THE CAB TECHNOLOGY INTEGRATION LAB: A LOCOMOTIVE SIMULATOR FOR HUMAN FACTORS RESEARCH

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The paper describes a new human factors research capability for the US Federal Railroad Administration (FRA) --- The Cab Technology Integration Laboratory (CTIL). The FRA sponsored the development of the CTIL in order to assess locomotive crew performance with the integration of new market controls, displays, and automation in the locomotive cab environment. Additionally, the CTIL will be used to assess and demonstrate new technologies and workstation configurations that may enhance human performance and human reliability by increasing the locomotive engineer's capabilities to communicate, plan, and control locomotives within the railroad system. The CTIL provides a platform for integration and prototyping of new locomotive cab technologies to assess the impact of the human-machine interface on locomotive crew performance as new capabilities are mandated to meet safety, cost, and security requirements.

INTRODUCTION

The Federal Railroad Administration (FRA) has developed a new capability called the Cab Technology Integration Laboratory (CTIL). The CTIL provides a platform for prototyping the human-machine interface of new locomotive cab technologies to assess their integration and impact on crew performance. As new capabilities emerge in the market place or are mandated to meet safety, cost, and security requirements, the CTIL can help to identify and mitigate risks and costs of technology integration in the locomotive cab by addressing risks associated with human performance.

Without such a resource, it is likely that the current pace of ad hoc development and installation of sensors, information processing, automation, and control/display technologies will continue. Ad hoc, or add-on approaches will prove costly in the long-term and put public safety at risk in the short term because of the increased risk of human error in operating such systems. Experience in other transportation domains strongly indicates that the costs of inadequate human systems integration can be significant.

Operationally, CTIL is predicated on a broad-based collaboration with industry, university, and government scientific and technical resources in railroad and non-railroad domains (e.g., aerospace and the military). The operations concept for the laboratory will make it readily available to a widely dispersed science and technology (S&T) community. The intent is to engage the broadest possible collection of the Nation's S&T resources in support of improvements in safety, security, and productivity of the railroad industry.

The CTIL is new and unique in the railroad domain, but draws upon features and capabilities that are well-established in aerospace and related domains. The laboratory can be readily relocated to gain access to industry resources, and is easily accessible to industry, university, and government researchers in support of a wide variety of programs.

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OBJECTIVES

The CTIL is a government owned research resource. The primary mission of the CTIL system is to support the FRA's ongoing research, development, test and evaluation (RDT&E) in human-system integration (HSI) and related human factors. First and foremost, then, CTIL is designed as a human factors research tool, capable of conducting research projects that capture data with the degree of fidelity that meet standard experimental designs for human factors research. The primary objectives in developing the CTIL are described below.

Objective 1: Methodology for Safety Assessments

Human factors specialists of the FRA are at times called upon by the FRA’s Office of Safety to provide informed assessments of safety implications for proposed rule changes, introduction of new technologies, and other matters that entail human factors. Experience in other transportation modalities indicates that careful, deliberate assessment of new technologies is required to address any potential risks before implementation. The CTIL is a tool to facilitate safety assessments where human perfroamnce is concerned.

Objective 2: Technology Assessments Related to Human Performance

One aspect of FRA's statutory responsibilities concerns promotion of America's railroad industry, by facilitating identification and introduction of new technologies that offer potential for improved efficiencies, or enhanced safety. In many cases, technologies are identified by the railroad industry, and proposed for introduction into rail operations. In other cases, promising technologies may be identified in other transportation modalities, or in other domains entirely, such as aerospace or defense. Some technologies directly impact human operators and human systems integration. CTIL will be employed in research projects to identify and evaluate new control, display, and information technologies in furtherance of the FRA's safety mission.

Objective 3: Identification of Roles and Functions for Automation

In addition to the obvious hardware and software technologies, such as new controls, displays, computer devices, and decision aids, it is highly likely that new automation technologies will begin to emerge that have potential application to the locomotive. Critical to the appropriate use of automation is the human-system interface, in which indicators of automatic system modes, status, and, in some cases, recent history, may be required to ensure adequate human oversight. The CTIL provides a robust environment for assessing the impacts of new cab automation technologies on crew and system performance.

Objective 4: Demonstration of Technological Innovations

In addition to its regulatory and safety roles, FRA is responsible for outreach to both the railroad industry and to the general public, to educate those audiences on emerging railroad operations issues, especially as may affect safety, but also as may affect capacity and efficiencies/costs. Introduction of new technologies that are motivated by desire for enhanced capacity and productivity, but which may also impact safety represent areas for prompt concern. Pursuant to this obligation, CTIL is a tool for demonstrating technology, concepts, and methodologies to the interested public and to the railroad industry.

Objective 5: Methodology for Assessing Efficiency, Capacity, and Operational Performance

Although safety is the FRA's highest priority, safety is rarely if ever decoupled entirely from efficiency, capacity, and operational efficiency. In order for potential safety improvements to be accepted and widely implemented, they must be shown to demonstrate minimal negative impacts or actual cost benefits on general operational performance, efficiency, and capacity. CTIL research studies will be conducted so that the impact on operational performance, efficiency, and capacity can be easily assessed.

GENERAL DESCRIPTION OF THE CTIL

The CTIL provides a faithful representation of parts of the railroad system, such as physical layout of a locomotive cab, the functional behavior of the train, and interfaces with the larger railroad system, such as Dispatcher functions. The features are represented with sufficient fidelity to achieve credible results in controlled experimentation typical of human factors research laboratories. The major elements of the CTIL are the Alion TS-2™ simulator, an AAR 105 control stand and Integrated Cab Displays, the Researcher Control Station (RCS) and a suite of video and audio sensors for capturing crew behavior. Figure 1 shows the cab shell and RCS, and Figure 2 shows the control stand.

Alion TS-2™ Simulator

The CTIL is based on an Alion TS-2™ simulator which is a high fidelity locomotive and track simulator that includes visual, audio, and display, and control characteristics of locomotive operation. It does not include motion simulation. It has been modified to provide access to simulator states and control inputs to support human factor studies.

Figure 1 CTIL Cab Shell and Researcher Control Stand


Figure 2 CTIL Interior and with AAR 105 Control Station

Cab Interior

The interior of the CTIL is a cab replica of a current SD70MAC locomotive provided with an AAR 105 control stand and Integrated Cab Displays currently used in the industry providing a realistic cab interior. Environmental conditioning is included along with high fidelity sound reproduction capable of reproducing typical sounds found in a normal locomotive operating environment such as locomotive engine sounds, train whistles, and grade-crossing bells.

Out-The-Window Views

The CTIL includes the capability to present computer generated visual displays of Out-The-Window (OTW) scenes, including interactive objects, such as vehicles crossing tracks, highways that run parallel to tracks, cityscapes, and countryside scenes. The scenes are geo-typical, meaning that they incorporate imagery similar to actual locations, together with simulated objects and entities. Field of view (FOV) of the OTW scene is sufficient to encompass continuous forward and side views from a single operator station within the locomotive cab. Figure 3 shows a typical OTW view from within the cab.

Figure 3 Out-The-Window views from within the cab

The CTIL includes the capability to easily build track miles, author a scenario by assembling items from a scenario library, and connecting visual objects to either scripts, or to intelligent models, to provide interactive actor agents in a scenario. The baseline configuration includes 50 pre-built, interactive track miles of scene generation.

Researcher Control Station

The Researcher Control Station (RCS) houses most of the system computers, the Input/Output (I/O) instrumentation for both the simulator and the human performance data capture capabilities, and all of the software for experimental design, control, analysis, and reporting using the CTIL. In addition, a suite of human performance modeling tools tailored for analysis of locomotive operations is included as part of the RCS.

Video and Audio Capture

The CTIL cab is instrumented with:

- Front and rear stationary cameras that can be placed in a variety of locations with the cab interior
- Two pan-tilt-zoom cameras that can be placed in a variety of locations within the cab
- Audio recording channels for ambient cab sound, two lavaliere microphones, and the cab-experimenter control station intercom
- A head and eye tracking system provide by Applied Science Laboratories (ASL)

This equipment and the data capture by them are controlled by and integrated using the Noldous Observer XT software. Synchronization with the simulator is also done using the Observer XT.

Re-configurability

CTIL is to be designed as a reconfigurable research simulator, packaged as separable modules. The modules include a reconfigurable locomotive cab, with physical controls and general layout consistent with typical freight and passenger locomotives, and a separate researcher operator's control and workstation capability. The locomotive cab is capable of being configured to represent all critical locomotive controls, together with in-cab and out-the-window visual and aural stimuli as well as accommodation of new control/display/automation technologies. The CTIL has incorporated provisions in hardware and software for connection to systems, components, and equipment provided by third-parties that conform to appropriate established industry and commercial standards. The system is designed to permit future growth in capability and in fidelity without major redesign.

Transportability

The CTIL can be readily packaged and transported to industry or public venues, as well as to university or government laboratories for technology demonstration or research purposes. The CTIL is configured to facilitate convenient shipment by commercial common carrier of the entire laboratory system. Packing and shipping can be accomplished within a day. The CTIL has wheels to enable it to be pushed or towed over a smooth level surface. The Researcher Control Station rolls into a custom-built crate that fitted with wheels and movable with a forklift. The system is built to moved with minimum disconnect of cables and custom configured heavy duty cases for devices not secured within the cab or station.

ARCHITECTURE

Figure 4 shows a simplified view of the computers in the CTIL. There are three computers internal to the cab. The CTIL-IO computer provides hardware inputs and reports the control positions of all operational controls in the cab back to the simulator engine in the SIMHOST. The CTIL-ICD computer controls the integrated functional display panels in the Cab. The POLYWELL computer runs the computer generated image engine for the simulator and displays the outside view in each of the 4 large format train window displays. In addition, it presents all the ambient sound in the cab over the surround sound system. All displays are presented based on instructions from the SIMHOST computer.

There are five computers housed in various portions of the Researcher Control Station -- the SIMHOST, OBSERVER, ASL, LAPTOP, and SERVER. The SIMHOST computer hosts the simulator engine and completes all the functions required to control the simulator including:

- Track, train, and other object editing tools
- The scenario builder for creating situations and conditions to be applied in the simulator
- Simulator control software providing static and dynamic changes to scenarios and conditions in the virtual environment during operation
- Collection and distribution of simulation related variables to the data collection computer.

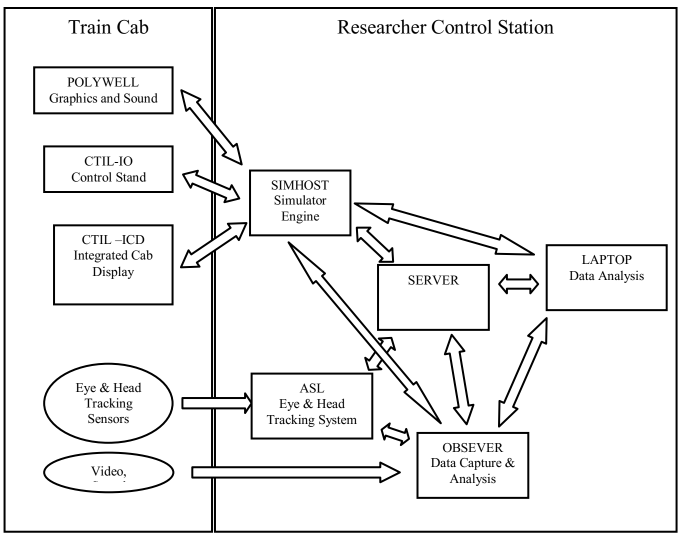

Figure 4 CTIL Architecture

The SIMHOST computer sends display outputs and receives control inputs from the CTIL-IO computer and display outputs to the CTIL-IFD computer. The SIMHOST computer also sends the location and other information to the POLYWELL computer needed to render the visual scene and provide sounds. In addition, a copy of Microsoft Office Suite is included on the SIMHOST.

The OBSERVER computer primarily runs the Noldous Observer XT 9.0 data collection software. During data collection this computer captures video feeds from 4 in-cab video cameras as well as wireless microphones and audio feeds from the communication system. In addition, the data from the eye tracker system, experimenter notes, operator questionnaire inputs and any other data being generated or coded is collected in real time.

After a run is complete the recorded simulator data is imported and included in the observer data file. The rate of data collection is predicted to be approximately 10GB per hour including the video and other data. To synchronize the simulator data and the eye tracking data, the Observer software sends a signal to both the SIMHOST and ASL computers at the start of data collection that is recorded in their data files. The Observer software uses this marker to synchronize the playback of the data capture session.

The ASL computer includes all of the software for the control of the eye-head tracking sensors, capture and integration of the eye gaze data, and eye gaze analysis tools.

The LAPTOP computer houses the rest of the human factors research software tools.

The SERVER has over 1 terabyte of storage capacity and allows storage of data from any of the other computers and applications. It also has a Blue-Ray disc writer to allow for backup storage to disc. It also has SQL Server installed.

HUMAN FACTORS RESEARCH TOOLS

Scenario Authoring

The CTIL includes provision for generating, saving, editing, and otherwise authoring experimental scenarios. This capability includes selection of geographical locale, visual and auditory presentations, interaction with the railroad system, including dispatchers, work crews, and other organizational elements. A dynamic time base applied to both conditional and distance-based triggers allows for a realistic flow of events to be experienced for each user of the system. This method allows for differing acceleration rates, top speeds, and many other factors that affect the overall timing of a scenario. The Scenario Authoring tools also supports definition of the train consist. The train consist is made up of the locomotives and cars, and is created as part of scenario authoring. Characteristics for the entire train can be defined, as well as the specifics for each car and locomotive in the consist.

Locomotive Performance Data Capture

Various locomotive performance evaluation criteria can be defined, monitored, and reported during or after the simulation run. These criteria consist of in-train forces, short time ratings, time limits, ammeter values, brake pressures, locomotive brakes, heavy brake reductions, running release, power braking, using air brakes before dynamic brakes, and cycle braking. The throttle position, the state of the brake system, train speed, and the automatic brake reduction may also be monitored. Performance parameters include disallowed braking, brake reduction, dynamic brake, excessive speed, average speed, throttle range, elapsed time, buff forces, draft forces, run-in forces, and run-out forces.

Noldus Observer 9.0 XT

The Observer software provides robust data capture and analysis capabilities. It supports several functions for data collection including:

- Setup and structuring of data capture and coding schemes
- Set up and control of the Noldous Subject Questionnaire Tool
- Real time annotation of the coding schemes during experimental runs

- Control of all video and audio inputs
- Integration and synchronization of both the eye-tracking and locomotive simulator data streams
- Automatically collecting and combining all data into an observational datasets for a simulator run

For analysis, the Observer provides the ability to score and insert events in the dataset after collection has been completed based on any timestamp or video observation. Virtually any experimental design is supported by tools in The Observer software which allow for definition of independent variables, separation of time periods and a user defined coding structure. The Observer XT 9.0 provides a set of data visualization tools and calculates a full range of descriptive statistics. For more advanced analysis observed results can be exported for use in Statistica (included) or other tools such as SAS, SPSS, Matlab, Minitab or MS Excel.

Applied Science Laboratories Head and Eye Tracking System

The Applied Science Laboratories (ASL) head and eye tracking system enables complete capability to identify, record, and analyze the location of engineer eye gaze. Eye gaze can be captured and overlaid onto a “scene” view from another camera (usually behind the engineer) or it can be overlaid onto a head mounted camera. The Noldous Observer software time-synchronizes the data capture and integrates the outputs of the ASL system with the other data streams.

Post-Run Analyzer

The Post-Run Analyzer software evaluates the performance of an operator on a run relative to standards set for that scenario. It allows for visualization of locomotive and engineer performance based on track, consist, and locomotive state.

Statistica

Statistica is a general purpose statistical software package that provides a full range of statistical analysis capabilities.

RAMSIS

RAMSIS is a human figure anthropometric modeling tool. It allows the manipulation and animation of human manikins in a 3D computer aided design representation of the cab. This is useful for evaluation of control and display positions, visual angles and other ergonomic considerations. It includes anthropometric manikin sizing for the US population, guidance and standards for seated operator cockpit design, and the ability to import of CAD drawings from a variety of third party tools.

LOCAT

The Locomotive Analysis Tool (LOCAT) is a human performance modeling tool and model representing and analyzing both physical and cognitive Engineer activities. LOCAT is a discrete event simulation software tool tailored to locomotive operations. LOCAT includes a number of control and display formats and can be used to calculate workload, situational awareness, task completion times, response time to alerts and other human performance factors of interest.

RESEARCH PRIORITES

The US Congress has mandated use of Positive Train Control (PTC) systems on passenger main-line and hazardous materials carrying routes by 2015. The FRA plans to begin research with the CTIL to address several questions related to locomotive crew performance and PTC including:

- What critical information should be easily accessible to the locomotive crew, in what forms and where?
- What is the adequacy of existing rail domain crew display standards or guidelines in relation to PTC?
- What is the usefulness and best design of track profile displays, (i.e., moving-map included in PTCs?
- How should current in-cab operating policies and procedures be adapted to take advantage of PTC capabilities while sustaining current safety levels?

Additional early priorities include establishing human performance baseline data for CTIL operation and investigations of crew performance.

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