Human Factors Evaluation of an Experimental Locomotive Crew Station

Matt Isaacs

Operations Research Analyst

Volpe Center

Railway Supply Institute

Rail Expo and

Technical Conference

10-3-16

U.S. Department of Transportation

Federal Railroad Administration

OFFICE OF RESEARCH & DEVELOPMENT

Volpe The National Transportation Systems Center

Advancing transportation innovation for the public good

Cab Technology Integration Lab (CTIL)

- Safe environment for evaluating human performance in rail
- Allows evaluation of displays and controls
- Highly reconfigurable
- Large suite of human factors evaluation tools
- Resource available to all rail stakeholders

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Recent Partners and Projects

- **Veolia Transdev**: Engineer training for reducing distraction
- **MIT**: iPad Moving Map demonstration; partner for Head-up Display Research
- **UMass**: Measuring the effect of moving map displays on detection of safety-critical events
- **General Electric**: Testing a potential future Trip Optimizer version based on recommendations from a hierarchical task model

Volpe intern using AAR-105 control stand

Rationale

- AAR-105 was principally developed before automation and computer displays.
- Adding displays has a limit and risks lowering out-the-window visibility.
- Advances in technology allow for more ergonomic designs.
- Engineers experience vibration and spend extensive time in a seated position.

Crewstation Requirements

- Capability for both seated and standing operation
- Ergonomic improvements
- Reconfigurable controls (to enable future iterations)
- Vibration dampening
- Ability to view and operate displays and controls from 180 degrees of chair rotation
- Enhanced comfort, including adjustability, headrest and footrest

Experimental Crewstation in seated position

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Experimental Crew Station, standing position with arm up

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Left rmrest

Right armrest

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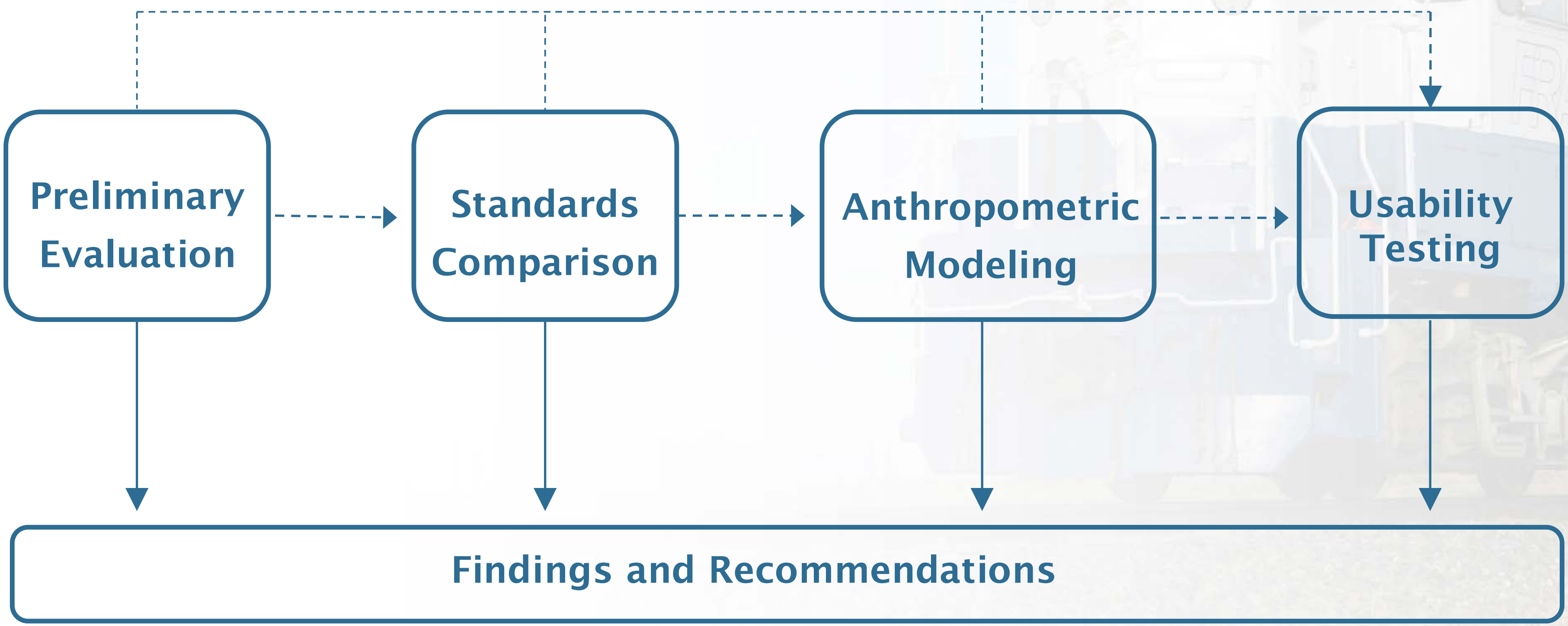
Armrest adjusters

Volpe Center's Role

- Evaluate the Experimental Locomotive Crew Station (ELCS) using the CTIL simulator human factors evaluation processes, making recommendations for improvement and noting areas of cab design that need further research.
- Process took place at the Volpe Center between other CTIL studies, totaling 5 months.



Evaluation Process

Preliminary Evaluation

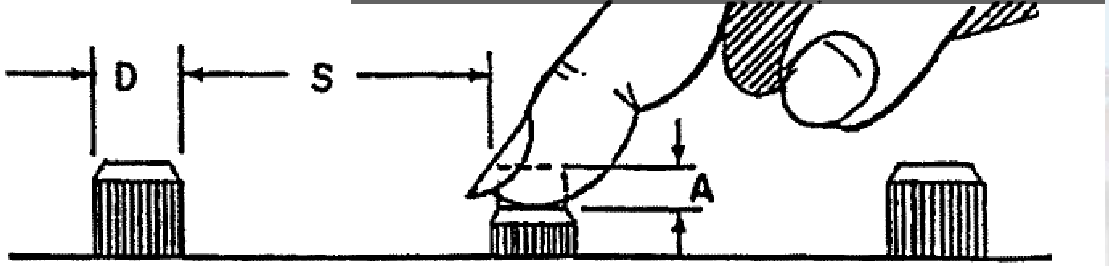
- Intended to (a) gain an understanding of potential problems from a high level, and (b) help focus later activities
- Evaluations made using general usability practices
- Full integration of ELCS into CTIL allowed evaluators to interact with the prototype

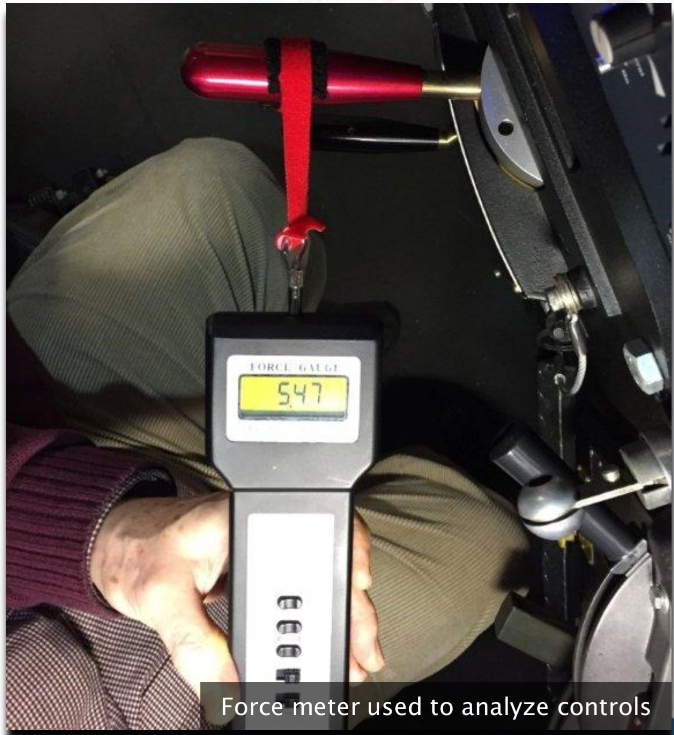
Evaluation Process

Standards Comparison

- Used military human factors standard MIL-STD-1472G (DoD, 2012) to address every feature of the design
- Evaluated both the experimental control station and the AAR-105 to understand the benefits of each design
- Facilitated by installation in CTIL for measuring egress, clearances and heights

MIL-STD-1472G drawings showing critical aspects of buttons





Force meter used to analyze controls

Evaluation Process

Anthropometric Modeling

- Created CAD models of all designs
- Used CTIL's RAMSIS software to model:
  - Clearances
  - Reachability
  - Viewing angles
  - Comfort level of key positions
- RAMSIS provides representative users for virtual testing. Sizes used:
  - 95th percentile male
  - 50th percentile female
  - 50th percentile male

RAMSIS being used in an automotive contexts (human-solutions.com)

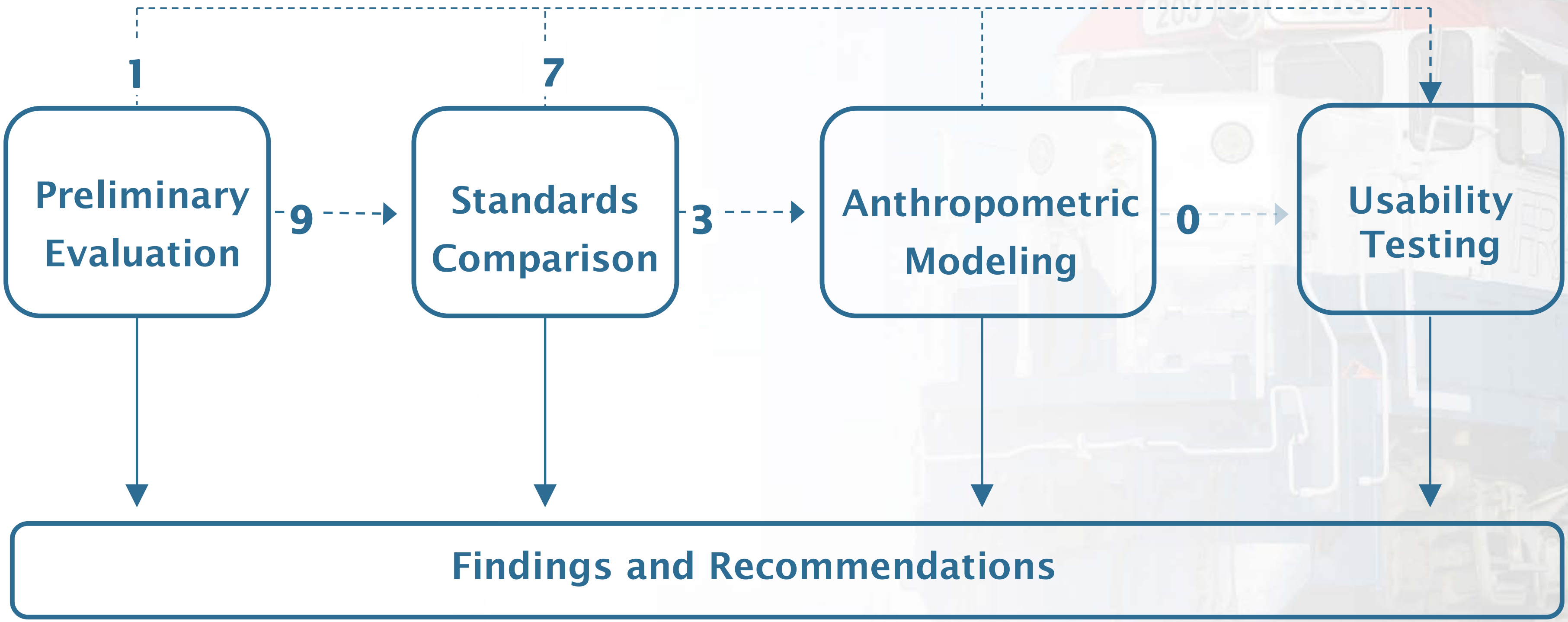
Evaluation Process

Usability Testing

- Put engineers through 7 scenarios in CTIL simulator based on concerns raised in earlier phases
- 4 freight engineers, 4 passenger engineers
- CTIL enabled collection and analysis of quantitative data and recording of user actions and comments
- Usability measured using System Usability Scale (Bangor, Kortum & Miller, 2008)

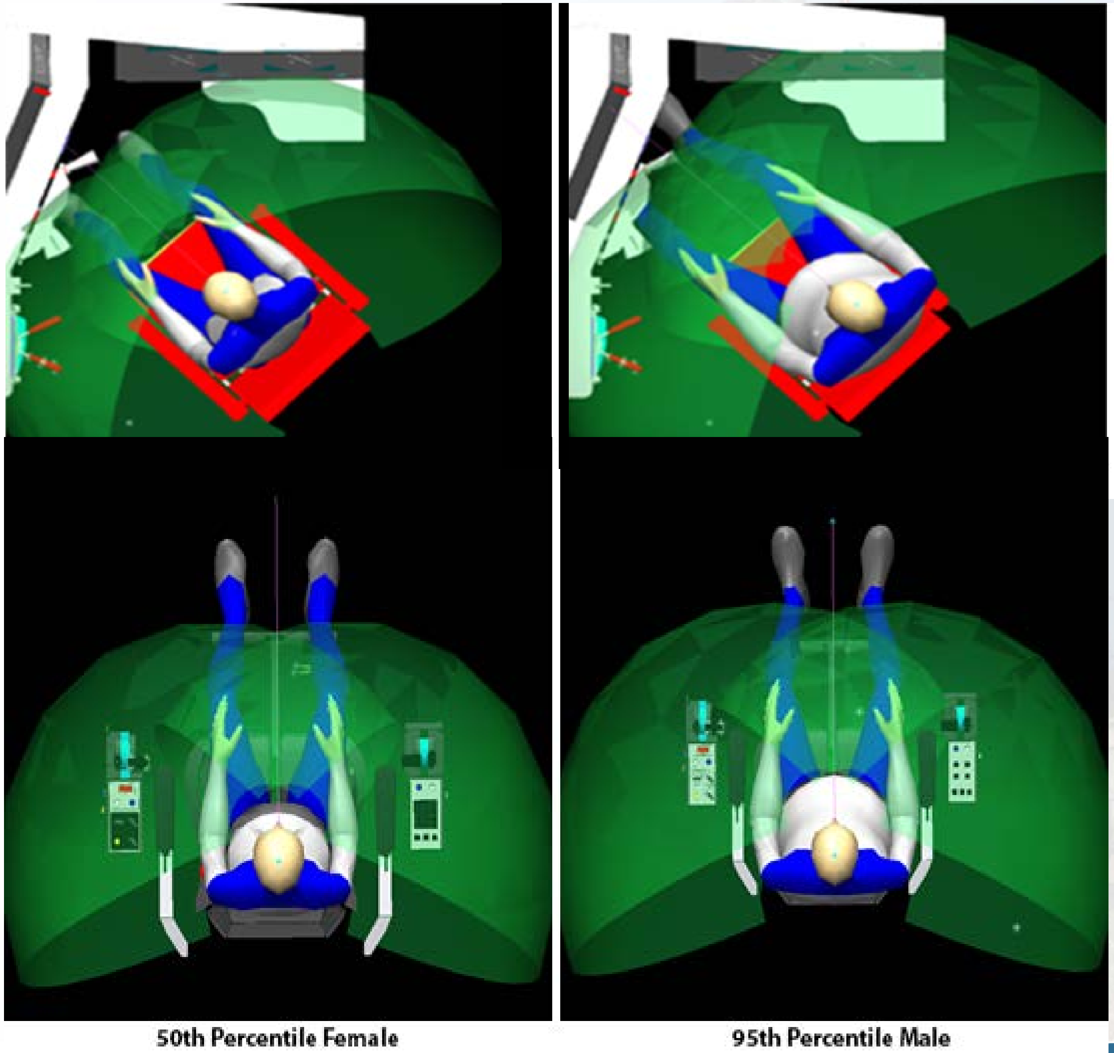

Recreation of a two-handed behavior exhibited by engineers during usability testing

Evaluation Process



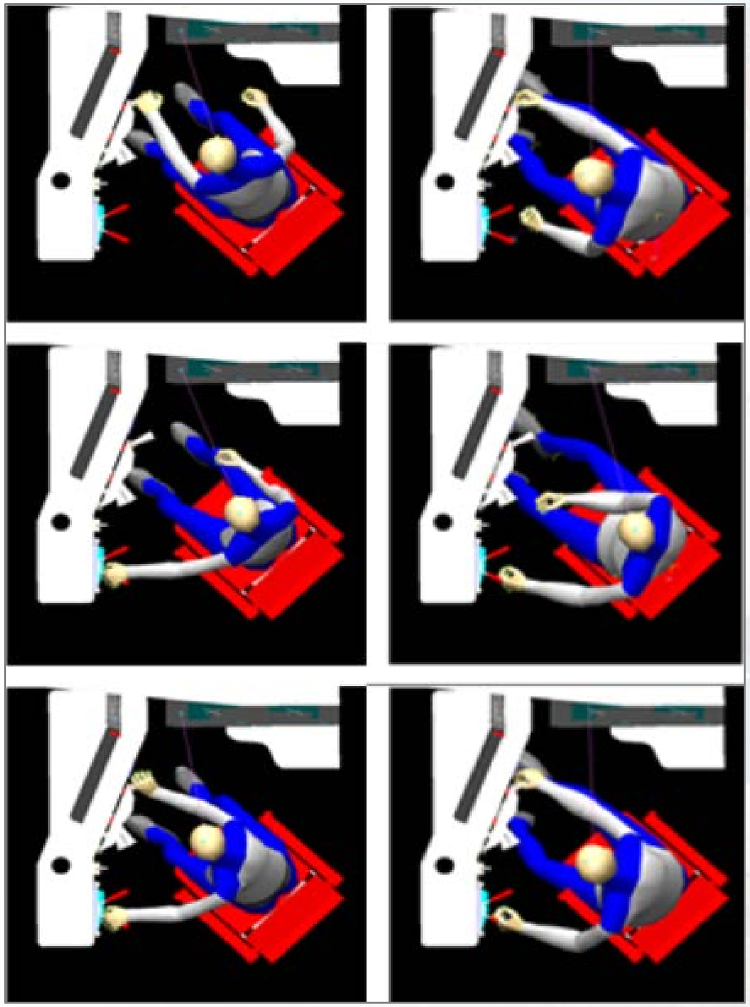
Reachability

- Even with an adjustable chair, most controls are at the edge of reach extents if engineer wants to use back support.
- ELCS places controls well within reach extents for all users



AAR-105: Body Positions

- Controls oriented to user, but not plane of motion
- Two areas of focus for engineer means twisting and reaching.
- Controls require exerting high force far from the body
- Moving seat closer to the throttle means moving away from the automatic brake



Throttle

Automatic Brake

Both

50th Female

95th Male

Comfort Comparison

- “Most comfortable” body positions for each task were measured using RAMSIS Body Discomfort score
- Score based on 1-8; 8 is most *un*comfortable
- Derived from an ergonomics study in which drivers rated discomfort in different areas of the body for different positions (Meulen, 2006)
- Differences greater than 1 considered significant

Discomfort Type	50th Percentile Female		95th Percentile Male	
	AAR-105	Experimental crewstation	AAR-105	Experimental crewstation
Neck	5.1	2.3*	4.6	2.2*
Shoulders	3.5	2*	4	2.3*
Back	2.8	1.7*	2.4	1.8
Buttocks	2.3	1.3*	2.3	1.4
Left Leg	3.5	2.1*	2.7	2
Right Leg	3.5	1.9*	2.4	1.7
Throttle Arm	5.2	1.7*	3.9	2*
Other Arm	2.8	1.9	1.8	2
Overall Discomfort	6.1	3.3*	5.1	3.5*

* Difference greater than 1

Benefits: Usability

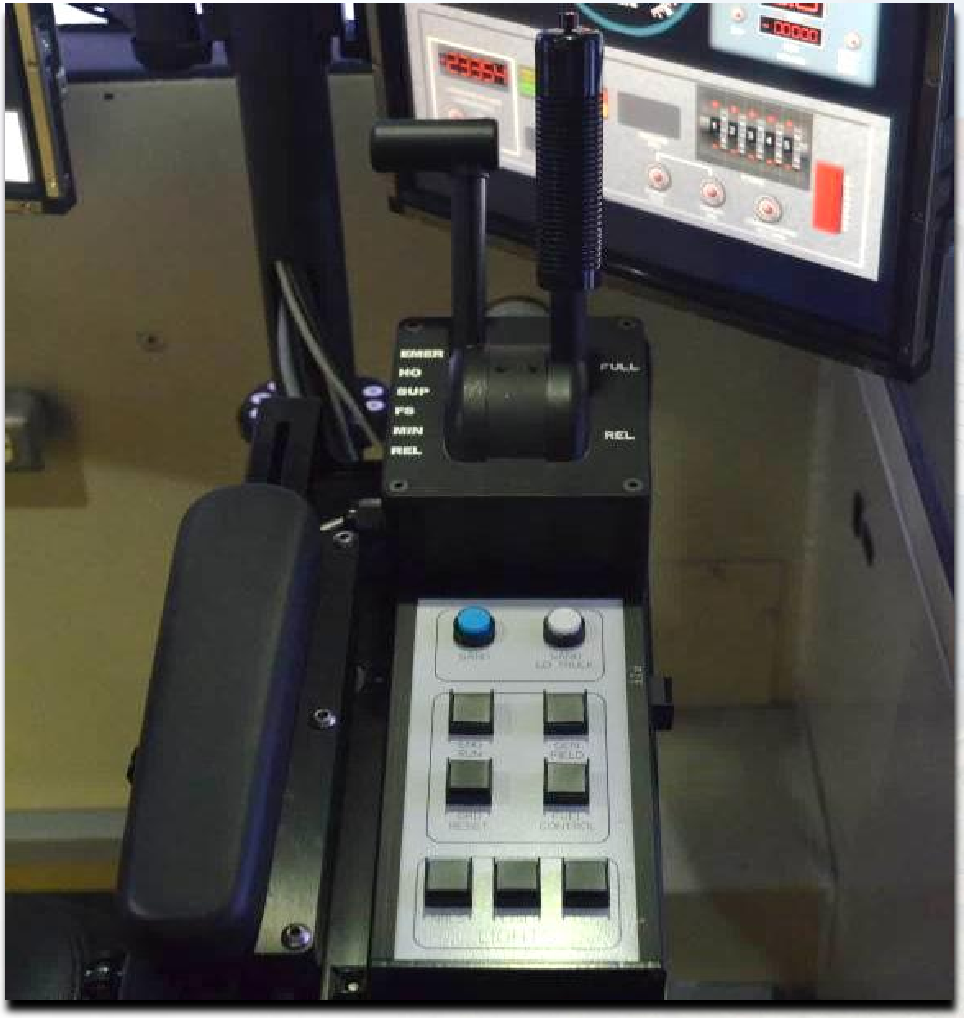
- Rated highly by engineers for usability using the System Usability Scale (mean 83.71, s = 8.8, top quartile)

	Strongly disagree				Strongly agree
1. I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Example Issue 1:Automatic Brake

Preliminary Evaluation

- The detents on the automatic brake are regularly spaced, unlike current brake designs.
- The “service range” appears small:
  - NYAB: 3.28 inches from minimum to release.
  - ECS: 1.76 inches from minimum to release



Example Issue 1:Automatic Brake

Standards Comparison

Design Criteria Regarding Accidental Actuation of Emergency Controls
5.1.1.3.9 Emergency shutoff controls. Emergency shutoff controls shall be accessible, not hidden, located to prevent accidental activation, and positioned within easy reach of the user (see 5.1.1.7 and 5.1.1.8). **5.1.1.8 Prevention of accidental actuation.** **5.1.1.8.1 Location and design.** Controls shall be designed and located so that they are not susceptible to being moved accidentally or inadvertently, particularly critical controls where such operation might cause equipment damage, personnel injury, system performance degradation, or system shutdown of mission critical equipment where a reboot period is necessary to restart the equipment. **5.1.1.10.2 Consistency of use.** A control used for a critical/emergency use function shall be dedicated to that function only. **5.6.3.4 Control of hazardous operations.** The operation of switches or controls which initiate hazardous operations shall require the prior operation of a locking control.

Table: Criteria from MIL-STD-1472G that address accidental actuation of emergency controls

Example Issue 1:Automatic Brake

Usability Test

- Eight engineers were asked to make four automatic braking applications using a non-moving simulated train.

Findings based on usability test performance data for over-braking

Task	Failures	Expected Frequency Based on Probability Matrix
Minimum service application	0 out of 8	Not significant (less than 5%)
Full service application	0 out of 8	Not significant (less than 5%)
15 pound application	4 out of 8	Small minority (greater than 5%)
20 pound application	5 out of 8	Large minority (greater than 20%)

- Comments from engineers echoed this performance:

"I think I had to look down a couple of times. Between the minimum and the full service it just seemed a little short."

"For only going five pounds it seemed you go a very long way. And [now] that's full service…20 pounds in less distance than what you go to minimum."

Example Issue 2: Documents

Preliminary Evaluation

"Where do you put your paperwork?"

Example Issue 2: Documents

Standards Comparison

Design Criteria Regarding Work and Storage Space

5.10.2.8 Storage space. Adequate space shall be provided on consoles or immediate work space for storing manuals, worksheets, and other required materials to include basic operational equipment.

5.10.3.1.2 Work surface. Unless otherwise specified (see 6.2), work surfaces to support documents such as job instruction manuals or worksheets shall be 90 to 93 centimeters (35.4 to 36.6 inches) above the standing surface. If the work surface is being used for locating certain types of controls (joystick, track ball, and keyboards), it shall be 102 to 107 centimeters (40.1 to 42.1 inches) above the standing surface. Care shall be taken, when combining a horizontal workspace and a control panel, to ensure that users will have adequate workspace (minimum of 25 centimeters (9.8 inches) deep) and that they will be able to reach the control panel (maximum of 40 centimeters (15.7 inches) deep).

5.10.3.2.3 Writing surfaces. If consistent with user reach requirements, writing surfaces on equipment consoles shall be not less than 40 centimeters (16 inches) deep and 61 centimeters (24 inches) wide.

Table: Criteria from MIL-STD-1472G that address work and storage space

Example Issue 2: Documents

Usability Test

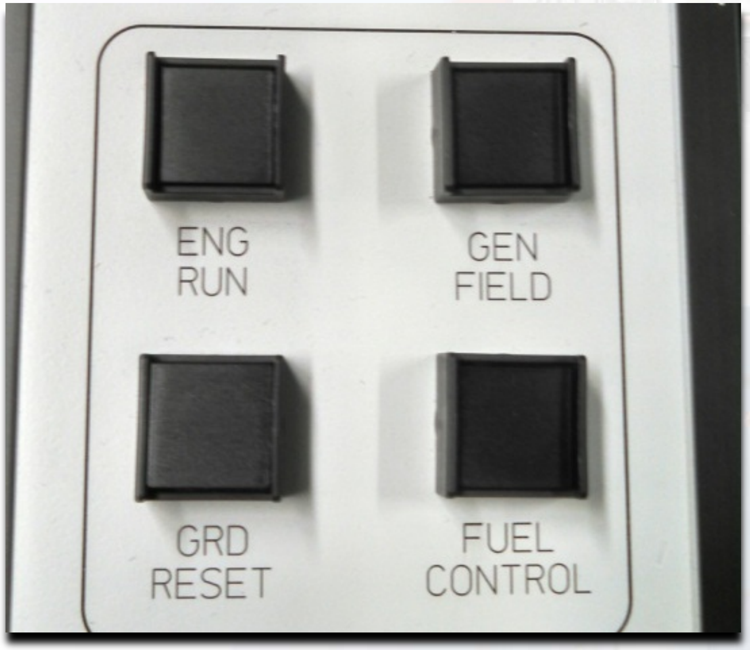
Example storage locations used by engineers included:

- On top of the monitor stand
- Balanced on the monitor stand
- On engineer's lap
- On windowsill

Example Issue 3: Push-buttons

Preliminary Evaluation

Which of these buttons are up? Which are pressed?



Example Issue 3: Push-buttons

Design Evaluation

Which of these buttons are up? Which are pressed?

Example Issue 3: Push-buttons

Usability test

- Test data
  - Engineers were presented with a scenario instructing them to operate the train over a distance of several miles. Before entering the sim, the experimenter set the "fuel control" button to the off position. When the scenario started, the engine cut off.
  - Seven of eight engineers were unable to find the fuel control button was set to "off" position, despite looking directly at the panel in all cases. (corresponds to an expected 50% of user population using binomial probability).
- *Quotes from engineers:*
  - *"On a locomotive, I mean we have an F40, we have a switch, down and up; up is engaged. So your eye would automatically scan that. There's nothing here to scan. It's just a black button."*
  - *"…It's easier with the switches there. You can just visually look at them and see everything is up as opposed to having to check. That I don't totally like, you've got to feel for it. You can't visually see so much what the issue is."*

Example Issue 4: Upward Visibility

Anthropometric Analysis

"Upward visibility shall extend to not less than 15 degrees above the horizontal."

Approximate eye height while using experimental crewstation

Test Case	Approximate Seated Eye-Height Including Chair (in)	Approximate Standing Eye-Height (in)
95th Percentile Male	65.25 - 67.00	69.68
50th Percentile Male	62.68 – 64.43	64.94
50th Percentile Female	60.32 – 62.07	59.69

Degrees of upward visibility using experimental crewstation

Test Case	CTIL Seated	CTIL Standing
95th Percentile Male	0º	0º
50th Percentile Male	1.13º	0º
50th Percentile Female	4.38º	5.25º

Some Other Issues Found

- Vibration Dampening optimized for vertical compression instead of the horizontal directions
- Unsteady display mounts
- Safety harnessing required for standing position
- Not enough adjustment parameters
- Difficult to rotate


~50th percentile female


~90th percentile male

Follow-on Work

- How do different AAR-105 control configurations affect key postures?
- Identify near-term and/or low-cost ergonomics upgrades to current designs.
- Conduct a time motion study to understand control use frequencies in various types of operations.
- Evaluate desktop-style configurations

Awkward wrist position in CTIL's AAR-105 control stand

CTIL as a Tool for Evaluation

In addition to the features described today, CTIL has many other tools which make it extremely useful testing displays, controls and technologies.

- Eye tracking with surface detection
- Live data for powering displays
- Head-Up Display projection
- Synchronization of data with audio and video
- GE Trip Optimizer
- I-ETMS Positive Train Control

Contact Program Manager Mike Jones for more information:

michael.e.jones@dot.gov