Moving Map Display Concept Development for Rail: A Human Factors Approach

September 18, 2008

Locomotive Moving Map Display Concept: Problem Statement

- *Purpose:*
  - *What are the display information and symbology requirements that will enhance a locomotive engineer's situation awareness (SA)?*
  - *Use a human-centered design approach to conceptualize a locomotive moving map display (LMMD)*
  - *Develop a concept in a desktop demonstration format*
  - ***Describe a process that will demonstrate the importance of using a human-centered design approach for the resulting concept***

Project : Why a Moving Map for Rail?

- Project Design Goals:
  - Improve situational awareness
  - Reduce workload
  - Enhance safety
  - Improve operational efficiency
  - Emphasize human-machine interface considerations
  - Avoid potential distractions
  - Avoid information overload

Briefing Overview

- What is Human Factors and Human-Centered Design?
- Literature Review
- Initial Requirements Analysis - Observed Environments
  - Task flow diagrams
  - Cognitive walkthrough
- Concept of Operations (CONOPS)
- Requirements Development
- Moving Map Demonstration

What is *Human Factors*

- “Human Factors (or ergonomics) may be defined as the technology concerned to optimize the relationships between people and their activities by the systematic application of the human sciences, integrated within the framework of system engineering” performance

  -- *FAA Human Factors Job Aid*

- A branch of applied science aimed at matching machines and tasks with the abilities of their human operators.

- The study, discovery, and application of information about human abilities, human limitations, and other human characteristics to the design of tools, devices, machines, systems, job tasks, and environments for effective human performance.

  -- *Alphonse Chapanis*

- Usability
  - The design and deliverance of useful, usable, desirable solutions; ones people can easily learn; that have (consistent) functions that allow people to do what they want to do and that are well-liked.

    -- *John Gould, IBM Research*

Advantages of a User-Centered Moving Map Display

- Increases the potential to achieve effectiveness and a higher degree of situational awareness
- Decreases the possibility of a high engineer workload and fatigue
- Reduces additional training
- Reduces additional processing
- Integrates information from several sources
- Provides engineer control of displayed information
- Potential for powerful computational ability
- Potential for a truly interactive system
- Improves efficiency and safety

Human Factors Display Design Standards (continued)

- **MIL-STD-1472F**
  - Section 5.1 Control-display integration

    Display response time, illumination, position relationships, grouping, multiple displays, location, access, etc.
  - Section 5.2 Visual Displays

    Priority coding, text, warning/caution, content, precision, format, contrast, redundancy, importance, viewing distance, color coding, positive feedback, etc.

- **Example MIL STD 1472 Guidelines:**
  - Grouping: Displays used frequently should be grouped together and placed in the optimal visual zone and all displays necessary to support an activity shall be grouped together.
  - Importance: Critical displays shall be located in the optimal visual zone, or otherwise highlighted
  - Color Selection: Unobtrusive colors should be used to display information used infrequently. Warm colors should be used to convey action or the requirement for a response. Cool colors should be used to convey status of background information. Reflective glare shall be eliminated or minimized by proper placement of the display screen relative to the light source.
  - Legibility: Sufficient contrast shall be provided to ensure symbol legibility under all expected viewing conditions.

Thirteen Human Factors Principles of Display Design

- **Five Perceptual Principles**
  - Making displays legible (or audible)
  - Avoid absolute judgment limits
  - Top-down processing
  - Redundancy gain
  - Discriminability

- **Two Mental Model Principles**
  - Principle of pictorial realism
  - Principle of the moving part

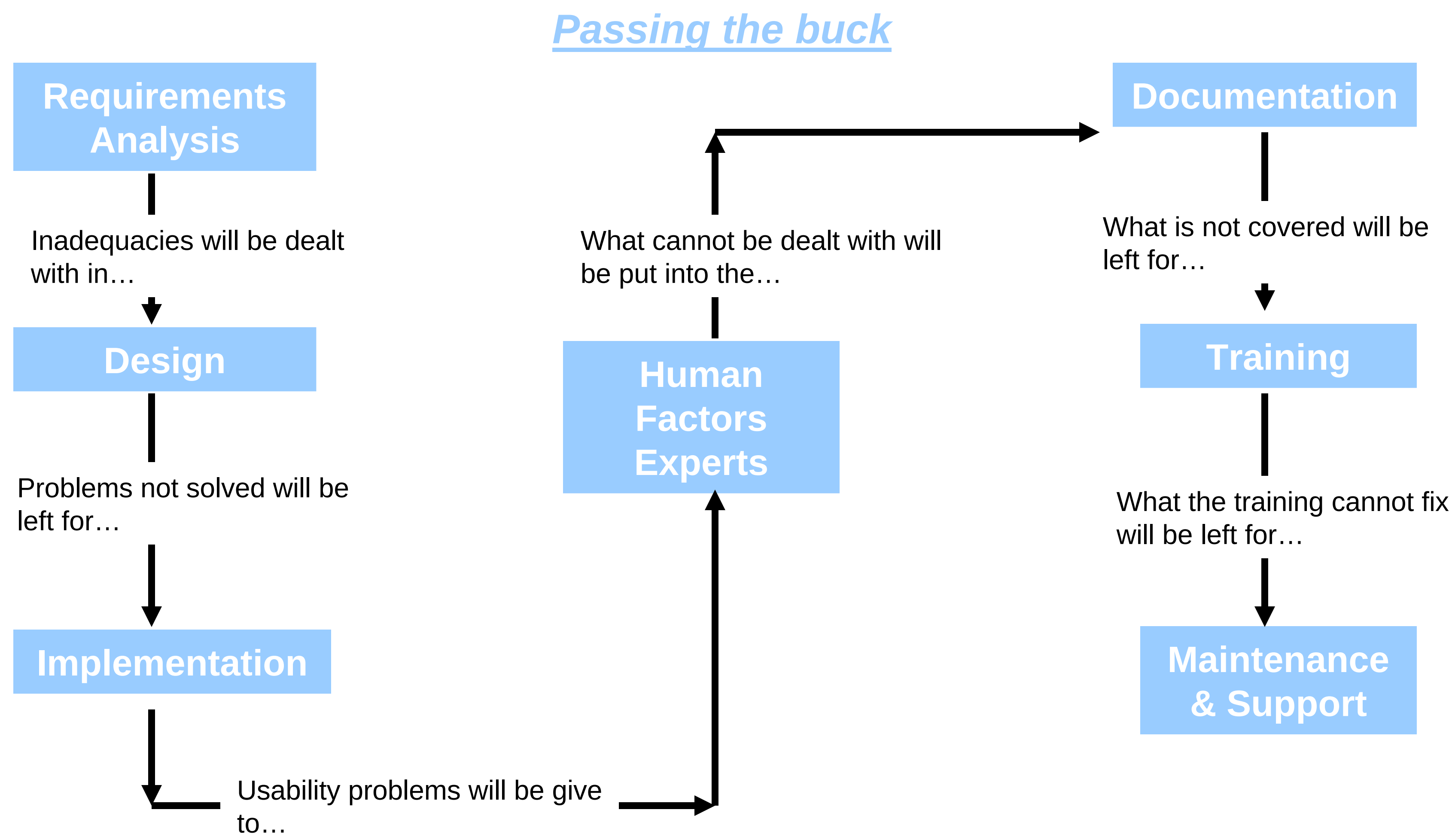
Reference: *An Introduction to Human Factors Engineering, 2nd Ed, Wickens, Lee Liu, and Becker*

Thirteen Human Factors Principles of Display Design (continued)

- **Three Principles Based on Attention**
  - Minimizing information access cost
  - Proximity compatibility principle
  - Principle of multiple resources
- **Three Memory Principles**
  - Replace memory with visual information
  - Principle of predictive aiding
  - Principle of consistency

Reference: An Introduction to Human Factors Engineering, 2nd Ed, Wickens, Lee Liu, and Becker

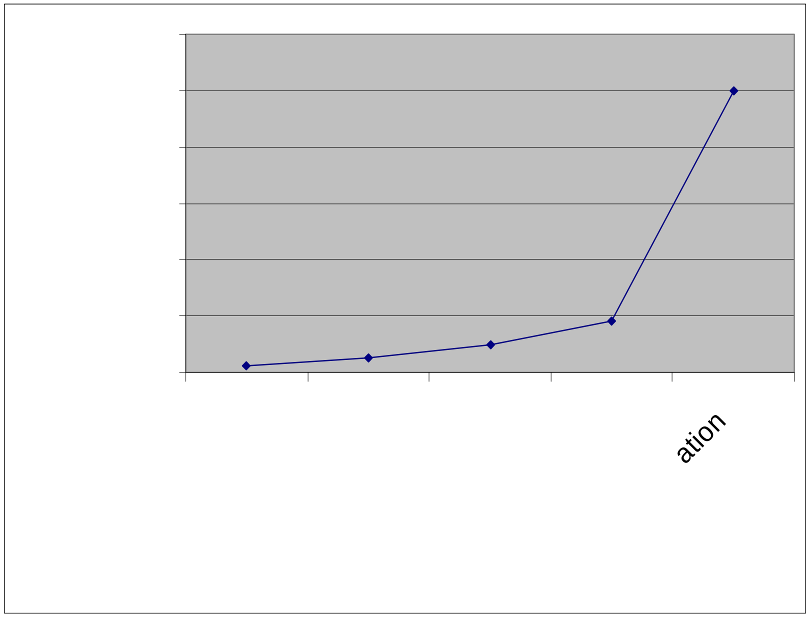
Consequences of Late or Inadequate Human Factors Input



Source: Eurocontrol, 1999

Reduced Programmatic Risk Due to Cost
---A Comparison from Software Engineering

- Relative cost of fixing a defect due to poor requirements rises as a program proceeds through the life cycle *[1]*
  - During coding, relative cost is about 10 times original cost
  - After a system is put into operation, relative cost is about 100 times original cost
- In addition to reduced cost, potential benefits for identifying poor requirements early include
  - Less risk to schedule
  - Improved usability
  - More satisfied users
  - Decreased need for training



[1] Weigers, K. (2003). *Software Requirements*. Redmond, WA: Microsoft Press.

Poor HF Display Design

Characteristics of Poor Display Design:

- Misuse of analog or digital displays
- Improper arrangement of instrumentation
- Small instruments that are difficult to read
- No use of color or graphics.
- Controls not organized according to importance or within human reach measurements

Reasons for Bad Designs:

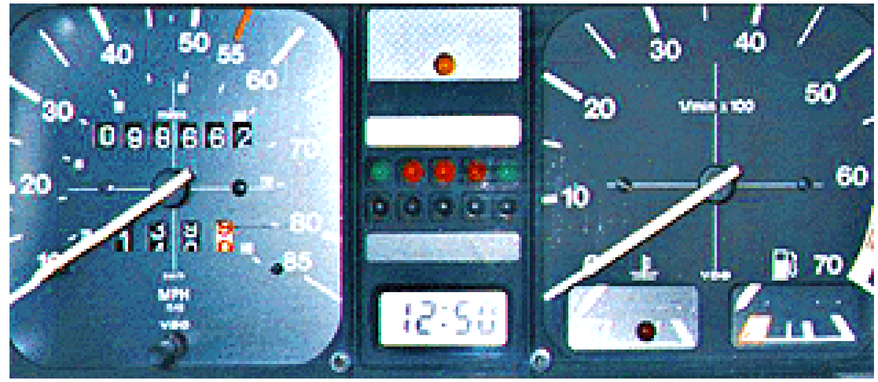
- Minimal or late involvement with users
- Poor requirements definition
- Requirements creep (complexity)

Consequences of Bad Designs:

- User frustration
- Misuse or non-use of a product
- Safety issues or catastrophic accidents

Poor HF Display Design

- **Confusing displays**
  - Tachometer adjacent to speedometer with similar scales and not clearly labeled



- **Design suggestion:**
  - Each display with distinctive scales
  - Clearly labeled with appropriate numerical units

(http://www.baddesigns.com/speedo.html)

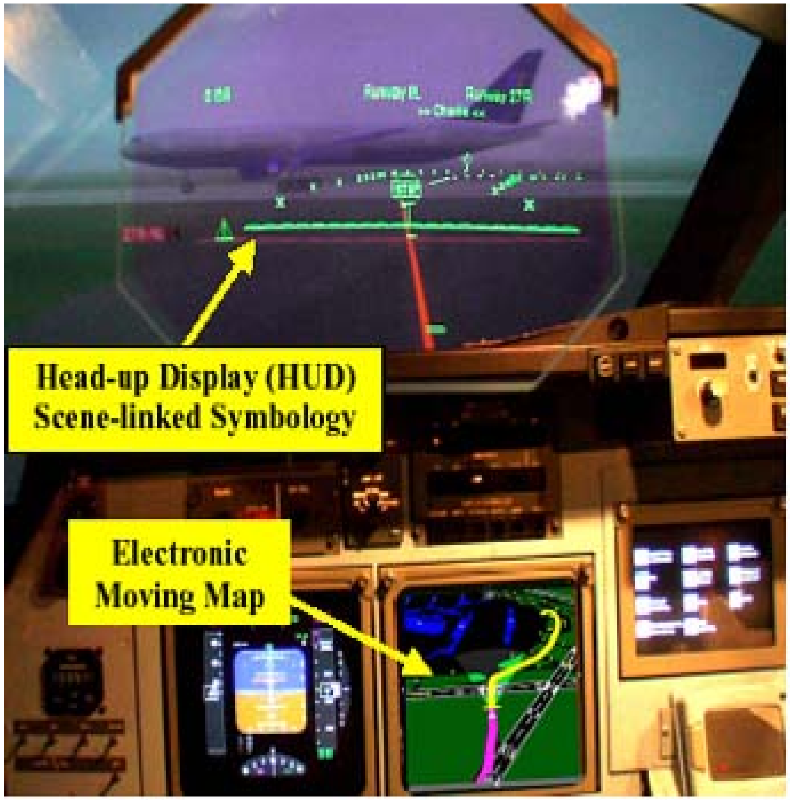
Poor HF Display Design – Prius Energy Display

Causes distraction to monitor a task that is not a top priority…

Example of a User Centered HF Display Design

T-NASA: Taxiway Navigation and Situation Awareness System

- Process: Task analysis, information requirements analysis, Iterative part-task and full-mission simulations, flight test.
- Head-Up Display (HUD) displays taxi route, runway clearance displayed using "scene-linked symbology"
- The airport layout, ownship position, taxi-route, and traffic information on Electronic Moving Map.
- Replaced paper maps



HF Design Features:

- Critical displays located in a privileged position in the optimum visual zone
- Display arrangement is consistent from application to application
- Displays arranged in sequence within functional groups to provide a viewing flow from left to right and top to bottom
- Minimized redundant information display
- Signals are displayed long enough for reliable detection under expected operator workload and environment

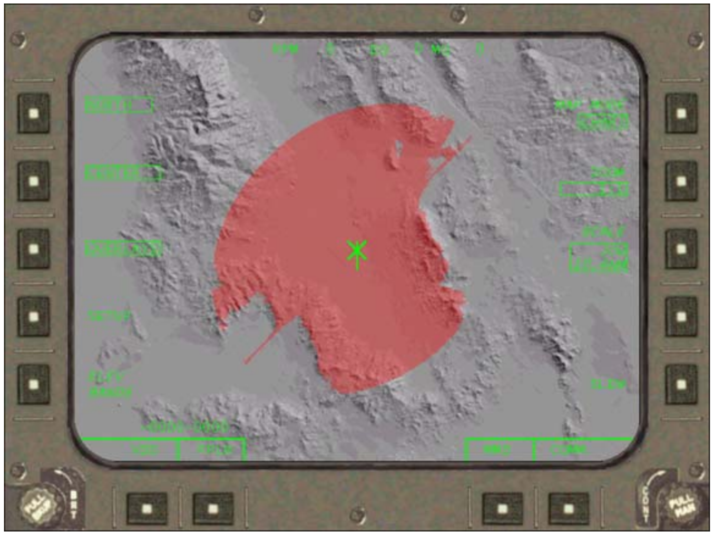
Example of a User Centered HF Display Design

US Army CECOM Helicopter Pilot Situational Awareness Display

- MetaVR visualization technology for helicopter pilot situational awareness display simulation-based prototyping

Design Features

- The multi-function display technology
- The MetaVR Digital Moving Map
- High resolution of the terrain elevation data allows precise characterization of the terrain features for maneuvering with confidence into areas that make the aircraft inaccessible to antiaircraft fire



http://www.metavr.com/casestudies/sadaaaa99cecom.html

Project Tasks for Locomotive Moving Maps Development

- Literature Review
- Initial Requirements Analysis - Observed Environments
  - Task flow diagrams
  - Cognitive walkthrough
- Concept of Operations (CONOPS)
- Requirements Development
- Map Demonstration

Literature Review - Overview

"*There are currently dozens of handbooks, guidelines, etc., for the design and choice of conventional displays and controls……The astonishingly poor quality of many…displays and control consoles is due only to the unwillingness of designers and engineers to make use of the information that is widely available.*" (Salvendy, 1957)

- Synthesize on-going work in the areas of:
  - Human-computer interaction (HCI) expertise and guidelines
  - Moving map display design in other domains
  - Railway operation including past and ongoing studies investigating the impact of new technologies on train crew performance

Literature Review - HCI Guidelines

Icon-Specific Design Guidelines
Represent the object or action in a familiar and recognizable manner
Limit the number of different icons used
Make the icon stand out from it background
Consider three-dimensional icons; while eye catching – can be distracting
Ensure that a single selected icon is clearly visible when surrounded by unselected icons
Make each icon distinctive from every other icon
Ensure the harmoniousness of each icon as a member of a family of icons
Design the movement of animation

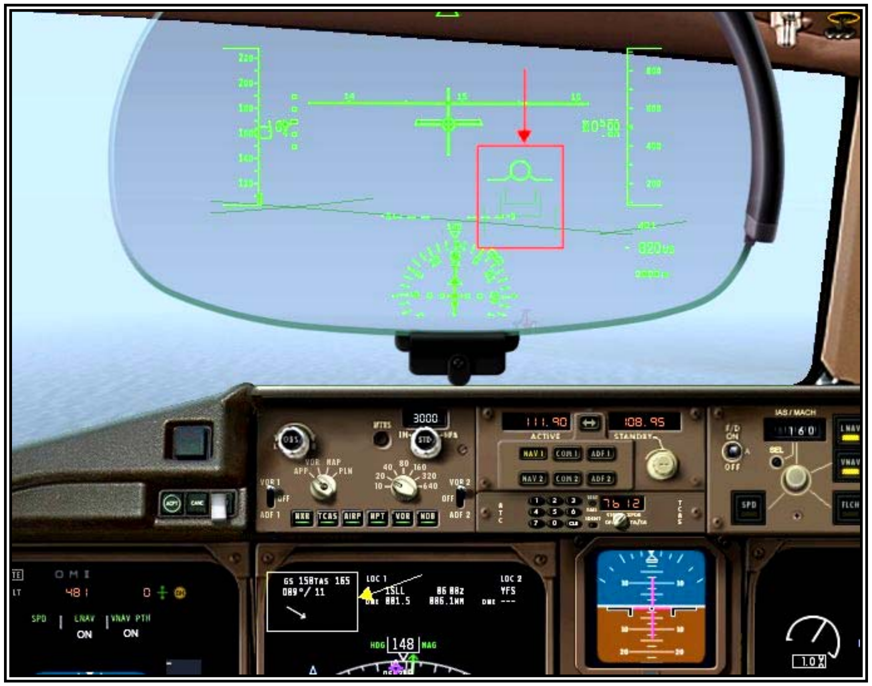
Example: HF Guidelines Quick Glance

<u>User Centered Display Research:</u>

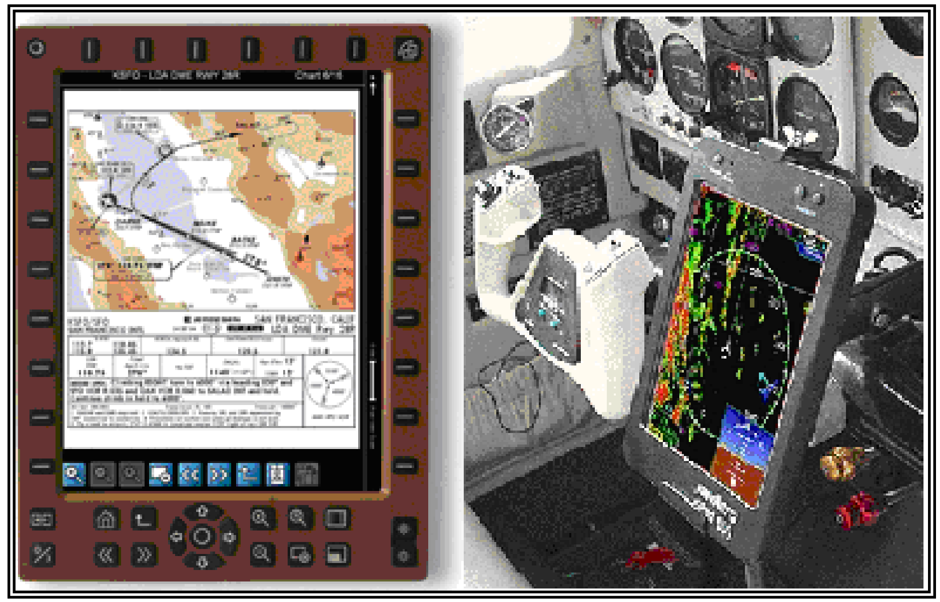
1. Guidelines using color in display design
2. Display indicators
3. Display selection consideration factors
4. Signal and warning light recommendations
5. Icon-specific guidelines for display design
6. Display clutter research
7. Cognitive Issues
8. Other visual displays

Literature Review
Moving Maps in Other Transportation Domains

- Aviation and Aerospace



Aviation heads-up display (HUD)



Stand-alone and bracket-mounted EFBs for general aviation

Literature Review
Moving Maps in Other Transportation Domains

Automobiles and Marine Systems

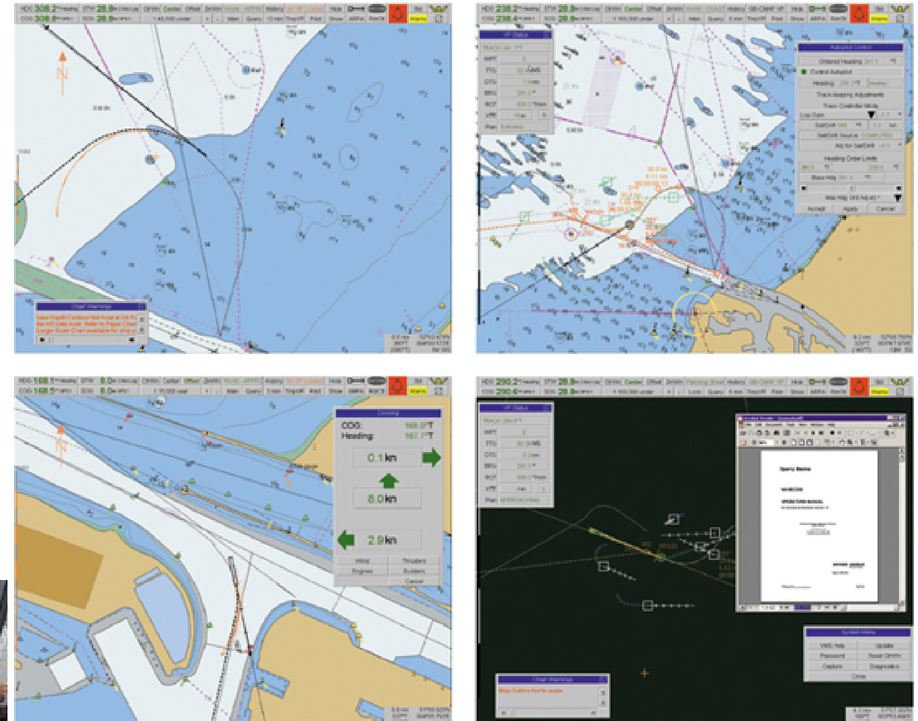
Garmin GPSMAP 3000

Various vehicle moving map display systems

Literature Review
Moving Maps in Other Transportation Domains

Electronic Chart Display Information Systems (ECDIS)

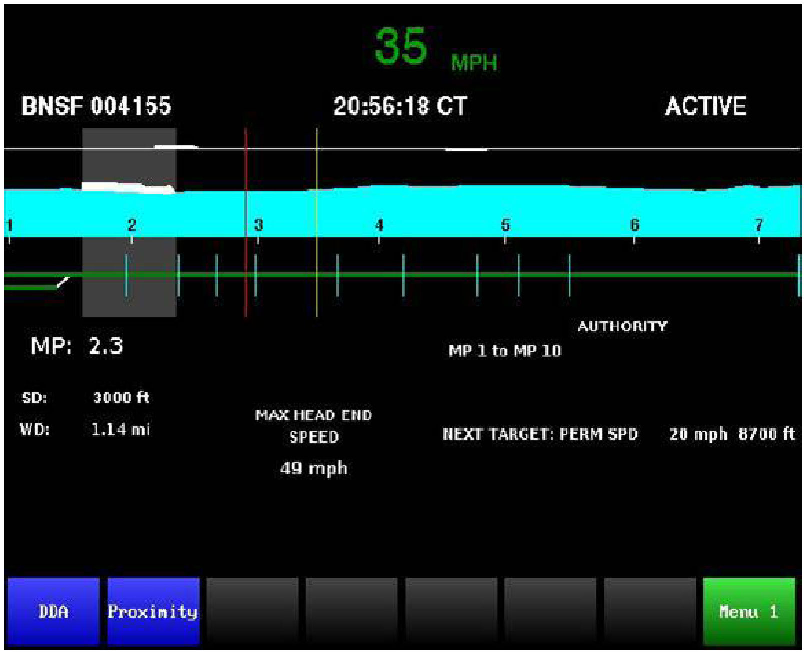
Integrated Bridge System for Naval Navigation



Literature Review – Current Rail Technology Initiatives

Moving Maps for Rail Applications

- Wabtec Railway Electronics
  - Track profile depicting location, consist, and track occupation
  - On-board computer for downloadable information (restrictions and movement authority)
  - PTC system tracks location, calculates warning and braking curves based on the train's consist, speed, length, weight, and grade
  - Predictive elements include predictive stopping distance and warning distance to end of current authority
- Amtrak's ACCESS
  - In-cab signal aspect display is updated periodically by position data
  - Position information from a passive transmitter/receiver system on base of the locomotive, updated as train passes over block transmitters on track
- PTC: GE, ARINC, Lockheed, Union Switch and Signal, and Siemans



Wabtec Moving Map Display Format

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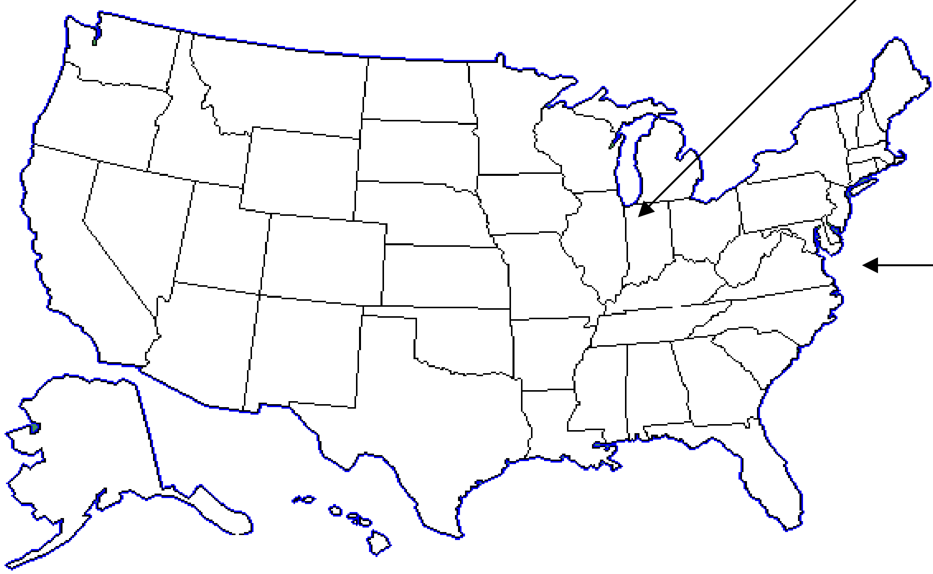
Observing the Baseline Environment

- Conducted observations of locomotive engineering environments
- Criteria: Class I railroad locomotives with and without traditional cab signaling
- Rail lines observed:

Union Pacific, Chicago



Amtrak, Northeast Corridor

Observing the Baseline Environment - continued

- Commuter locomotives observed

Amtrak commuter locomotive cab layout

Acela commuter locomotive cab layout

Observing the Baseline Environment - continued

- Commercial freight locomotive observed

Union Pacific locomotive cab layouts

Observing the Baseline Environment - continued

- Observation Goals:
  - Observe operations in signaled territory
  - Document the information needs of the locomotive engineer
  - Document the tasks performed by the locomotive engineer
  - Assemble site visit observations in information requirements review

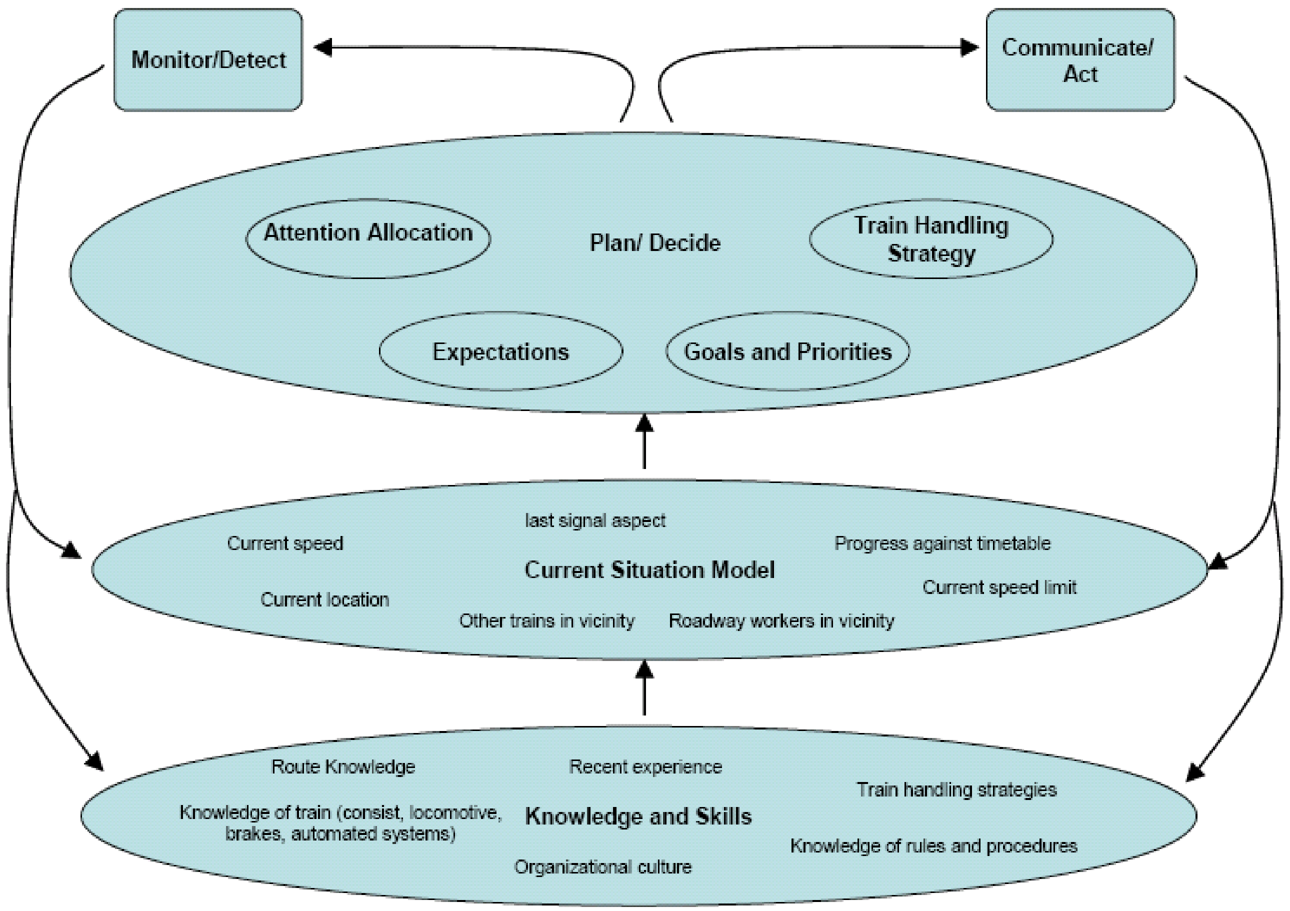
Observing the Baseline Environment - continued

- Observations conducted in
  - Multi-directional route traffic
  - Low, medium and high traffic density environment
- Data collection methods
  - Observation
  - Informal interview
- Analysis methods
  - Task flow diagrams – Performed from the start of the train ride, during continuous operation, and during stopping of locomotive
  - Cognitive walkthrough
    - Prompted to better understand the information and process for train operation
    - Of particular interest was information required to comply with speed restrictions and information referred to by engineer to complete a navigational process

Observing the Baseline Environment - continued

- Information serving as basis for moving map requirement

Simplified model of the knowledge and cognitive functions and processes that underlie locomotive engineer performance (Roth & Multer, 2007)



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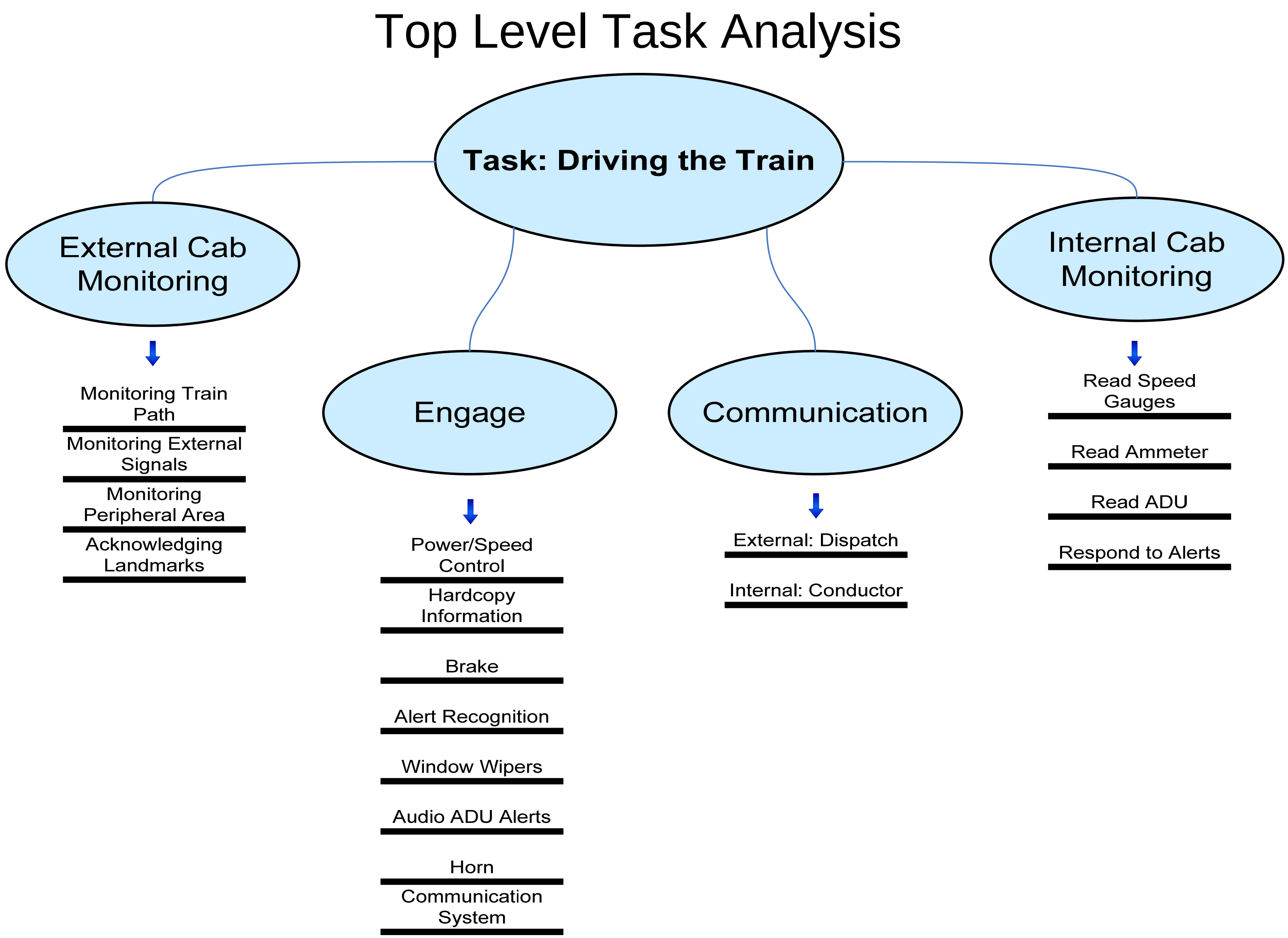
Observing the Baseline Environment - continued

- Information Items for Consideration
  - Own cab position/location/heading
  - Other trains track positions/location/heading
  - Own cab speed
  - Own cab acceleration/deceleration
  - Location of last car
  - Track profile
  - Train consist
  - Track speed
  - Mile post markers
  - Temporary speed restrictions
  - Work zones landmarks
  - Grade crossings

Observing the Baseline Environment - continued



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Concept of Operations (CONOPS)

Operational Need - Current Issues

- Crew must stay current on 800 – 1000 miles of railroad
- Crews must access and retain a high level of information on heavily traveled routes, in spite of fatigue, poor visibility, and distractions
- "According to the Federal Railroad Administration Office of Safety Analysis data for 2007…, there were 13,236 accidents or incidents involving trains and 792 deaths resulting from the accidents. The cause of the accidents were most often human error (38.36% of the time), followed by equipment defects and miscellaneous causes (about 12 percent each)."

  (Article by Norm Schneider, Associated Press, after Chatsworth train accident, Sep 13, 2008)

CONOPS – continued

- Operational Need
  - Scope of system for consideration
    - System will rely on Global Positioning System (GPS)
    - Technology will need to integrate harmoniously with current cab technology
    - Designed to complement existing crew operations instrumentation
    - Will include an anchoring and/or bracing mechanism to attach to the control stand
  - Organizational constraints
    - Railroads are privately owned, each with its own plant infrastructure
    - Difficult for government to mandate changes to infrastructure
  - System Users
    - For use by engineer and/or conductor
    - Class I railroads and passenger railroads

CONOPS – continued

- System justification
- Human Factors challenges is to design a solution with an operator focus in mind to gain user acceptance
  - To be effective the system must:
    - present information needed with no extraneous information
    - present visual information using human factors display design principles including size, dimension, color, and iconography
    - be intuitive and not require any cognitive or physical resources vital to other concurrent tasks
    - design system using a human-centered design approach

CONOPS - continued

- LMMD Assumptions and Constraints
  - Assumptions
    - Railroad operators have a stake in increased safety and operational efficiency
    - Railroad operators have a stake in increased railroad capacity
    - Many technologies required to implement a moving map are currently available (GPS, transponders, sensor technologies, track technologies)

Must provide proof that incorporating human systems integration (HSI) principles into rail operations is a logical, cost-effective approach

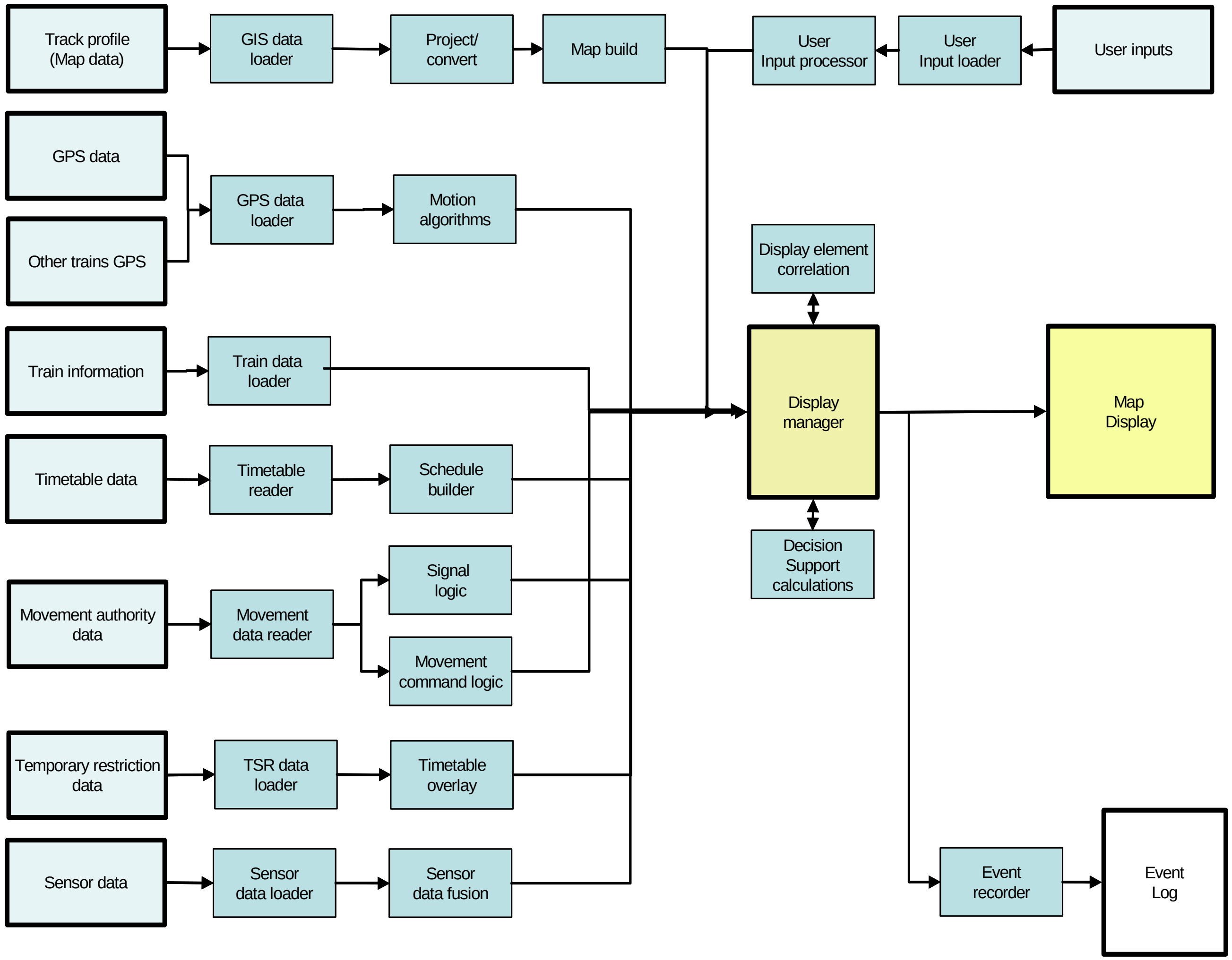
- Provides tangible (cost savings) and intangible benefits (improved labor relations)

CONOPS - continued

- LMMD Assumptions and Constraints
  - Constraints on acquisition of new technology
    - Lack of clearly defined and established standards
    - Uncertainty regarding certification of new technology systems
    - Major investment required to provide cab and trackside infrastructure
    - Risks to current interoperability of freight railroad equipment
    - Unclear risk/benefit proposition for systems architecture
  - Constraints to system development
    - GPS and LORAN do not work in all rail environments, e.g. tunnels and under bridges
    - Availability of data to support a map database may be difficult to obtain since many types of data are considered proprietary

Prototype Moving Map

- Conceptual Model Major components
  - GPS data loader
  - Track profile assembler with map database
  - Ability to read a process data-linked information



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Moving Map Display Demonstration for Rail: A Human Factors Approach

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Overview

Development Process Overview

Screen Descriptions

LMMD Demonstration

Step-by-Step Analysis of the Demo

Development Process Overview

- Document Review
  - CONOPS
  - Cognitive Task Analysis (CTA) from Volpe National Transportation Systems Center
- Task Analysis
- Storyboarding
- Animation Development
  - Google Earth
  - CSX Fact Sheets
  - Animation Script

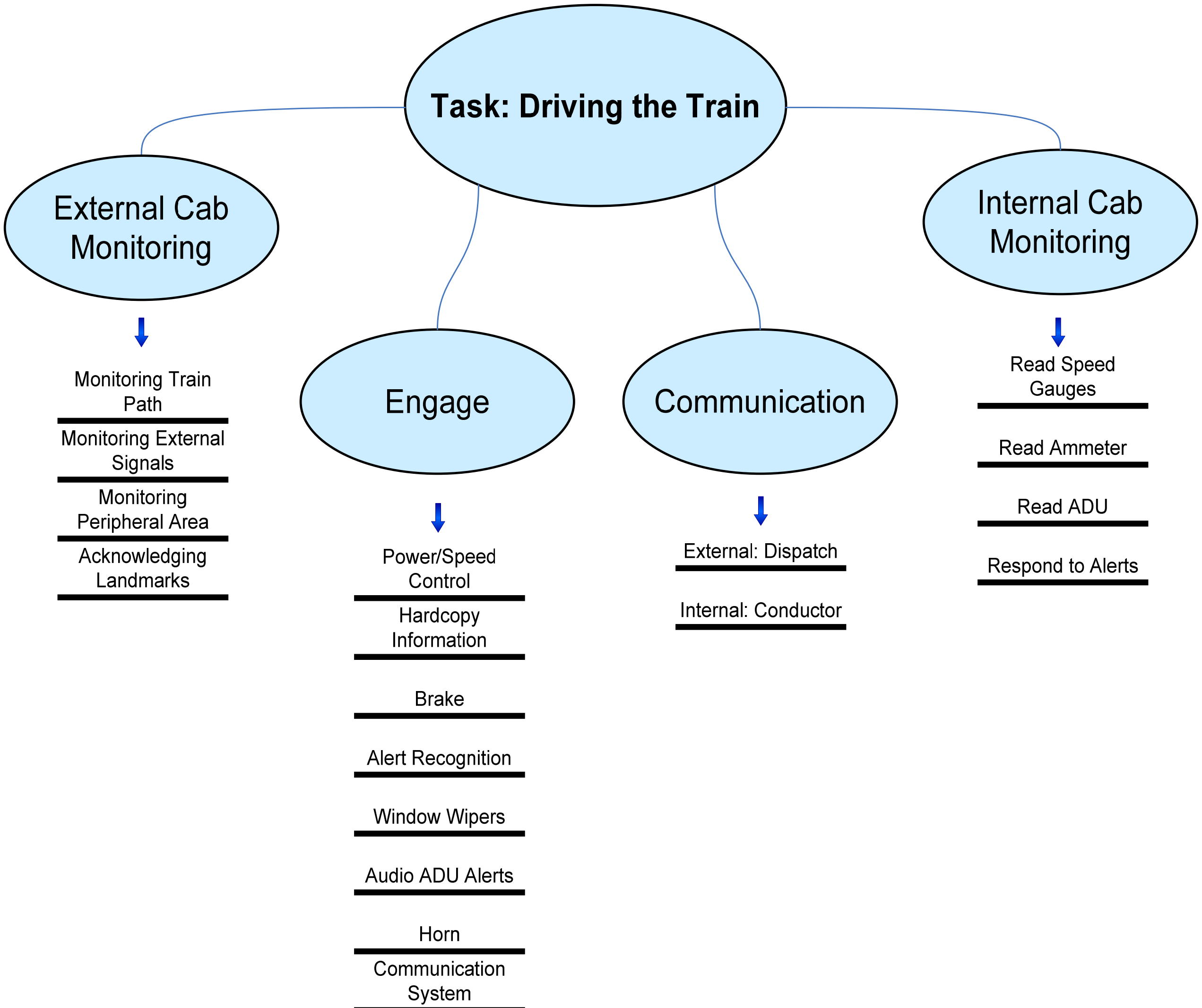
Document Review

- Concept of Operations
  - Train location
  - Situational awareness of train environment
  - Track navigation
  - Electronic schedule data
- Cognitive Task Analysis (Volpe NTSC)

Task Analysis

- Flowchart Used for Initial Development
- Physical Chart is in the Requirements Document
  – Example will follow
- Locomotive Engineer Actions
- Observed Tasks
- Why Include Actions/Tasks on Moving Map?

Task Analysis (continued)



Task Analysis Example

Task	What Information provides/allows	Allocate this info to moving map?	When information is presented	Where information is presented (screen)	How information is presented on the screen	Rationale for moving map allocation
External Cab Monitoring						
Monitoring Track Path						
Track	forward progress of train	yes	Continuous	FP	Actual outline representation of a track on the ground	Main Map Component
Track	forward progress of train	yes	Continuous	MAP	solid black line depicting the current track path	Main Map Component
Signals	Permission to proceed, halt, etc	Yes	Time/distance allocation before reaching	FP	All tracks shown with signal and switch states in detail	Signals' widely represented in ADU system; ADU transmission capability does not currently available on all tracks
Signals	Permission to proceed, halt, etc	Yes	Continuous	MAP	Signal pane will show the next block signal aspect and indication as it would be displayed on the trackside signal mast.	Signals' widely represented in ADU system; ADU transmission capability does not currently available on all tracks
Track Condition	Repair/Upkeep condition of track	No	n/a	n/a	n/a	Technical capability for linking does not currently exist

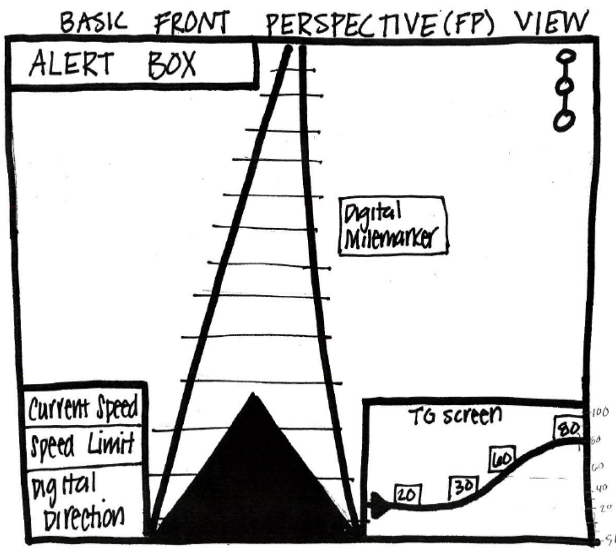
Storyboarding

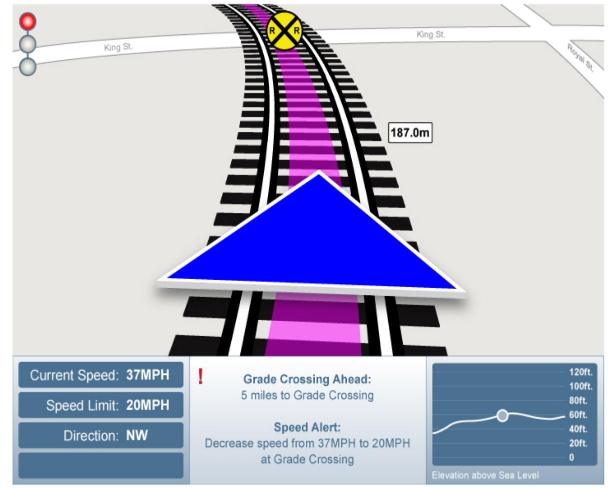
- Deciding on Different Scenarios
  - Crossing bridges
  - Negotiating sharp curves and steep hills
  - Grade crossings
  - Work zones
  - Overall situational awareness
  - Movement authority
- Two Approaches
  - Textual
  - Visual/Graphical

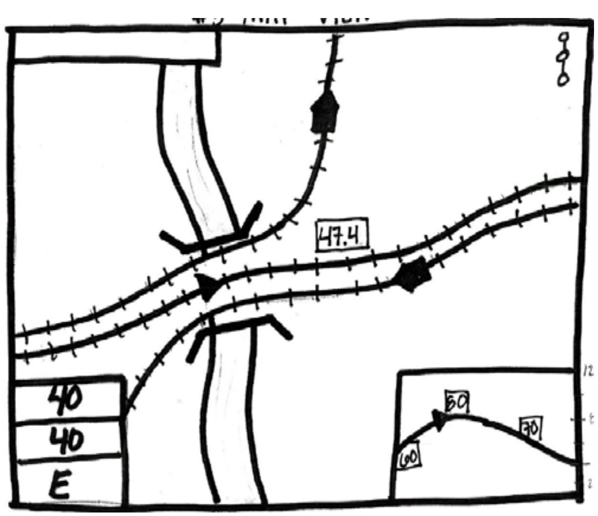
Storyboarding (continued)

- Static Components = Screen Basics
  - Signals
  - Speed
  - Direction
  - Own train location
  - Track
  - Mileposts
  - Terrain Grade screen
  - Alert Box

Idea drawings → Graphical Representations







Software Engineer vs. Graphics

- Software Engineer
  - Using code to change the locations, colors, speed, etc.
- Graphics (3 Adobe graphics programs)
  - Illustrator – Vector-based drawing software
  - Photoshop – Graphics editing software
  - After Effects – Digital motion, compositing, 2D/3D animation software

Animation Development

- CSX Fact Sheets
- Baltimore Division Timetable
- Google Earth
- Animation Script
- Final Product Revisions
- Lessons Learned

Animation Development (continued)

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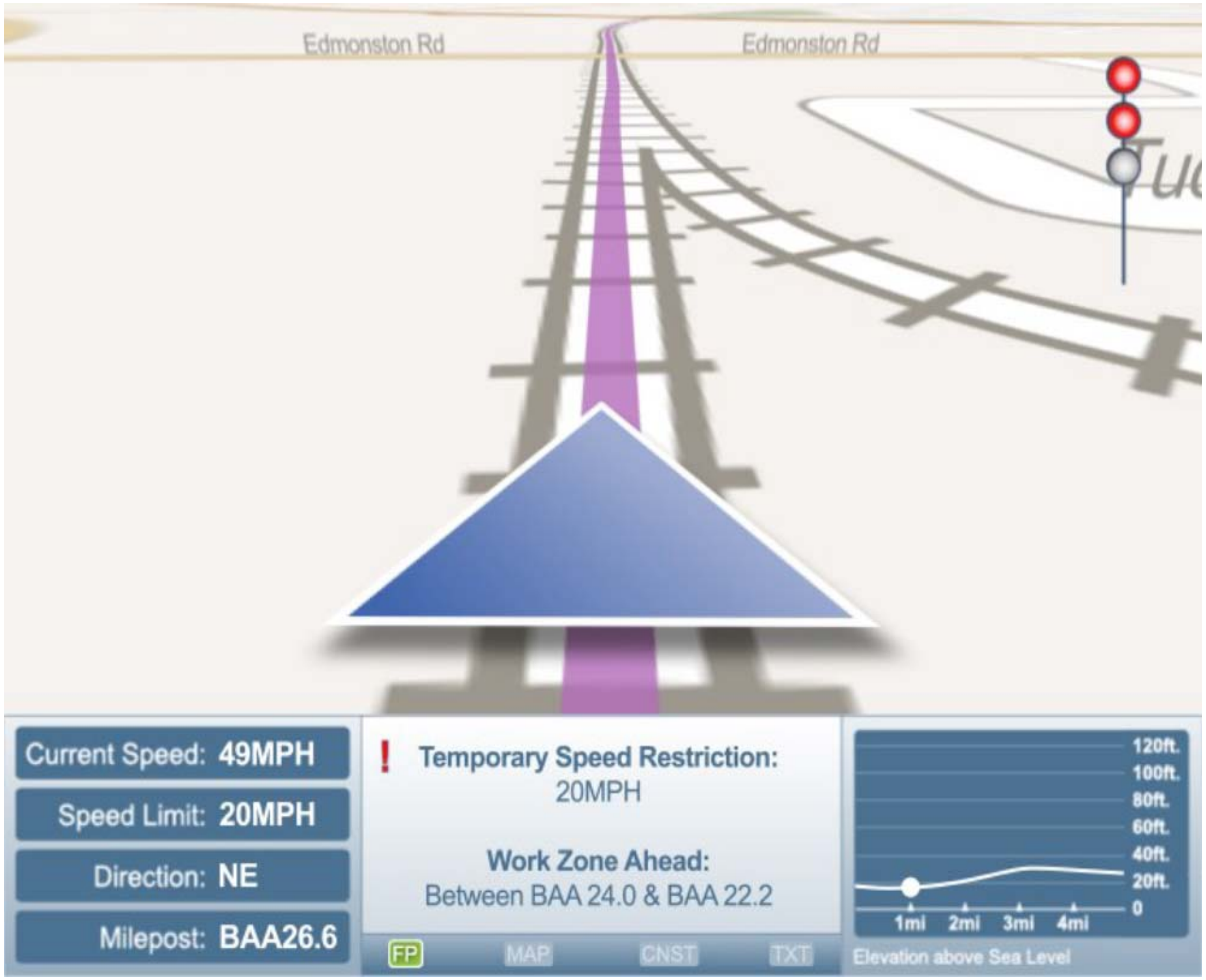
Screen Descriptions

- Front Perspective View (FP)
- Text View (TXT)
- Map View (MAP)
- Consist View (CNST)
- Associated Human Factors Principles
  - **Redundancy gain**
  - **Discriminability**
  - Principle of pictorial realism
  - Principle of multiple resources
  - Replace memory with visual information

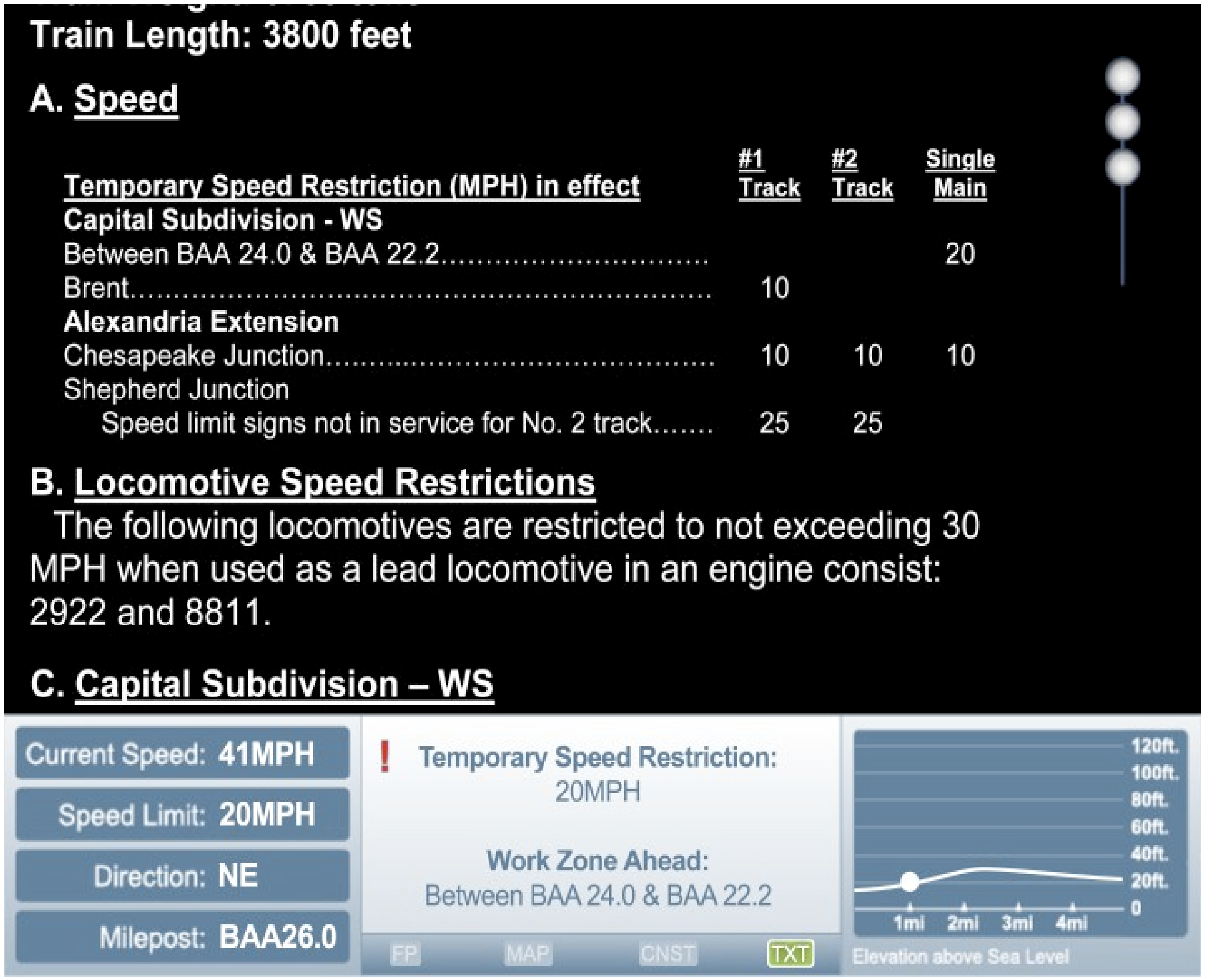
Front Perspective View (FP)

- Principle of Pictorial Realism



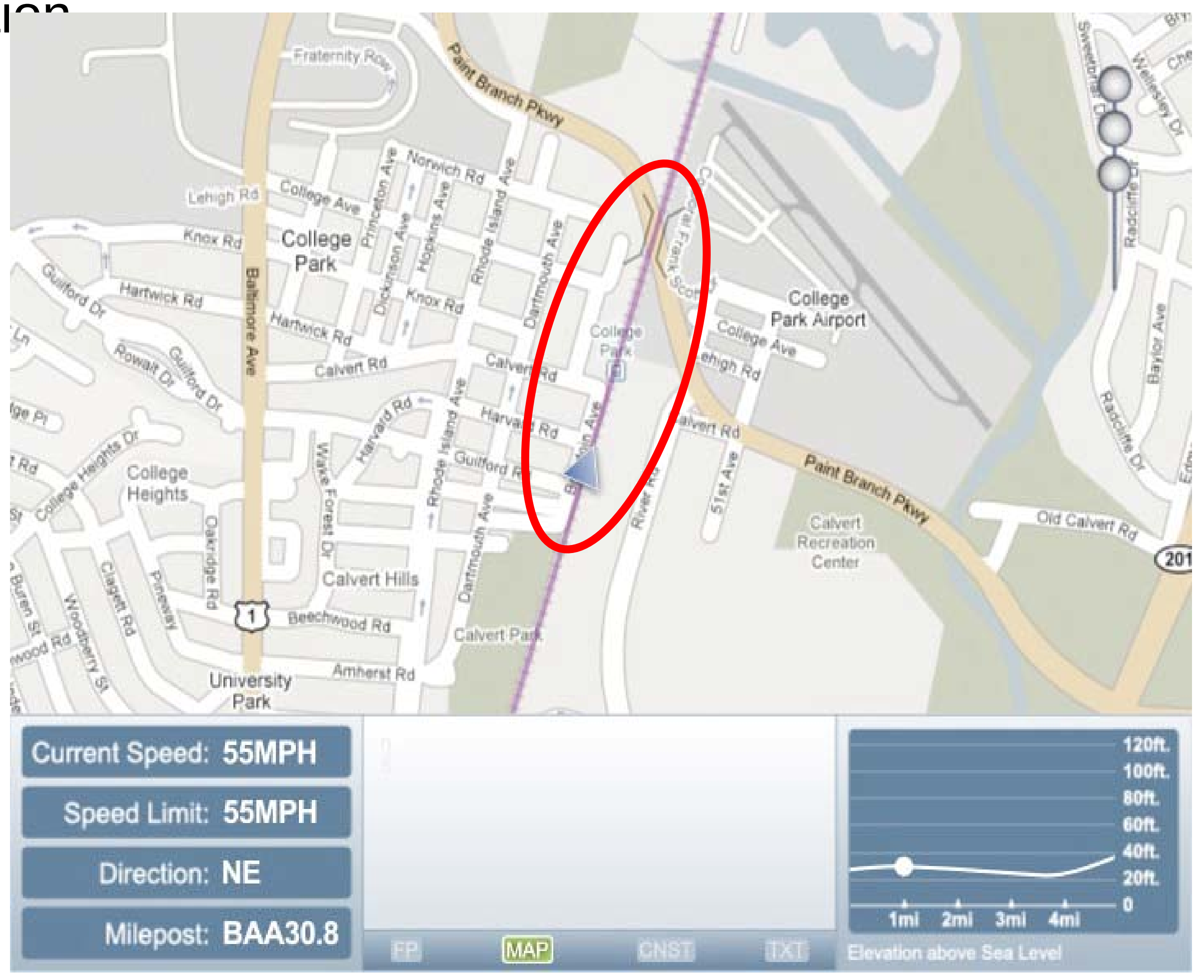
Text View (TXT)

- Principle of multiple resources

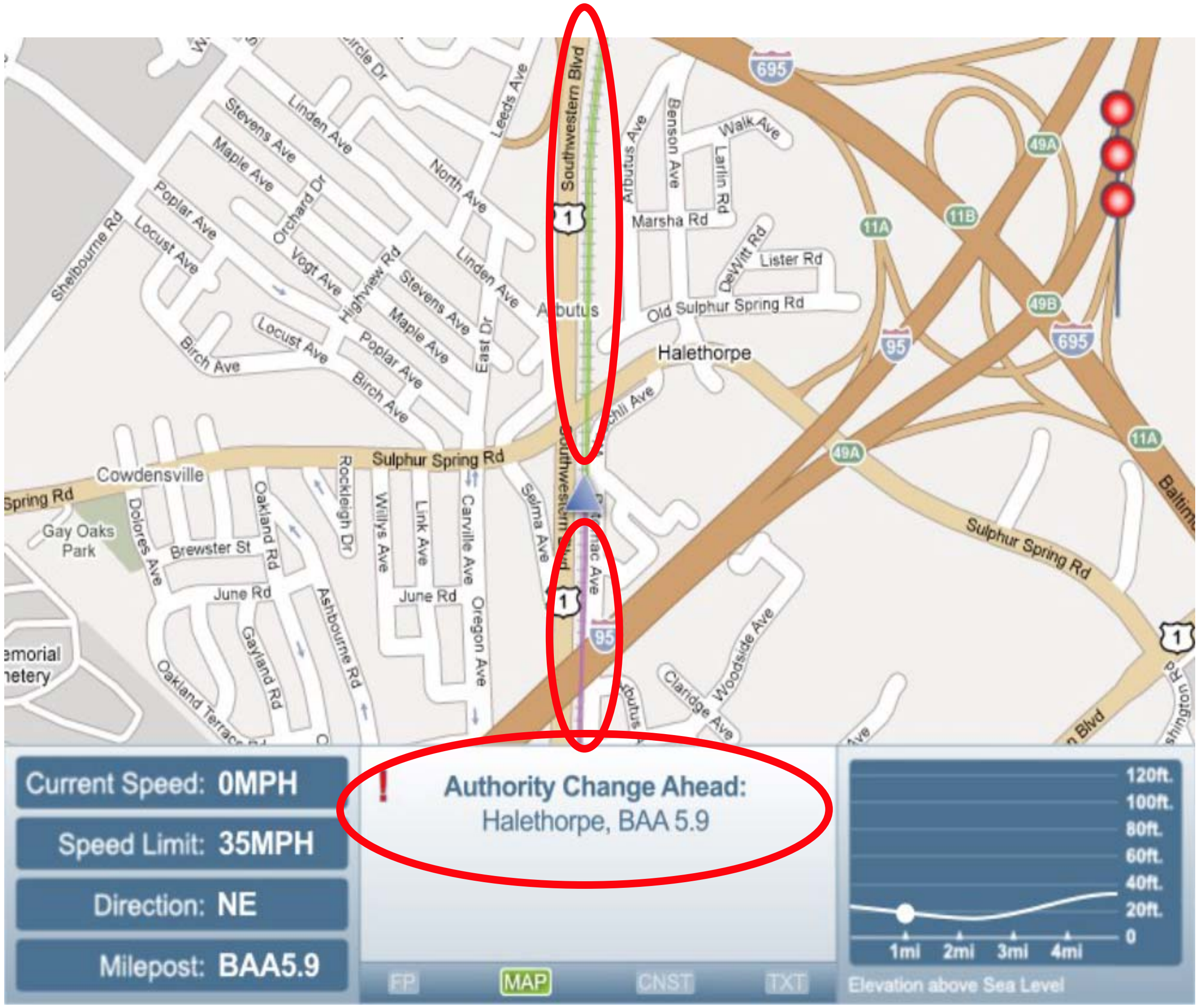


Map View (MAP)

- Replace memory with visual information

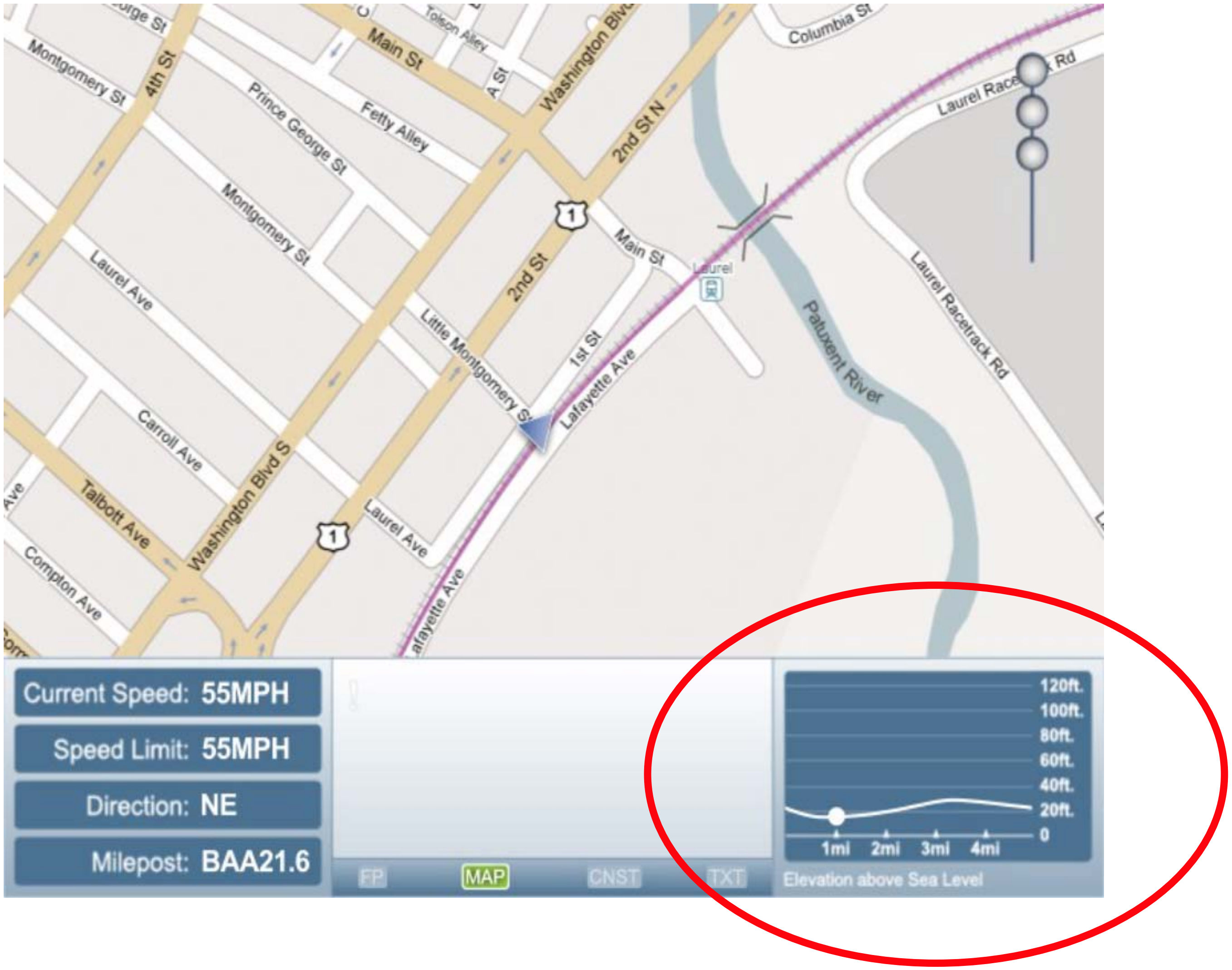


Redundancy Gain



Discriminability

Terrain Grade Screen



Locomotive Moving Map Display Demonstration

Candidates for Additional Research

- Additional Scenarios/Situations
  - Sideouts, crossovers, and meets
  - Yards/Stations
  - Multiple tracks along route
  - Other trains
- Other HFE Principles
  - Multi-sensory displays
  - Placement of the LMMD
  - Illumination concerns
  - Brightness/contrast controls