Moving Map Displays: Using CTIL and Eye Tracking Technologies to Measure Operator Glance Durations and Performance in

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ABSTRACT

Background: Distraction is a growing problem in the cabs of modern locomotives. The 2008 commuter train collision at Chatsworth, CA resulting in 28 fatalities, points to the dangers of distractions inside the cab. In that case the NTSB investigation determined the operator was texting while in control of the train, and failed to stop the train movement behind a red signal. Distractions are not the only problem that interferes with an operator's ability to detect safety critical events such as a signal malfunction or a trespasser on or near the tracks. New technologies such as Positive Train Control (PTC) can potentially help reduce the impact of workload and distractions on locomotive engineers. While the Federal Rail Safety Improvement Act of 2008 originally mandated PTC implementation on US railroads.[1] by December 2015, this system will not be mandated for another five years due to an extension granted by Congress. However, a specific feature of the PTC system is rapidly becoming an important part of the rail interface, the moving map display. Moving map displays are electronic maps that provide locomotive engineers with dynamic updates as the train moves along a track (similar to a GPS). The electronic moving maps contain all the information that can now be found on the paper track charts. **Objective:** This study aims to determine if locomotive engineers using an electronic moving map display will be less distracted in general and detect more safety critical events in particular than locomotive engineers using the current paper map charts. **Methods:** Sixteen locomotive engineers from Keolis Commuter Services volunteered and were randomly assigned to one of two cohorts (moving map display or paper map display). Each participant completed two 39-mile trips, programmed as automated interactive scenarios and displayed within the CTIL from Aurora to Chicago while wearing a head mounted eye-tracker. Safety critical events appeared throughout the simulated trip. **Dependent Variables:** Our measures included train control performance, rule compliance, track bulletin performance, unplanned event performance, gaze duration and location inside the cab, and gaze location outside the cab. **Results:** The number of safety critical events detected by the locomotive engineers in the Moving Map Display was significantly greater than this number in the Paper Display. All participants were used in this analysis. Based on eye tracking data we were able to determine that engineers using the Moving Map Display had over 61% more especially long glances inside the cab (defined as glances over 2 seconds) compared to engineers using the Paper Display and spent over 64% more time glancing inside the cab for longer than 2 seconds than did engineers using the Paper Display. Especially long glances inside the cab greatly reduce the time that an engineer has available to respond appropriately (e.g.: emergency brake application or required radio notification) should a safety critical event appear on the track. The analysis of the glance durations was based on only two of the 16 locomotive engineers, perhaps explaining the discrepant results between the direct measure of safety critical event detection and the indirect measure (glances inside the cab).

KEYWORDS

Railroad, Railroad Safety, Distraction, Rail Simulation, Moving Map Displays, Positive Train Control, CTIL, Eye Tracking, Attention Maintenance, Situation Awareness

INTRODUCTION

Distraction is a growing problem in the cab of locomotives. The Chatsworth crash of 2008 points all too clearly to the dangers of distraction inside the cab, texting in this case (Archibold 2008). While many distracting activities associated with personal electronic devices can be banned, there are good reasons to consider introducing new locomotive cab technologies such as Positive Train Control (PTC). While they have obvious safety benefits associated with their introduction there may be some unintended side effects on distraction inside the cab of a locomotive similar to those seen with personal electronic devices in the cabin of an automobile. In particular, if locomotive engineers spend more time glancing inside the cab with PTC technologies installed, the likelihood that the engineer misses a safety-critical wayside visual cue such as a trespasser or a vehicle in the row increases dramatically. Reaction time is of the essence here. Although the locomotive engineer may not be able to stop the train in time to avoid a crash with a vehicle, the sooner they are able to initiate an audible warning by sounding the whistle, the more time the pedestrian or motorist will have to move out of the way.

Figure 1. *Prototype of Moving Map Display with input window displayed*

While PTC systems are still not fully implemented across the rail network, a feature of such systems, the Moving Map Display, is becoming an important part of the rail interface as engineers become accustomed to having it (Figure 1). Because moving maps can provide information about the relative location of signals, gradients and curvature over the entire length of the route, and for several miles in advance of the train position, it has been hypothesized that they would lead to an increase in the situation awareness of engineers, improving their performance thereby. In fact, a previous study that supplied locomotive engineers with preview information indicated that the locomotive engineers responded favorably to such preview information (Einhorn, Sheridan & Multer, 2005). However, there are also anecdotal concerns that engineers may be spending too much time looking at the moving map displays and not enough time looking out the window. Therefore, it is not entirely clear how moving map displays would affect the performance of locomotive engineers during safety critical events.

Thus, a pilot study was undertaken on the Cab Technology Integration Laboratory (CTIL) at the John A. Volpe National Transportation Systems Center to determine the difference between engineers' performance with a combined moving map and paper chart display.[2] vs. only a paper chart display (Melnik, Rosenhand and Isaacs, 2013). Seven participants, none who were trained locomotive engineers, were asked to drive 13 miles of virtual track on the CTIL (Figure 2). Interestingly, the average time that the surrogate locomotive engineers spent operating over the speed limit was less in the combined paper chart and moving map condition than it was in the paper chart only condition. Moreover, the average velocity while operating over the speed limit was almost identical in the two conditions. In short, train performance improved with the moving map.

Figure 2. CTIL. (View out front four windows. Fish eye view is used to present full 180 degrees.)

Thus, the next obvious step was to use real engineers in a study to determine whether the effects of distraction could be quantified. One of the ways to quantify the level of distraction would be to introduce events on the forward track that could only be mitigated if the locomotive engineer were looking up (and

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Paper charts are railroad engineering track profiles that correlate railroad right-of-way milepost locations with physical characteristics relative to rail gradient, curvature, wayside signals & appliances, track switches, stations, highway-rail grade crossings, bridges, terminals, etc not down inside the cab). These events, what we will call *safety critical events*, are defined here both as events which are planned (e.g., permanent speed restrictions) and events, which are unplanned (e.g., a vehicle on or near the tracks).

Given that it appears moving maps increase the safe operating envelope of the train (Melnik, Rosenhand and Isaacs, 2013) and that distraction can be quantified, it remains to be seen whether moving maps will lead to fewer missed safety critical events than paper maps. There are two ways to measure distraction inside the cab. The first is to use the detection of safety critical events as a proxy for distraction. The second is to use an eye-tracker to determine the frequency of especially long glances inside the cab (glances over two seconds) and the proportion of time spent looking inside that is over two seconds for both the moving map and paper map. The threshold of two seconds is the one used in driving an automobile (Klauer et al., 2006). The driver of an automobile can take evasive actions which can remediate a crash given the glances are under the two second threshold. The engineer in a locomotive cannot take evasive actions, but can sound a warning that could prevent a crash by giving a pedestrian or driver of a vehicle time to get out of the way.

METHODOLOGY

In brief, the CTIL was used to present engineers with safety critical events during two separate trips from Aurora to Chicago (the difference in the trips is the location of the safety critical events). Eye movements of the locomotive engineers were monitored throughout.

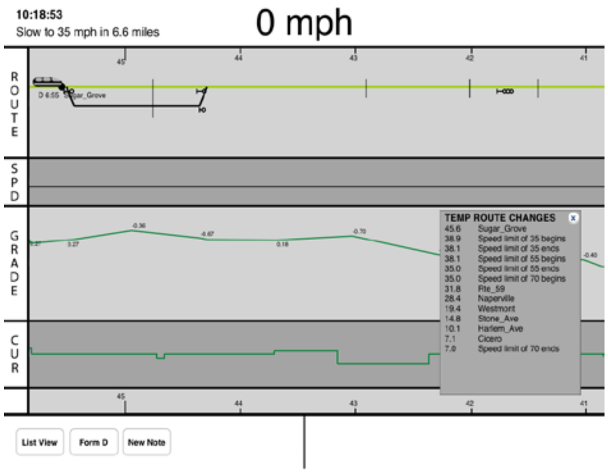
Participants

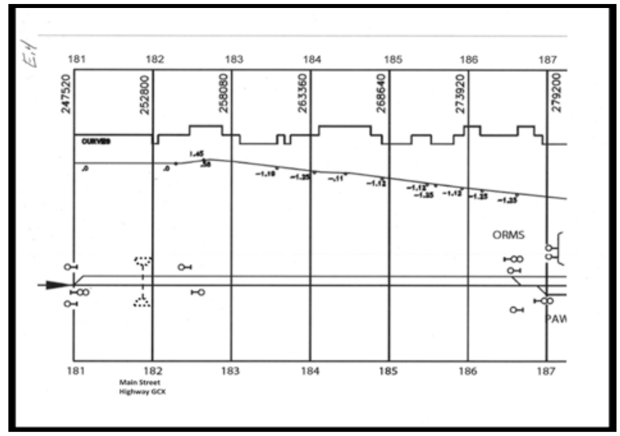
Sixteen licensed railroad engineer volunteers were recruited from the Brotherhood of Locomotive Engineers and Trainmen (BLET) Division 50. Participants had an average of about 8 years of passenger rail experience (range of 0 to 21 years, sample standard deviation of 7.53) and an average of about 13.5 years in the railroad industry (locomotive engineer or other positions) (range of 3 to 26 with a sample standard deviation of 6.72). None of the participants were qualified over the route driven in the simulation and none had previous experience with this route.

Equipment

For this study, the Federal Railroad Administration's (FRA) Cab Technology Integration Laboratory at the Volpe National Transportation System Center was utilized (Figure 2). Alion Science and Technologies built the CTIL cab and CORYS Thunder provided the simulation used for the practice and experimental runs. It is a mobile, full sized locomotive simulator with an 180˚ degree field of view, an AAR 105 control stand, and a four way adjustable chair. The CTIL is configured with tools to analyze crew performance (Melnik 2013). The train dynamics simulate the operation of a SD40 locomotive pulling five coaches traveling in Illinois from Shady Grove to Cicero (39.0 miles). The section of track is part of BNSF's Chicago subdivision. An Applied Science Laboratory (ASL) Mobile Eye XG (Figure 3**)** was used to determine the participants' point of gaze and ASL software Results Plus Gaze Mapping was then used to analyze a majority of the gaze data. The ASL software defines a gaze as 3 or more fixations within a predefined area.

Figure 3. ASL Mobile Eye.





Moving Map and Paper Map Displays

The moving map used for this study was developed by students at MIT under the supervision of Dr. Andrew Liu. The application was installed on a 2nd generation iPad and was modeled after current moving maps that have been deployed. The biggest differences were its portability, touch screen interface, and ability to add notes (Figure 1,4). Current models of the moving map are hard wired into train cabs and utilize a bank of buttons to operate. The iPad was placed on the front desk but participants were free to move the iPad at any point during either of the two trips. Most participants elected to leave the iPad on the desk where it was placed by the experimenter. The moving map application displayed the track and train route, signals, grade crossings as well as any permanent speed restrictions, gradient and curvatures, and other information that was input by the user, such as temporary speed restrictions and work zones. The paper map displayed largely the same information with the exception of speed restrictions and the real time location of the train.

Safety Critical Events

Each experimental run consisted of 10 safety critical events: 2 work zones, 2 quiet zones, a malfunctioning hot box detector, a vehicle in right-of-way (*ROW*), a stop and protect order, a bridge strike order, a trespasser in row, and a signal drop. These events are described in more detail in Table 1 (exclusive of the quiet zone events).

Safety Critical Events (Scenario No.)	**Description**
Work Area (1,3)	As the participant approaches a work area a radio call should be transmitted to the foreman in charge asking permission to travel through the work zone. Participants are notified of one work zone during their job briefing and the second work zone while they are stopped at a station.
Quiet Zone (9,10)	Upon entering a quiet zone the participant should not blow the horn when passing over a highway-rail grade crossing (where a road intersects the railroad tracks). The locomotive engineer was informed of these quiet zones during the pre-trip job briefing.

Malfunctioning Hot Box Detector (2)	A wayside hot box detector informs the locomotive engineer of the axel bearing temperature status via an automated radio transmission. In this malfunction the detector fails to make any radio announcement. When an announcement is not made from the hot box the participant should report this to the train dispatcher via radio. The location of the hot box detectors is listed on the paper chart, the moving map display, the operating railroad timetable and told to the locomotive engineer during the job briefing.
Vehicle in Row (4)	A vehicle on or near the tracks. The locomotive engineer should blow the horn, sound the whistle, and bring the train to an emergency stop. Upon coming to a stop the locomotive engineer should contact the line's train dispatcher via radio for further instructions.
Stop and Protect Order (5)	A stop and protect order is issued when there is a report of a broken or malfunctioning highway-rail grade crossing warning device. The locomotive engineer should come to a complete stop prior to the grade crossing and allow the conductor to get off the train in order to inspect the grade crossing signal. This order is given while the participant is stopped at a station.
Bridge Strike Bulletin (6)	A bridge strike bulletin is issued when a vehicle strikes an overpass that contains railroad tracks. The locomotive engineer must reduce the train speed to 5 mph over the affected bridge until all train cars are clear of the bridge. This bulletin is given while the participant is stopped at a station.
Trespasser in Row (7)	A person is spotted on or near the tracks. The locomotive engineer must sound their horn a inform the train dispatcher
Signal Drop (8)	A signal changes from green to red as the locomotive engineer is approaching it. This change could signal an opposing train operating on the same track. The locomotive engineer should bring the train to a safe stop and contact the line's train dispatcher for further instructions.

Table 1 Description of Safety Critical Events

Examples of the work zone and trespasser in right-of-way (ROW) safety critical events are shown in Figure 5**.** Clearly, a locomotive engineer who was looking inside the cab could potentially fail to see a work zone employee or a person on the tracks or right-of-way. The sooner that the locomotive engineer sounds the horn, the more time the individual involved has to move out of the way.

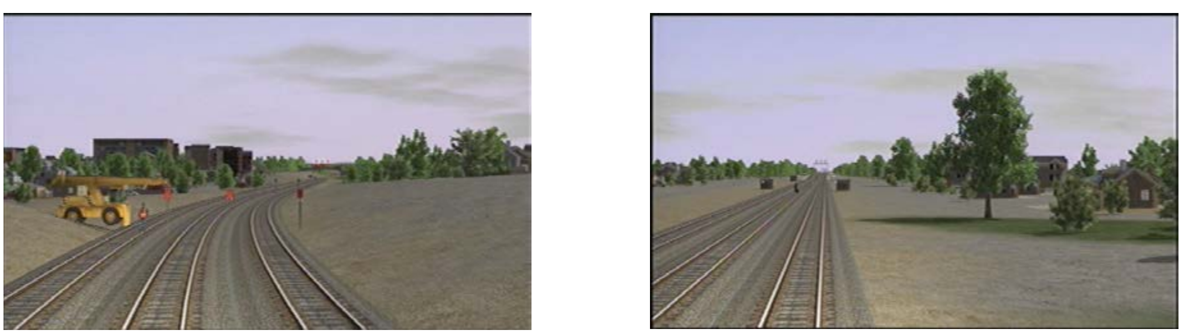


Figure 4. Example of Work Zone (left panel) and Trespasser in Row (right panel).

Experimental Design

Events occurred at different locations for each of the experimental runs A and B. The initial run was counterbalanced across participants, half receiving A and then B, the other half receiving B and then A.

Procedure

All participants arrived for their session at 8:30 am. Before beginning, each participant read then signed an informed consent form. Following their consent they filled out a short demographic questionnaire. Participants then attended a job briefing, where they were randomly assigned to either the moving map (displayed in Figure 1) or paper map (displayed in Figure 4) condition. The job briefing simulated the daily briefing given to train engineers before they depart each day. The job briefing covered the speed restrictions and/or work orders that were in place that day as well as which station stops would be made. For participants using the moving map display, this job briefing was also used to teach them how to utilize the new technology. Once the participants were familiar with the device and understood the entirety of the job briefing a practice run was initiated. The practice run was 17.8 miles in length and lasted approximately 25 minutes. This practice run allowed the participants to become familiar with how the simulator and/or the moving map worked. Upon completion of the practice run the participant took a brief break followed by a second job briefing to go over the speed restrictions and work zones for the first experimental run. During this job briefing participants were given time to input notes on the moving map or write notes on the paper displays. The experimental run was 39.0 miles and lasted approximately 1.5 hours. Once the first run was complete the participant was allowed up to a 20-minute break followed by a third and final job briefing. The second experimental run was also 39.0 miles and lasted about 1.5 hours. Once both experimental runs were completed, participants completed a post experiment questionnaire as well as a payment voucher.

RESULTS AND ANALYSIS

Safety Critical Events Results and Analysis

All 16 participants were individually scored by a rail safety expert. Each event was rated in a binary fashion, receiving a score of 1 for following the correct procedure or a score of 0 for not following correct procedure. For example, a participant would receive a score of 1 for the vehicle in ROW scenario if the operator brought the train to a safe stop and contacted the dispatcher and would receive a score of 0 if one or both of those procedures was not followed. The descriptive statistics for each scenario are displayed in Table 3. On average, across all 10 safety critical events, 80.8% of them were detected by locomotive engineers using the moving map whereas locomotive engineers using the paper display detected only 75.9%. Excluding the quiet zone events, 77.5% were detected by locomotive engineers using the moving map, 73.7% were detected by locomotive engineers using the paper display. As can be seen from Table 3, for any given scenario there are few evident differences in the percentage of participants that correctly complied with the safety critical event between those in the moving map (MM) and paper map (PM) cohorts. The only two differences can be seen during the vehicle in row event (4) during Run A and the signal drop event (8) in Run B.

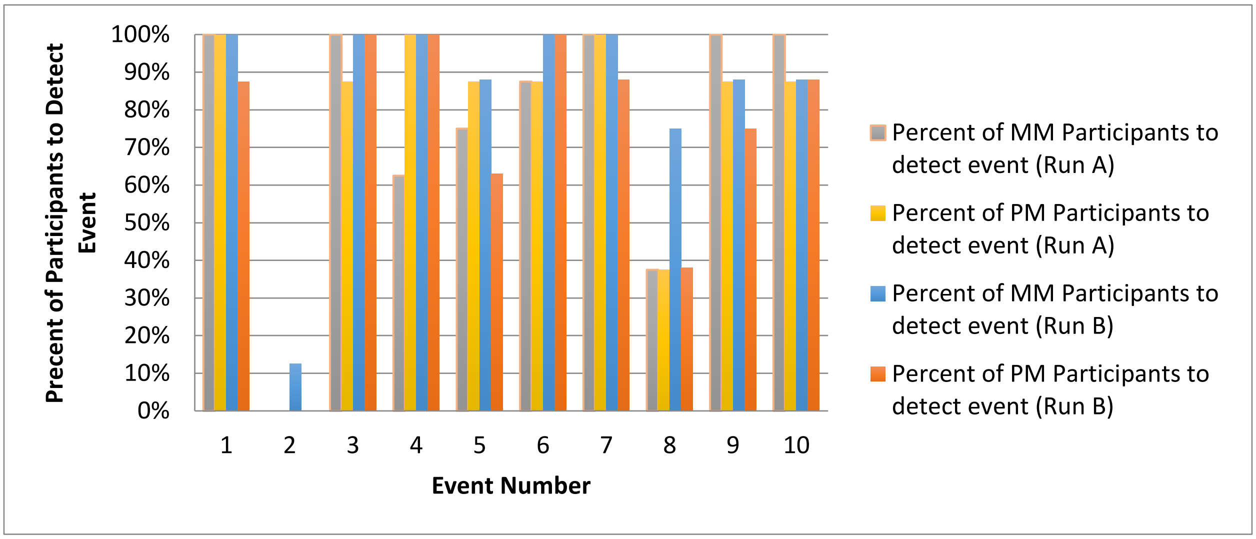


Table 2. Percent of participants to correctly comply with safety critical event. [Event on x axis. 1 - Work Area Gonzales; 2 - HBD No Announcement; 3 – Work Area Jones; 4 - Vehicle In Row; 5 - Stop and Protect; 6 - Bridge Strike; 7 - Trespasser in Row; 8 - Signal Drop; 9 - Quiet Zone; 10 - Quiet Zone.]

In order to analyze whether train engineers successfully responded to safety critical events across the different alternating conditions, a logistic regression within the framework of Generalized Estimating Equations (GEE) with a logit link function was used. The model included one between subjects factor – (a) Type of Map: Moving or Paper Map – and two within subjects effects – (b) Scenario (10 unique scenarios) and (c) Run Number (Run A or Run B). All second and third order interactions were also included. This analysis was preformed both with and without the quiet zones. When the quiet zones were included the all-higher order interactions were found to be highly significant [Third order: Wald X_1^2=0.008; p<0.005]. However, when the quiet zones were taken out of the analysis, using a backwards elimination procedure, the model showed no significance in the main effects for Type of Map [Wald X_1^2=0.674; p=0.412] and Run Number [Wald X_1^2=2.142; p=0.143].

Eye Tracking Results and Analysis

Twelve of the participants' eye-tracking data have been processed using software created by ASL (ASL Results Plus GazeMap). They include six participant using the moving map display and six participant using the paper display. We defined six (paper map) or seven (moving map) areas of interest to determine where the locomotive engineer was looking (Figure 6). We defined our areas of interest as the front window, gauge panel, iPad (for moving map condition only), table, accelerator panel, brake panel, and clock. If the participant is not looking in one of these areas the program considers them to be looking "outside" the area of interest.

Figure 5. Eye tracker with 4 areas of interest displayed

As you can see in Figure 7 moving map participants were looking out the front window a bit over 42% of the time (light blue-gray bar). Very little time (under 4%) was spent looking at the iPad (navy blue bar).

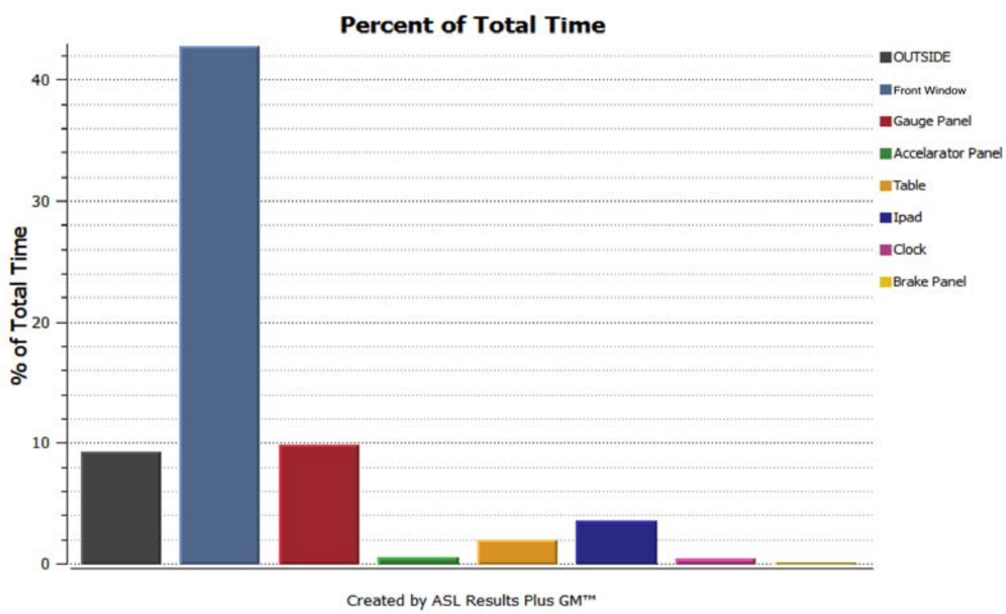


Figure 6. Moving Map Participant Glance Data

Locomotive engineers using the paper map spent some more time, about 52% (Figure 8), looking out the front window and about 4% of the time looking down at the table in front of them where they kept their paper map.

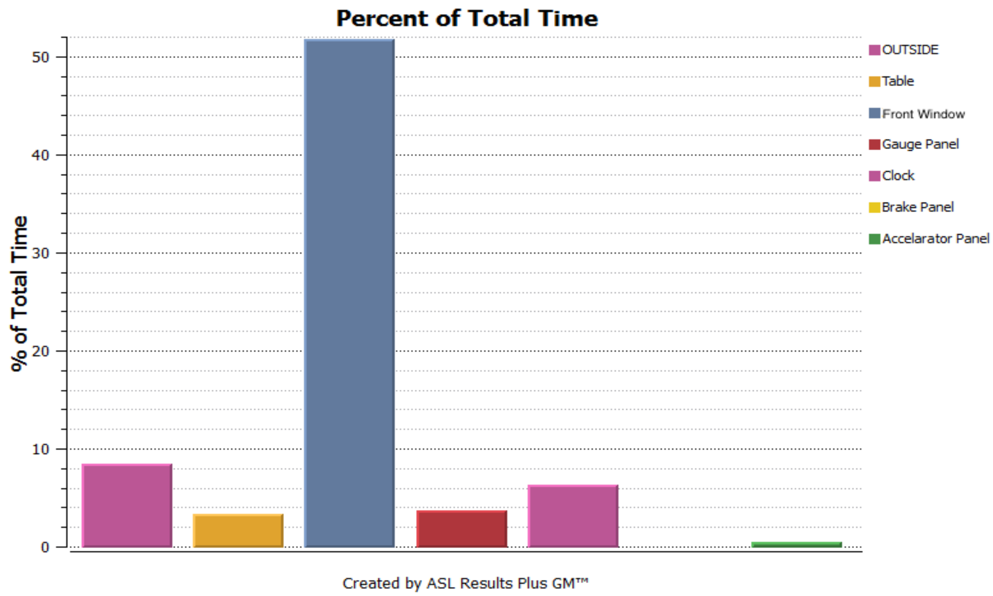


Figure 7. Paper Map Participant Glance Data

After it was determined where the participants were looking during their runs we were able to determine head down time. From this we were able to determine the proportion of time looking inside the cab over 2 seconds and the percentage of especially long glances taken by each participant. We defined an especially long glance as any glance inside the cab over 2 seconds. The moving map participants had an average total run time of 3,765 seconds and spent 421 seconds over our 2-second threshold for looking inside the cab compared to the paper map participant whose total run time was 3,793 and spent 550 seconds over the threshold looking inside the cab. These results gave the moving map participant a proportion of 0.112 while the paper map participant had a proportion of 0.145 for the same measure.

Similar results were seen when we looked at the proportion of glances over two seconds. The moving map participant had 140.57 glances and had 141 glances that were over 2 seconds leading to a proportion of 0.258. This is compared to 0.275, the proportion seen for the paper map participant (507 total glances and 139.425 glances over 2 seconds).

DISCUSSION

Summary

The current study examined the distracting effects of a moving map display inside train cabs. The intent of such displays is that they are simply an additional support tool for the engineer, not that they are would be heavily relied upon for constant visual scanning. While more analysis needs to be completed to better understand how locomotive engineers actually interact with and use this device, the current research is a good starting point. If the pattern of a high percentage of especially long glances continues to be seen in participants using the moving map then this is something for the railroads to take into account as they develop their training and procedures.

Limitations

While the preliminary results from the research seem promising there are several limitations associated with the experimental design that are discussed here. First, while all participants were licensed railroad engineers none of the participants were qualified for the route that was given. Second, the sample size of the current effort is too small to generalize the results to the entire population of commuter rail engineers. This is especially true of the eye glance data where only two participants were analyzed. While it is still too early to determine if this is a fair assessment across all participants it is a good starting point. If this difference continues to be seen across the remaining participants then a training program would need to be implemented to teach locomotive engineers how to properly utilize the device. Third, this study was performed on a simulator and it is unclear if the results would be transferable to a real world scenario since no field study was conducted. The final limitation can be found in the moving map display, since it was a prototype, the results may differ for the final software that is distributed as part of the PTC system.

Future Works

In order to address some of the current study's limitations further research is needed. Primarily the next study will utilize a larger population of licensed engineers qualified for this specific route. Second, an updated PTC system will be utilized. Finally, a field study would be performed to determine the moving maps effectiveness in the field.

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