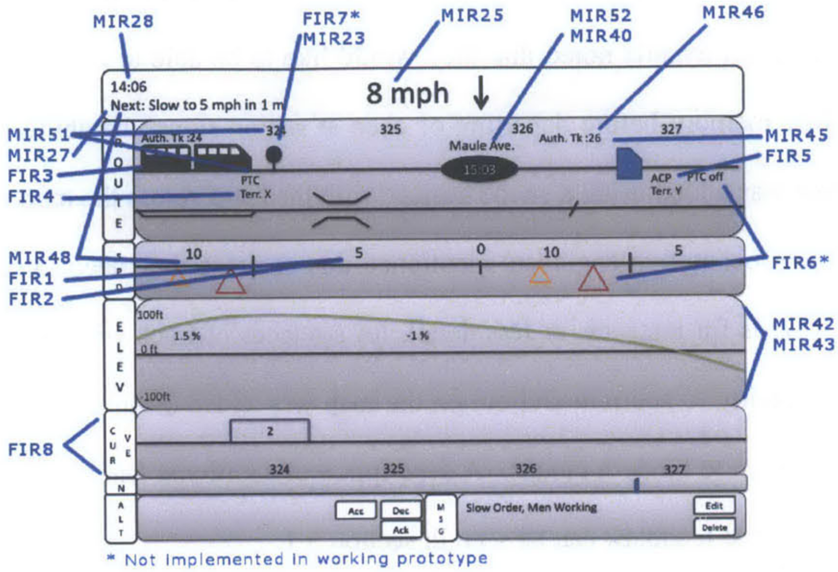


Figure 15: Computer Graphic Initial Design

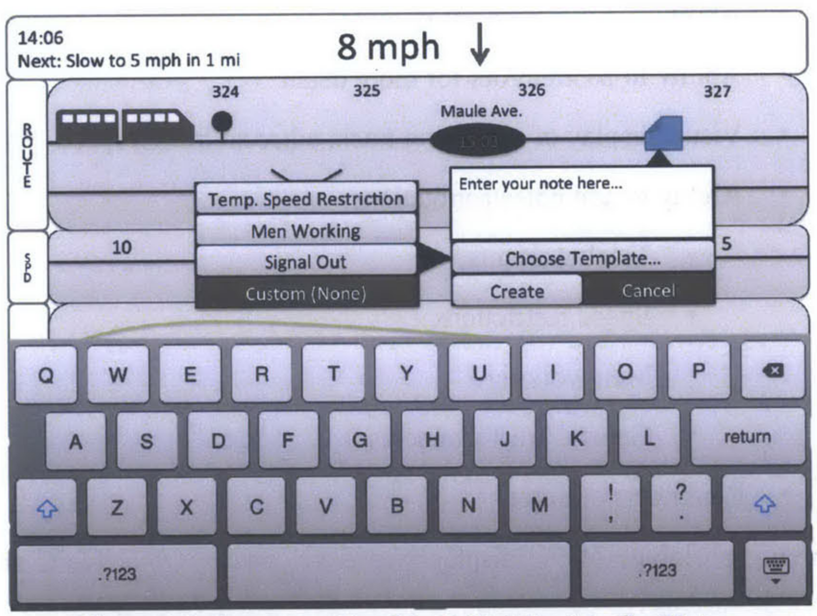


Figure 16: Computer Graphic Initial Design for Notes

4.2. Iterative Design Process

The design process is an iterative one that involved showing iterations of the design to domain experts and incorporating their feedback. As a result, there are some design features that emerged that are directly related to 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. A description of additional features that were added as a result of informal feedback can be seen in section 5.1.

A list of some the main features of the resulting design include:

- Ability to pan across entire route
- Ability to zoom in/out for more detail
- Visual display of upcoming track, adjacent tracks, speed, grade & curvature
- Ability to add notes/annotations
    - Track warrants
    - Speed restrictions
    - Men working
    - General/freeform notes
- Reminders of notes

A working prototype of the display was developed in Objective C so that it could be demonstrated on an iPad. A screenshot of the prototype is shown below in Figure 17.

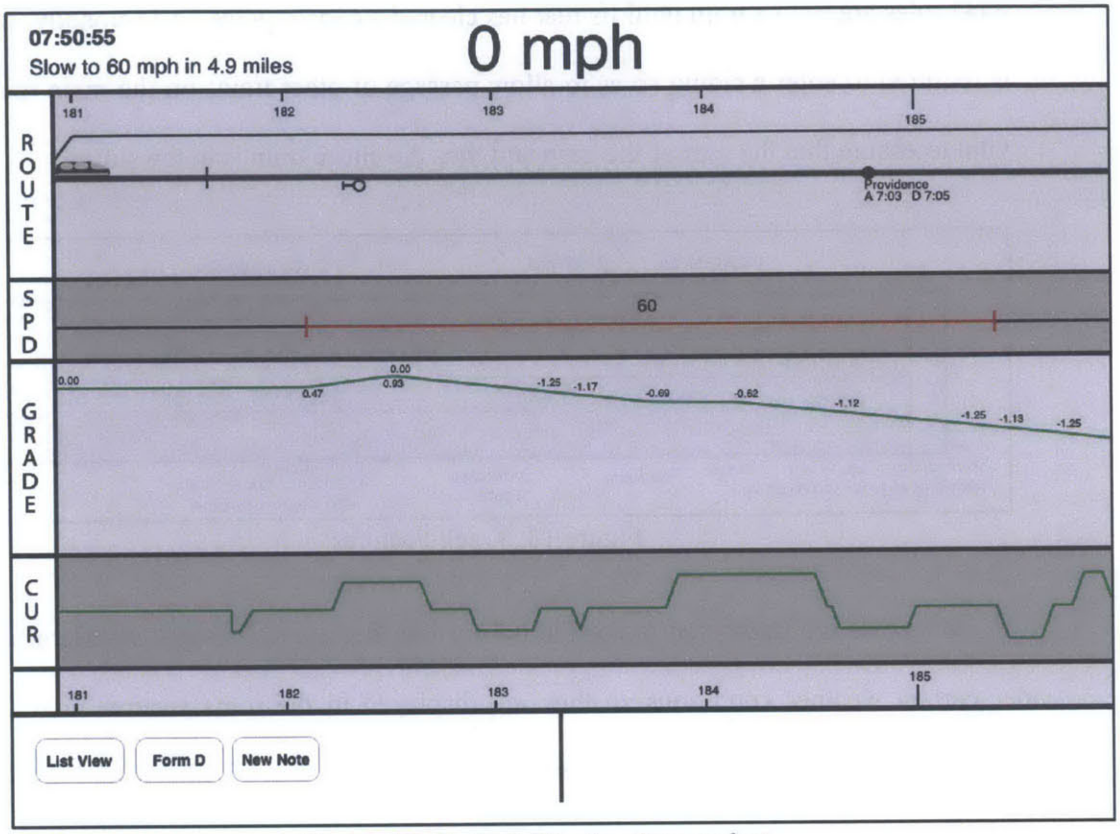


Figure 17: Default Display Screenshot

4.3. Description

A description of the display is broken up into the following subsections.

4.3.1. Track Features

The Route section of the display contains the majority of the IRs since it depicts track features in a way as to aid the locomotive engineer in determining where he/she is located. In Figure 18, the intended route of travel is in bold and parallel tracks or sidings are depicted by the subdued horizontal lines and labeled as "Other tracks." 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 rules apply to a train until its rear has cleared a certain point. Additionally, if a train is required to enter a siding so as to allow 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.

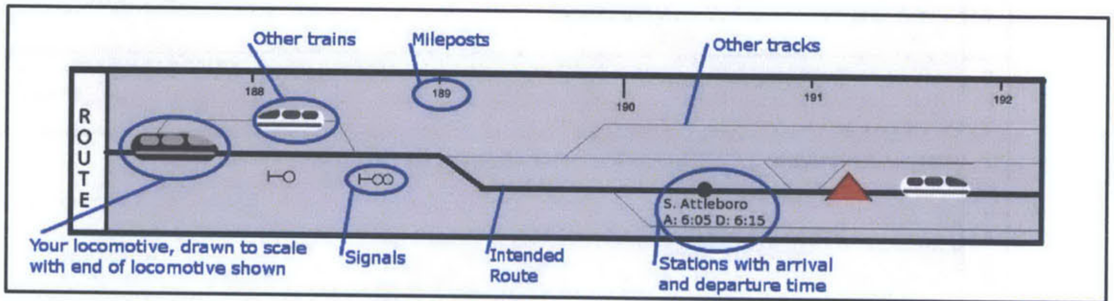


Figure 18: Track Features

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. Milepost location is important for locomotive engineers to know exactly where they are but also to communicate their location if needed for 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 to keep an eye out for the signal as they approach in order to remain in compliance with the rules for the next block of track. Lastly, names of important landmarks such as stations, crossings, bridges, major roads, etc. are labeled along the track and in the case of stations, if the station is a required stop for the route, the arrival and departure times are also indicated.

4.3.2. Speed Restrictions

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 19 below shows a permanent speed restriction of 45 mph, areas of track where the speed limit is set to the default for the track, and a temporary speed restriction of 30 mph. Permanent speed restrictions are emplaced for sections of the track that have long-standing 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.

Figure 19: Speed Section

4.3.3. Grade and Curvature

The grade section and the curvature section (Figure 20) of the display, abbreviated "CUR," is directly below the speed section. Directly below the curvature section is another set of milepost labels for reference. Grade is given in percent of 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.

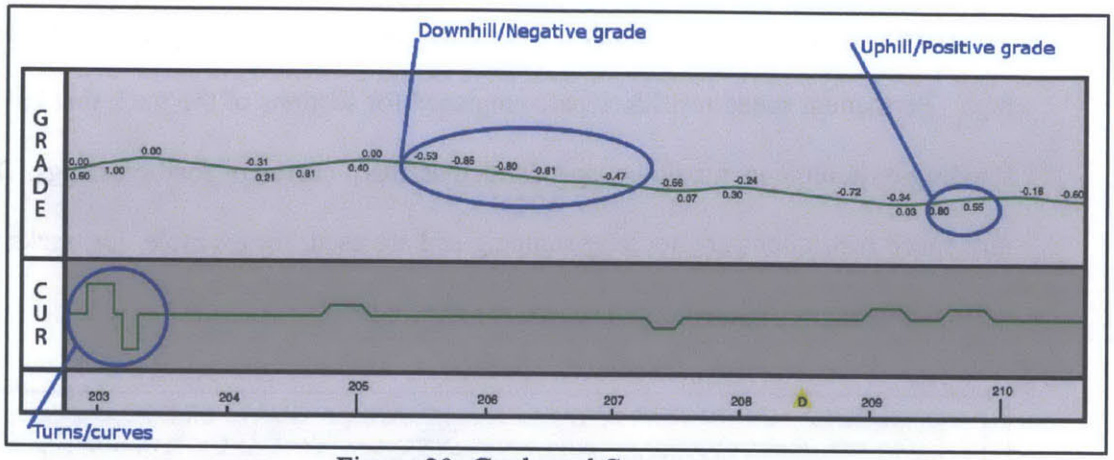


Figure 20: Grade and Curvature

4.3.4. Next Action

Next action comes in two forms, the first is labeled in Figure 21 as "Text describing the next action" and presents itself for upcoming actions such as speed restrictions, station stops or areas where dispatchers must be called for permission to proceed. If the user selects/clicks on this text, a vertical dotted line appears to indicate the location to which the text refers.

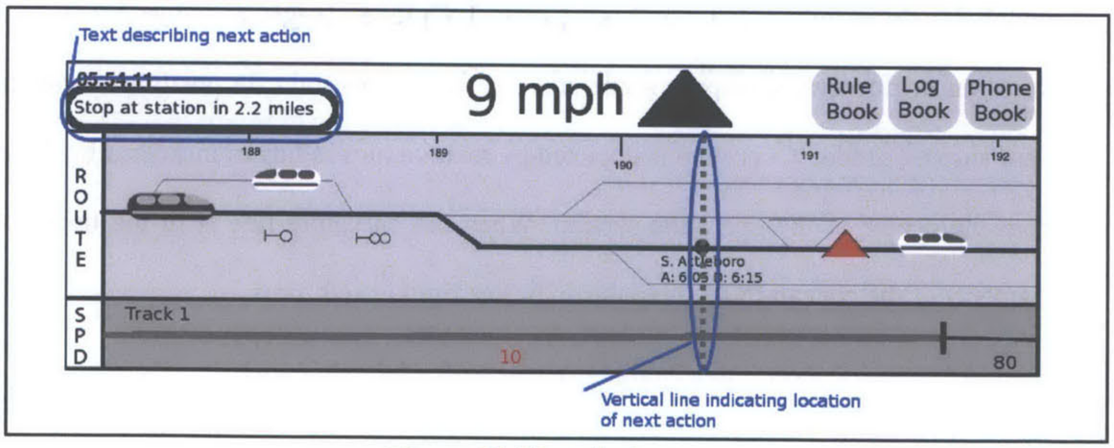
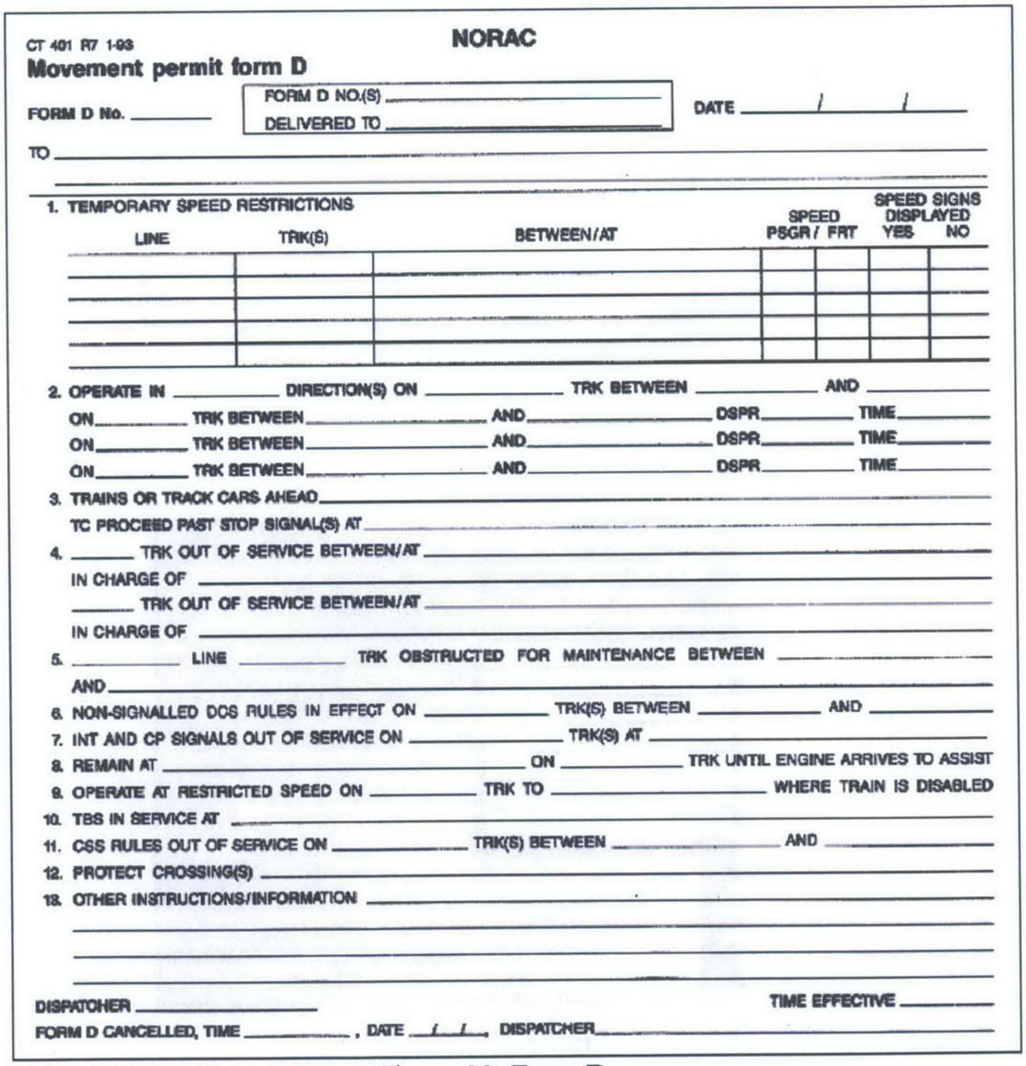


Figure 21: Next Action

4.3.5. Notes

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 dispatch. Track warrant forms vary across territories so the format and even the title for these notes would need to conform to the standards/rules in the territory in which the display would be used. An image of the Form D is shown below in Figure 22.



CT 401 R7 1-93

NORAC

Movement permit form D

FORM D No. ______ FORM D NO.(S) ______ DELIVERED TO ______ DATE ___/___/___

TO ______

1. TEMPORARY SPEED RESTRICTIONS

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

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

DISPATCHER ______ TIME EFFECTIVE ______

FORM D CANCELLED, TIME ______, DATE ___/___/___, DISPATCHER ______

Figure 22: Form D

When using the form above, dispatch indicates by number which section will be dictated before relaying the remainder of the information. Figure 23 shows the corresponding screen to this action; after users select the "Form D" button, a pop-up window appears with the same header information and choices (1-13) given on the Form D.

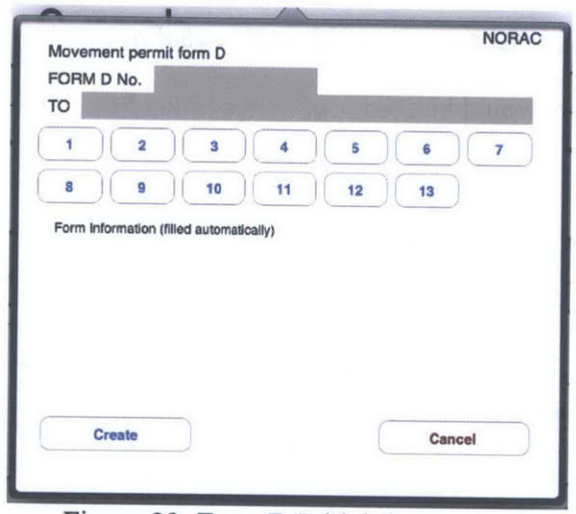


Figure 23: Form D Initial Screen

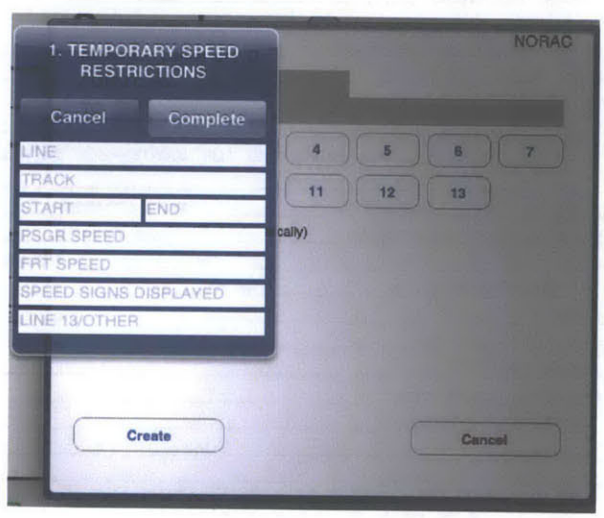


Figure 24: Form D Line 1

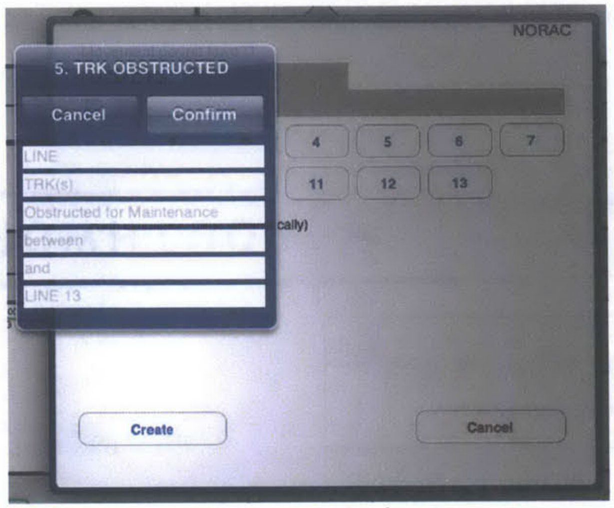


Figure 25: Form D Line 5

Depending on the option selected, different pop-up windows appear requesting information specific to the selection. For example, for Temporary Speed Restrictions (Figure 21), users are prompted to enter the track number, starting/ending mileposts, speeds for passenger/freight, and any additional information provided by dispatch. 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.

Free-form notes are customizable where the user can enter any text. There are also non-Form D templates, or note notes, that are available for speed restrictions or men working. After the "New Note" button is selected, a menu appears for creating a note (Figure 26) which allows the user to input his/her own text or to choose a template (Figure 27). Either option allows the user to input the specific milepost as indicated by the number 181.73 in Figure 27.

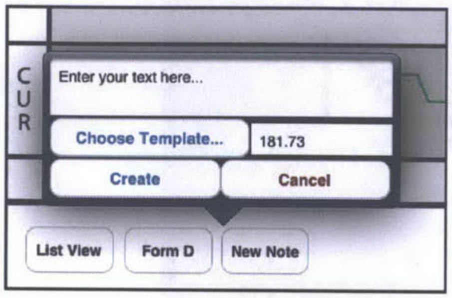


Figure 26: Creating a New Note

Figure 27: Note Template Menu

If the user elects to enter his/her own text by clicking inside the box that says "Enter your text here" (Figure 26), then the screen in Figure 28 appears with a keyboard for entry. If the user selects a template, such as men working, then a pop-up window appears at the location specified (Figure 29). Figure 30shows the result of inputting a free-form note and a men working template. A red triangle appears to designate men working and a blue square appears to designate the free-form note; if either symbol is selected, the associated text appears in the message box along with options to edit or delete the note.

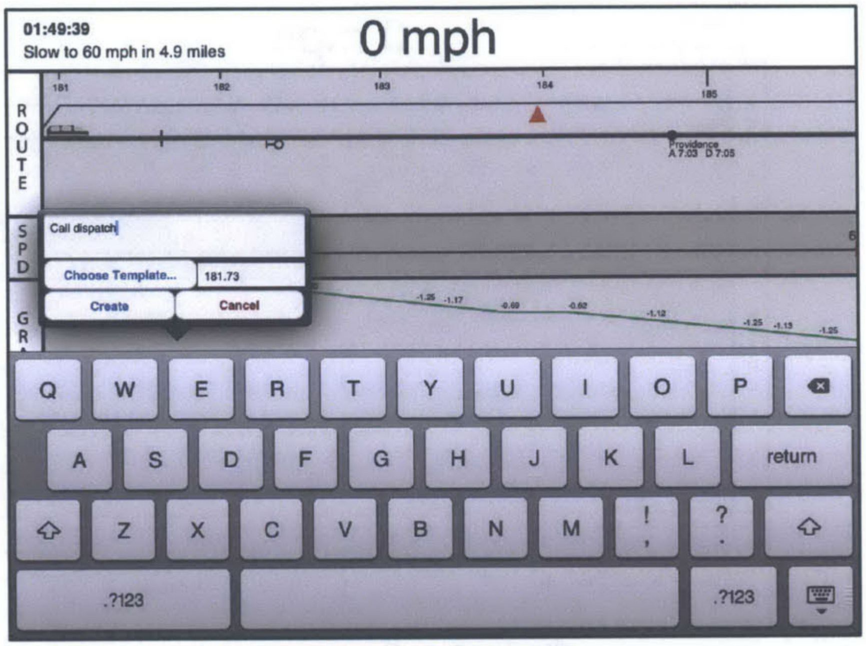


Figure 28: Free-form note

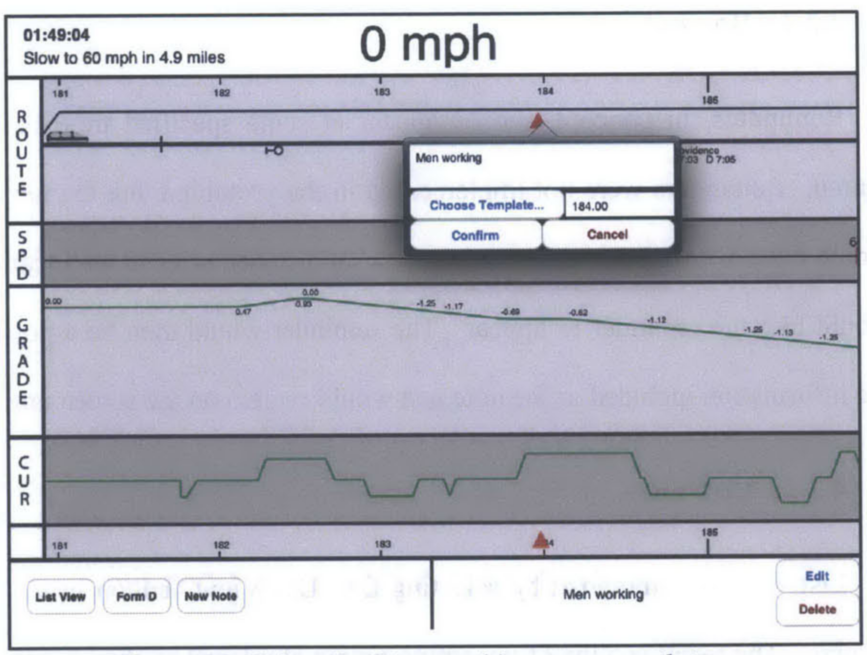


Figure 29: Using the Men working note template

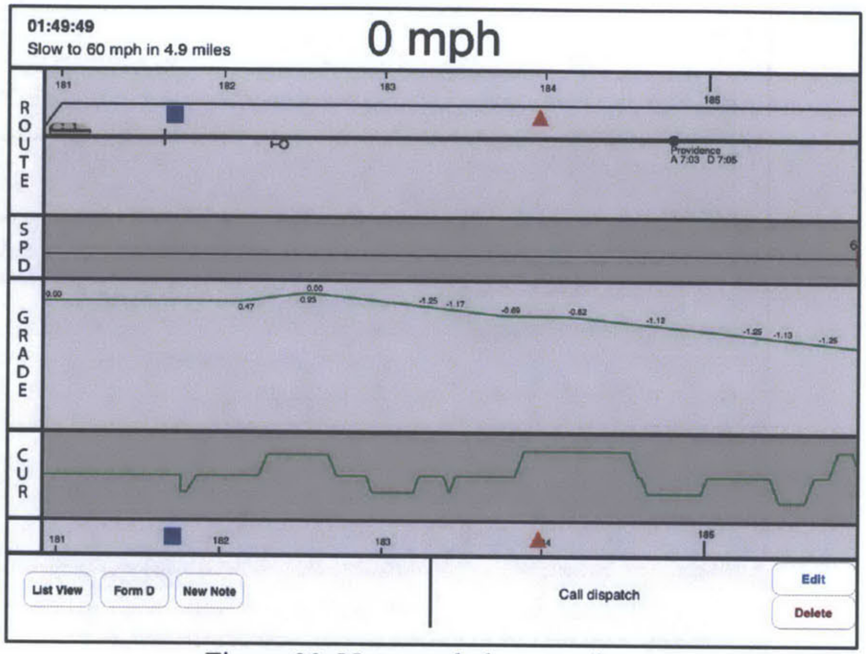


Figure 30: Note symbols on track

4.3.1. Reminders

Reminders, in concept, should appear at some specified time before action is required. Reminders were not implemented in the prototype, but the next phase of design would have allowed the user to select at what distance prior to the location of a note they would like the reminder to appear. The reminder would then be a pop-up window with the information included in the note and would remain on the screen until acknowledged.

4.3.2. List View

List view is summoned by selecting the "List View" button in the lower left of the display. The result is a list of upcoming points of interest in chronological order. 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.

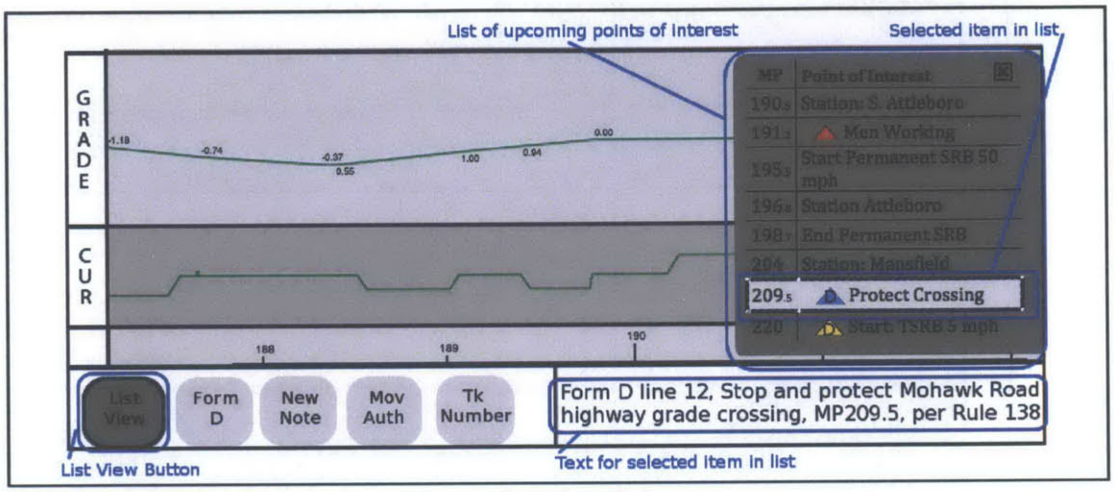


Figure 31: List View

4.3.3. Switch Not Aligned

When the position of a switch is set to reroute a train off of their intended route (bold line in the route section), a number of indicators are posed in order to warn the locomotive engineer of this potentially dangerous situation (Figure 32). The most noticeable indicator is the vertical line that appears along with the red dots and incongruous bold line. The vertical line spans almost the entire screen making it more visible to the user and the red dots draw the eye to the specific portion of the display graphically showing the issue. In addition, there are two textual warnings, both in the upper left and lower right corners of the display.

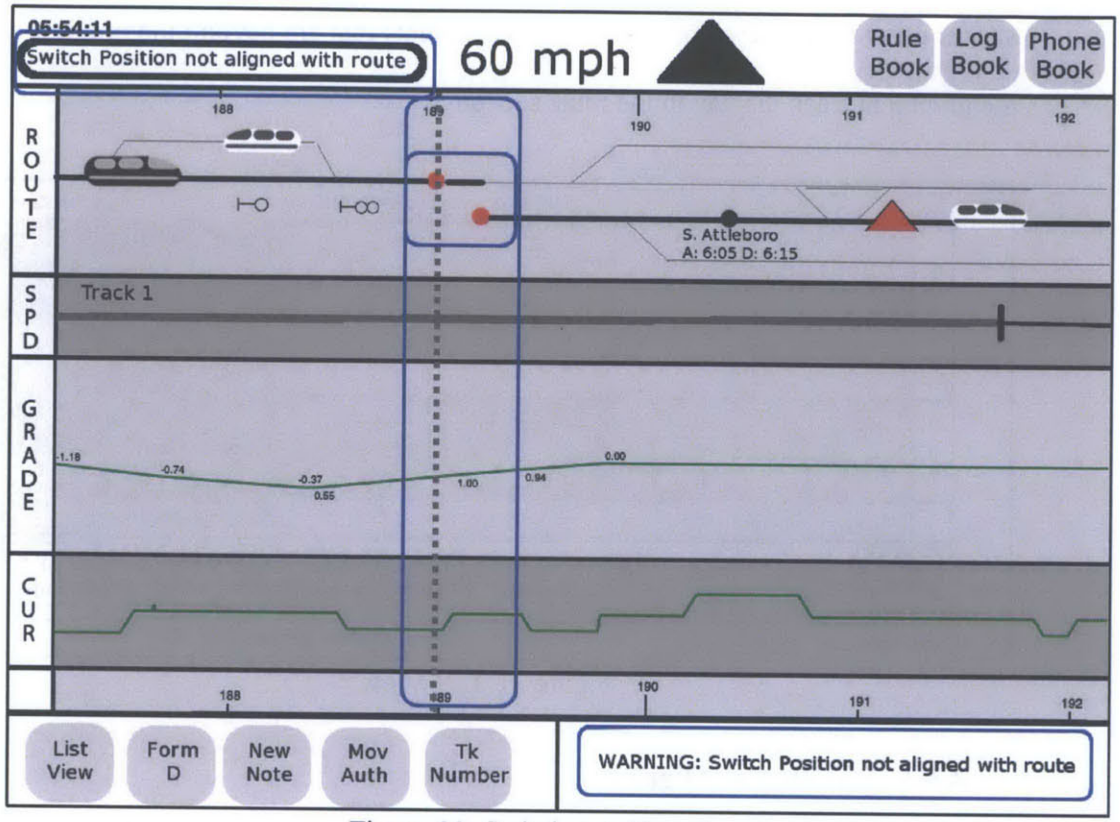


Figure 32: Switch not aligned

4.3.4. Movement Authority

Movement authority indicates the rules providing permission for trains to operate. For example, in "dark territory" or regions without signals, all movement is coordinate through a dispatcher. In the following example (Figure 33), the authority is automatic block signaling (ABS) so locomotive engineers know that they can follow the instructions given by the signals. Additionally, there may be specific rules that apply to portions of the track that are also given in the message box area of the display (lower right). This information is displayed by selecting the "Mov Auth" button, short for "Movement Authority."

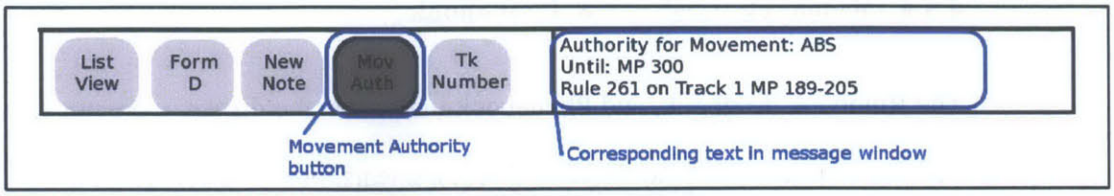


Figure 33: Movement Authority

4.3.5. Track Number

Each track on a line is numbered and this information is only needed if a train is being directed to an unfamiliar track and the locomotive engineer does not recall the numbering for the track. This information can be quickly displayed by selecting the "Tk Number" button, which is short for "Track Number." When the "Tk Number" button is selected, the track numbers are overlaid on the track in the route section and the current track along with any upcoming track changes for the intended route are displayed in the message box (Figure 34).

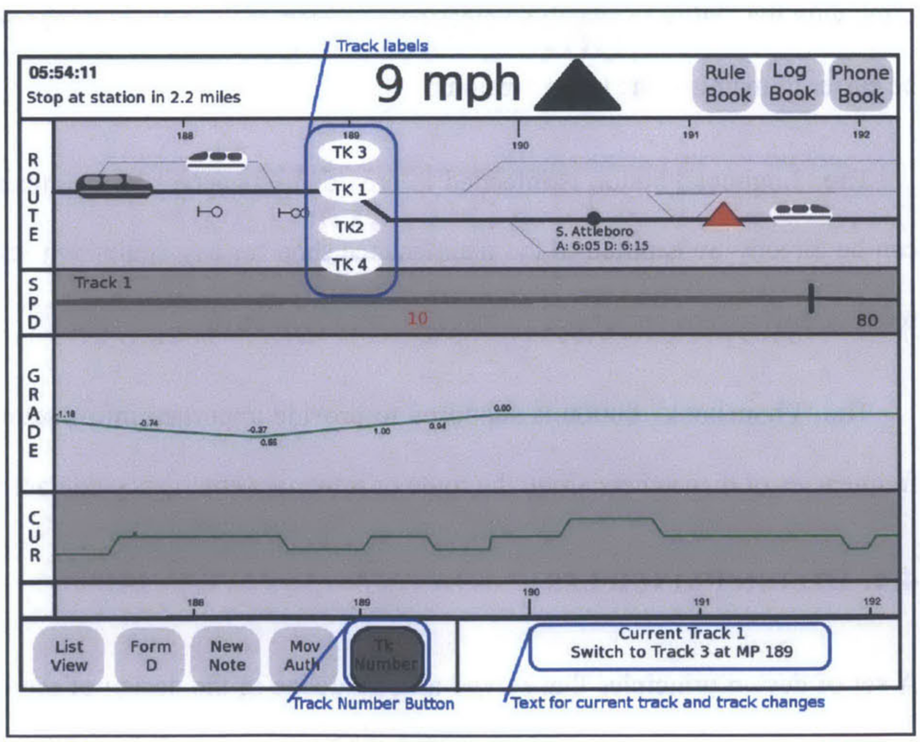


Figure 34: Track Numbers

4.3.6. Rulebook, Logbook & Phonebook

The Rulebook, Logbook, and Phonebook buttons on the display were not specifically derived from information and functional requirements, but were requested after informal feedback was solicited from the first iPad prototype. These functions were not implemented in the next phase of the prototype, but rather the buttons were added to a graphic of the display (Figure 35).

Figure 35: Rulebook, Logbook & Phonebook

Locomotive engineers are required to carry physical rulebooks along with the latest additions onto every train they operate. Ideally, the "Rulebook" button would provide users with the ability to search an electronic version of their paper rulebooks and it would be easier to maintain the latest versions.

The "Logbook" button is intended to provide users access to maintenance forms that can be directly transmitted to the maintenance shop for any equipment issues noticed en route or any actions performed to maintain the locomotive.

The "Phonebook" button is supposed to provide important information such as radio frequencies of dispatchers along the route or important emergency contact information.

4.4. Design Principles

A set of design principles that served as a guideline in the design of the display and examples of how these guided the display are listed here:

- Words, symbols and concepts in the system should map to those with which the user uses in the environment where he/she works or interacts [48].
    - Track warrant input is in the same format as the paper forms that are filled out when dispatchers read the information over the radio.
- The design should be minimalistic in order to provide only pertinent information and to not detract from aesthetics [48].
    - Contents of the notes, consist information, track numbers, etc. are hidden until selected or a reminder presents itself.
- Ensure that users know current status of what is going on and that information is current/not out of date [49].
    - Speed, acceleration and location on a rolling map are provided to users as they traverse across track.
- Features that interface with the user do so in a consistent and understandable manner [49] .
    - Notes and track warrant inputs have similar formats. In addition, selectable buttons have the same appearance.
- The information or functions available should be pertinent to the task(s) at hand [50].
    - Notes appear on the upcoming track and list view according to how far out the user wants or needs to look ahead.
- The system should provide "clear and timely" indication to the user that his/her actions are achieving the desired effect in the system [50].
    - Users can check that their notes took effect by scrolling to that portion of the track or accessing list view.
- Reduce workload by consolidating information, reducing recall and reducing mental comparisons [50].
    - Track information is displayed directly on the moving map.

5. EVALUATION

An assessment of displays from the subject matter experts in the job is an important verification and validation step. Both informal feedback and formal feedback was elicited for this display. Informal feedback involved showing the display to locomotive engineers and others with domain knowledge, allowing them to interact with the features and then asking for their thoughts and recommendations in an open-ended manner. This informal feedback was incorporated into some aspects of the design before the formal feedback portion. Formal feedback was elicited via a cognitive walkthrough which is a method of assessing usability of a system by giving subjects minimal training, asking them to complete tasks, and asking for their feedback [51].

The display was also evaluated against the original set of requirements and also high-level goals for the system. Lastly, based on the results of these evaluation methods, recommendations for the display are suggested.

5.1. INFORMAL FEEDBACK

Showing domain experts the display and allowing them to interact with it provided informal feedback. They were told that the display was to aid locomotive engineers en route and after having time to interact it and ask questions, they were asked to provide thoughts, impressions and recommendations. Features that were added or modified as a result of this informal feedback are listed below:

1. Provide access to the rulebooks via the display
2. Display other trains in the vicinity

3. Ability to access maintenance/mechanical logs to submit reports or to see open issues
4. Train/Consist information such as coaches that are powered, coach numbers, etc.
5. Display signals on the side so that they show directionality (tail to head follows the direction of travel). See Figure 36.

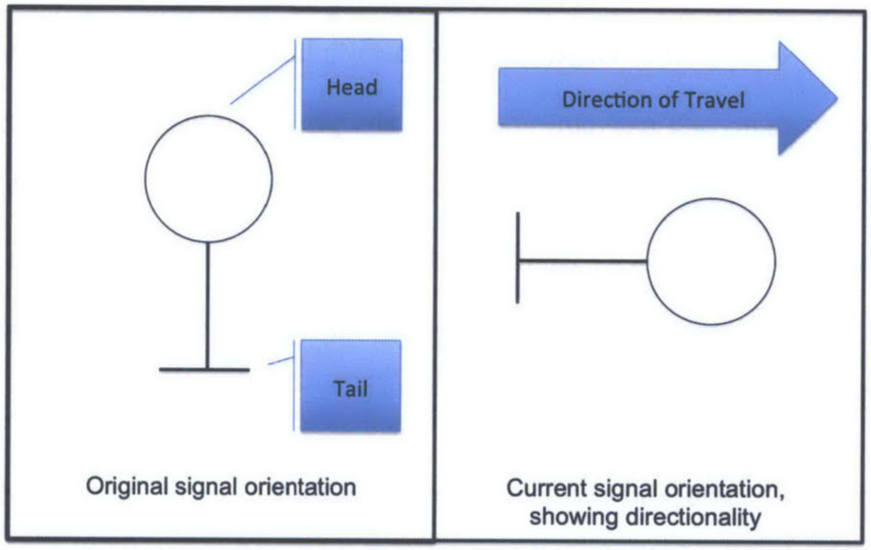


Figure 36: Signal Orientation

Design change 1, access to the rulebook, was addressed by adding a "Rulebook" button on the upper right of the display (see Figure 37) that will provides users with an electronic version of the rulebook that is text-searchable. This feedback motivated a different instantiation of FIR 4, Territory Information, which was only previously conveyed via the Movement Authority Function. Therefore, the initial interpretation of the IR was incomplete; locomotive engineers at times require more information on the territory than the movement authority. Certain portions of track have complicated rules that cannot be conveyed in a small message box.

Figure 37: Header with Rulebook, Logbook & Phonebook Buttons

Design change 2, location of other trains in the vicinity, was added as Informational and Functional Requirement FIR 9. Although none of the displays researched show this information, locomotive engineers said that they often memorize the schedules of other trains in relation to their routes as well as listen to radio conversations that are not directly relevant in order to get a better sense of where other trains are in the vicinity.

Maintenance/mechanical logs, design change 3, were not added as an IR since these tasks were not identified in the En Route phase of the STO, the phase from which the requirements were created. These activities would fall under Before Departure, Departure Preparation or End of Trip phases of the STO. However, after speaking with locomotive engineers, these tasks were deemed important to the task of operating a train and digitizing the maintenance logs to send directly to maintenance as well as make them searchable were added to the design. This feature was added in the design as the Logbook button (Figure 37).

Design change 4, consist characteristics, in the original version of the Informational and Functional Requirements (FIR 3) only included the consist length, which was represented by the length of train icon (drawn to scale on the track and resized as the preview scope of the track is changed). However, in the updated version of the design, the consist information includes the locomotive number, the length of the consist (in number of cars and in meters), and consist weight (See Figure 38).

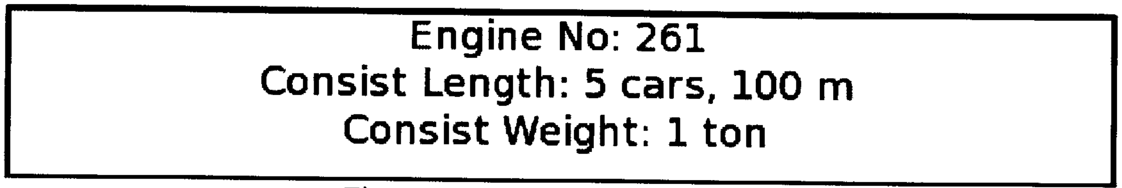


Figure 38: Consist Information

5.2. Cognitive Walkthrough

A cognitive walkthrough is a method of assessing usability of a system by giving subjects minimal training, asking them to complete tasks, and asking for their feedback [51]. The cognitive walkthrough was conducted with ten participants who were all current locomotive engineers with four to twenty-three years of experience running locomotives. The average (mean) years of experience is roughly fourteen years with a standard deviation of seven years. Two of the participants spent their entire careers running freight locomotives, seven spent their entire careers running 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 participants were first shown a slide presentation outlining the purpose of the study and their requested involvement (Appendix B). After the consent forms were signed, the participants were asked to complete a demographic questionnaire and given a short demonstration of some of the functions of the display.

For the main part of the cognitive walkthrough, subjects were handed an iPad on which the display was hosted and asked to answer questions and perform actions using the display. Feedback was solicited by a combination of questions administered directly after performing a task, a five-point scale survey, and questions asked after the display interaction phase was complete (Appendix D, Appendix E, Appendix G). At the end of the cognitive walkthrough, subjects were also asked questions about their experiences with the introduction of new technologies which will be discussed in throughout Chapter 1. The entire process lasted between one and two hours per subject.

The cognitive walkthrough portion consisted both of an interactive element, where subjects interacted with the display, and an observational element, where subjects were asked questions based on screen shots of enhanced future display features, i.e., features that were not yet implemented into the prototype. Example questions/tasks include describing track features around a landmark or inputting track warrants which include additional information pertinent to the route for a given period of time. The questions and related screen shots for both types of questions are found in Appendix C.

5.3. Cognitive Walkthrough Results

Subjects were asked to perform actions and answer questions based on the display or screen shots; the specific questions can be found in Appendix C. It is important to note that this was not a performance-based test; subject success per task is broadly characterized by if they were able to answer the question/perform task on their own, if they required some prompting or if the experimenter had to tell the subject the answer or tell them/demonstrate how to perform a task. There is a level of subjectivity involved by the experimenter in terms of when to prompt or when to convey the answer. In all instances, prompting is attempted first before the answer is conveyed. The results will be discussed by key feature or question type and also include user feedback on these specific features. Some subject data is incomplete so not all reported numbers are out of ten subjects; the total subset will always be provided when reporting numbers. Additional results are included in Appendix H.

5.3.1. Ability to Identify Information

Subjects were asked a number of questions regarding the track features shown on the display in order to assess their comprehension of those features. Figure 39 shows the percentage of correct responses per task. 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 improved correct response percentage.

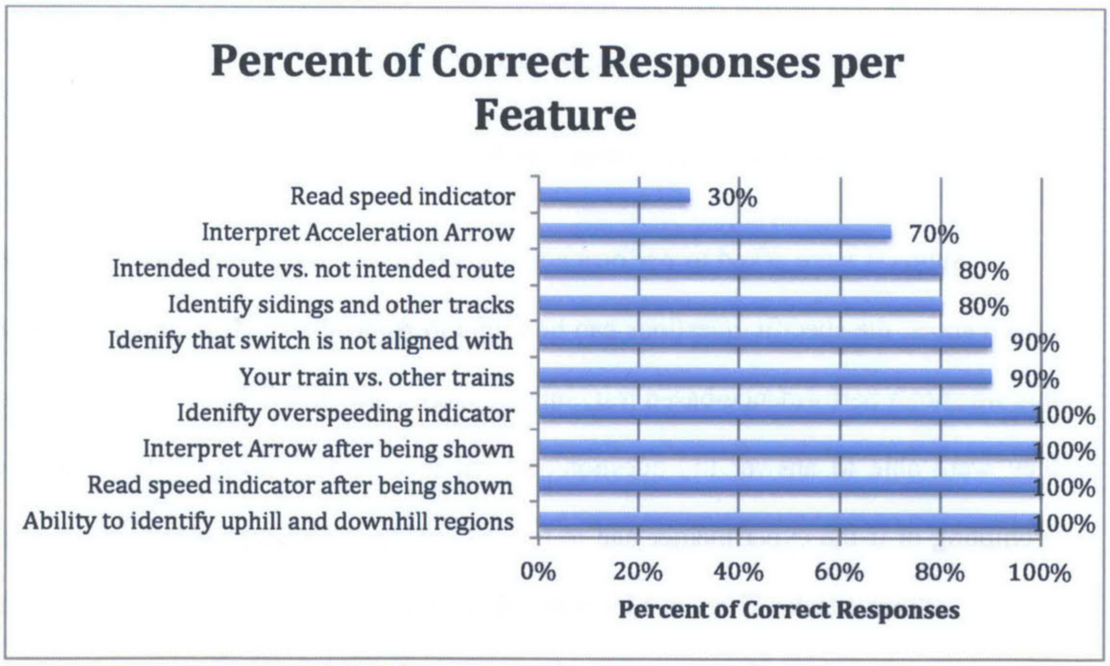


Figure 39: Percent of Correct Responses per Feature

The thirty percent 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 accidents that occurred in Spain and New York in July and December of 2013 [12, 13]. Up until this question, subjects were directed to look at the interior of the display, denoted by the gray background, which 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 40 shows the image subjects were given and

Table 2 lists the corresponding questions (Q2-5, QQ4); the correct response was nine miles per hour, but subjects who responded incorrectly, responded with ten miles per hour (the question numbers refer to those in Appendix C). When asked the same question for a similar screenshot, all subjects responded correctly.

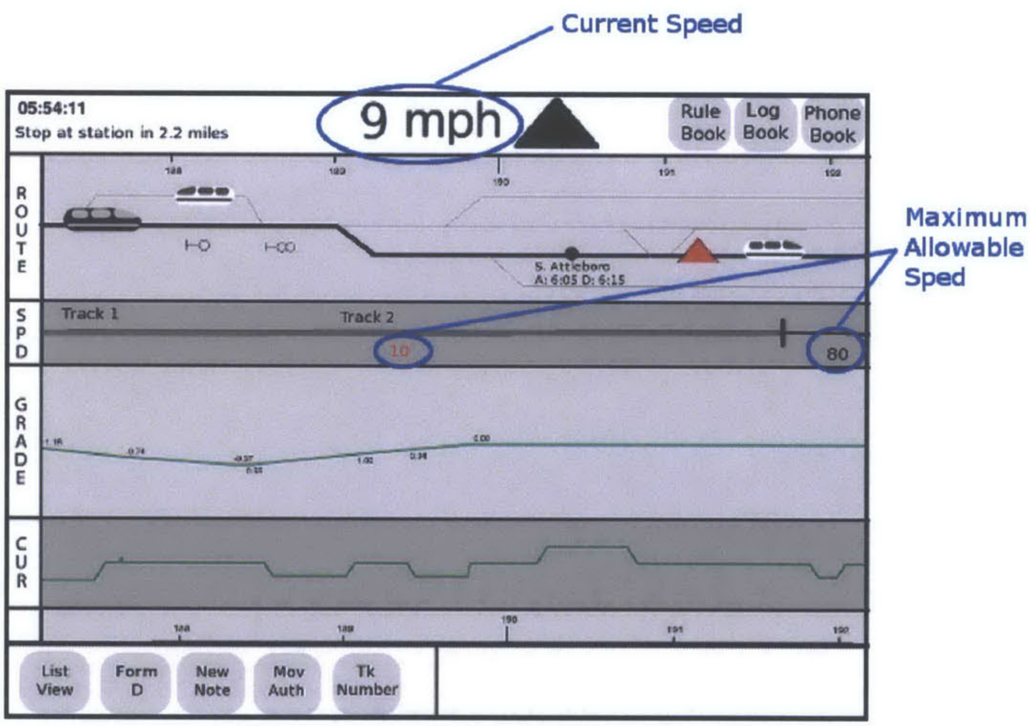


Figure 40: Screenshot for questions Q-2-5, QQ4

Table 2: Cognitive Walkthrough Questions Q2-5, QQ4

Question Number	**Question**
Q2[6]	What is your current speed?
Q3	Are you accelerating or decelerating?
Q4	What is the difference between the darker and lighter tracks?
QQ4	What would you expect to happen or would like to happen if you clicked on Rule book, Log book or Phone book?
Q5	Can you explain the difference between the black and white objects on the route section?

Given the high success rate of subjects entering Temporary Speed Restrictions and verifying that they took effect (Appendix H), a surprising number of subjects were not able to correctly identify the speed at which they should operate between two stations. Question Q1 from Appendix C is "**Q1:** *At what speed will you operate between Providence and South Attleboro? You may use the display to answer the question"*. The response required recognizing that the default speed is the maximum allowable speed (80 mph for this route) and then a speed restriction of 60 miles per hour takes effect and finally a station requires the locomotive engineer to come to a stop (see Figure 41). None of the subjects described slowing down for the station. Only two of ten subjects correctly identified the first two speeds without prompting. Six of ten subjects identified one of the two speeds and after the experimenter asked if they were answering for the entire requested portion, they then verbalized the other speed restriction. Two of the ten subjects were unable to identify the speed restriction.

[6] Questions are given the prefix of "Q" and qualitative questions, those asking for a description, are given the prefix of "QQ".

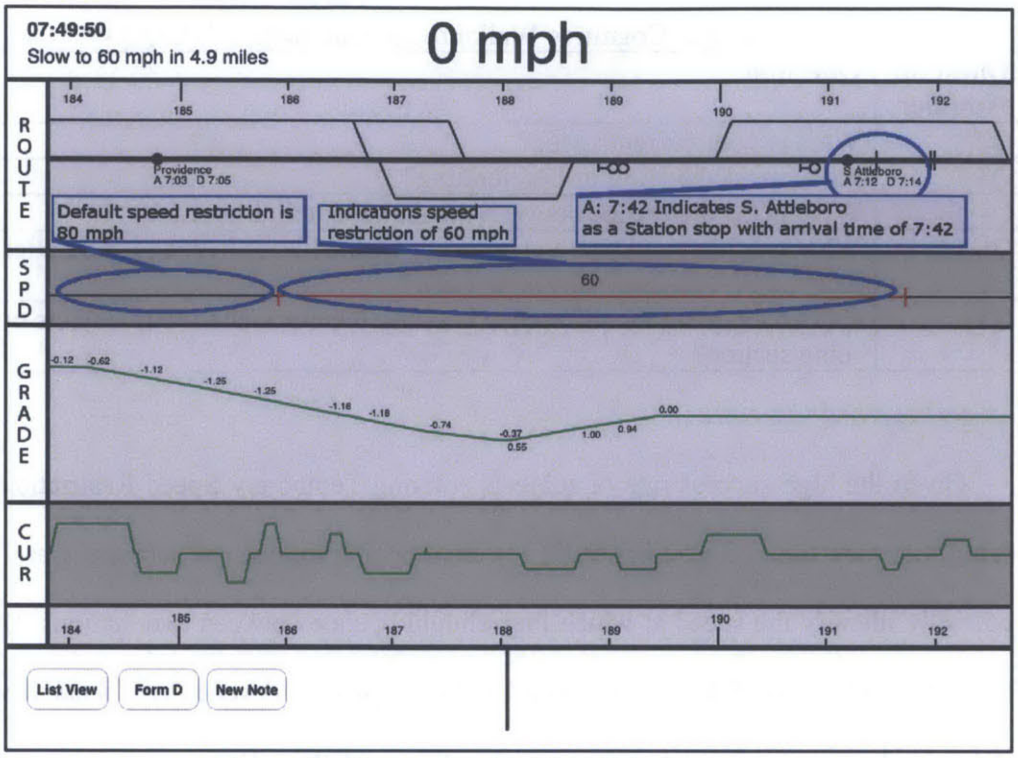


Figure 41: Screenshot for identifying speeds

With a correct response percentage of twenty percent, it is recommended that the experiment be repeated to see if either emphasizing the speed section of the display in the tutorial or emphasizing the speed section graphically in the display improves the number of correct responses. The placement and/or salience so the speed restrictions should be reevaluated.

The remaining features had correct response percentages of eighty percent or higher. The common misconception regarding the bold track (question Q4) was that it signified the main track, not the intended route (see Figure 40). Also regarding the route window, twenty percent of subjects failed to identify sidings and other tracks at the Mansfield station interlocking; this may be attributed to a number of reasons, one of which is that the task (task T5) was open ended, "*Look at the Mansfield Station interlocking and zoom in for a 3-mile section of track and tell me what you see.*" Another reason could be that the phrasing of the task included the answer and subjects may not have felt compelled to explicitly restate that they observed the interlocking. Subjects were expected, at a minimum, to identify the presences of sidings and/or the interlocking, the station stop and signals present. Additionally, subjects could point out the speed restriction of 45 miles per hour or qualitatively describe the grade and/or curvature in that section of track.

Nine out of ten subjects were able to quickly identify that the switch was not aligned in the screenshot shown. Figure 42 is the screenshot that subjects were shown with the addition of the blue outlines in order to convey to the readers the portion of the display showing that the switch is not aligned; the blue rectangles surround the two text boxes and the blue circle surrounds the switch. If the switch were aligned with the intended route, the red dots would not be present and the bold line indicating the intended route would be continuous. A common misconception was that the red circles around the divergence points indicated a stop signal, which was not the case. When asked, "*What would you do if you saw this display?*" one subject excitedly said, "I'm gonna dump it. My heart would be in my throat right now--what the hell! I'm not going through the switch if I can help it. Because I saw that red and I know what that means." When subjects were asked if they would display this any differently, the only comment was that the vertical line did not need to go all the way down the screen into the grade and curvature sections.

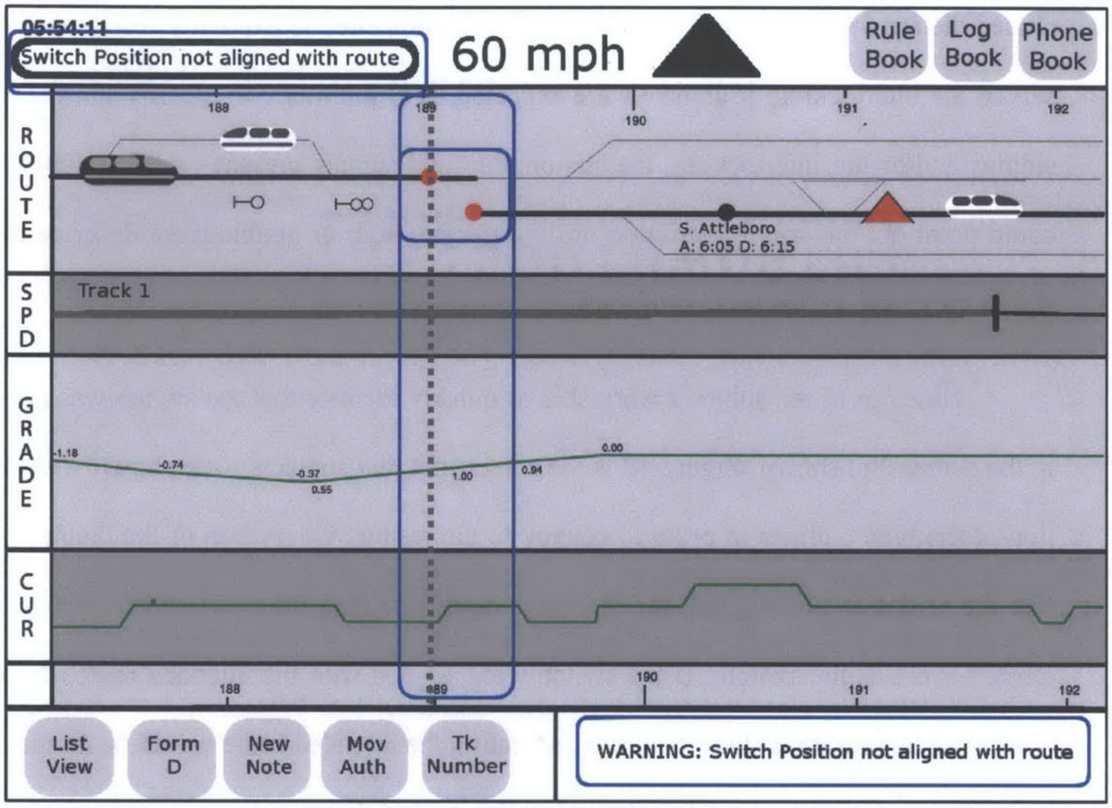


Figure 42: Switch Misalignment

5.3.2. Usability Survey

After performing tasks and answering questions using the display and screenshots, subjects completed the five-point scale survey composed of sixteen questions that can be seen in Table 3; the form presented to subjects can be seen in Appendix E. Subjects were asked to rank their level of agreement with the first ten statements in the survey, where higher values indicated agreement. The last five statements of the survey asked subjects to rank their level of agreement according to qualifiers such as difficult/easy, confusing/logical, very unclear, very clear and unsuited/suite.

Table 3: Five-Point Usability Survey Questions

Question Number	Question
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
N4	I find the software cumbersome to use
P5	I feel confident in using this software
N5	I think I need to learn many things before using this software
P6	The characters are:
P7	The accessing information is:
P8	The organization of information is:
P9	Recalling how to access display functions is:
P10	Scrolling and zooming on the map is:
P11	How suited is this display for operating en route?

The survey included a total of eleven positively worded statements and five negatively worded questions (marked by P and N in Table 3 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 43. All except for one positively framed questions had a mean response of 4.4 or higher while all negatively framed questions had a mean response of 1.4 or lower.

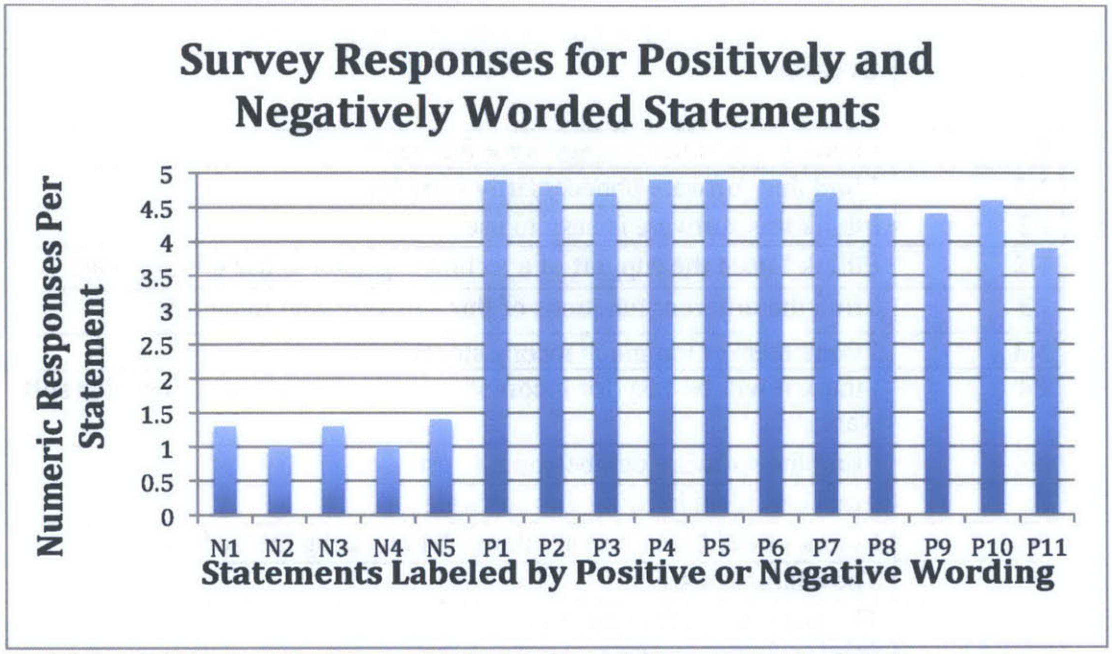


Figure 43: Survey Responses for Positively and Negatively Worded Statements

The question that deviated most from the most favorable score was the positively framed question, "How suited is this display for operating en route?" 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/left it open-ended. He/she gave said that they would want the display in front of them so that he/she could quickly glance down to view the screen and remarked that when another system was placed above him/her it was inconvenient and difficult to interact with.

Overall, the survey provided extremely positive feedback on the easy of use of the display. Subjects indicated that the display is easy to learn and that they would feel confident using it based on their exposure times of two hours or less. The survey brought to light concerns of interacting with the display while in motion and mounting locations. In order to address the former, policy makers must first decide what actions locomotive engineers can perform while in motion and then sensitivity settings and other usability features can be fine-tuned to those scenarios.

5.4. Fulfilling Needs, Goals & Requirements

Recall that the high-level goal of the display is ***to provide railroads and their locomotive engineers with information that they need to increase SA and make decisions in a manner that is safe and efficient; by allowing them to easily interact and access this information***. This section will decompose this goal into a prioritized list of sub-goals, metrics and evaluate the sub-goals against these metrics in a fashion similar to that described by Crawley and Cameron [34].

The sub-goals and related metrics are shown in Table 4 below and were developed keeping the overall needs and goals of the railroads, the ones who would purchase and maintain such a display, and the locomotive engineers, the users. The text that follows the table lists the sub-goals and metrics and an evaluation of how successful the display is at achieving the sub-goals.

Table 4: Sub-goals and Metrics

Sub-Goals	Metric
To reduce accidents and incidents (rule violations that did not result in accidents)	as measured by number of accidents and rule violations
To centralized all sources of in-	as measured by the principle of proximity

formation required for a locomotive engineer to perform job in one location	
To provide easy access to information	as measured by user feedback, access times and correct interpretation and action of information provided
To provide easy methods for inputting data	as measured by user feedback, input times and input accuracy
To comply with standards	as measured by approval of regulators
To provide context-specific information in a minimalistic manner	as measured by identifying information required for certain scenarios, providing only relevant information, and human-testing

To reduce accidents and incidents (rule violations that did not result in accidents) ***as measured by number of accidents and rule violations***

Reducing accidents can be measured when the system is deployed in a representative operational setting. Data should be collected over a reasonable amount of time and should be compared against a similar sample of operations without the system in use.

Since the system is currently in the prototype stage, it has not yet been tested on board a moving locomotive. While it may be difficult to test the reduction of accidents on simulator-based experiments, it is possible to assess rule compliance that can be achieved while using the display. In particular the main question is:

> *Does the ability for a locomotive engineer to view and interact with a detailed map aid in his/her ability to respond correctly to changes in the normal route over the current standard (i.e., relying on memory, viewing multiple displays and using paper notes)?*

Our hypothesis is that an interactive in-cab display will:

1. Improve rule compliance, especially for temporary route changes
2. Will increase the locomotive engineer's Level II (Comprehension) and Level III (Projection) Situational Awareness

However, such assessments cannot be made using the cognitive walkthrough results or informal feedback so this goal cannot be assessed at this time; additional testing should be performed.

To centralize all sources of information required for a locomotive engineer to perform job, in one location, ***as measured by identifying information required and comparing to information delivered by system***

The list of information and functional requirements derived from the hCTA process are compared against the information provided by the prototype (Appendix A). The IRs that are not addressed in the current prototype/delivered by the system are shown in the table below. The "Reqt #" column lists the requirement number identifier used in Appendix A. A brief assessment is given describing the impact that this missing requirement has on the goal of centralizing information. In most cases, the requirement was not included in the design either because it was not appropriate for a display of this type (the MIRs were originally developed for a scheduling display, not a moving map display) or that as a prototype it was not practical to include given limited resources.

Table 5: IRs not implemented

Reqt #	**Information /Functional Requirement**	**Impact on Goal**
MIR5	Incoming radio transmission	Auditory radio communication, due to safety concerns, would not be consolidated into a visual display. The display could offer a redundancy where the information conveyed over the radio also appeared in text form on the display. *Minimal impact* on consolidation goal.
MIR24	Current Throttle/Brake lever positions	Currently there are two channels for operators to receive this information (haptic and visual). The current speed is provided. *Minimal impact* on consolidation goal.
MIR26	Goal speed	This is the speed that should be followed to allow for optimal

		fuel usage or correct arrival time (some schedules have a lot of built in slack and arriving early can cause problems when tracks are shared with other trains). *This has moderate impact on the consolidation goal but is mitigated* by the fact that users can insert their own free-form notes with this goal speed along the route.
MIR44	Potential impact of rail grade on speed	Most of the operators that were interviewed said they use their experience and training to determine the impact knowing the grade, train make-up, throttle/brake pressures. *Minimal impact* on consolidation goal
FIR6	Positive Train Control (PTC) information	*No impact* on consolidation goal for trains that are not equipped or not required to have PTC. *Impact* on trains that are required to have PTC systems as they need to know the speed and braking curves that would impose penalties. Additional investigation is required to determine how much of an impact this would have an a PTC environment.
FIR7	Trackside Equipment Indicators	Interlocking states are addressed as well as location of trackside signals. However, the coloring (signal aspect) is currently not conveyed. This has *minimal to moderate impact* on the consolidation goal and can be fixed by coloring the signals on the display (assuming that the data is available and can be updated real-time)

To provide easy access to information *as measured by user feedback, access times and correct interpretation and action of information provided*

Access time, the time it takes users to retrieve information, was not measured and is more appropriate for an experiment. However, user feedback and correct interpretation and actions were measured as a part of the cognitive walkthrough. The results of subjects' ability to correctly interpret information are covered in section 5.3.1 and reflect positively on accessing information. The results of subject's ability to perform actions/functions are summarized in Appendix H.

To provide easy methods for inputting data *as measured by user feedback, input times and input accuracy*

Similar to access times, input time was not measured and is more appropriate for an experiment. Input accuracy was loosely measured during the cognitive walkthrough if subjects were able to complete the tasks; there were times when subjects made typographical errors but these instances were not recorded nor were they the focus of the cognitive walkthrough.

Regarding ease of entering data, user feedback from the cognitive walkthrough was elicited. When asked if subjects liked inputting notes electronically over the traditional paper form, seven of nine subjects said that they liked it while two of nine were neutral. One of the neutral subjects said that he/she is accustomed to having the paper in front of himself/herself and would want to see the reminders pop up. The other neutral subject said, "It would be a change because we are used to the paper and use to having it in your face. It's just a different way of seeing it; we would adjust." One subject stated that he/she liked this method of input and was not frustrated while interacting with it; however he/she did note that, "I just have fat fingers but I would get use it and get better at it."

The remaining subjects cited that they liked ability to input reminders directly into the display because it was more legible, reduced the amount of paper and centralized the information in one place. One statement from a subject exemplifies two of these points, "Everything is in one spot . . . this is better than paper. There is too much paper and nowhere to put it on the brake stand." Other related results on the walkthrough regarding the ability to input information can be seen from the usability survey results in section 5.3.2 and results for specific tasks as discussed in Appendix H.

To provide context-specific information in a minimalistic manner *as measured by identifying information required for certain scenarios, providing only relevant information, and human-testing*

The information required for the en route phase of operation is identified by the information and functional requirements (IRs) described in Table 1 that were a result of the hCTA. Table 6 identifies which sections of the display address each IR.

Table 6: Comparison of IRs to Display

Item #	Information Requirement	Display Section that addresses IR
MIR5	Incoming radio transmission	Refer to Table 5, information conveyed via radio could be transmitted as a Note
MIR23	Location of security signals along route	Route
MIR24	Current T/F lever position	NA-Refer to Table 5
MIR25	Current speed	Header
MIR26	Goal speed	NA-Refer to Table 5
MIR27	Speed differential	Header, Speed, Message box
MIR28	Current time	Header
MIR40	Departure time	Route station stop
MIR42	Current train route rail grade	Grade
MIR43	Rail grade along train route	Grade
MIR44	Potential impact of rail grade on speed	NA-Refer to Table 5
MIR45	Current track	Route
MIR46	Track assignment	Route
MIR48	Speed change indication	Speed
MIR51	Train route with current location	Route
MIR52	Next waypoint with scheduled arrival time	Route for station stops, Header Next Action Text
FIR1	Temporary Speed Restrictions-from train order/time table	Speed via Note feature
FIR2	Temporary Speed Restrictions-from track warrant (en route)	Speed via Note feature
FIR3	Consist Characteristics	Route, Message box when train selected
FIR4	Territory Information	Message box when Movement Authority button is selected, Rulebook when Rulebook button is selected
FIR5	Movement Authority	Message box when Movement Authority button is selected, Rulebook when Rulebook button is selected
FIR6	Positive Train Control information	NA-Refer to Table 5
FIR7	Trackside Equipment Indicators	Partially introduce in route-Refer to Table 5
FIR 8	Curvature	Curvature
FIR 9	Location of Trains in the vicinity	Route

Context specific information is addressed by providing a preset preview distance in the default display of the upcoming track and also by allowing users to select information when they need it. These selectable options are listed below:

- Consist information
- Track information
- Rulebook, logbook and phonebook
- Movement Authority
- Note information

Human testing, as described above for the sub-goal and metrics of "**To reduce accidents and incidents (rule violations that did not result in accidents)** ***as measured by number of accidents and rule violations"*** should be conducted as the human-testing metric described for this sub-goal.

5.5. Display Recommendations

The results of the cognitive walkthrough suggest that the features and the associated gestures are easy to learn and apply although refinement of sensitivity and considerations for people with less finger dexterity are needed, such as enlarging the size of entry windows and keypad. The cognitive walkthrough results also suggest that that more training is required regarding the current speed, acceleration indicator and speed restrictions. The symbols used for the "switch misalignment" should also be reevaluated to ensure that they are not mistaken for stop signal symbols. Lastly, mock-ups for the reminders as well as the logbook (maintenance log) and rulebook interfaces should be created and evaluated by users given the feedback received during the cognitive walkthrough.

An evaluation of the display against its original goals reveals that further investigation is needed to assess the impact the display has on improving the SA of the locomotive engineer and the impact of not including all of the identified IRs. Two features that should be strongly considered, based on the evaluation of IRs, in the next iteration of the display are the inclusion of the signal aspects and PTC information.

Multiple subjects remarked that the conductor would benefit from such a display since he/she is the one who would input data while en route. Moreover, specific attention must be brought to interacting with display through various riding conditions to include roughness of the ride and ambient lighting. In addition, mounting locations and mount configurations (permanent vs. fixed, degrees of freedom, etc.) are highly dependent on current and future locomotive cab configurations and the entire interior system must be considered.

The display should be architected considering the entire cab but also the many sociotechnical factors that impact the implementation of such a display. These issues will be discussed in the following chapters.

6. TECHNOLOGY TRANSITION IN U.S. RAIL

6.1. TECHNOLOGY TRANSITION BACKGROUND

Technology transition, the implementation of technology into a field or industry, has been studied under a variety of names and specializations [52]. For example, technology infusion is the implementation of a technology into existing or planned product architectures [53], technology transfer usually refers to the adoption of technology from federal research institutions into the private sector [54], and technology diffusion is the process by which technologies are adopted [55].

What makes technology transition so difficult? Organizational momentum alone can make any change difficult, but the larger the effort and the greater the sociotechnical influences, the more difficult technology transition can be. In a study of 60 large engineering projects such as airports and highways, Miller and Lessard cited three types of risks that impede such projects [56]:

1. Technical and operational risks
2. Market-related risks
3. Instructional and social risks

Although the work of Miller and Lessard does not explicitly cover technology transition, it does cover many of the challenges and success factors for the implementation and execution of complex projects which will be covered in Section 6.3.

In another field of work by Marais and Weigel, the authors develop a framework for technology transition in civil aviation, a subset of which is depicted in the Figure 44 below [52].

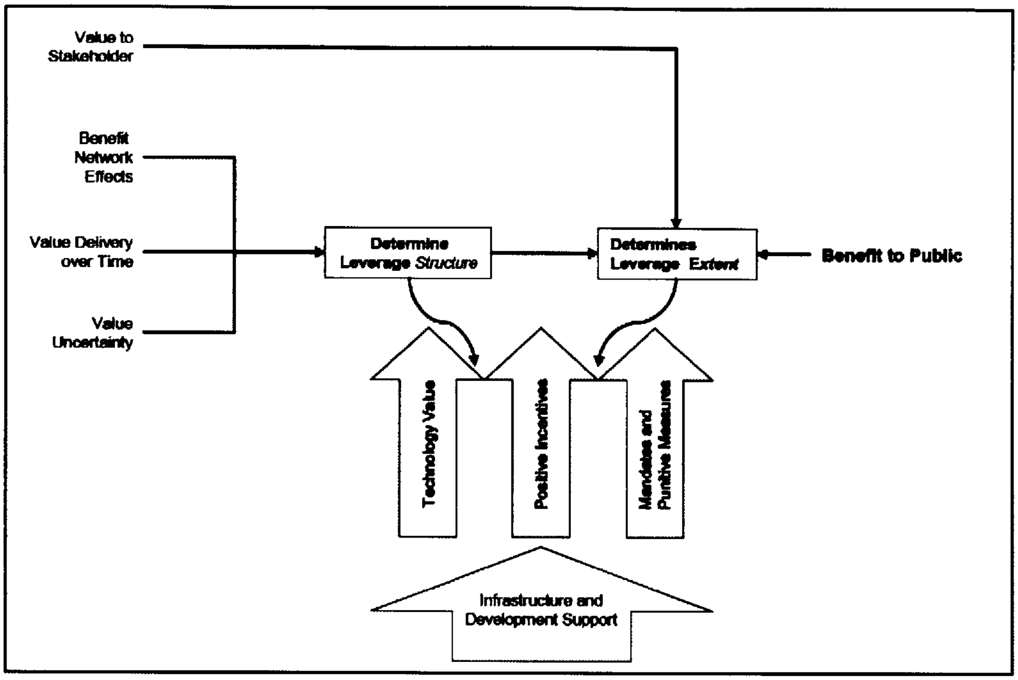


Figure 44: Technology Transition Framework from Marais & Weigel [52]

Marais and Weigel's framework involves identifying the value distribution of the technology transition among the stakeholders and over time. In addition the framework entails analyzing network effects in order to understand the relationship of benefit to the level of adoption of the technology and to prescribe incentives or support for initial infrastructure if needed. Finally, value uncertainty must be considered, communicated to stakeholders, and mitigated.

The Miller and Lessard work is leveraged in section 6.3, a discussion of shaping the environment for implementation, and in section 6.4.2, the upstream and downstream influences [56]. The application of Marais and Weigel's framework to U.S. Rail is seen is section 6.5 and in chapter 7, specifically the notions of network effects and the distribution of value delivery are discussed [52].

6.2. CURRENT PATHWAYS

There are a variety of pathways through which technology goes from conception to implementation in the U.S. Rail industry. A description of these pathways is based on discussions with FRA representatives, a National Legislative Director [57], attendance at a Railroad Operational Safety Committee meeting [7], and attendance at a technical advisory group to establish standards for locomotive control stands, displays and overall cab layout for the next generation cab [6]. The pathways revealed via these discussions are detailed below.

Employee-initiated suggestions. Locomotive engineers or other employees of the railroad generate ideas for improving their work after becoming subject matter experts and have an in-depth understanding of the tasks and use context for performing their jobs. Suggestions are borne from seeing an area for improvement or from observing technology from another industry and realizing that its application in rail could be beneficial. All but one major railroad has an open suggestion box whereby employees can submit these suggestions [57]. Railroad foreman are also a channel for locomotive engineers to flow up their suggestions. These employee suggestions may bring about the initial concept, but the railroads are the next step in deciding to take these concepts further.

Railroad-requested. Class I railroads often have committees to identify changes that need to made regarding the locomotives and then a railroad representative approaches the OEMs or third party manufacturers to see what changes can be accomplished economically. However, it seems that these requests are mostly based on user preferences such as seat comfort or location of hand brakes, according to an employee of a leading OEM who said that railroads often ask for varying configurations of the same hardware [7]. While most of the discussions revolved around hardware, in general, software iterations and modifications can be implemented more rapidly than hardware modifications assuming the processes for testing and incorporation take equal amounts of time. However, just because modifications are feasible does not mean that they should be implemented at every request; a holistic analysis should be conducted of the requirements and the impact of such a modification on all of the users.

Railroads also pursue or investigate emerging technologies for possible incorporation. For example, the Union Pacific railroad states that it evaluates technologies to improve its environmental impact: "As technology improves and our employees continue to focus on innovation, Union Pacific is always exploring opportunities to further reduce the railroad's environmental footprint" [58]. Norfolk Southern has a Research and Test group that actively experiments with technologies for potential applications for Norfolk Southern [59]. Other railroads might have similar business units such as CSX's Technology Business unit [60] or less formal methods of technology development and/or evaluation.

Vendor-initiated. Vendors, which include OEMs and their suppliers, often propose technologies and innovations to railroads that they have either developed for railroad applications or transferred from other industries. One of the venues through which vendors communicate their technologies is through tradeshows such as the Railway Interchange which in 2013 was the largest railway tradeshow in North America [61]. Various tradeshows occur two to three times a year and often include a conference or technical presentation component [62]. There are a number of trade associations that work to connect vendors with customers for various areas of the rail industry. Some of these trade associations include the Railway Supply Institute (RSI) which also advocates for standards and legislator that benefit vendors, Railway Engineering-Maintenance Suppliers Association (REMSA), and Railway Systems Suppliers, Inc. (RSSI) [62].

Research-institutions. There are a number of research centers either affiliated with universities or independent from academia. Some of the university affiliated research centers include the Center for Urban Transportation Research at the University of South Florida, the Center for Railway Research as a part of Texas A&M Transportation Institute [63], and the Center for Transportation and Logistics at MIT [64]. The Department of Transportation funds the FRA's Transportation Technology Center (TTC) [65] and the Volpe Center, a National Transportation Systems Center [38]. Government institution research is typically made available for open use while the university, which can commercialize technologies by selling patents or encouraging startups, typically owns university-based research.

Industry. Industry-funded research either occurs in company internal research and development groups or as a part of industry-wide technical work committees or technical advisory groups that are comprised of many stakeholders, including a variety of industry representation. This path is similar to that of Railroad-requested and Vendor-initiated, but the key difference is that the industry has deliberately decided to form a multi-stakeholder group in order to form a consensus and decide on the state of a particular technology.

6.3. Shaping the Environment for Implementation

"Successful projects are not selected but shaped," states Miller and Lessard in their work, "Evolving Strategy: Risk Management and the Shaping of Large Engineering Projects" and although their work is on large engineering projects, many of their points are applicable to technology transition since they share many of the same issues [56]. This shaping process must begin early in the life of a technology in order to overcome barriers to implementation.

Miller and Lessard stress the importance of "momentum building" in order to convey the value of a project/technology starting as early as the conception stage. During "momentum building," risks should be identified and stakeholder concerns should be addressed with action, not just promises of future action. Risks and uncertainty go hand-in-hand, so implementation should be flexible; long-term constraints and costs of switching to alternative decisions should be minimized.

"Governability" is another success factor addressed by Miller and Lessard and involves strong sponsors who advocate for the effort throughout its lifespan to include when significant changes such as regulatory, political, or economic changes endanger current plans. The sponsors are responsible for fostering relationships among stakeholders so that they can help redefine or revive the effort in the face of such changes. Sponsors also help create the right climate for the success of the implementation by helping to ensure that "laws, regulations, and practices" and community attitudes are conducive to the effort. For the rail domain, sponsors should exist within each of the organizations involved in a transition to include the railroad companies, represented labor force, OEMs, suppliers, legislators, Department of Transportation, and trade associations. Of course, the scale of the effort and the extensiveness of changes required influences the level of involvement of sponsors across the organizations. Major efforts, those involving many stakeholder organizations and significant changes to the status quo, should have a focused and collaborative group of sponsors.

Lastly, any roadmap for a major project or technology implementation is evolutionary and decisions should be revaluated periodically, advice shared by Nightingale, Rhodes [66], Katz, and Allen [67]. Many factors and influences can and will evolve over the many years it can take for a concept to be realized and implemented.

6.4. Sociotechnical Considerations

There are many approaches and methodologies for developing systems that take into account sociotechnical factors such as Enterprise Architecting [66], System Architecture [34] and the CLIOS (Complex, Large-scale, Integrated, Open Systems process) [68]. These methodologies have a common step of characterizing the stakeholders and the influences on them from a holistic perspective. This section will combine and extract from these approaches in order to understand the key factors at play when attempting to introduce new display technologies in locomotive cabs. Together with the technology transition discussion from above, this portion will inform the concluding chapter of recommendations for U.S. Rail.

6.4.1. Stakeholders

Crawley and Cameron suggest categorizing stakeholders into three categories described below [34]:

1) Charitable Beneficiaries-stakeholders who receive value, but do not give back in return
2) Beneficial Stakeholders-stakeholders who both receive and provide value
3) High-Leverage Stakeholders-stakeholders that provide value, but receive little in return

The key stakeholders involved or impacted by cab technologies are categorized into charitable beneficiaries, beneficial stakeholders and high-leverage stakeholders in Figure 45 below.

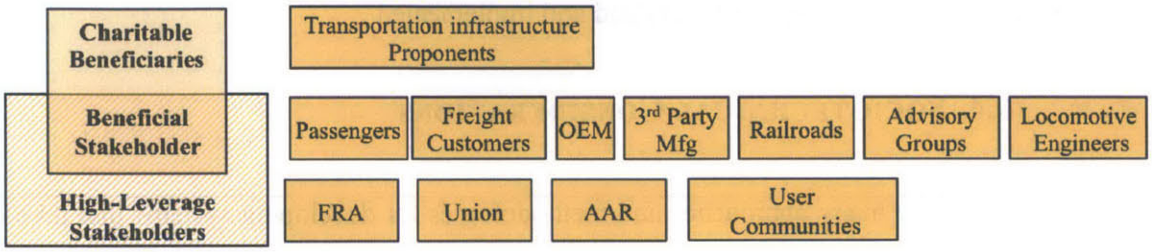


Figure 45: Stakeholder categorization adapted from Crawley & Cameron [34]

The charitable beneficiaries are transportation infrastructure proponents. Transportation infrastructure proponents are those that benefit from the transportation infrastructure either directly by utilizing services or indirectly by the economic gains that result from the infrastructure, such as a business owner who gains from the addition of a subway stop near his store.

The beneficial stakeholders, in no particular order, include those who gain via exchange of goods or services from cab technologies, those who use cab technologies, and advisory groups that are composed of a variety of stakeholders. Rail passengers and freight customers receive transportation services that are enhanced by cab technologies via increased reliability, efficiency, or safety. Original Equipment Manufacturers (OEMs), third party manufacturers, and railroads exchange goods, i.e., the technologies for payment. ***The locomotive engineers are the primary beneficiaries in that they are the ones that receive the primary value of the system which to deliver increased situation awareness to the locomotive engineers*** [34].

The high-leverage stakeholders are the Federal Railroad Administration (FRA), unions that represent the represented workforce, organizations such as the Association of American Railroads (AAR) that promote and support the rail industry, and user communities. These stakeholders are high-leverage because they are very influential, but because they act as agents they get little in return. The FRA is an agent for the general public; the union is an agent for the represented workforce, and the AAR is an agent for the rail industry. User communities refer to the numerous online forums and online communities for those working in the railroad industry to discuss issues that impact them regionally and nationally [69].

6.4.1.1. Value Flow

It is often useful to characterize the relationship that stakeholders have amongst each other in order to understand the entire ecosystem at play. One method of doing this is a value flow map where blocks represent stakeholders and the value that flows between the blocks is indicates by arrows [34]. The direction of the arrow/head of the arrow points towards the stakeholder that receives the value. Figure 46 demonstrates a value flow diagram for the enterprise of "Cab Design" where "Moving Map Display" design is a representative subsection of the cab design enterprise.

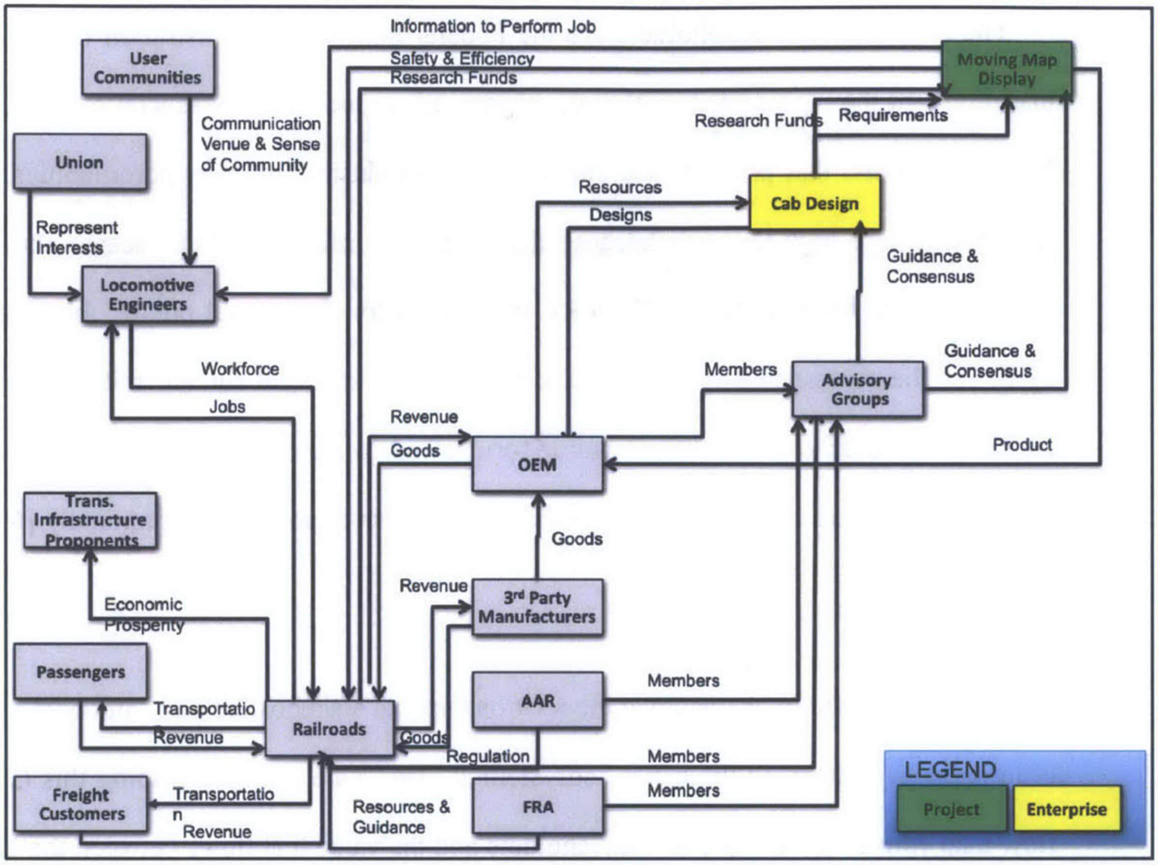


Figure 46: Value Flow Diagram

From the value flow diagram above, it is clear that the railroads are central to this enterprise exchanging goods and services for payment in addition to providing requirements to cab design and the display. Conversely, the locomotive engineers as the primary beneficiaries do not have as many exchanges. In fact, the users do not have a direct route to provide input to cab design or the displays; their needs are only conveyed to the railroads that are then responsible for interpreting and passing along user input with their own needs. Based on comments made by two Class I Railroad representatives at a Railroad Operational Safety Committee meeting, a common practice is for the railroad to hold a committee that meets twice a year to discuss user feedback about changes that should be made in cabs [7].

During the cognitive walkthrough discussed in Chapter 1, Sections 5.2 and 5.3, one subject who is a locomotive engineer for a commuter railroad, recalled that before a new cab was introduced, pictures of the layout were posted in break rooms and contact information was provided if anyone had any feedback or suggestions. Another venue through which locomotive engineers provide input to designs, other than when specifically solicited by the railroad, is by joining a working group or advisory group tasked with cab design. Typically, locomotive engineers are represented by a labor representative or someone with many years of rail experience, but who may not be currently running routes. The primary beneficiary, the locomotive engineer, has little direct influence on the value they receive from the display which may be the reason that current displays and cab designs may have less than optimal interfaces or functions.

6.4.2. Upstream & Downstream Influences

Now that the stakeholders and their interconnections have been identified, it is important to identify the influences that act on them. Crawley and Cameron [34] as well as Osorio et al [68] use this notion of upstream and downstream influences. The latter work defines them as follows:

> Dominant Upstream Influences (DUI) include the regulatory and legal environment that affects form and function, corporate and marketing strategy, the influences imposed by customers and beneficiaries through their needs, the effects of the competitive environment, the evolution and availability of technology, and other strategies and internal competences. Dominant Downstream Influences (DDI) include those arising from the design, implementation, operation, and evolution of the system [68].

The dominant influences for cab and display design will be discussed in the following subsections.

6.4.2.1. Upstream Influences

6.4.2.1.1. Regulations

There are a number of major regulations passed by Congress regarding the railroads such as the Rail Passenger Service Act of 1970 establishing Amtrak [70], the Staggers Rail Act of 1980 allowing freight railroads more freedom to choose service offerings and pricing [70], and the American Recovery and Reinvestment Act of 2009 which provides funding for intercity rail and high-speed rail corridors [10]. These Congressional Acts set the economic tone for the future of freight and passenger rail and play a major role in the capital investment railroads are willing to make to redesign or upgrades their equipment and therefore are a major influence in cab display improvements.

In addition to federal regulations, various territories have varying regulations/operating rules. The General Code of Operating Rules (GCOR) has been adopted by the majority of Class II railroads and all Class I railroads west of the Mississippi River [8]. Northeast Operating Rules Advisory Committee (NORAC) is used in the northeast by Amtrak, Conrail and other smaller commuter railroads [8]. Class I railroads CSX and Norfolk Southern along with a few other railroads use their own rulebooks [8]. With this diversity of rules and lack of standards for cab and display design described in Chapter 1, it is difficult to have a universal design [41] [42]. Commonality in design benefits design efforts, manufacturing, training, and maintainability resulting in reduced costs across these lifecycle phases. In addition, certain railroads share locomotives, i.e., locomotive engineers on one railroad may operate locomotives belonging to another railroad in order to increase efficiencies making commonality even more important in these instances [7]. There are many benefits to commonality that diversity in rulebooks and operating practice may make infeasible. Furthermore, based on discussions with those in the industry, railroads do not want to be dependent on any one supplier, which may also inhibit commonality. Commonality in displays can improve safety as locomotive engineers are less likely to mistake critical input interfaces, alerts, messages, information, etc. among various displays.

The transportation agencies have been moving away from "prescriptive standards towards Safety Management Systems (SMS) and performance-based regulations that emphasize the management and control of risk" [1]. Cost effectiveness [1] and railroad buy-in are noted as reasons for this movement away from prescriptive standards.

An additional regulatory influence to cab and display design is that Class I railroad carriers and selected passenger rail providers are gradually transitioning and/or preparing to transition to PTC systems for a subset of their routes as mandated by the Rail Safety Improvement Act of 2008 [2]. However, railroads are not expected to meet their deadline of 2015 according to a report to congress entitled, "Positive Train Control Implementation Status, Issues, and Impacts" due to a variety of factors that will be discussed throughout the next two chapters [1]. This mandate may dissuade railroads from considering major redesigns to the cab or displays because of the capital and effort required to implement PTC. Although the infrastructure that must be emplaced for PTC can directly support many other in-cab technologies, such as the interactive moving map, it may be difficult for railroads to justify another major change to locomotive cab displays in the same timeframe they are facing pressures to implement PTC.

6.4.2.1.2. Legal

Litigious environments are often not the best incubators for improvements and collaboration, technology related or otherwise. In the railroad industry, the legal environment impacts the relationship between railroad workers and their employers (the railroads) and also the relationship between the railroads and the government. This section will discuss some of the implications of negligence, the legal sense, and also the legal authority of government to enforce safety standards.

A few of the cognitive walkthrough participants noted that some locomotive engineers view technology inclusion in the cab as an attempt to observe and record their actions so as to be able implicate the locomotive engineers in the event of an incident or accident. Although one participant acknowledged this perception, he/she also remarked that the inclusion of outward facing cameras actually was instrumental in exculpating a locomotive engineer in a recent case. Perception of ulterior motives, such as gathering evidence to form a legal argument, could make it difficult for locomotive engineers to adopt the use of a technology. Participants told a few anecdotes of locomotive engineers that disabled or ignored displays because of distrust issues or because they did not see the value in using them.

The Federal Employers' Liability Act (FELA) of 1908 is still in effect today which arguably places railroad employees at a disadvantage as compared to employees of other industries in terms of liability and negligence [41, 71]. Since 1908, FELA was only amended in 1936. The two major changes to FELA eliminated the "traditional defense of assumption of risk" where railroads before defended themselves via the argument that employees assumed the risks by virtue of employment and prevented "contributory negligence" from being an absolute block on employee recovery [71]. Aside from harbor workers, railroad workers are still the only workforce in the United States that are not covered by a no-fault workers' compensation system for on-the-job injuries [71]. FELA creates an environment where if railroads can demonstrate employee negligence, they may not be obligated to pay the employee recovery for injuries or may be able to reduce the amount. This legal environment could contribute to the workforce's reluctance to change for fear that unfamiliar technologies could change the assessment of negligence.

What is the relationship between railroads and the government? Part of the Federal Railroad Administration's mission is "issuance, implementation, and enforcement of safety regulations [72]," however; they are cited for deficiencies in their oversight in priority, ability, and metrics to track impact [14]. For instance, a 2007 U.S. Government Accountability Office report says that the FRA is only able to inspect 0.2 percent of tracks [14]. The FRA has been improving in oversight areas, but railroads still have significant doubts that the FRA will have an adequate verification program for PTC and fear that this will result in increased downtime of PTC-equipped locomotives [73]. The FRA may attempt to enforce standards but has a long way to go in leading the "issuance, implementation, and enforcement" industry-wide. Currently, one of their main actions against violators is to issue civil monetary penalties to the railroads [73]. A 2013 Government Accountability Office report states that, "FRA is a small agency relative to the railroad industry, making the railroads themselves the primary guarantors of railroad safety [73]." This is in stark contrast to the Federal Aviation Administration (FAA), which has many mechanisms in place to oversee compliance and enforcement actions that range from administrative to criminal charges against individuals or businesses [74].

In industry discussions, it was mentioned that the research or suggestions published by government organizations were in some cases used in litigation cases where railroads did not follow these recommendations. As a result, certain agencies are reluctant to publish research, instead funding companies, universities, or research institutes. This deterrent keeps these government organizations, to some extent, from publishing research findings.

Therefore, cab and display design must take into consideration the legal implications and the relationships legal precedence has between railroads and their employees and between railroads and the Federal Railroad Administration.

6.4.2.1.3. Strategy/Competitive Environment

Railroads are companies whose goal is to generate positive revenue while still operating safely. Other goals such as productivity and efficiency contribute towards the goal of positive revenue. Railroads have very high fixed costs; their cost of capital is roughly equal to their profitability and their fixed infrastructure costs account for roughly twenty-five percent of overall costs [75]. This means that large investments should have demonstrable returns financially or otherwise. An example of a non-financial return would be improved safety; although safety improvements can be estimated in terms of financial savings or cost avoidance of accidents, it can be more difficult to quantify over technologies or changes in operating practices that save fuel or reduce required manpower.

One of the main factors inhibiting PTC implementation is the high cost. The FRA assesses that the cost-to-benefit ratio of PTC for the railroads is an overwhelming 22:1 [76]. Additionally, intercity/passenger rail are subsidized by government and as a result lack capital to invest and implement the technologies [1]. The strategy and competitive environment plays a key role in whether companies are willing and able to invest in in-cab displays and the associated costs of research, implementation, training, maintenance, etc.

6.4.2.1.4. Customers

Passengers and freight customers impact the bottom line for railroads and as a result, railroads are understandably hesitant to make changes that could interrupt the quality, reliability or services provided to their customers unless these changes are specifically requested or demanded by their customers. Therefore, in this enterprise, because customers usually do not directly benefit from changes in locomotive cabs and implementation could temporarily impact service to customers, customers as an upstream influence create an uphill hurdle for changes to locomotive cabs.

6.4.2.1.5. Technology

The existence of applicable technologies is an upstream influence on architectures of systems and sub-systems related to locomotive cabs. Although railroad industry research is conducted in research institutions such as the Transportation Technology Center, Inc. (TTCI), universities and Tier 1, 2 and 3 firms, the U.S. Rail industry has not been known for its cutting-edge technology since the nineteenth century [65]. However, in the last decade, rail technologies have burgeoned globally and it appears that the U.S. will be following this trend (the majority suppliers to the U.S. also serve other countries) [10]. Furthermore, U.S. aviation has made large strides in technology implementation from automation to heads-up displays to Electronic Flight Bags (EFB) and it would be reasonable to expect U.S. Rail to move towards similar changes especially as thirty-four countries have implemented PTC in the form of European Railway Traffic Management System (ERTMS) [4] and multiple foreign cities operate passenger service without a driver [11]. Although technology has not been a significant influence in the last century in U.S. Rail, due to global technologies implementation in rail and technology implementation in adjacent industries such as aviation, technology is now an important upstream influence in the U.S. Rail industry.

6.4.2.2. Downstream Influences

6.4.2.2.1. Infrastructure/Information

As stated above, infrastructure costs account for roughly twenty-five percent of total fixed costs for railroads in part due to the thousands of miles of track and all of the rolling stock that must be maintained. Additionally, capital costs account for 60-80% of total costs [77]. Therefore, any widespread changes will come with significant costs so the addition of displays should be easy to retrofit current cabs. This also means that due to the variety of cab designs, installation should be flexible unless a display change is part of a larger cab redesign. This infrastructure influence may be a reason against having the interactive moving map display permanently mounted in the cab. To avoid large installation costs, the display could be portable and used with a variety of mounting devices. On the other hand, a touch screen display meeting the needs for use on board a locomotive could be incorporated in cabs and software such as the moving map could be installed on the displays with less effort than a physical retrofit.

However, the introduction of such a display involves more than its physical presence in cabs and localized software. An entire communications infrastructure must be present that also includes the ability for dispatch centers and maintenance shops to interact with the displays. Part of this communication/information infrastructure involves technologies that provide locations of trains within tolerable levels of accuracy, precision and time. Additionally, moving maps require accurate track databases in order to populate the displays which may/may not be available for every portion of track or available in usable electronic formats. If a moving map display is intended to be used across the entire country, track database formats and lack of an adequate information infrastructure could be a significant hurdle. However, many of these issues are being addressed, at least in part, during PTC implementation.

A common communication/information infrastructure is important in regions where tracks are shared (freight and passenger rail traverse along the same tracks) or where locomotives are shared across railroads. Interoperability among railroads is essential and is one of the top technical challenges faced by the implementation of PTC today. The list of "technical obstacles" reported in the FRA's "Report to Congress: Positive Train Control: Implementation Status, Issues, and Impacts" are similar to the ones discussed above [1]:

- *Communications Spectrum Availability*
- *Radio Availability*
- *Design Specification Availability*
- *Back Office Server and Dispatch System Availability*
- *Track Database Verification*
- *Installation Engineering*
- *Reliability and Availability*

Due to the expansiveness and high costs of infrastructure in U.S. Rail, implementation and integration details must be planned in great detail before large-scale efforts are attempted. Technical and organizational challenges should be identified and resolution plans should be agreed upon by all of the key stakeholders before beginning large endeavors involving infrastructure changes.

6.4.2.2.2. Training

"Today the railroad industry is beginning to capitalize on new educational technologies that make training our workforce achievable without divorcing the employee from his job for an extended period of time," states the former president of the American Short Line and Regional Railroad Association, "This only succeeds, however, if senior management has employee development and competence as a priority, and invests the resources to pursue training programs that improve employee skills and professionalism" [78]. Indeed, the railroad depends greatly on its skilled workforce for its daily operations and training is a key component to developing and maintaining such a workforce. Locomotive engineers undergo extensive training and route qualification before operating locomotives. This training is either done on the job or contracted out to third party companies or at universities. Continuing education is achieved through online training modules, webinars, DVDs, mobile training classes or designated training facilities owned by the railroads.

Changes in the railroad are accepted more readily when the time is taken to introduce those changes before they are implemented and sufficient training is given. A number of the cognitive walkthrough participants, when asked to reflect on the introduction of a new technology, stated that there were instances where new technologies "showed up" without any prior training. One subject in particular said he/she was running late on a route and was informed that the locomotive he/she was taking over was instrumented with a new technology and he/she did not have time to look over the manual. He/she reflected on the experience: "The trainer went two stops, then I went two stops. Like a new car, you don't just get in and drive. You want to know where everything is in case something happened. If something were to happen, the trainer would have had to take over because I wasn't familiar with it."

The best experiences subjects had with the introduction of technologies involved classroom training with some sort of mock-up or the opportunity to operate a cab equipped with the technology. However, providing this training comes at the additional expense of removing workers from operating, with additional costs for training equipment and instructors. These downstream considerations should impact how systems are architected—can a simulator be developed to provide training, how different is the interaction from what users are accustomed to?

One cognitive walkthrough participant, after interacting with the display said that the display would be invaluable for route qualification or refreshing oneself on routes, especially those that may change frequently. This would be contingent on the display being provided in a portable form and introduced in the early phases of training. However, the display might be able to reduce the amount of classroom training for route qualification.

6.4.2.2.3. Operation

How the systems, products, technologies, etc. will be used in operation is a key downstream influence, especially in an operationally heavy industry such as rail. It is important to understand the use context; this is a major component in any task analysis and also recommended by Crawley and Cameron [34].

Maintainability is a key downstream influence in the rail industry because the service/value delivered is dependent upon functioning locomotives, rail cars, tracks, etc. As a result, systems designed to be easy to maintain will be more attractive to industries such as rail. Features in cab that would make it more maintainable include self-diagnosis, easy access to panels, wireless updates and parts that are easily replaced.

6.4.2.2.4. Safety/Processes

Railroads transport a variety of goods including hazardous materials and human passengers. As a result, safety is a top priority for the industry. Safety measures can be added as features of equipment or via procedural protocols. In systems that provide information to locomotive engineers, all possible failure modes must be assessed prior to deployment.

Currently, there is no official testing agency to verify the safety and reliability of railroad hardware and software. The Code of Federal Regulation (CFR) only mandates that the railroads develop and maintain a hardware and software safety program with some specifics, such as those in Title 49 CFR 238 Part 105 Subpart D which states:

> (1) Hardware and software that controls or monitors a train's primary braking system shall either:
> (i) Fail safely by initiating a full service or emergency brake application in the event of a hardware or software failure that could impair the ability of the engineer to apply or release the brakes; or
> (ii) Provide the engineer access to direct manual control of the primary braking system (service or emergency braking). [41]

However, it appears that the FRA is moving in the direction Department of Defense (DoD) Acquisitions where systems undergo Test and Evaluation processes by independent agencies [79]. For example, CFR 236 Appendix F prescribes third party assessment for PTC systems [41]. Therefore, safety as a downstream influence becomes more complex as additional safety evaluation processes are added; such changes may impact the development of systems such as a moving map display where a phased approached may lend itself better to testing.

In-cab displays can improve safety assuming that the displays and communication infrastructure meet requirements for reliability, robustness, and quality of service. In 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 less speed violations; better signal adherence' less time between passing a signal indicating speed should be reduced and initiating braking; and worse at station-stopping accuracy due to the insufficient resolution in the display [33].

6.4.2.2.5. Organization

One of the largest downstream influences for technology transition or any major change is the organization(s) involved. Aside from the external agencies and stakeholders, if the core organization/organization implementing such a change is unable to execute it, then all efforts outside of that core organization are obviated. In the case of a locomotive display such as an interactive moving map, if all regulators approved its use and OEMs were able to integrate and test it, but the railroads were unable to introduce the technology with little interruption to operation, then the technology would face steep implementation barriers within the railroad.

Many organizational factors impact an organization's ability to handle change, but the factors that are most relevant to railroad organizations include incentive structures, organizational inertia, and perceptions of management. Rail is an industry that measures itself against efficiency, productivity, and safety that are achieved, in part through adherence to policies and operating practices. Any change, even those that promise great returns, threatens the routine and the metrics for which employees and the organization are measured against. Ralph Katz and Thomas Allen discuss the difficulty of this "dualism" within organizations that must continue to deliver while at the same time continue to innovate in "Organizational Issues in the Introduction of New Technologies" [67]. Katz and Allen suggest that in order to alleviate the competition of resources between current operations and future innovations, innovation efforts should be separated from day to day operations into Research and Development groups with separate incentive structures.

Organizational inertia, or an organization's propensity to maintain its status quo, makes change even more difficult. In organizations with strong inertia, the time it takes to implement change might exceed the career lifespan of current leaders or may make the organization reactive instead of protective to external changes. Organizations who are not accustomed to dealing with change are ill equipped to handle changes, especially ones that may be mandated within short timeframes.

Because changes in organizations require support and buy-in from many affected employees, perceptions of management who might be in charge of implementing these changes are a strong influence to the success of these changes. Perceptions of management and technological change can be damaged if there is a history of failed efforts [80]. Interviews with most of the cognitive walkthrough participants alluded to technology implementation efforts that did not go smoothly. When one subject recalled his/her experience with a new locomotive control stand, he/she felt that he/she was inadequately trained and unprepared: "here it is, good luck. I don't know how to do this; I don't know how to do that. I don't know where to look, where to fix things." Another barrier is if the technology might change the job function and employees feel uncertain about how this impacts skills, expectations job security [80].

Depending on the extent of change, whether it is incremental or paradigmatic, parts of the organization may need to transform before such changes can be successfully implemented.

These shifts should be deliberate and take into account the current states of organizations before they are attempted.

6.5. CHAPTER SUMMARY

This chapter has covered technology transition research, current pathways to technology transition, the importance of shaping the environment for implementation, and the main upstream/downstream influences in the rail industry. One way of summarizing some of the major issues facing in cab technologies in the rail domain is to use Crawley and Cameron's framework of business and architectural influences impacting each other (Figure 47).

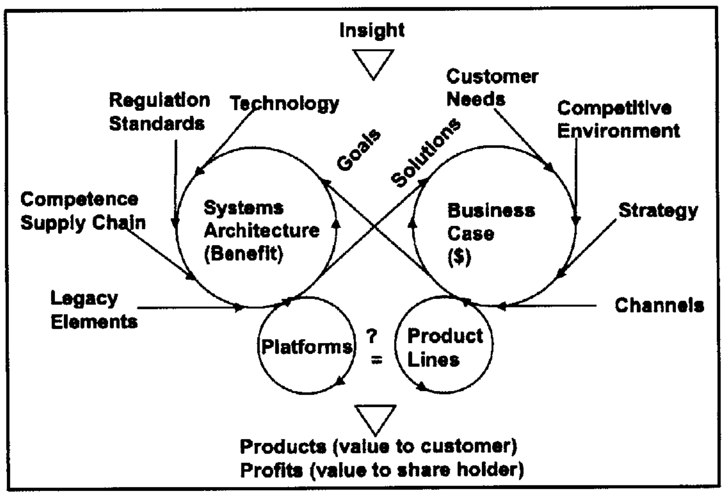


Figure 47: Architecture-Business Case Interrelationship [34]

Table 7 captures how the architectures of locomotive displays and locomotive cabs generally evolve for each of the factors illustrated in Figure 47, but also how they should evolve based on the insights discussed in this chapter and the previous chapter. In this table, "the enterprise" refers to the cab redesign subsection of the industry with a focus on locomotive display design.

Table 7: Evolution of Architecture & Interrelation with the Business Case adapted from Crawley & Cameron [34]

Architecture Case	How architecture is evolved	How architecture should evolve
Goals	Goals are developed reactively to accidents or user preference. This is evident by the fact there are multiple cab configurations	Goals should be derived from the needs of the stakeholders
Context (whole product, and use)	Operating environment in the cab not considered (vibration, noise, lighting, visibility). One interviewee said, "It's as if they (the designers) have never sat in a cab"	Operational concepts should cover the range of uses so that the architects have a holistic view of the use cases
Architecture (Function, Concept, Form)	Form is usually constrained by the limited real estate in the cab. Function does not fully consider context and the concept is limited to existing methods (knobs, dials, analog gauges, digital screens)	The enterprise should employ human-centered systems engineering processes in cab redesign
Technology	The U.S. enterprise borrows/adapts technology from other industries and railroads in other countries (Japan, Europe, etc.)	The enterprise should be more involved in Research and Development to create technologies that are specific to its needs
Regulation	The architectures are reactive to mandates	Architectures should have flexibility for anticipated regulation changes or general improvements
Legacy/Supply Chain	Architectures are often evolved around legacy systems due to high costs of the cab	Architecture should drive future cab designs, especially in an era where more advanced systems (that control the train) require displays that help the locomotive engineers
Platform Alignment	Due to the higher costs of cabs, displays usually conform to various cab configurations	Cabs should be architected so that modularization of displays is universal across cabs, making the integration of displays less costly
Plans (Design, Implementation, Operations, Upgrade)	Implementation and upgrades of new display systems are usually introduced to the locomotive engineers during a cursory class but there is little hands-on training (simulator or en route) before introduction	Given the importance of the operators (and influence of the Union), the architecture should lend itself to phased implementation or more extensive training before implementation
Interface and Architecture Control Plans	The OEMs are often given 3rd party equipment that the railroads want and the OEMs are forced to add it to their architecture	An industry committee should develop standards and provide implementation guidance for interfaces and new system architectures

Table 7 highlights the need for a more holistic, needs-driven process rather than an evolution that is reactive and highly dependent upon existing configurations. However, it is an easier exercise to capture the current and desired states than it is to actually make that transition.

An uneven distribution of rewards versus responsibilities is a barrier that Marias, Weigel [52], Miller, and Lessard [56] identified and may explain the lack of stakeholder cohesion among OEMs, suppliers, railroads, and locomotive engineers. The market share amongst OEMs and suppliers is highly segmented making it difficult to focus on holistic design and more apt to focus on specific customer requests. One OEM representative stated, "if we don't build what the railroad asks for, someone else will." The establishment of multi-stakeholder groups is a move in the right direction. Two such examples are the AAR Locomotive Cab Technical Advisory Group, whose goal is to establish standards for locomotive control stands, displays, and overall layout for the next generation cab and to not be limited by current configurations [6] and the Railroad Operational Safety Committee's conference on "The Future Locomotive: How to Manage What You Have Today With an View to the Future" [7]. Common designs, standards, and operating practices that are agreed upon by all stakeholders may help to create cohesion in the design enterprise.

Another consideration that builds upon the issue of uneven distribution of benefit is the concept of network effects. In the case of air traffic management systems, Marais and Weigel acknowledge that system benefits may require a certain threshold adoption before benefits can are worthwhile and in these instances, aviation agencies should assist in the installation of a "minimum infrastructure" and provide "positive incentives" for adoption [52]. Moving map technologies whose benefit is partly based on a reliable and high quality communications infrastructure and databases may also require a threshold of adoption in order for value to be achieved by railroads. Federal investment may be needed in order to kick start implementation. It is also likely that much of the needed infrastructure will be in place for PTC and can be leveraged for the moving map.

The ability to clearly and quantifiably convey benefit of a new technology from its early stages is key to shaping the environment for its implementation. In an industry with high operating costs and capital costs, quantifiable benefit is important to the railroads. The value of a technology to the locomotive engineers is key to adoption by the users who might otherwise distrust the intent of management pushing the implementation. Part of this communication is to actively solicit feedback and provide prototypes and testing for use in simulators and in the field. Ensure that the technology has influential sponsors across the many stakeholders and all levels of the organization; these advocates can be called, "connectors, mavens and salesman" and help to communicate the value across the organization [18].

Lastly, in order to overcome the challenges of "dualism," or the competing interests of maintaining the current state but also investing in future technologies, organizations should vary its incentive structures for new technologies and consider easing thresholds for efficiency or productivity until implementation is more mature. Organizations should not expect change to be seamless and should expect some overall degradation of normal operations until benefit is achieved. Organizations should view technology transition as a long-term investment towards continuous improvement.

7. CONCLUSION

Throughout this investigation of moving map technologies, as a representative in-cab display technology for U.S. Rail, three major issues are uncovered regarding the industry's inability to transition such technologies:

1. Lack of a unified industry stance on the direction of in-cab technologies, specifically a lack of a committee chartered to develop roadmaps for the next evolution of in-cab technologies
2. Ineffectiveness in developing, implementing, and overseeing standards and regulations for in-cab display technologies
3. Need for a systems approach throughout the lifecycle of a technology, from concept to obsolescence

Recommendations for each of these issues are discussed below and are based on the findings from the previous chapters.

7.1. TECHNOLOGY DEVELOPMENT & IMPLEMENTATION COMMITTEE

Currently there is an absence of a committee that continuously looks prospectively towards technology trends and disruptive technologies to determine *if* and *how* these technologies can transform the industry. Perhaps the more difficult question is *should* these technologies be supported by the industry? A unified, big picture approach is needed for the industry to be able to successfully (efficiently, affordably, safely) transition these technologies across U.S. Rail. As discussed in Chapter 1, technology implementation and transition efforts require thorough consideration of the upstream and downstream influences; analysis of value delivery across stakeholders; and sponsors/advocates that can shape the environment for success. Furthermore, the plan must take into account uncertainties in the environment and also requires periodic reevaluation as influences evolve.

The Federal Railroad Administration (FRA) has an active research and development (R&D) program and the Association of American Railroads (AAR) stands up many valuable technical committees with focused scope, but these groups lack the over-arching ability to drastically influence technologies in the rail domain. According to the 2013 to 2017 Research and Development Strategic plan, the FRA R&D Program's main priority is safety and is organized into the following divisions each with sub goals of reducing risks: Railroad Systems Issues, Human Factors; Track; Rolling Stock; Train Control and Communication [16].

While safety should be the utmost priority, due to the competitive nature of rail, business cases may also influence introduction of technologies. In addition to improving safety and reducing accidents, technologies have the potential to produce fuel savings, reduce wear on equipment, provide enhanced diagnostics, ensure more on-time arrivals, etc. Fuel management systems and automation are key examples where safety is not necessarily the only benefit driver. As stated throughout this work, automation is a growing trend globally in rail systems and in other industries; it can allow for safer operations with increased throughput [11].

One of the charters of the Technology Development & Implementation Committee should be to develop an "Advanced Automation Roadmap" for the rail industry that goes beyond the tasks of the FRA R&D Human Factors and Train Control and Communications Divisions of:

- Develop technology, automation and systems design to minimize the potential for human errors
- Support the railroads in meeting the deadlines for implementation of Positive Train Control (PTC)
- Advance safety technologies, education and community outreach to improve grade crossing and trespass safety through local pilot trials, and then publicize successes
- Explore opportunities offered by Intelligent Transportation Systems (ITS) to improve grade crossing and trespass safety [16]

The committee should develop high-level objectives for the use of automation, outline the expected impacts, and work towards realizing the benefits while mitigating risks across all stakeholders from vendors to railroads to locomotive engineers. Although automation systems encompass more than in-cab displays, many of the same lessons apply to the development, design, and transition of the moving map, a representative in-cab technology.

The Technology Development & Implementation Committee should have the following attributes:

- Comprised of representatives of all stakeholders
- Contain the ability to influence policies, regulations, etc.
- Input into the allocation of R&D funding

Furthermore, the committee should be responsible for the following tasks:

- Identify technologies for which roadmaps are needed
- Continuously reevaluate roadmaps and the state of technology in rail
- Formalize processes for the identification, evaluation, and development of strategic plans for technology implementation

The need for advanced technologies, such as in-cab and automation technologies have resulted in disjointed attempts at implementation in U.S. Rail-technology implementation should be conducted within a larger strategic vision for value delivery across multiple stakeholders and can be drastically facilitated by such a committee.

7.2. DEVELOPMENT & ENFORCEMENT OF STANDARDS

Standards for displays and equipment produce a level of commonality which can improve safety as locomotive engineers are less likely to mistake critical input interfaces, alerts, messages, information, etc. Standards and protocols for transmitting information also allows train systems to be interoperable with each other and also reduce errors when communicating with entities outside of the locomotive such as dispatch centers, maintenance shops, or emergency services.

As a part of the PTC implementation effort, the Interoperable Train Control Committee comprised of the UP, CSX, NS, and BNSF Class I railroads have developed some interoperability standards, but a lack of "firm interoperability standards" along with lack of "onboard display standards" are two of the reasons cited for the PTC implementation delay [1]. Despite a long history of display use in cabs, it is not surprising that there are no display standards for PTC since there are no display standards for any in-cab technologies. Title 49 Code of Federal Regulation (CFR) 229 Part 236 Subpart E does not prescribe requirements for the cab display other than they are plainly visible/audible and tested daily upon departure [41]. AAR Manual of Standards and Recommended Practices Section M Locomotive System Integration Operating Display Standard states that the "appearance of the display items will be determined by the individual railroad" [42].

Transportation agencies have been moving away from "prescriptive standards towards Safety Management Systems (SMS) and performance-based regulations that emphasize the management and control of risk" [1]. Cost effectiveness [1] and railroad buy-in are noted as reasons for this movement away from prescriptive standards. While it is true that the FRA lacks the quantity of resources to oversee and enforce standards compliance and less prescriptive measures may be more effective for safety programs, performance-based regulations will not facilitate wide-scale technology transition [73]. When it comes to advanced technologies such as moving maps with network needs, high degrees of human interaction, and automation, standards are necessary to ensure commonality and interoperability.

Just because standards tend to be prescriptive does bar stakeholder buy-in; on the contrary, the development of standards for in-cab technologies should include all stakeholders and should evolve as upstream/downstream influences evolve. The process through which standards are developed should follow many of the same processes for designing a system, as described in the following section. In addition to the development of standards, regulators must have achievable plans for enforcing these standards. The lack for FRA resources for compliance enforcement is an issue that must be addressed at the government level.

7.3. Summary of Recommendations

In summary, the main recommendations for developing, designing, and transitioning moving maps, as a representative in-cab locomotive technology, are:

1. Instantiation of a Technology Development and Implementation Committee responsible for identifying the technological direction of U.S. Rail, developing roadmaps for technology implementation, and facilitating the execution of the roadmap. One of the subcommittees should be devoted automation and related in-cab displays
2. Development of specific standards for in-cab displays and how they interact with other systems
3. Utilize a systems approach when designing a system or developing standards to include understanding the needs/goals/problem, incorporating human engineering, analyzing the influences on the system, and revaluating as influences evolve.

While the findings and recommendations in this work may seem straightforward, the suggested changes require transformations in organizations, attitudes, and operating mindsets in an industry that has been slow to adapt to technologies. A holistic, cross-disciplinary, and systems-thinking approach is needed for such an undertaking.

Appendix A HYBRID COGNITIVE TASK ANALYSIS

This appendix details the adaptation and updating of the Alstom hybrid Cognitive Task Analysis (hCTA) for this effort [46].

This hCTA was created with a focus on passenger rail but is also generalizable enough for freight operations as well. Furthermore, later stages in the hCTA assume a non-PTC operating environment for execution; this is because PTC will not be able to be simulated with the experimental tools that will be available at the time the experiment will be conducted.

Scenario Task Overview

The first five phases used for the Alstom hCTA were maintained and the sixth phase, End of Trip, was added [46].

(1) Departure Preparation
(2) Before Departure
(3) Leaving Station
(4) En Route
(5) Arrival at Station
(6) End of Trip

Departure Preparation and En Route were determined to be the phases most applicable to this project for the following reasons:

Early interviews identified the cognitive demand of dealing with temporary changes to the normal route as an issue (these changes are given in the form of track bulletins before locomotive engineers board their trains and En Route)

Departure Preparation

Table 8 lists the high level tasks associated with the Departure Preparation Phase. The Scenario Task Overview (STO) ID and Interaction Medium columns have been updated from the Alstom hCTA [46]. The Information Column shows the new/altered text in **bold.**

Table 8: Departure Preparation-STO

Departure Preparation Phase-Scenario Task Overview (STO)		
STO ID	**Information**	**Current Interaction Medium**
STO DP-1	Desired Route **(assume engineer has been qualified on the route)**	Paper
STO DP-2	Stopping locations of specific route **(station stops and other required stops)**	Paper-Timetable & Bulletin Order
STO DP-3	Schedule for specific route	Paper-Timetable & Bulletin Order
STO DP-4	**Crew Members: Conductor, Engineer in Training**	Paper
STO DP-5	Special speed restrictions **and special instructions** for the region that day **(Temporary speed restrictions, work zones, grade crossings with broken gates, etc.)**	Paper-Bulletin Order
STO DP-6	Current (and projected) weather conditions	Paper-weather forecast
STO DP-7	**Consist Characteristics (tonnage, weight, distribution of weight, powered cars, braking system, etc.)**	Paper
STO DP-8	**Identify territories, authorities, dispatcher, etc. along route**	Paper-Timetables
STO DP-9	**Gather rulebooks for each territory**	Paper-Rule books
STO DP-10	**Enter Engine number, crew names, route (destination, direction, start time)**	Paper
STO DP-11	**Organize applicable restrictions/additional actions needed for specific route of travel**	Paper, highlighters, sticky notes, erasable markers on glass

En Route

Table 9 lists the high level tasks associated with the En Route Phase. The STO ID and Interaction Medium columns have been updated from the Alstom hCTA [46]. The Information Column shows the new/altered text in **bold.**

Table 9: En Route Phase-STO

STO ID	Information	Current Interaction Medium
STO ER-1	Monitor train vitals and troubleshoot if error detected **(to extent permissible while in motion)**	In-cab display
STO ER-2	Monitor for radio transmission and respond if needed	Auditory Channel
STO ER-3	Monitor external lighting and change headlight based on current conditions	Out-the-cab
STO ER-4	Monitor tracks and prepare to stop, or activate horn, if interference is detected	Out-the-cab, Brakes, Horn
STO ER-5	Monitor tracks to detect steep grade/**sharp curves** and adjust speed and if detected	Out-the-cab, Brakes/throttle, Speedometer
STO ER-6	Monitor weather and sand wheels if rainy weather	Out-the-cab, Controls for sanding wheels
STO ER-7	Monitor track assignment and prepare to break if wrong track detected	Out-the-cab, Dispatcher Notification Brakes
STO ER-8	Monitor and respect internal/external security signals	Out-the-cab, In-cab signaling, if applicable
STO ER-9	Monitor brake cylinder and pipe pressure	In-cab display
STO ER-10	Monitor for changes **in maximum authorized speed** and respond accordingly	Speedometer, Memory, Signal aspect, Temporary Speed Restriction Markings, Work Zone Markings, Paper bulletin/personal notes
STO ER-11	Monitor time and speed to determine whether on-schedule; adjust speed accordingly	Watch, Timetable, Memory, Speedometer
STO ER-12	**Monitor alerts**	**Auditory Channel, In-cab display**
STO ER-13	**Monitor for upcoming station stops**	**Memory, Out-the-cab, Track chart, Timetable**
STO ER-14	**Monitor for upcoming stations that are not stops**	**Memory, Out-the-cab Track chart, Timetable**
STO ER-15	**Monitor for grade crossings**	**Out-the-cab, Memory, Track Charts**
STO ER-16	**Monitor for control points**	**Out-the-cab, Timetable**
STO ER-17	**Monitor for Interlocking and verify signals and corresponding equipment (i.e., switches, derails) support intended route of travel for locomotive and locomotives in vicinity**	**Out-the cab, Memory, Track chart**

STO ID	Information	Current Interaction Medium
STO ER-18	**Monitor for malfunctioning track equipment (signals, crossings, Detectors)**	**Out-the-cab, Memory, Radio notification**
STO ER-19	**Monitor current and next territory**	**Memory, Track Chart**
STO ER-20	**Monitor if PTC is activated or not activated**	**In-cab display**
STO ER-21	**Monitor PTC braking profiles**	**In-cab display**
STO ER-22	**Monitor PTC target speed**	**In-cab display**
STO ER-23	**Monitor for work zone & temporary speed restriction markings**	**Out-the-cab**
STO ER-24	**Monitor pulling and compressive forces (freight in particular)**	**In-cab display, Rear mirror/view of cars behind locomotive**
STO ER-25	**Communication with Conductor**	**Radio**
STO ER-26	**Communication with Dispatcher (request permission to proceed, notification of emergency stop, receive track warrants, etc.)**	**Radio, Track Warrants**
STO ER-27	**Communication with foreman, if applicable**	**Radio**
STO ER-28	**Conduct brake test**	**Brake Pressure gauges, Brakes**
STO ER-29	**Conduct speed test**	**Watch, Specially marked mileposts**

Event Flow Diagrams

In the Alstom hCTA, an Event Flow Diagram was created for each phase [46]. The Event Flow contained a block for every task listed in the scenario task overview which graphically depicted processes, loops and decisions and their temporal relations.

Instead of creating an event flow diagram for every addition to the STO, one particular "mega-task" was the focus going forward. This "mega-task" is the process of monitoring where the train is in relation to the next action required to achieve a planned objective. A planned objective refers to responding correctly to known operating rules or route characteristics such as speed restrictions or signals. This task was selected because this prospective memory task is known to be difficult for operators in general and was identified as a cognitive demand in interviews and in the Cognitive Task Analysis published by the Department of Transportation (especially for temporary changes to the route) [81].

The Event Flow Diagram is depicted in Figure 48. The complex decision, "Is action required within current mental track segment?" requires further explanation. The current mental track segment refers to the current physical segment of track that the locomotive engineer uses to mentally section off the route. For example, some engineers memorize the route from station to station; others will break up their mental segments according to the number of landmarks, signals or actions required.

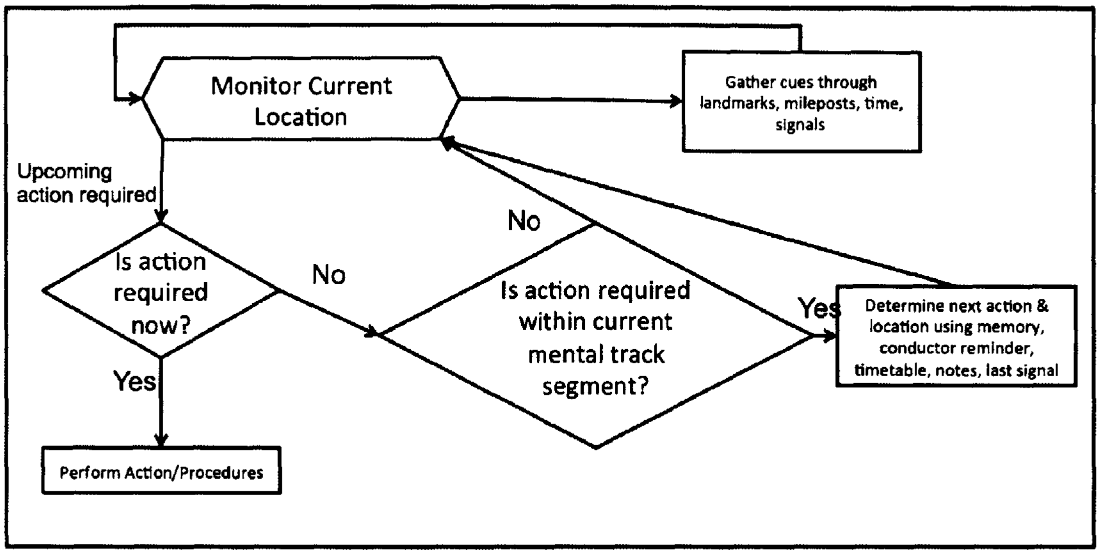


Figure 48: Event Flow Diagram

Decision Ladders

The complex decision, "Is action required within current mental track segment?" from the figure above was used as the basis for the decision ladder used for the rest of the hCTA. The primary decision ladder is depicted in Figure 49. The locomotive engineer should be continuously monitoring his/her location and the entry point for the complex decision is that the locomotive engineer remembers or is informed that there is an upcoming action required but it is not required immediately. The exit conditions are either the upcoming action is far enough in the future that the locomotive engineer does not have to prepare for the action until he/she is in his/her next mental track segment or the action is required in the current mental track segment.

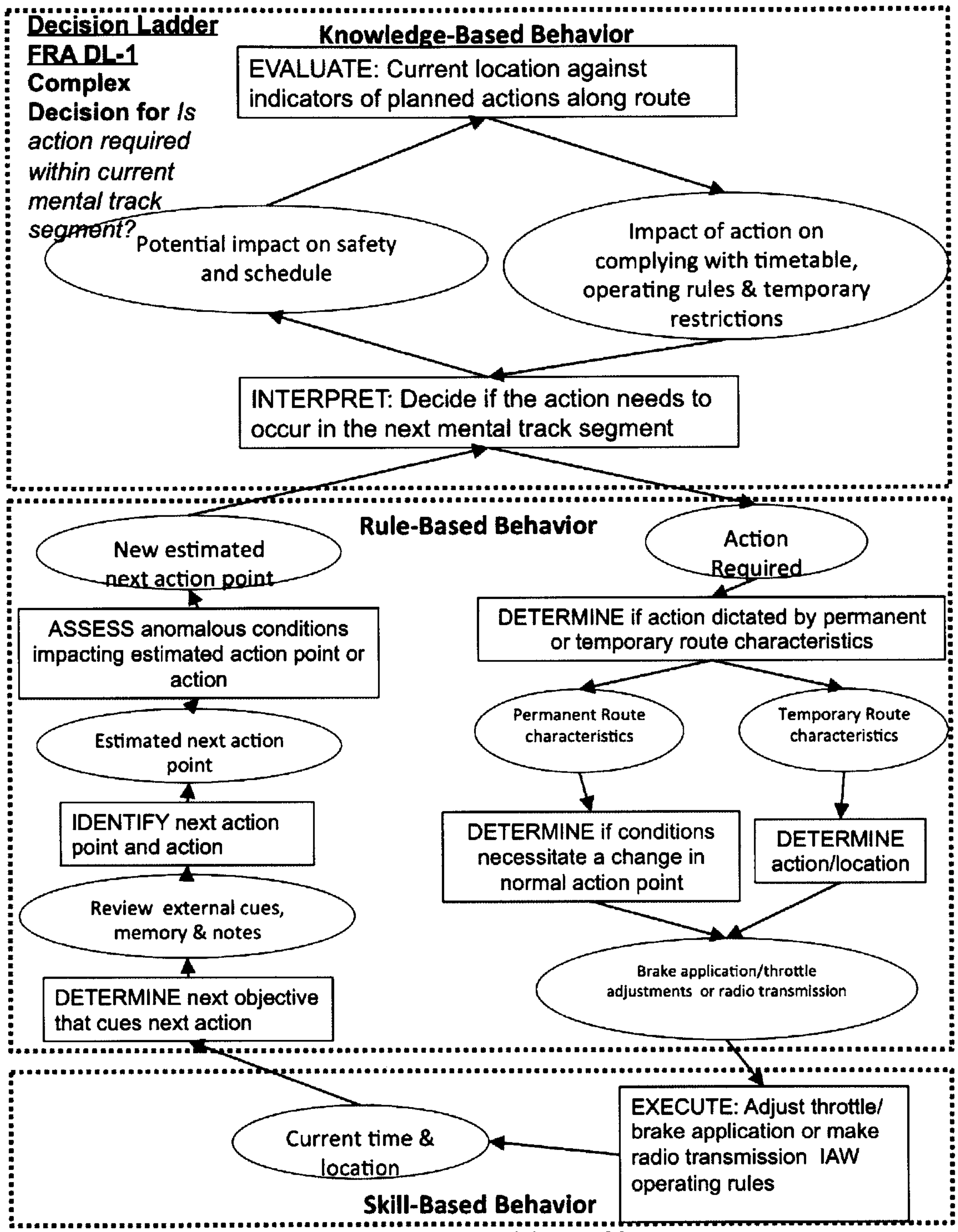


Figure 49: Decision Ladder

Note that there are two types of planned objectives which create a split on the right side of the Decision Ladder: 1) those that are a permanent part of the route as memorized in route qualification and in long-term memory 2) those that are temporary for a given period and are issued in track bulletins before departure or En Route as a track warrant.

Next, display requirements are overlaid on the primary decision ladder, see Figure 50.

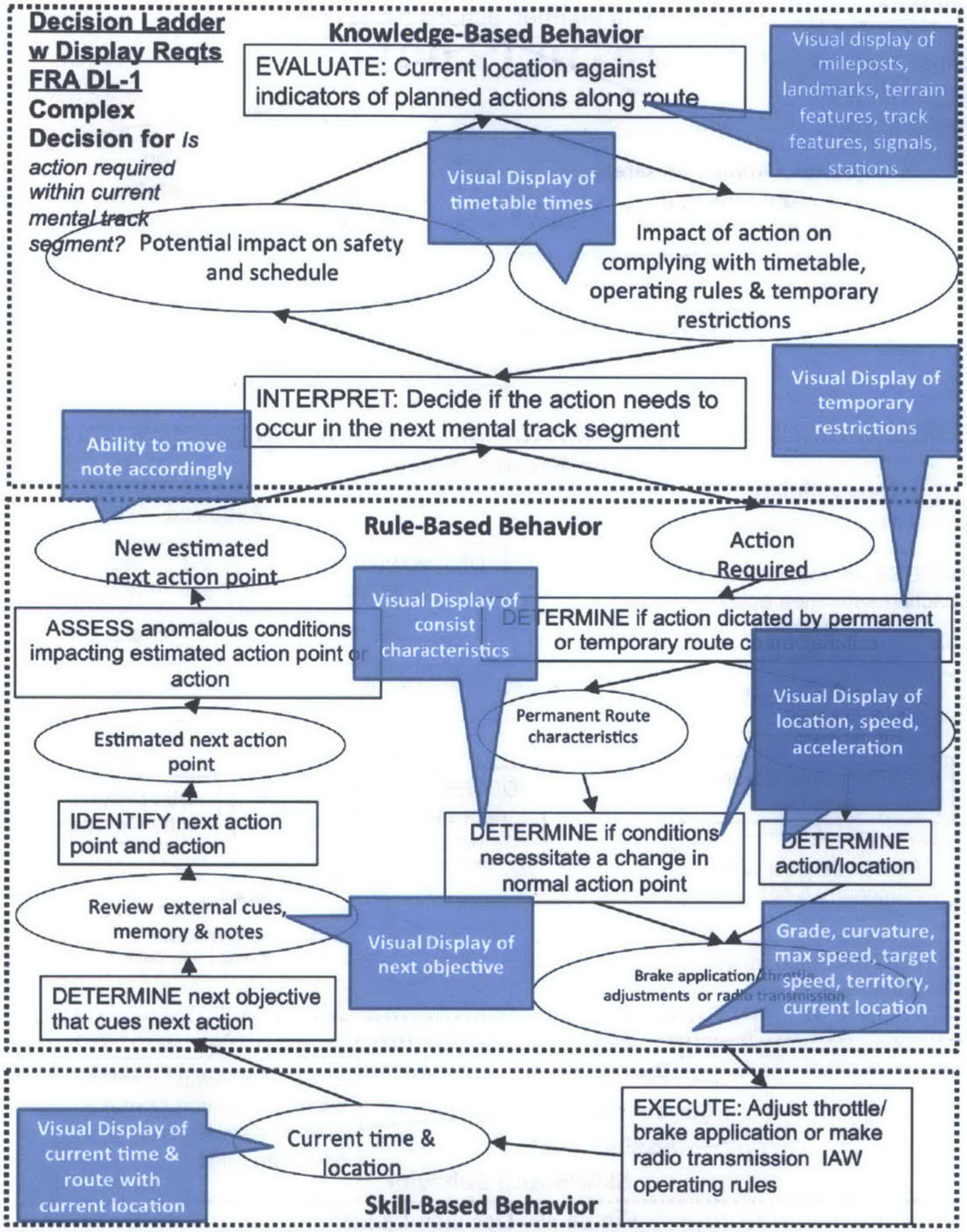


Figure 50: Decision Ladder with Display Requirements

Situational Awareness Requirements

Situational Awareness Requirements, SARs, were updated from the Alstom hCTA for the En Route phase [46]. The table below lists the SARs for the En Route Phase. The SAR ID's are unique to this project. The Level I, Level II and Level III columns show the new/altered text in **bold.** Deletions from the Alstom hCTA are not shown.

Table 10: En Route Phase-STO

SAR #	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
SAR-1	Visual/auditory feedback of overall train system state	All train systems operational	
		Recognition of appropriate response to detected operational error(s)	Effect of operational error(s) and **responses needed** on **safety**, schedule **and next action**
SAR-2	Visual/auditory feedback of incoming radio transmission	No current transmission **or directly relevant transmission**	
		Recognition of appropriate response to received communication	Impact of transmission on **schedule and next action**
SAR-3	Visual and auditory feedback of external obstacles	No obstacles	Portions of route where obstacles are likely
		Recognition of appropriate response to obstacle on track	Impact of obstacle **and subsequent threat procedures** on schedule **and next action**
		Recognition of appropriate response to obstacle beside track	
SAR-4	Visual feedback of current route rail grade/**sharp curve**	**Negligible** rail grade	Portions of route where there are steep rail grades/**sharp curves**
		Recognition of appropriate adjustment of **throttle/braking** to compensate for rail grade/**curvature**	

SAR #	**Level I (Perception)**	**Level II (Comprehension)**	**Level III (Projection)**
SAR-5	Visual detection of weather	Weather conditions stable	Weather forecast
		Recognition of appropriate response to inclement weather	
SAR-6	Current track, track assignment	Track and assignment match	Track changes
		Recognition of appropriate response to track mismatch	Impact of track mismatch on **safety,** schedule **and next action**
SAR-7	Visual feedback of internal/external **track** signals	No **track** signal	**Track** signal locations during route traversal
		Recognition of appropriate response to detected **track** signal	
SAR-8	Visual feedback of pressure level in brake cylinders and pipes	Pressure levels normal	
		Recognition of appropriate response to brake pressure failure	Effect of low pressure level on train operation and schedule
SAR-9	Visual/auditory feedback of upcoming speed change	No signal detected	Changes in speed limit
		Recognition of appropriate response to detected speed signal	
		Recognition of appropriate response to detected emergency signal	Effect of emergency signal on **safety,** schedule **and next action**
		Recognition of appropriate response to upcoming station stop	Changes in speed limit
		Recognition of appropriate response to upcoming station (not a stop)	**Changes in speed limit**
		Recognition of appropriate response to grade crossings	

SAR #	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
		Recognition of appropriate response to control points	Changes in speed limit or location call to dispatcher to proceed at normal current speed
		Recognition of appropriate response to interlocking	Changes in speed limit
SAR-10	Length of Train	Recognition of the location of the rear of the train	Stopping locations for stations, sidings, etc
			Applicability of speed restrictions
SAR-11	Visual/auditory feedback of trackside equipment	Expected feedback received	Locations of equipment and usual aspects
		Recognition of appropriate response to malfunctioning equipment	Equipment with history of failure, Impact of on safety, schedule and next action
		Recognitions of appropriate response to track side equipment with unexpected feedback	Impact of on safety, schedule and next action
SAR-12	Visual feedback of trackside markings for temporary restrictions	Markings and bulletin/notes match	Portions of track with recent restrictions
		Markings do not match expectation	Impact of on safety, schedule and next action
SAR-13	Visual feedback from memorized route/auditory feedback from dispatcher on current Territory and Movement Authority	Recognition of operating rules for territory, radio frequency and dispatcher	Locations of transition for territories and movement authorities
SAR-14	Fat time built into schedule	Recognition of appropriate response to extra time current in schedule	Target speeds for portions of track to prevent early arrival (passenger)

SAR #	Level I (Perception)	Level II (Comprehension)	Level III (Projection)
		Recognition of appropriate response to delays in current schedule	Portions of track where time can be recovered (normal target speed is less than max allowable speed
SAR-15	Train Characteristics	Recognition of appropriate responses to varying tonnage, weight distribution, brake systems, powered cars, coupling lengths, etc.	Train handling strategies
SAR-16	Visual/auditory feedback of current speed against target speed and braking profile	Recognition of appropriate responses to PTC systems	Train handling strategies for PTC operating conditions

Information and Functional Requirements

The Information and Functional Requirements from the Alstom hCTA (MIILO hCTA) are identified by "MIR" and the Information and Functional Requirements added for this project are identified by "FIR." Only the Information Requirements from the Alstom hCTA that were applicable to the en route phase of U.S. Rail operations are included to form the baseline Informational and Functional Requirements for this effort [46].

Table 11: Information & Functional Requirements

Item #	Information Requirement	Source	Details
MIR5	Incoming radio transmission	DL1-FRA	A networked system could allow the dispatcher to push updated information to the display to complement dispatcher transmission and Form D annotations
MIR23	Location of security signals along train route	DL1-FRA SAR-11	A networked system could send signal states to display for last signal and upcoming signal (in-cab signaling)
MIR24	Current T/F lever position	DL1-FRA	Engineers will refer to "Operating Displays" or will know the position through touch and experience
MIR25	Current speed	DL1-FRA	One of the most frequent pieces of information read by locomotive engineers

Item #	Information Requirement	Source	Details
MIR26	Goal speed	DL1-FRA	This is different that maximum allowable speed. Trains should not be excessively early to a station and may run at less than max speed to achieve this. Usually this is memorized, but may need to be calculated if delayed by an emergency or TSRB
MIR27	Speed differential	DL1-FRA	Difference between desired speed and actual speed (desired speed is either goal speed for the route or on a shorter level, desired speed curve to obtain objective speed for a circumstance)
MIR28	Current time	DL1-FRA	Engineers are required to have a functional watch, but time is referenced often.
MIR40	Departure time	DL1-FRA SAR-14	Usually memorized, but if route schedule has changed, timetable is referenced
MIR42	Current train route rail grade	DL1-FRA	More concerned with specific values when coming to/from a stop or around times where speed change is needed.
MIR43	Rail grade along train route	DL 1-RA	Memorized for route, but does play large part of train handling. Would be used most often when unfamiliar with route or has not run route in a while
MIR44	Potential impact of rail grade on speed	DL1-FRA	Notes can be inserted if there is a particular part of the route the engineer has trouble remembering, but otherwise the impact is learned with the route and through running trains
MIR45	Current track	DL1-FRA	Current track and current authority (rules in place)
MIR46	Track assignment	DL1-FRA	Track assignments can change en route and are controlled by the dispatcher
MIR48	Speed change indication	DL1-FRA	Speed refers to the maximum allowable speeds
MIR51	Train route with current location	DL1-FRA	Location context: mileposts, track features, bridges, control points, stations, grade crossings. Grade and curvature also provide contextual clues
MIR52	Next waypoint with scheduled arrival time	DL1-FRA SAR-14	Similar to Departure time IR
FIR1	Temporary Speed Restrictions-from train order/time table	DL1-FRA	Beginning and ending mileposts, reason for restriction and special instructions
FIR2	Temporary Speed Restrictions-from track warrant (en route)	DL1-FRA SAR-12	Track warrants are issued via the radio from the dispatcher. Engineers must enter information on a Form D and repeat back to the dispatcher. Form D's must be kept by the engineer for 7 days

Item #	Information Requirement	Source	Details
FIR3	Consist Characteristics	DL1-FRA SAR-10 SAR-15	Consist information includes tonnage, weight distribution, number of cars, which cars are powered, etc. This effects train handling required to maintain smoothness and to obtain objective speeds and stopping points
FIR4	Territory Information	DL1-FRA SAR-13	Determines which operating rules must be followed; can vary from territory to territory
FIR5	Movement Authority	DL1-FRA SAR-13	Determines who is granting the train permission to move (dispatcher in dark territory, signals, timetable, etc)
FIR6	Positive Train Control information	SAR-16	Braking curves, target speeds and speed/location above/beyond which penalty brake application is applied. Not included in display
FIR7	Trackside Equipment Indicators	SAR-11	Signals and corresponding interlocking states should be displayed as preview information so engineers can verify their intended route/actions at signals and interlocking in advance
FIR 8	Curvature	SAR-4	Memorized for route, but can play large part of train handling. Would be used most often when unfamiliar with route or has not run route in a while
FIR 9*	Location of Trains in the vicinity	SAR-3	Locomotive engineers indicated that they listen to radio traffic or memorize trains in their vicinity for a given route in the event that an anomaly with a surrounding train may impact his/her coarse of action

* Not in initial hCTA, added after informal feedback

Interactive Moving Map for Locomotive Engineers- Evaluation Study

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Agenda

- People
- Purpose
- Your part
- Compensation
- Breaks
- Forms

People

- MIT Humans and Automation Laboratory (HAL)
  - http://halab.mit.edu
- Researchers:
  - Masters Candidate: Kathleen Voelbel
  - PI: Charles Oman, Ph.D
  - HAL Director: Missy Cummings, Assoc. Prof.
  - Research Scientist: Andy Liu, Ph.D
- Research supported by FRA Contract DTFR53-11-C-00016

Purpose

- The purpose of this study is to evaluate the usability of this display. The collected data will be used for research purposes, not to evaluate individual performance
- Structured method for obtaining feedback called Cognitive Walkthrough or Usability Study
- Results from this study will contribute to a Master's thesis by Kathleen Voelbel.

What are you asked to do?

- Complete a demographic questionnaire about your background (10 min)
- Watch a video/PowerPoint tutorial that explains the project and the functionality of the display (10 min)
- Perform actions and answer questions using the display assuming you are in a typical operating environment (20 min-1hr)
- Complete a usability and technology transition interview (20 min)

Confidentiality

- Your name will be kept strictly confidential and will be kept in a locked safe for the purpose of financial audits only.
- The data from this study will be kept separate from your name.

Compensation

Time (minutes)	Payment for comple-tion	Payment for early withdrawal
60	$35	$17.50
72	$42	$21
84	$49	$24.50
96	$56	$28
108	$63	$31.5
120+	$70	$35

- Complete "Payment for Human Subject Testing Form"
  - Check will be mailed to address provided

Breaks

- This study is expected to last 1-2 hrs
- There will be a planned 10 minute break after 1 hr, but if you need to take a break at anytime, please let us know

Consent Forms

- MIT Committee on Use of Humans as Experimental Subjects requires participates to signs consent forms
  - Consent to Participate in Non-Biomedical Research
    - Participation voluntary
    - May withdraw at any time
    - Contact information
    - Your rights
  - Consent to Audio Recording of the Session
    - Purpose of the optional audio recording is to help the investigators evaluate the data and only for their use. Direct quotations in reports/publications will only be used if direct consent is given and will never be used with your name.

Pre-Cognitive Walkthrough Survey

- Please complete survey

Questions?

- Next: Explaining the display

Context for the display

- This display is intended to provide you with operating information you may need to operate the train
- Assume that the Railroad and FRA have authorized the use electronic devices in the operating cab for the purpose of aiding the engineer and crew.
- The device could either be permanently mounted in the control station or it may be a portable device

Additional Display Info

- Track speed for your line is 80 mph. Permanent speed restrictions and TSRB speed restrictions are already listed in the display.
- Only signals in your direction of travel (East bound signals) are shown on the display

Routes & Rules

- The route is loosely based on the Boston-Providence line (NEC). It is not intended to be an identical representation of this line.
- Pretend that you are at the controls of your train about to begin a typical run. You will be operating under NORAC rules
- We are evaluating the display, not your performance. Your performance will not be graded.

Tutorial

- Pan across entire route
- Zoom in/out for more detail
- Visual display of upcoming track, adjacent tracks, speed, grade & curvature
- Ability to add annotations
- Track warrants
- Speed restrictions
- Men working
- General/freeform notes

Appendix C COGNITIVE WALKTHROUGH QUESTIONS

Italicized text is read to subjects. Non-italicized texts are notes or instructions to the experiment administrator. The question numbers are labeled in the appendix and given a prefix according the questions type. Tasks are given the prefix of "T", questions are given the prefix of "Q" and qualitative questions, those asking for a description are given the prefix of "QQ". Some tasks were specifically covered in the tutorial while others were not. In the case where a task/function was not covered in the tutorial, the purpose was to assess if subjects were able to answer the questions/perform the tasks without explicit instructions.

As a reminder, you are Train number 802 and the default speed for your line is 80 miles per hour.

Now you are on your locomotive prior to leaving time. You are starting your trip from Providence. You have completed your brake test and review of the maintenance paperwork. We will now give you a Temporary Speed Restriction Bulletin (TSRB); the TSRBs that affect your route have been automatically updated into the display.

The TSRB was then provided (Appendix D).

You may also be given an addition to enter into the display via From D's.

Below is the default screenshot of what they see on the display when it is first handed to them.

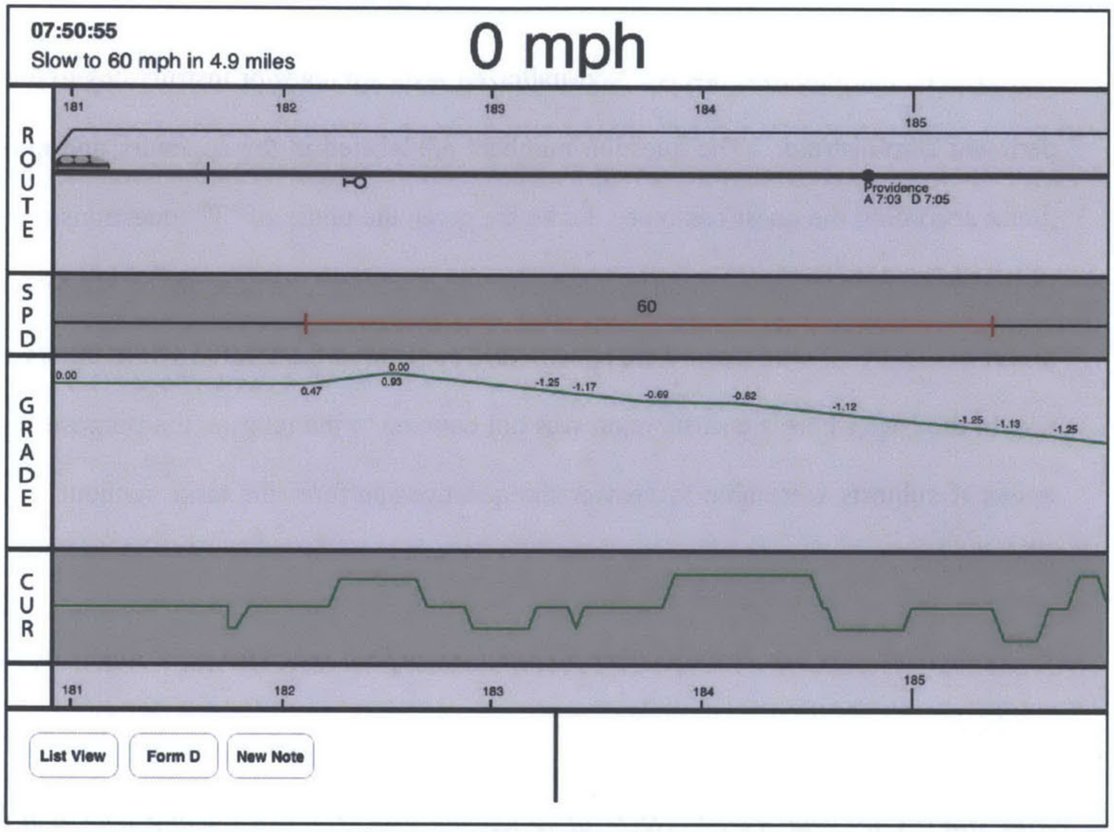


Figure 51: Default Display

T1: *Dispatcher is on the radio and says, "Form D number M1* DDMMYYYY *C&E Train 802 at Providence, let me know when you are prepared to copy."*

Wait for the subject to say that they are ready. And ensure that they accessed the window depicted below by selecting the "Form D" button.

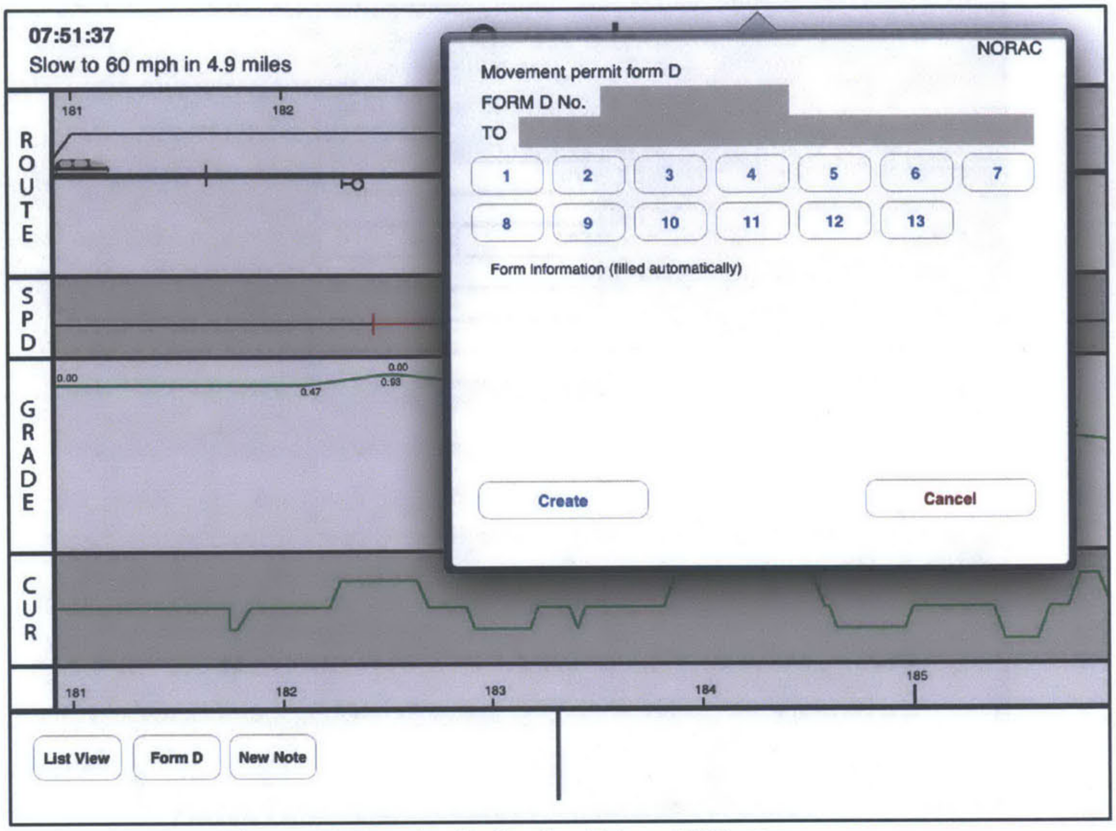


Figure 52: Result of selecting "Form D" button

Form D Circle Line 1: PVD Line Track 2 Start: 208.5 End: 209.4 Passenger Speed 30 Freight Speed 20.

Verify that subjects have entered the information as shown below.

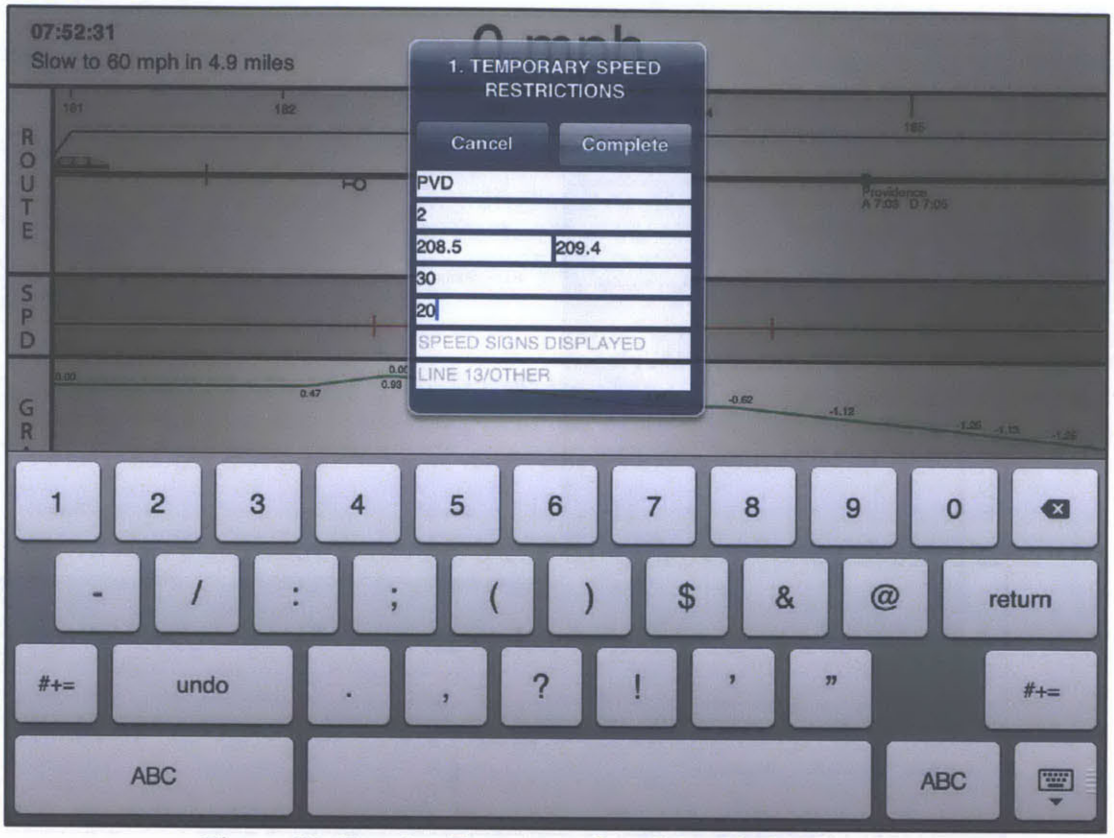


Figure 53: Entering Temporary Speed Restriction

If subjects do not repeat the message back on their own, prompt them to read the screen. Continue after you have verbally verified that the subject recorded the information correctly.

Form D M1, time effective: current date and time

T2: *How would you verify that this Form D took effect?*

If subjects do not indicate that need to pan, prompt them. If they start panning on their own and still can't find it, direct them to mile post 208.5.

Figure 54: Resulting screen shot for T2

T3: *Dispatcher is on the radio and says, "Form D number M2* DDMMYYYY *C&E Train 802 at Providence, let me know when you are prepared to copy."*

Wait for the subject to say that they are ready. And ensure that they accessed the selected the "Form D" button.

Form D Circle Line 5obstructed for maintenance between Mile post 202 and 203. Line 13: Call foreman Jones for permission to enter

Ensure that their display looks like Figure 55.

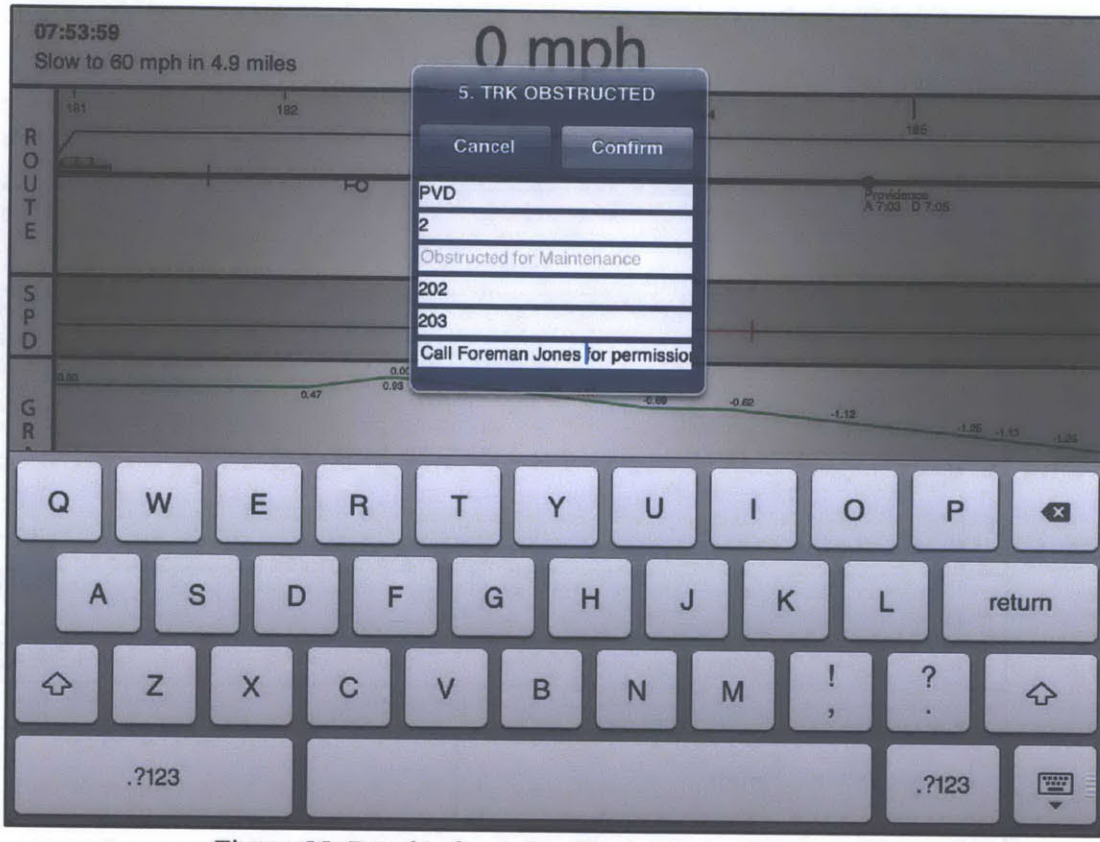


Figure 55: Result of entering Track Obstruction

QQ1: *Would it be helpful to be able to input Form D's directly into the display like you just did as opposed to the paper form?*

T4: *If you wanted to see the track from Providence to South Attleboro, approximately twelve miles of track, how would you do that on the display?*

Subjects must pan then zoom using pinching and expanding figure gesture. Figure 56 is the expected result.

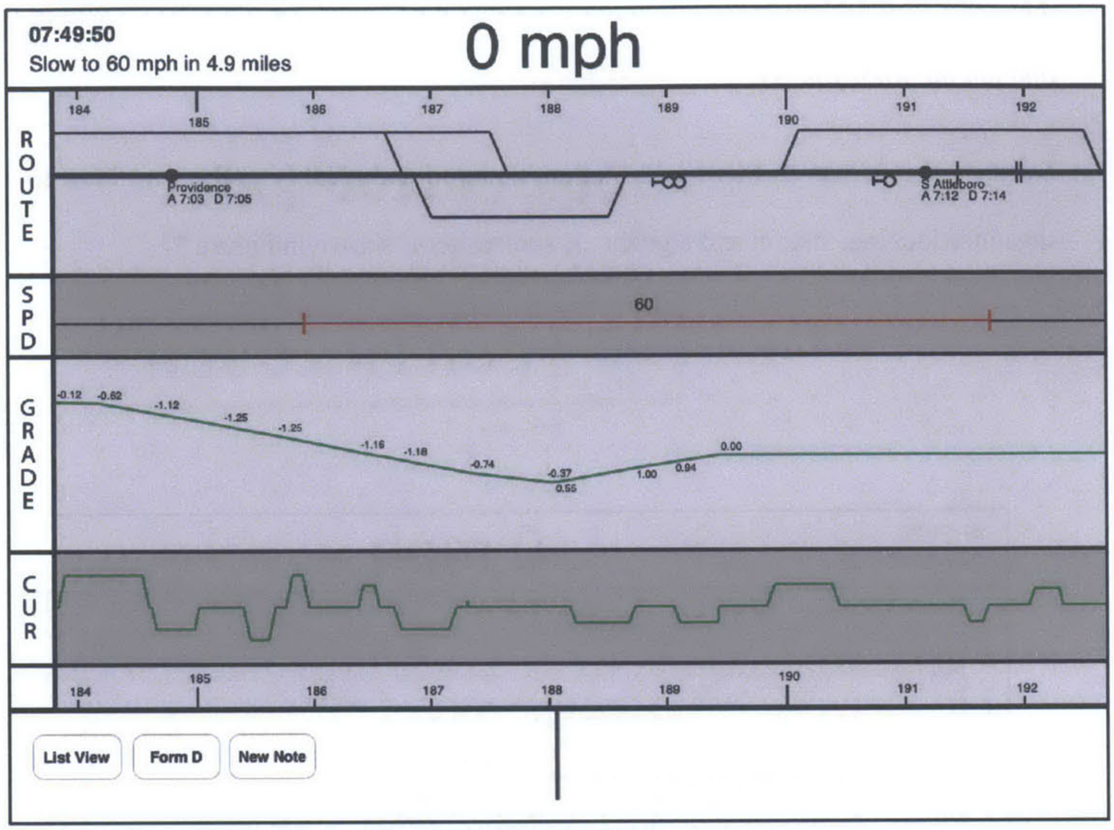


Figure 56: Result of T4

Q1: *At what speed will you operate between Providence and South Attleboro? You may use the display to answer the question.*

Subjects should say that they leave Providence at 80 mph, but by milepost 186 they must be at 60 mph. If they interpreted S. Attleboro as one of their designed stops, then they should say that they would slow down to a stop at S. Attleboro. Answers of 80mph or 60 mph are followed by the prompt, *"For the entire way?"*

T4: *Go back to the original view*

Subjects should double tap the screen.

T5: *Look at the Mansfield Station interlocking and zoom in for a 3-mile section of track and tell me what you see.*

Subjects should pan to Mansfield Station, zoom in and identify at the very least the sidings/interlocking, station and signals. A screenshot is shown in Figure 57.

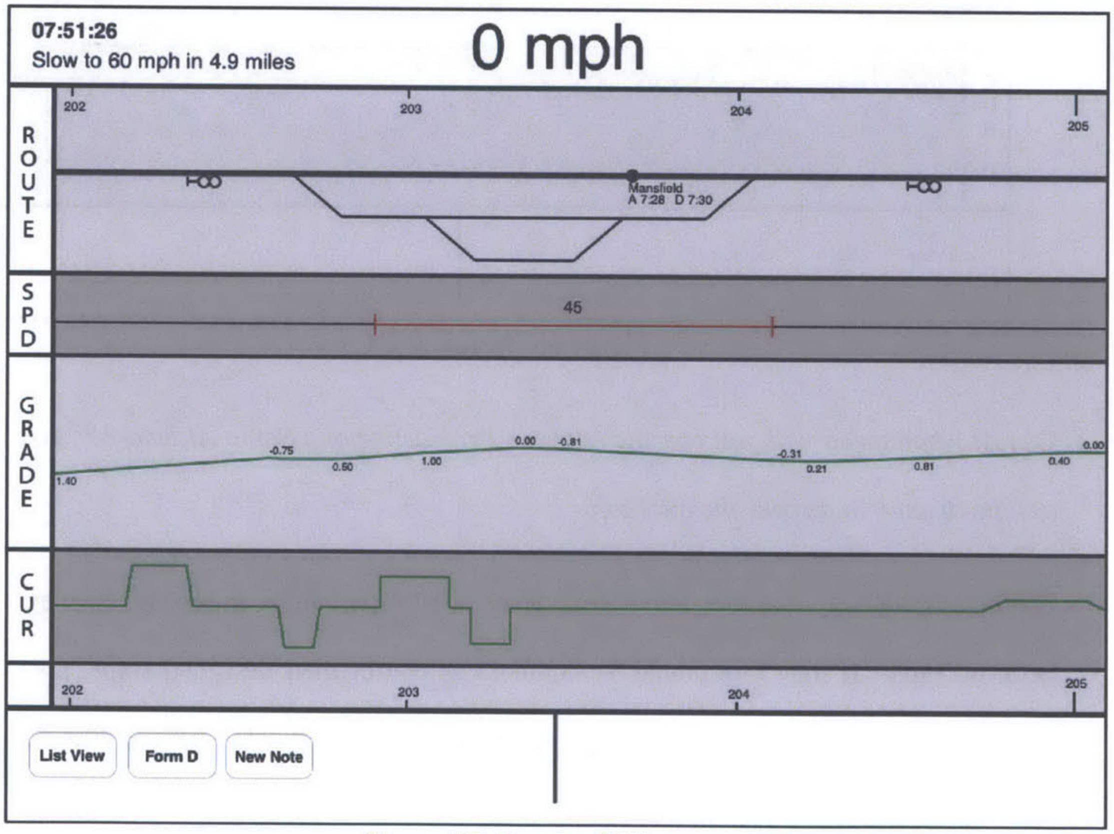


Figure 57: Result of T5

T6: *Review your whole route and verify that the TSRBs were uploaded correctly.*

Using the provided TSRB (Appendix D), they should identify that the display shows a speed restriction of 60 mph at mile post 185.9 (Figure 58: Result of T6)

If subjects do not identify the TSR, point it out to them. After the subject has seen the discrepancy, ask, *"What would you do if this situation happened to you?"*

Expect them to say that they would call dispatch or comply with the most conservative rule, in this case, the 60mph restriction.

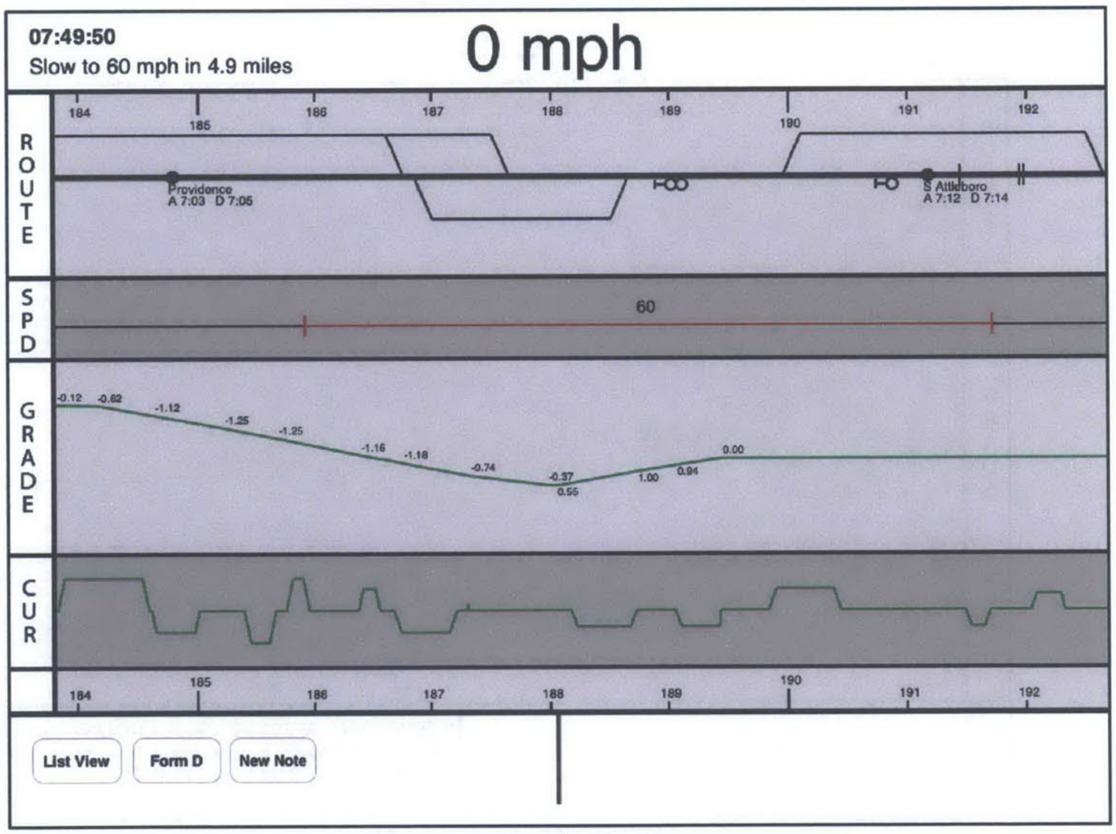


Figure 58: Result of T6

T7: *You are leaving Providence Station, can you describe the track grade between Providence and S. Attleboro?*

Expected answer is that it is downhill until mile post 186 then uphill until around milepost 189 then relative flat through S Attleboro. (Figure 59).

T8: *After leaving Mansfield Station (at mile post 204), what is the next rule with which they must comply?*

Subjects should identify the 30 mph TSR that they entered as a Form D as part of their first task. If the mention the signals, ask them what is after the signals.

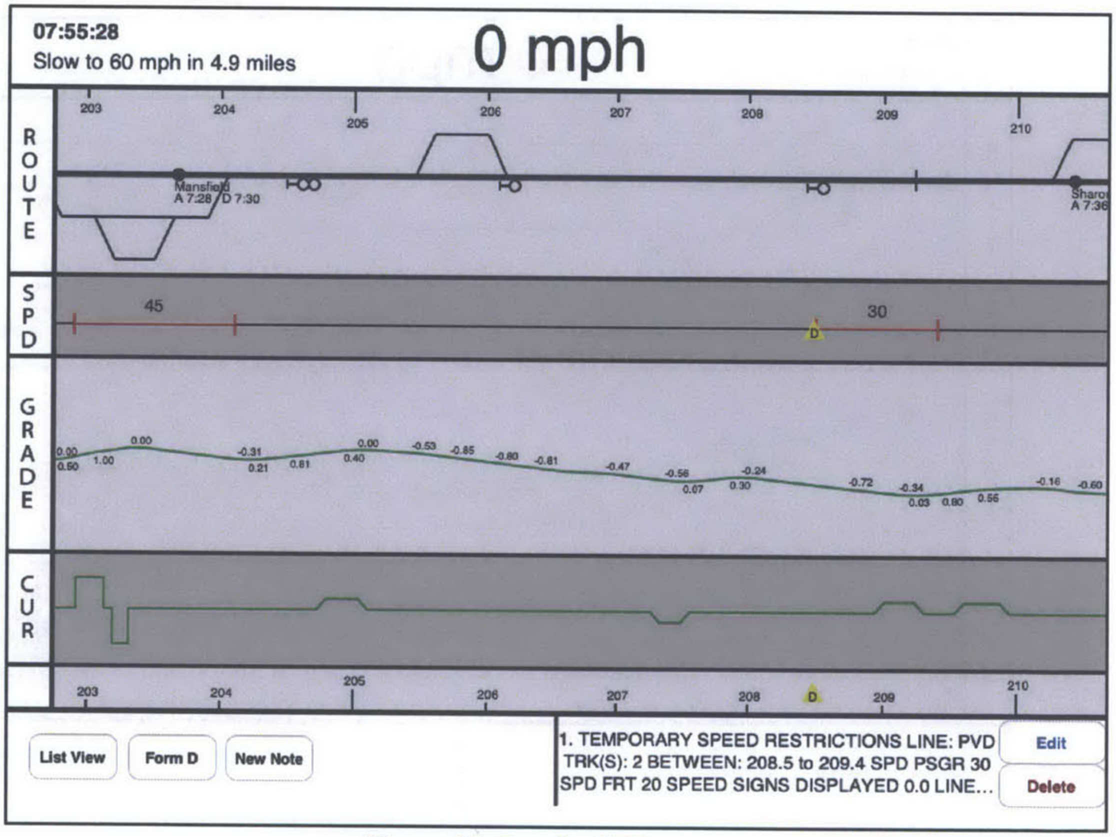


Figure 59: Result of T7

QQ2: *If you could se a reminder for these restrictions, or anything upcoming, how would you set it?*

QQ3: *How would you like the reminder to present itself?*

Now we'd like you to look at screenshots of the next version of the display with a few more capabilities. We will then ask you another series of questions.

Figure 60 applies to the following questions: Q2-5, QQ4.

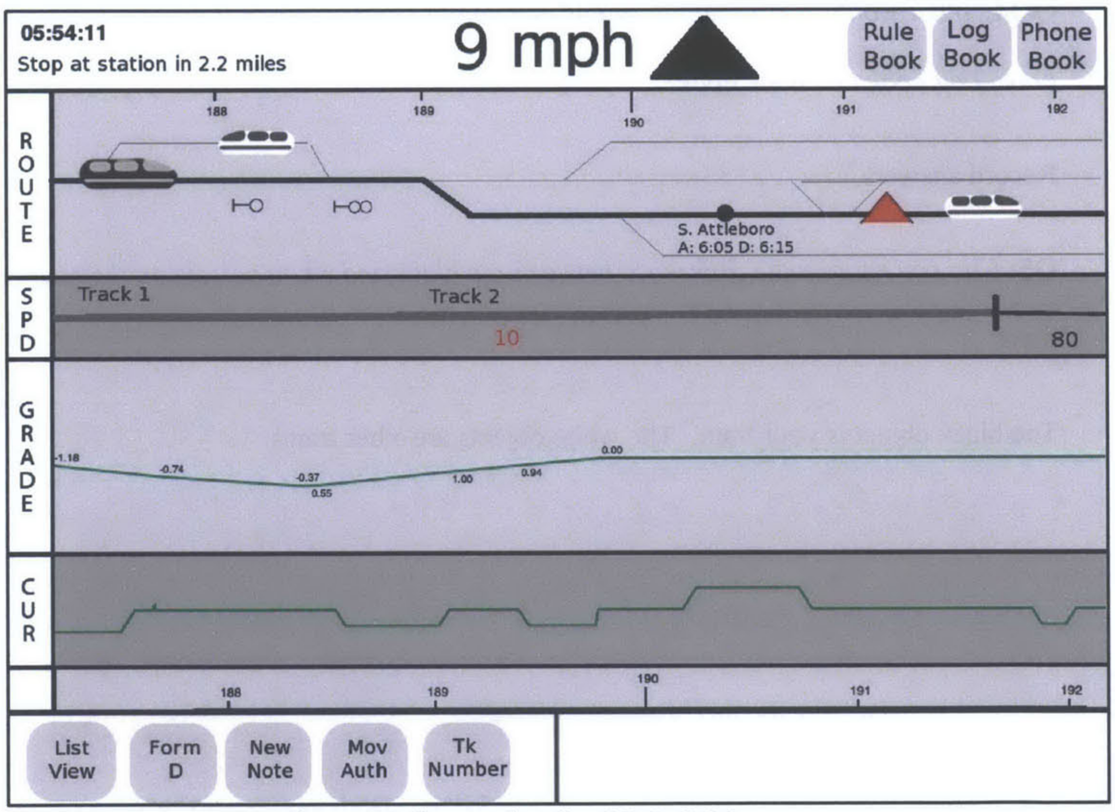


Figure 60: Screenshot for Q2-5, QQ4

Q2: *What is your current speed?*

If subjects say 10mph, indicate that is their maximum allowable speed and pause. If they don't say 9mph, point to the top center of the screen.

Q3: *Are you accelerating or decelerating?*

If subjects do not say accelerating, point to the arrow. (See screenshot below)

Q4: *What is the difference between the darker and lighter tracks?*

The dark or bold track is the intended route. The lighter tracks are tracks that are not on the intended route.

QQ4: *What would you expect to happen or would like to happen if you clicked on Rule book, Log book or Phone book?*

Record answers.

Q5: *Can you explain the difference between the black and white objects on the route section?*

The black object is your train. The white objects are other trains.

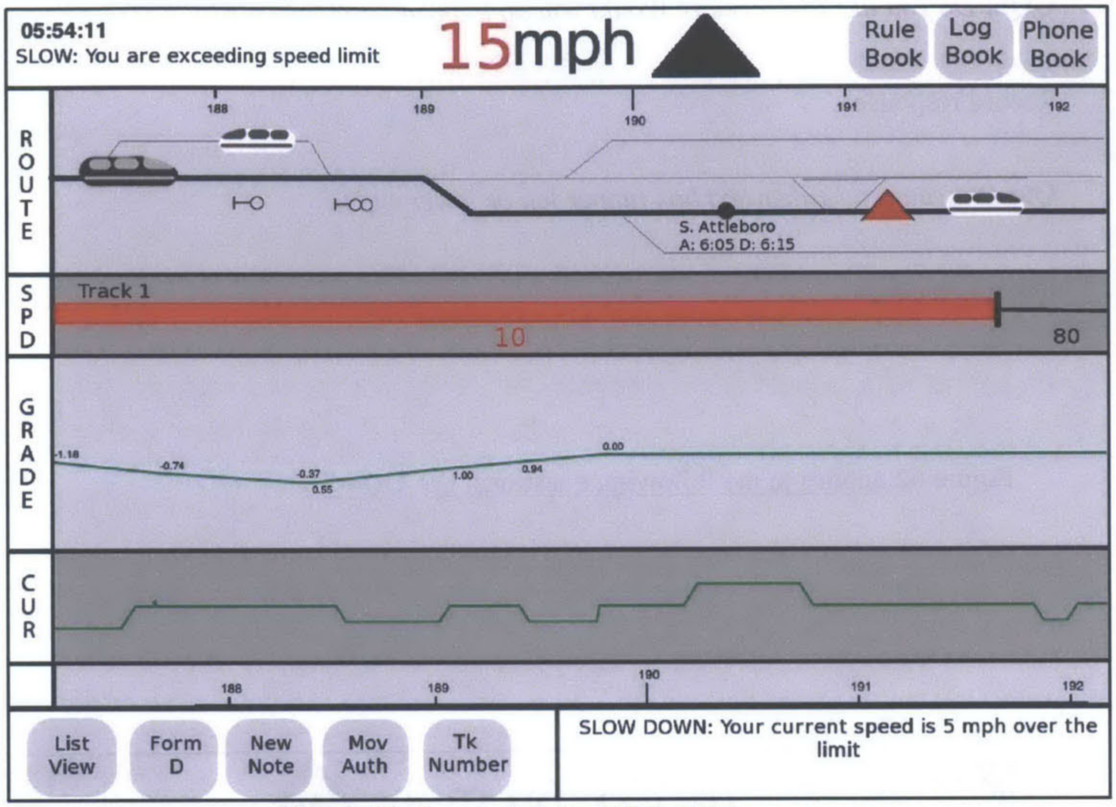


Figure 61: Screenshot for Q6-9, QQ5

Q6: *What is your current speed?*

Subjects should respond with 15 mph

Q7: *Are you accelerating or decelerating?*

Subjects should respond with accelerating.

Q8: *What information is the display providing you?*

The display is indicating that the locomotive is exceeding its speed limit by 5 mph (limit is 10mph and they are going 15mph)

QQ5: *Do you like this format? Would you do it any differently?*

Record responses.

Q9: *Did you read either text box (upper left or lower right)?*

Record responses.

Figure 62 applies to the following questions: Q9, QQ6-7.

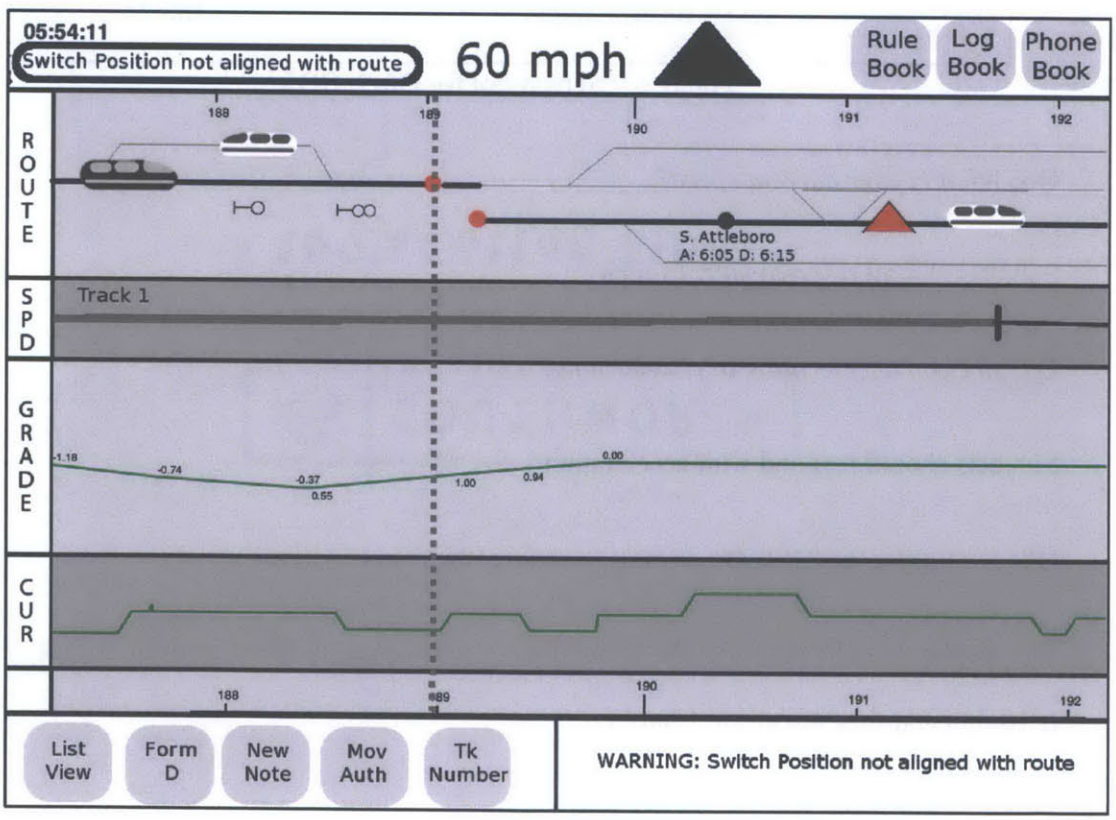


Figure 62: Screenshot for Q9, QQ6-7

Q9: *What would you do if you saw this display?*

Subjects should indicate that they would stop because the switch is not aligned and they are less than 2 miles from the switch. They might also mention that they would call dispatch.

QQ6: *Is it clear that the switch is not aligned with your intended route?*

Record response

QQ7: *Would you display it differently?*

Figure 63 applies to the following questions: Q10, QQ8-10.

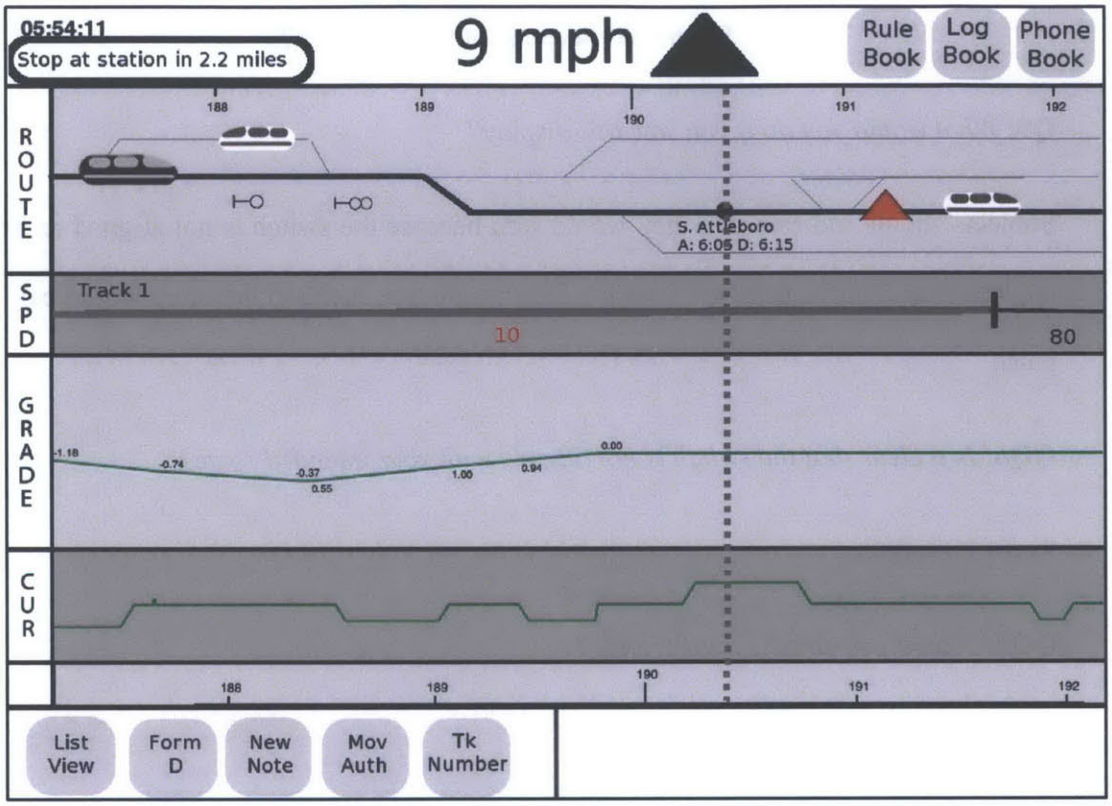


Figure 63: Screenshot for Q10, QQ8-10

Q10: *Upper left text is supposed to tell you your next action. You have clicked on it and the screen shot shows the result of this click. What happened?*

The vertical dotted line appeared at South Attleboro which corresponds to the next action text of "Stop at station in 2.2 miles."

QQ8: *Do you like this function?*

Record response

QQ9: *Do you like how it is displayed? How would you improve it?*

Record response

QQ10: *When would you use it?*

Record response

Figure 64 applies to the following questions: Q11, QQ11.

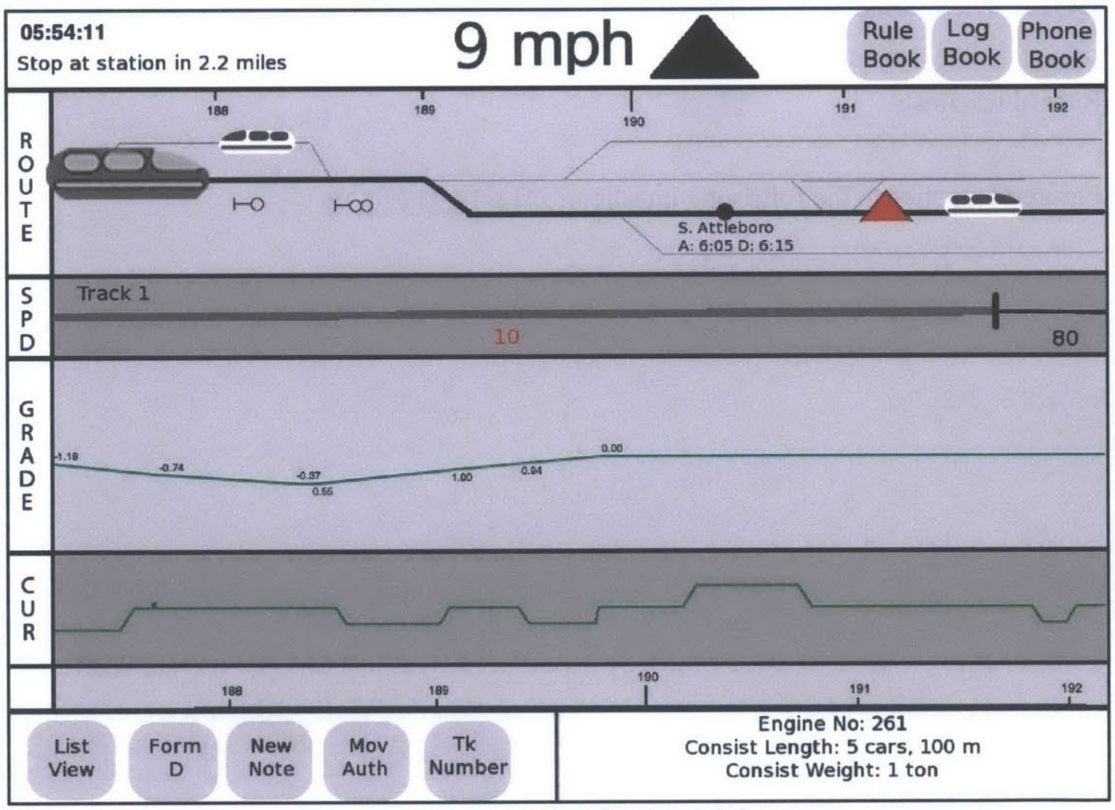


Figure 64: Screenshot for Q11, QQ11

Q11: *You have clicked on the black train icon and the screen shot shows the result of this click. What happened?*

The train symbol enlarged and the engine number, length and weight is displayed in the lower right text box.

QQ11: *Do you like this function?*

Record response

QQ12: *Do you like how it is displayed? How would you improve it?*

Record response

QQ13: *When would you use it?*

Record response

Figure 65 applies to the following questions: Q13-14, QQ14-16.

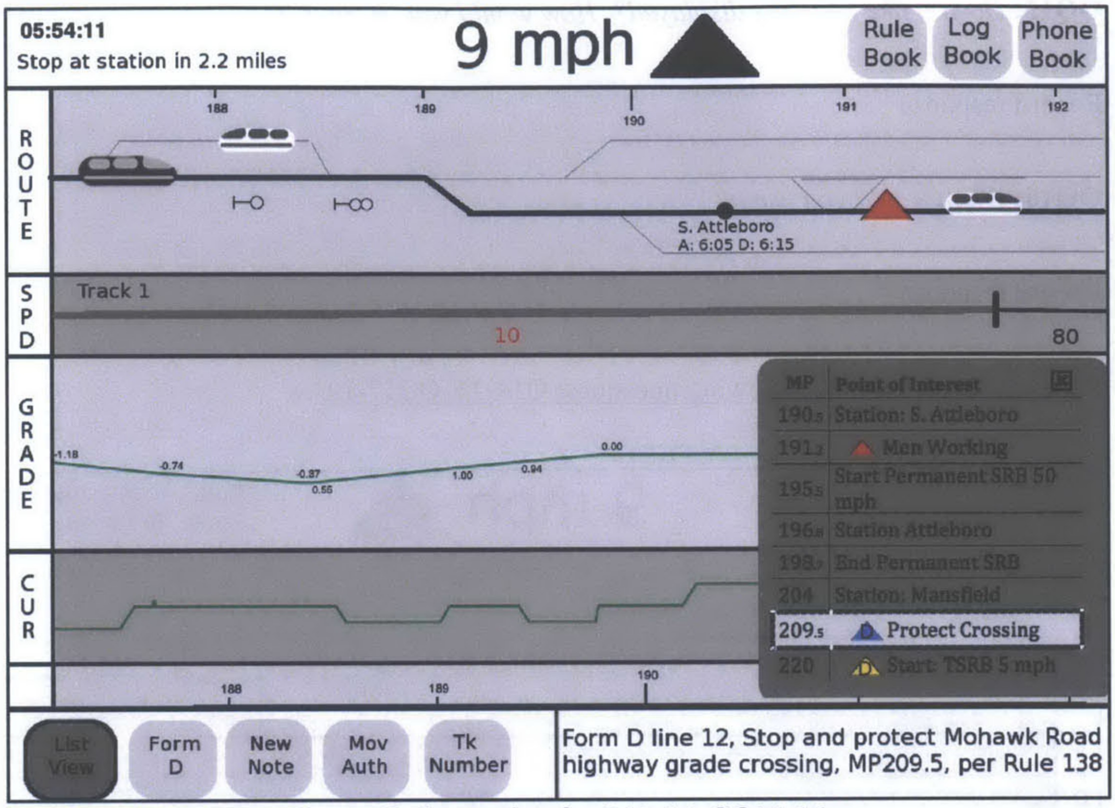


Figure 65: Screenshot for Q13-14, QQ14-16

Q12: *You have just clicked on the List View button (lower left) and the screen shot shows the result of this click. What happened?*

A gray box pops up with points of interest and mileposts. The List View button also changes color.

Q13: *What is happening at milepost 209.5*

Must stop and protect Mohawk Road highway grade crossing

QQ14: *Do you like this function?*

Record response

QQ15: *Do you like how it is displayed? How would you improve it?*

Record response

QQ16: *When would you use it?*

Record response

Figure 66 applies to the following questions: Q14-15, QQ17-19.

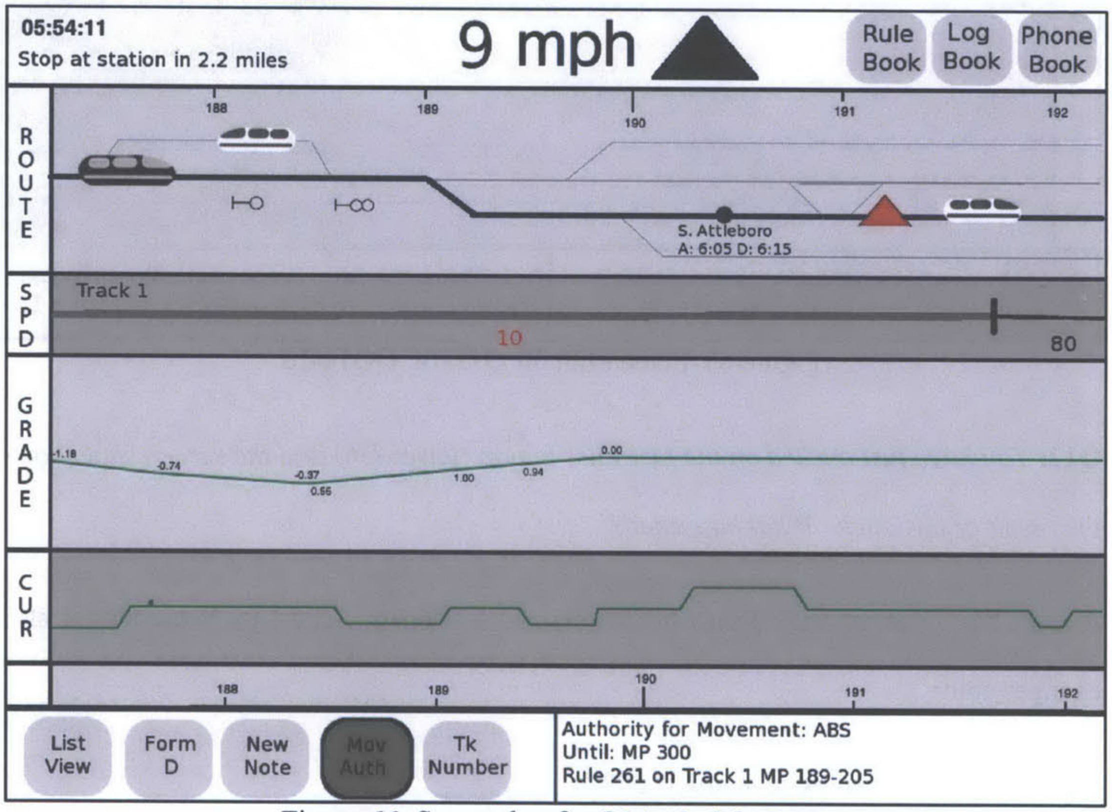


Figure 66: Screenshot for Q14-15, QQ17-19

Q14: *You have just clicked on the Movement Authority button (lower left) and the screen shot shows the result of this click. What happened?*

Text box on lower right indicates that the movement authority is automatic block signaling until milepost 300 and that Rule 261 applies on Track 1 from milepost 189-205. The "Mov Auth" button also changes color.

Q15: *What is happening at milepost 189*

Rule 261 applies on Track 1 is in effect.

QQ17: *Do you like this function?*

Record response

QQ18: *Do you like how it is displayed? How would you improve it?*

Record response

QQ19: *When would you use it?*

Record response

Figure 67 applies to the following questions: Q16, QQ20-23.

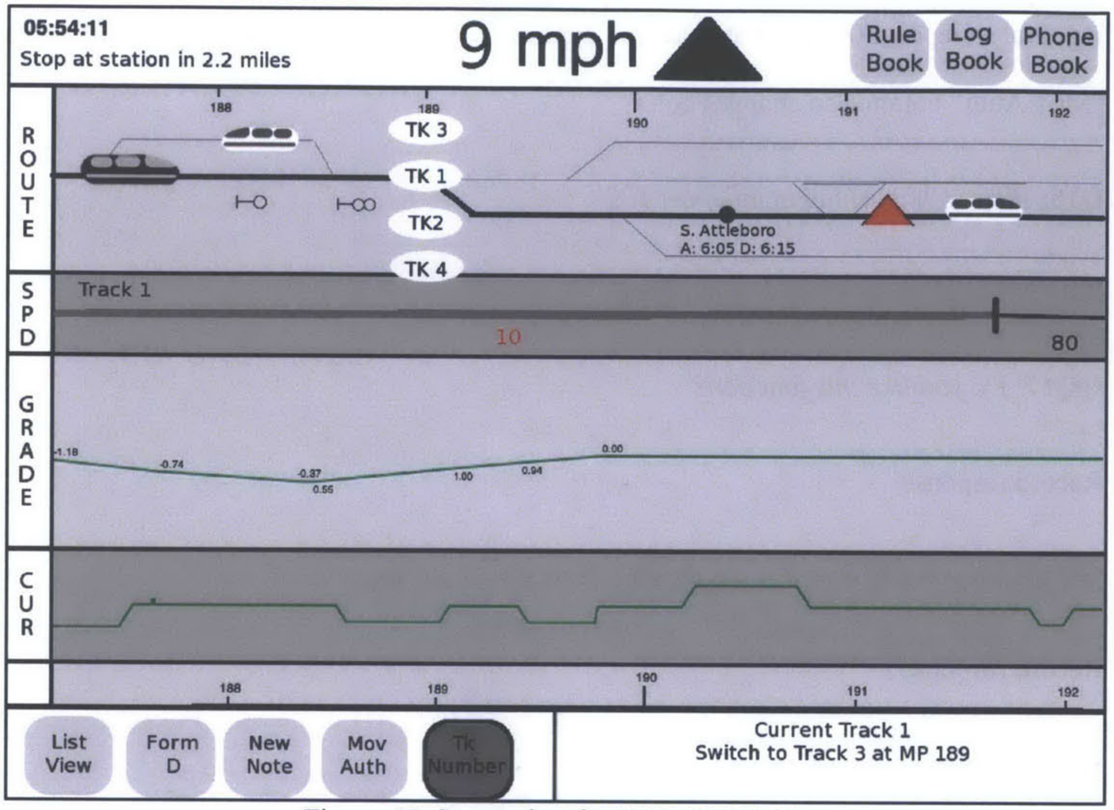


Figure 67: Screenshot for Q16, QQ20-23

Q16: *You have just clicked on the Movement Authority button (lower left) and the screen shot shows the result of this click. What happened?*

Text box on lower right indicates that the movement authority is automatic block signaling until milepost 300 and that Rule 261 applies on Track 1 from milepost 189-205. The "Mov Auth" button also changes color.

QQ20: *Do you like this function?*

Record response

QQ21: *Do you like how it is displayed? How would you improve it?*

Record response

QQ22: *When would you use it?*

Record response

QQ23: *Do you like the text in the lower right?*

Record response

Appendix D TSRB USED IN THE COGNITIVE WALKTHROUGH

NORTEAST DIVISION TSRB-EAST

Effective 5:00 AM

Supplemental Bulletin Order(s) in Effect: 1-V

A. TEMPORARY SPEED RESTRICTIONS

Between/At	Track 4		Track 2		Track 1		Track 3		Other Trks		Signs	Time Can-celled	Dspr
	Psgr	Frt	Psgr	Frt	Psgr	Frt	Psgr	Frt	Psgr	Frt			
Main Line-Mill River to Springfield (MRS):													
MP 31.9 and 32.1			30	10							Yes		
MP 35.5 and 36	30	30									Yes		
MP 42.8 and 42.9	60	40									Yes		
MP 58.9 and 60.0			30	25							Yes		
Middleboro Main Line (MM):													
None													
Main Line-Providence to Boston (PVD):													
MP 195.5 and 198.6			50	10							Yes		
M 202.9 and 204.1			45	10							Yes		
MP 213.6 and 214.1			50	10							Yes		

B. RESTRICTIONS RECEIVED IN ROUTE:

Line	Between/At	Track(s)	Psgr	Frt	Signs	Time Effective	Dspr	Time Cancelled	Dspr

C. BRIDGE STRIKE SI 132-S2 IN EFFECT:

Line	Between/At	Track(s)	Psgr	Frt	Signs	Time Effective	Dspr	Time Cancelled	Dspr

Appendix E USABILITY FIVE-POINT SCALE SURVEY

Question#		1	2	3	4	5
		Disagree		**Neither agree nor disagree**		**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					
N4	I find the software cumbersome to use					
P5	I feel confident in using this software					
N5	I think I need to learn many things before using this software					
		1	**2**	**3**	**4**	**5**
		Difficult to read		**Neutral**		**Easy to read**
P6	The 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?					

*Note: The question numbers were not present when given to the subjects

Appendix F USER FEEDBACK RATINGS

Question Number	Positive-ly/Negatively Word-ed	Mean	Median	Std. Dev.	Min	Max	Range	Mode
P1	Positively	4.9	5	0.32	4	5	1	5
N1	Negative-ly	1.3	1	0.95	1	4	3	1
P2	Positively	4.8	5	0.42	4	5	1	5
N2	Negative-ly	1	1	0.00	1	1	0	1
P3	Positively	4.7	5	0.48	4	5	1	5
N3	Negative-ly	1.3	1	0.67	1	3	2	1
P4	Positively	4.9	5	0.32	4	5	1	5
P5	Positively	4.9	5	0.32	4	5	1	5
N5	Negative-ly	1.4	1	1.26	1	5	4	1
P6	Positively	4.9	5	0.32	4	5	1	5
P7	Positively	4.7	5	0.48	4	5	1	5
P8	Positively	4.4	4.5	0.70	3	5	2	5
P9	Positively	4.4	5	1.26	1	5	4	5
P10	Positively	4.6	5	1.26	1	5	4	5
P11	Positively	3.9	5	1.66	1	5	4	5

Appendix G COGNITIVE WALKTHROUGH FEEDBACK SURVEY

Feedback Survey

Questions about the Display as a result of interacting with it

1. Were there aspects of the interface that you particularly liked or disliked?

2. Were track features represented clearly and straight-forward to understand?

3. Which section(s) of the display do you think you would use most often?

4. Which section(s) of the display do you think you would rarely use?

5. Which section(s) of the display do you think you would never use?

6. How would you prefer the notes alert/reminder notify you (visually, auditory, other)? And why?

7. What changes would you make to the display?

8. Were you at all frustrated when interacting with the display?

9. Would this display be helpful to you when operating a train? How?

10. How do you think your colleagues would react to this display? (new and experienced engineers)

11. How do you think the following would react to this display:

    a. Your superiors
    b. Other crew members
    c. Anyone else?

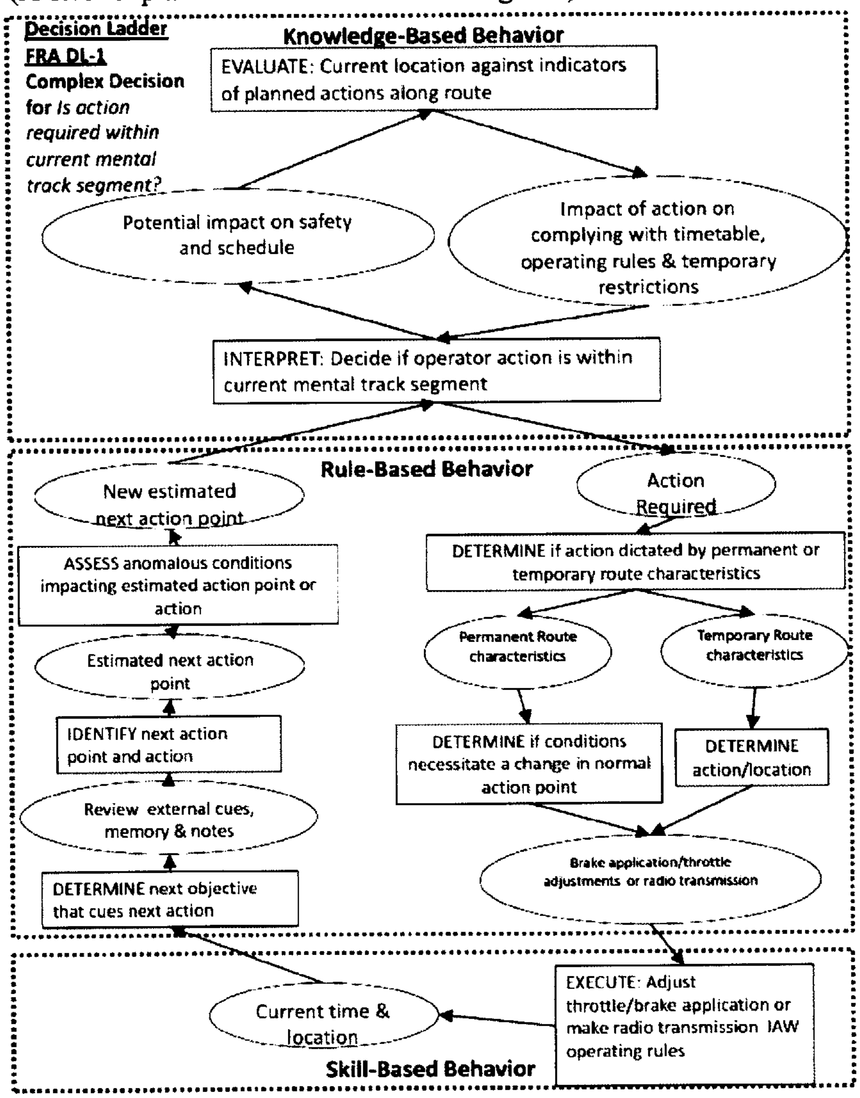
12. Do you think a display such as this would improve safety?

13. Do you think a display such as this would allow engineers to concentrate more on running the locomotive?

14. Do you think this display could be a distraction?

15. Do you think this display would alter the way in which you run your locomotive?

16. Look at the flow chart below. Do you think it is accurate for how you currently operate? (A brief explanation of the chart will be given).



Questions Regarding Decision-aiding technologies

1. Do you currently use any external aid that helps you make decisions enroute, provide recommendations or provide preview information? Please describe.

2. How do these decision-aiding displays alter the way you operate vs. not having the displays? Refer back to the flow chart if necessary.

3. Comments/recommendations:

Appendix H COMPLETING TASKS AND FEEDBACK ON FEATURES

Notes & Reminders

Notes refer to the ability to input notes at specified locations along the track or elsewhere on the display. Notes appear as shapes on display and include textual information, which can be free form or entered via a track warrant template. Instead of showing subjects instantiations of reminders (notes that present themselves before action is needed), subjects were asked how they would prefer to be reminded of notes and other actions that they must execute while en route.

All ten subjects were able to correctly enter a track warrant, or permission/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. In this experiment and for the display, the track warrants are called "Form D's" because this is terminology for which the majority of the subjects are accustomed as it complies with Northeast Operating Rules Advisory Committee (NORAC) operating practices. The task of inputting Form D's 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 this task, however, 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 guided or told that they needed 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 (See the blue circles that surround the track showing the speed restriction and associated text in Figure 68 below). This may indicate that these subjects were not fully aware of the information they input into the display or aware that the default screen did not contain the stretch of track where they input the data.

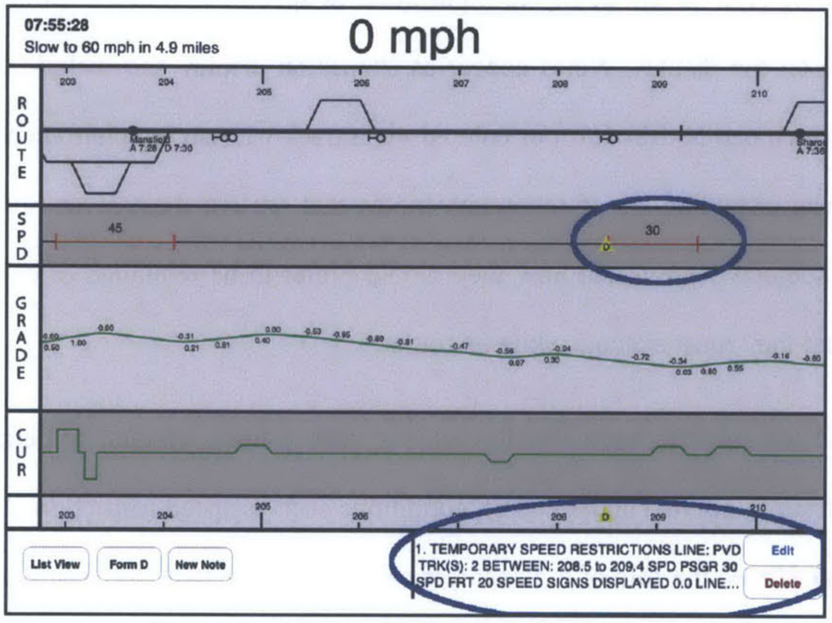


Figure 68: Temporary Speed Restriction

Subjects were asked to imagine they were leaving Mansfield station at milepost 204 and describe the next rule with which they must comply; the answer was the 30-mile per hour speed restriction that they input previously (ten tasks/questions had elapsed since the input). All seven of seven subjects that were asked this question were able to answer it correctly. Figure 68 shows the screen that subjects needed scroll to in order to answer the question and the blue circles indicate the portion of the screen that subjects would have needed to look at in order to answer the question correctly. This question conveys to subjects an example use case for the input of notes and demonstrates that the subjects were able to comprehend the action of entering a note.

When asked if subjects liked inputting notes electronically over the traditional paper form, seven of nine subjects said that they liked it while two of nine were neutral. One of the neutral subjects said that he/she is accustomed to having the paper in front of himself/herself and would want to see the reminders pop up. The other neutral subject said, "It would be a change because we are use to the paper and use to having it in your face. It's just a different way of seeing it; we would adjust." One subject stated that he/she liked this method of input and was not frustrated while interacting with it; however he/she did note that, "I just have fat fingers but I would get use it and get better at it." This suggests that the size of entry windows and keypad may need to be enlarged.

The remaining subjects cited that they liked ability to input notes directly into the display because it was more legible, reduced the amount of paper and consolidated the information in one place. One statement from a subject exemplifies two of these points, "Everything is in one spot . . . this is better than paper. There is too much paper and no where to put it on the brake stand."

Despite favorable reactions to the note functionality, one subject cited concerns of the display crashing and another remarked that they would continue to use paper in addition to the display until they had gained confidence in the display.

When subjects were asked how they would prefer reminders to be presented to them, their answers typically covered when and how. Eight of ten subjects identified that they would want an alert at some distance prior to the location of the note. These distances ranged from one to six miles and some subjects indicated that they would want the distance to be variable based on speed or user-defined preference. Other subjects stated that they would want the reminders to come up during periods of low workload such as when they are stopped at a station or if there is a stretch of track where few actions are required.

Regarding how the reminders present themselves, six of ten subjects described they would want an audible alert. All ten subjects said that they wanted a pop-up window with an additional visual cue such as distinct color or automation (e.g. a flashing screen).

Further development of these reminders is a topic of further research and is best suited for a controlled, performance-based experiment to determine the optimal conditions and configurations. However, it is clear that subjects see the value of these reminders and would want to ensure that they do not miss the associated messages and information conveyed therein.

Scrolling and Zooming

The default screen for these experiments depicted five miles of track and when subjects were asked to display approximately twelve miles of track (between the station stops of Providence and South Attleboro), nine out of ten subjects were able to scroll to the specified section of track and use the pinching gesture to display the requested twelve miles of track. Both the scrolling and pinching gestures were covered in the tutorial; additionally, the scrolling gesture was needed to verify a "Form D" input from a previous task. Subjects were asked if they were frustrated when interacting with the display, one subject said that he/she was frustrated trying to zoom and pinch to get it where needed. These results suggest that these functions and the associated gestures are easy to learn and apply although refinement of sensitivity and considerations for people with less finger dexterity are needed.

Additional Informational Features

A series of features were also shown to subjects and their feedback was solicited; subjects were not asked to retrieve information or perform a task based on these features. Subjects were told that the information related to these features was only presented when the user selected an icon for it to appear. These features include Next Action, Consist, List View, Movement Authority, and Track Number (Refer to Section 4.2 for an explanation of these features). The percent of subjects that liked, sometimes liked and disliked the features presented is shown in Figure 69, additionally the raw numbers are shown in Table 12. "Sometimes Liked" is a category in which subjects recognized value in the feature for specific circumstances that may not exist day-to-day.

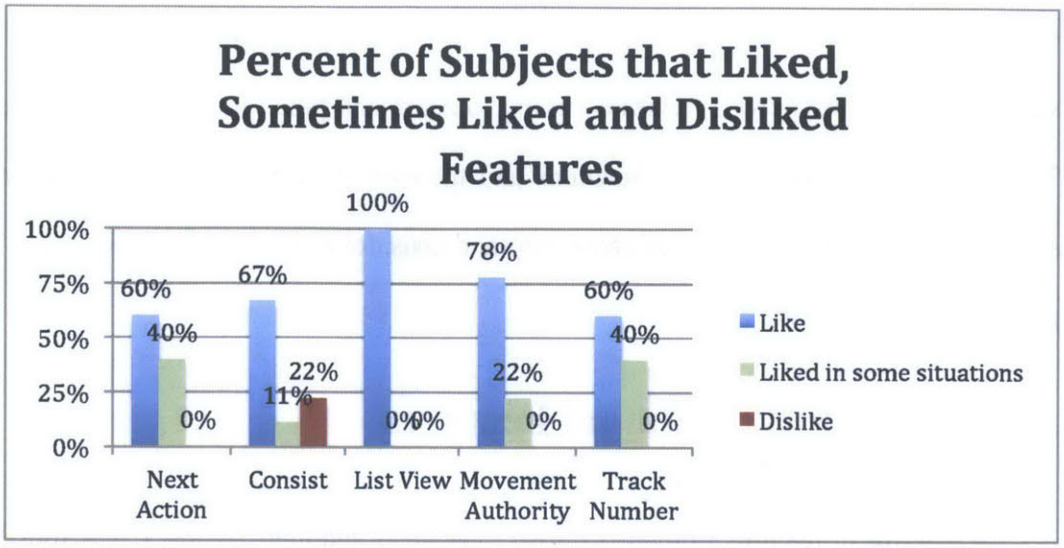


Figure 69: Percent of Subjects that Liked, Sometimes Liked and Disliked Features

Table 12: Number of Subjects that Liked, Sometimes Liked or Disliked Features

Number of Subjects that Liked, Sometimes Liked or Disliked Features				
Feature	Like	Dislike	Liked in some situations	Total
Next Action	6	0	4	10
Consist	6	2	1	9
List View	10	0	0	10
Movement Authority	7	0	2	9
Track Number	6	0	4	10

The Next Action feature required the most explanation in order for subjects to understand. The example that was presented was for a station stop and some subjects remarked that they would not need it for that. Four subjects cited that this feature would be useful for route for which they were not familiar. Three subjects remarked that they would use this feature when there was poor visibility citing fog or white out conditions where they are "just feeling [their] way along" or "searching for mileposts on the side to figure out where [they are]". Two subjects said that they would use this feature as an additional indicator for men working. One of the freight engineers mentioned that he would use this feature to ensure that the rear of his train had cleared certain points.

The *consist* information consisting of engine number, number of cars and weight was generally well received by subjects; the two that said they would not use this feature said that they always look at the paperwork before leaving and would look at this information afterwards. One subject said that he/she tends to forget how many cars he/she has because he/she "gets off one train and gets on another and is thinking about the other train." Four subjects said that they would like more detailed information about the train makeup such as coach numbers, powered coaches or empty cars. The last two recommendations impact train dynamics and how the freight locomotive engineers run their locomotives. Coach numbers were cited as useful in situations where dispatch may ask for a specific control car or coach number or if they have to communicate the location of a medical emergency. Currently, they would have to reach for paperwork, but felt it was "better if in a central location."

All ten subjects liked the List View function, which provides a pop-up window of upcoming actions by upcoming mileposts. One subject said, "It's like your own little checklist; I won't have to write on the window anymore," and another remarked, "its good to be able to look at information beyond the preview information of the map." Figure 70 shows a screen shot depicting that List View was selected and the item at milepost 209 was also selected.

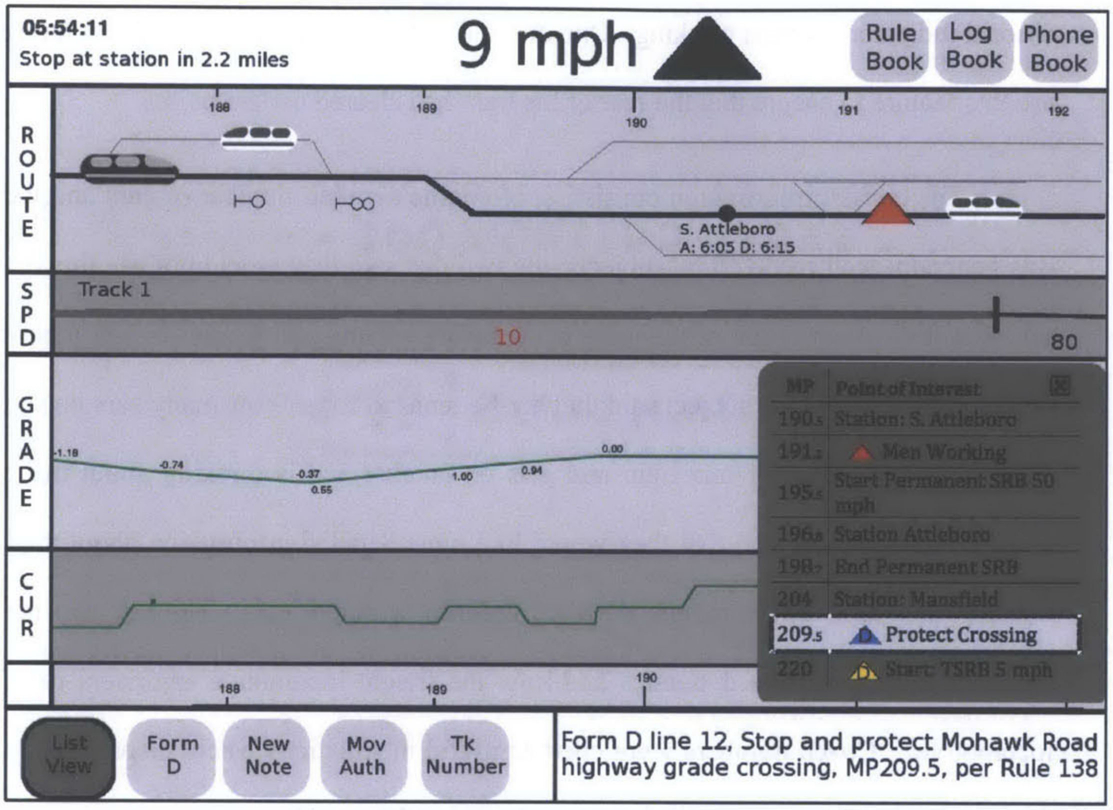


Figure 70: Screenshot of List View

The Movement Authority feature received positive feedback from all subjects; however subjects who operate under the same authority for the entire route or have already memorized the movement authority for the entire route said that they would not use this feature under those circumstances. One subject liked how the information provided was specific to the track he/she was on, that the pertinent information was provided directly. One suggestion that a subject made is to display the rule near the track, and not in the lower right-hand text box because this is how they see in on their track charts. The subject went on to say that this could replace paper track charts, be used as a qualifying tool to help engineers learn the track as opposed out having the rulebook and track charts open, and help engineers maintain qualification on route that they have not done lately.

The ability to display the track numbers and information on which tracks the locomotive will be routed was seen favorably by all subjects. Some subjects said that they would only use it if they were being switched to a track that is normally not used or on a route they had not traversed in a while. This feature was also mentioned as helpful for learning a route for qualification.

Rulebook, Logbook & Phonebook

Rulebook, Logbook, and Phonebook icons were displayed on the upper right corner of some of the screen shots. There were no mock-ups of how these features would present themselves, instead subjects were asked what they would expect to see or would like to see after selecting one of these icons.

Most subjects said that they would not use the Phonebook because not only are they not permitted to use personal cellular devices, they communicate via the train radio and anyone that they cannot contact directly, the dispatcher contacts on their behalf. Some subjects said that radio frequencies might be useful for different sections of the track, but those are typically included in the rulebook. As a result of this feedback, the Phonebook icon should be removed and important contact information should be included in the Rulebook function.

The Rulebook received positive feedback all around as many of the subjects said that they found it cumbersome to carry heavy bags with paperwork, to include all of the pertinent rulebooks. In addition, subjects said that they would like to be able to search the rulebook by rule number or key words to be able to quickly bring up the information they need. Another subject said that it would be easier to handle changes and updates on electronic versions and would want changes to be marked clearly.

The Logbook feature was interpreted as either a place to input notes about a trip/your routes or as a place to indicate equipment issues. Subjects said that for notes, they would want to include information about delays and causes of delays, bad signals or anything relevant to a track or line, including if certain routes had extra time in the schedule. Subjects who originally stated they would use it for general notes also liked the idea of using Logbook as a maintenance log with presented with the idea, however, they would have preferred that the icon to be labeled more descriptively if this were its function. Subjects also particularly liked the ability to fill out the maintenance log and transmit the information directly to the mechanical department.

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