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# MULTIMODAL DISPLAYS TO REDUCE DISTRACTION IN LOCOMOTIVE ENGINEERS

Rachel Grice

University of Maryland Baltimore County

Donald Fisher Matthew Isaacs

Volpe National Transportation Systems Center

Andrew Liu

Massachusetts Institute of Technology

Multi-modal displays that allow the locomotive engineer to delay safety-critical dispatches in high workload scenarios offer the promise of reducing the cognitive distraction that occurs when the locomotive engineer must listen to a dispatcher's communication. In an effort to determine whether locomotive engineers could delay safety-critical information from the dispatcher in high workload scenarios, we developed and evaluated such a multi-modal display system. It was hypothesized that locomotive engineers, when provided with the ability to postpone the delivery of information from the dispatcher, would perform better than locomotive engineers who were not provided that capability. Contrary to the above hypothesis, an analysis of the eye tracking measures indicated that the engineers performed more poorly in the multi-modal display system condition, indicating that the system as designed did not allow the engineer to safely delay dispatch messages. We conclude that aspects of the new system that seemed to increase distraction should be redesigned to modify how and when the engineer uses the system to access information and allow for a safe delay of safety-critical information.

## INTRODUCTION

To preserve safety, a locomotive engineer and a railroad dispatcher must maintain constant communication. Voice radio is the predominant communication tool between these two sets of employees, but this method is prone to problems that could potentially lead to human factors accidents. For instance, the temporal and transient nature of the information provided over the radio can place a higher cognitive workload on the train engineer (Malsch, Sheridan, & Multer, 2004). This is especially problematic during high workload times when the engineer should be paying attention to events on the forward track. An engineer may hear the information provided by the dispatcher, which is not immediately pertinent to what s/he is doing, thereby forcing him/her to remember it while performing other activities. Although some engineers may write the information on paper, this still increases workload and glance time off the forward track because of the time and effort needed to write the information.

Multi-modal displays that use both visual and auditory channels offer the promise of reducing cognitive distraction in high workload scenarios by allowing the engineers to delay their retrieval of safety-critical information. An engineer who is not cognitively distracted will more easily be able to predict when a threat may emerge (i.e., when a trespasser may step into the foul of the tracks) if s/he is not cognitively engaged by a voice conversation with the dispatcher (Wickens & McCarley, 2008).

When examining the amount of task interference and performance degradation to the engineer involved with dispatch radio communications, one must consider the costs associated with accessing the information and the extent to which multiple tasks compete for the same resources. Multiple Resource Theory (MRT) predicts that two tasks that both

demand visual attention are going to interfere more than one task demanding visual attention and one task demanding auditory attention (Wickens, 2002). One can now use MRT to predict the level of distraction caused by conflicting resource demands between the primary task of driving the train and other secondary tasks, such as communicating on the dispatch radio. The dispatcher's radio message demands auditory attention, and the track ahead demands visual attention, so according to the predictions of MRT, the current situation in the locomotive cab seems acceptable. However, MRT does not address how and when humans allocate limited resources to the separate channels. Research in task interruptions and task management, described next, attempts to fill this gap.

Some tasks and their corresponding interactions with interfaces require an immediate response, and other interactions can allow for a delayed response (Ho, Nikolic, Waters, & Sarter, 2004). Train operators face the same dilemma: they must decide whether a task demands an immediate response or can be delayed. In particular, operators must avoid unnecessary interruptions in their main task, operating the train, during safety-critical sections of track. The typical scenario in which such a choice needs to be made would be the train engineer performing the ongoing visual-manual task of train driving, while monitoring for hazards and being periodically interrupted by a message from the dispatcher. While MRT would predict that the audio-visual pairing of tasks would lead to more efficient time-sharing than a visual-visual pairing of tasks, auditory preemption would predict the opposite. This is because auditory messages are salient and disruptive in nature, and are more likely than a visual one to draw attention away from the primary task (Lu et al., 2013). Additionally, research shows that there are methods of managing two simultaneous tasks that could mitigate the negative impacts of the interruption. For example, studies

have shown that resumption of an ongoing task (say monitoring the forward track) after an interruption (a dispatcher's message or, perhaps better yet, an indication that a dispatcher's message was in the queue) was easiest when there was a delay between the interruption and the suspension of the ongoing task, which allows the operator to choose a good place to leave the ongoing task (Wickens & McCarley, 2008).

The Federal Aviation Administration's (FAA) Next Generation Data Communications (Data Comm) system is an example of an operational system that allows users to delay interaction during periods of high workload. The pilot is alerted via text that a message has arrived from the air-traffic control (ATC), and can retrieve the message when desired. Data Comm is now used by the FAA for visual text communications between air traffic controllers and their crew (Naylor, 2016) and has successfully improved performance and satisfaction measures (Lennertz, 2015). Since rail dispatcher communication is similar, adapting this approach to rail may allow the operator more time to focus on more important and safety-critical tasks (Federal Aviation Administration, 2017). We wanted to use this ability to delay a message in our prototype communication system as a solution to the performance decrements that auditory preemption theory would predict.

The previously described delay capability would also necessitate an alert icon to let the operator know a message had arrived. There are several ways to alert an engineer that a message has arrived including an auditory tone, a vibratory display (e.g., seat), or a visual display (e.g., Heads-Up display or HUD). The first two methods could well prove both annoying and relatively distracting because of the need to issue the alert repeatedly until it was answered. Also, vibratory displays would not be feasible in a locomotive cab, which has high levels of vibration. An alert provided on a visual display is less likely to prove annoying and/or distracting since it can simply remain unobtrusively visible at one location. For the present study, we decided that a HUD visual alert would best improve safety and efficiency in situations when the locomotive engineer may be distracted by dispatcher's communication. HUDs increase the amount of time an operator is looking out of the forward window and therefore reduces the likelihood that a critical event will be missed (Holder & Pecota, 2011).

The display in this current study consisted of an in-cab display screen that performed two functions after the visual alert was delivered on the HUD. One, the display spoke the message to the engineer (auditory mode). Since the message was spoken, the engineer did not have to look down to retrieve the message. The system is consistent with the auditory-visual pairing that is optimal from MRT. Additionally, we expected the synthetic speech message to lower cognitive workload because it would eliminate the difficulty in understanding "garbled" voice radio messages (Lennertz, 2015). Given that the engineers could delay the incoming message, if auditory preemption did occur with the spoken message, we expected it to be in sections of track without safety critical targets. Two, the display simultaneously displayed the message on a screen on the in-cab panel (visual mode), eliminating the need for the

receiver to take notes on the message content. Visually displaying the textual instructions has been shown to reduce the demands on a pilot's working memory, thus they may have an opportunity to complete higher priority flights tasks before responding to or complying with ATC instructions (Helleberg & Wickens, 2003). This is unlike the conventional radio communication with ATC, which typically requires an immediate response (Helleberg & Wickens, 2003).

To summarize, Multiple Resource Theory predicts that auditory displays could improve performance in dual-task situations, yet auditory preemption theories predict that auditory displays may be detrimental to performance. However, the literature shows that there are modifications a designer can make to offset some of the performance decrements that preemption may cause, such as providing an alert that a communication is upcoming and a delay between the interruption (alert) and the suspension of the ongoing task. Additionally, providing a permanent visual text display reduces working memory taxation that may be challenged by incoming auditory information, and/or the need to write the incoming auditory information.

HUDs and the digital transmission of communication have been researched heavily in other domains such as aviation and car driving, but these technologies have not yet been applied to rail. We hoped the improvements in safety that the delay of interrupting communications has provided aviators would translate into similar improvements in safety for locomotive engineers.

## METHODS

The primary goal was to reduce the cognitive distractions that arise from radio communications by understanding how the delivery of safety-critical radio information affected engineer threat awareness. To do this, an experiment using a HUD and multi-modal in-cab display was conducted on the Cab Technology Integration Laboratory locomotive simulator at the Volpe Center in Cambridge, MA. Twenty-four male certified locomotive engineers navigated two 60-minute sections of track in the simulator. On each section of track, the participant encountered a different sequence of scenarios, described below. There were two experimental conditions for message delivery: 1) the radio and 2) the HUD system. In the radio condition, the locomotive engineers received the radio dispatches through the conventional voice radio.

In the HUD-system condition, the engineers first received a yellow message alert icon in the lower right corner of the HUD indicating an incoming dispatcher message. When ready, the engineer pressed a button to display the message on a screen in the instrument panel and to play the auditory voice reading of the same message; see Figure 1. The dispatch message text remained visible until a new message had arrived. The HUD also contained additional symbology for the engineer to reference, such as an upcoming station stop symbol, a milepost indication, a speed restriction symbol, and a speed indication symbol.

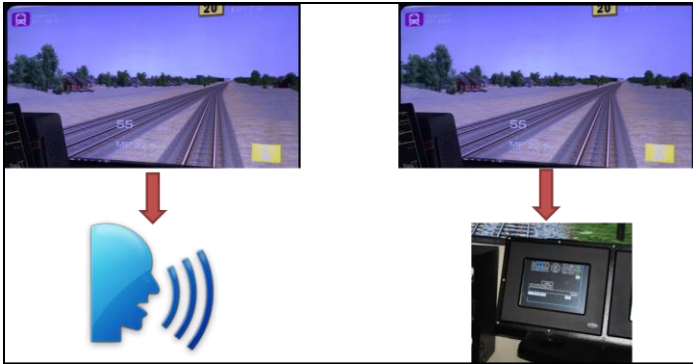


Figure 1. HUD condition. (Information is conveyed via voice and an in-cab display of the text message. The yellow icon at the bottom right of the two top screens is an indication that a message is waiting. The speed is indicated in the left bottom center of the two screens.)

Seven threats (scenarios) were used in the final analysis; see Table 1. The pre-cue region is an area where cues to an upcoming threat or safety-critical appear. As an example, this might be the point where grade crossing gates first become visible. Radio messages and the yellow HUD message icon both were delivered in the pre-cue region. The yellow icon remained visible until the engineer pressed a button on the in-cab display screen to display the message audio and text. S/he could choose to retrieve the message at any time.

Table 1. Scenarios engineer encountered with a description of the target for the engineer to detect.

Interlocking	• Interlocking switch points
Gate Malfunction	• Gates in air
Grade Crossing	• Truck and area where truck is (in safe position behind gates)
Trespasser	• Visible pedestrian
Work Area	• Hidden worker (in safe location)
Signal Drop	• Signal change to red
Station Blow Through	• Passenger too close to edge

Figure 2 is a representation of the track and the path the engineer would follow upon approaching a target, traveling first through the safety-critical section (the section where the engineer needed to glance towards the latent threat) and then the adjacent section (the section where it was hypothesized that the engineer would retrieve the dispatcher’s communications in the HUD condition).

The display modality (radio or HUD system) and the Scenario (1-7) were the two within-subjects variables. The order of the display modality was a between-subjects variable used to counterbalance exposure to the radio or HUD conditions and the scenarios. Participants’ eye-glance behaviors were recorded throughout the simulation using an Applied Science Laboratory Mobile Eye XG head-mounted eye tracking system. An independent scorer with more than a decade of experience in eye movement research labelled the fixations and scored whether or not the engineer detected the target of the safety-critical event in the safety-critical section.

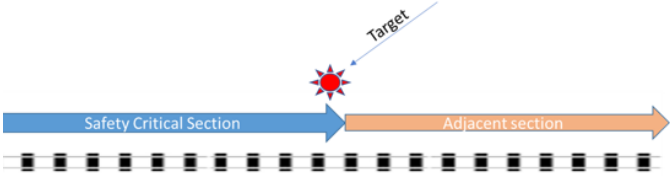


Figure 2. Visual representation of the sections of track. (The safety-critical section of track is the location where the engineer needed to glance towards the threat.)

We hypothesized that locomotive engineers in the HUD condition would delay the incoming message (Hypothesis 1) and that those who delayed the incoming message would have better target detection performance than the engineers in the radio condition (Hypothesis 2). Put slightly differently, it was hypothesized that the radio communication would decrease performance relative to engineers in the HUD condition who delayed the message by diverting attention to the secondary auditory task, one that is not immediately associated with the engineer’s primary driving task.

FINDINGS

The first point of note is whether engineers, as we predicted, would indeed successfully delay retrieval of the dispatcher’s message until after they exited the critical section of track containing the targets. The results show that only 2 of 24 engineers delayed message retrieval in all 7 scenarios, a finding contrary to Hypothesis 1. The remaining 22 engineers accessed the message within the critical section of track at least once.

We then evaluated whether the engineers successfully detected the targets for each scenario by averaging the target detection rate over all the participants for each condition; see Figure 3. For the Scenario 6 in the HUD condition, the engineer had to detect the signal changing from yellow to red, but only half of the engineers detected the change in signal color. In comparison to Scenario 4 in the HUD condition, 96% of the engineers successfully detected the target--the trespasser along the tracks. This variation in target detection is typical in what sees of studies of hazard anticipation.

The significance of the differences between conditions was tested using a logistic regression within the framework of Generalized Estimating Equations (GEE) with a logit link function and an exchangeable covariance matrix. The model included two within-subject fixed effects (a) Type of Display (HUD or radio) and (b) Scenario (7 unique scenarios), and a dependent variable of target detection. The subjects were modeled as random effects.

There was a significant average reduction in the probability of target detection with the HUD ( $p=.036$ ; see Table 2). In other words, the chance of target detection was lower for engineers in the HUD condition than in the radio condition. Of note, the type of Scenario, in some cases, had a significant impact on the probability of target detection.

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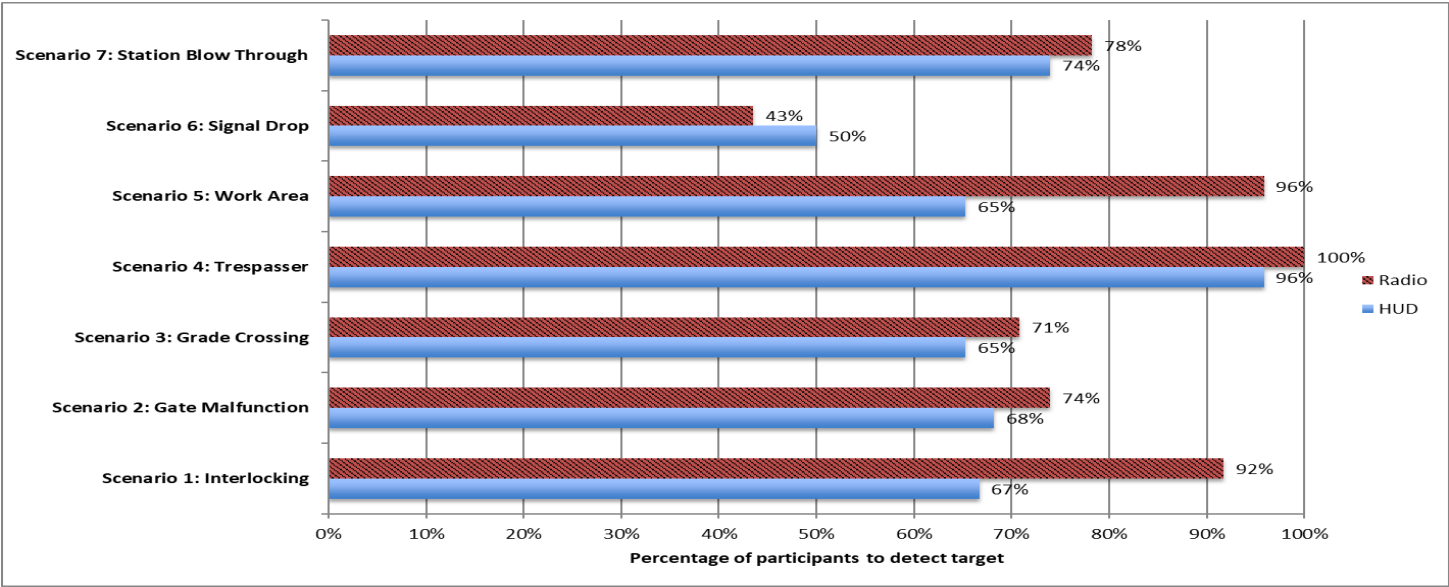


Figure 3. Percentage of participants to successfully detect the target in each safety-critical event across radio and HUD conditions.

Table 2. Parameter estimates from GEE.

Parameter Estimates							
Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.445	.4371	.589	2.302	10.933	1	.001
[Scenario=1.00]	.204	.4428	-.664	1.072	.212	1	.645
[Scenario=2.00]	-.261	.4503	-1.144	.622	.336	1	.562
[Scenario=3.00]	-.419	.5702	-1.536	.699	.540	1	.463
[Scenario=4.00]	2.562	.9759	.649	4.474	6.890	1	.009
[Scenario=5.00]	.309	.5323	-.734	1.352	.337	1	.561
[Scenario=6.00]	-1.282	.4334	-2.131	-.432	8.748	1	.003
[Scenario=7.00]	0 <sup>a</sup>						
[HUD/Radio (0/1)=.00]	-.615	.2937	-1.191	-.039	4.385	1	.036
[HUD/Radio (0/1)=1.00]	0 <sup>a</sup>						
(Scale)	1						
Dependent Variable: Target detection (hit or miss)							
Model: (Intercept), Scenario, HUD/Radio (0/1)							
a. Set to zero because this parameter is redundant.							

Target detection likely suffered in the HUD condition because the results showed that across scenarios, 52% of the engineers retrieved the message in the safety-critical section of the track. In other words, most of the time, engineers, as a group, were retrieving messages before passing the critical zone, as described previously. We calculated this percentage by averaging the proportion of participants who accessed the message early, and did this for each scenario. For instance, in Scenario 1, approximately 67% of engineers accessed the message in the critical section, in Scenario 2, 54%, Scenario 3, 58%, and so on. Then, we averaged those proportions from each of the 7 scenarios to obtain the 52%.

To examine whether delayed retrieval of communications enabled engineers to maintain their detection of potential threats, we compared the target detection performance and glance behavior of those engineers who delayed the message in the HUD conditions with their target detection performance in the radio condition (Hypothesis 2). In the HUD condition, a target was detected 83% of the time

when an engineer delayed the message in a given scenario while same engineer in the given scenario detected the target 82% of the time in the radio condition. This indicated that engineers were similarly distracted in the HUD condition and radio conditions, if they delayed the message.

DISCUSSION

Our analysis showed that the engineers in the HUD condition who delayed the retrieval of the message until after the safety-critical section were slightly more likely to detect the safety-critical event than were these same engineers in the radio condition, but the difference was much smaller than expected. Two questions are paramount to understanding the difference. First, why might engineers who did delay retrieval of the message not be more likely to detect the safety critical event? One possibility is that the appearance of the visual icon in the periphery stimulates the peripheral object detection mechanisms and draws the engineers attention (Jonides & Yantis, 1988). We thought the peripheral location would lessen the likelihood of visually interfering with train operation, but this may not have been the case.

Second, why might engineers not have delayed retrieval of the message? When the engineer accessed the message, they would also read the message when it was shown, and at a time when the engineer should be paying attention to the forward track! Perhaps the yellow icon triggers a dopamine-induced loop, similar to what occurs when both receiving and then retrieving a text message (Weinschenk, 2012). However, this effect can be attenuated or reversed by modifying the method of alert or reducing the unpredictability of the cues (Weinschenk, 2012).

In additional analyses beyond the scope of this paper, many glances were made to the yellow icon in the HUD condition resulting in longer head-down time and longer glance durations. One possible explanation for this is that since the HUD is a new technology, the engineers may have

looked at the icons more often. More exposure to the system might reduce the number and length of fixations. This is analogous to changes in eye movement behavior as novice drivers learn what to look at and how to manage all the information as they gain experience (Horswill, 2016). Relatedly, if we trained engineers to delay the message and not fixate on the yellow icon, one would expect less head-down time and fewer especially long glances, and as a result, improved target detection in the HUD condition.

Given that the engineers in the HUD condition were looking at the visual displays, our results are consistent with predictions from the Multiple Resource Theory. We predicted that when an engineer operates a train (visual task), presenting the dispatcher's message through a voice recording on the HUD system would yield benefits over presenting the dispatcher's message on the display as text. When the engineer accesses the message at a safe time with the HUD system, their detection performance is similar to the voice condition. In contrast, auditory preemption theories predict that incoming radio (auditory) messages will interrupt the ongoing primary visual task of operating the train while in a safety-critical section of track. We predicted that this interruption would cause the engineer to miss the target in the safety-critical sections for the radio condition. By contrast, we predicted that the HUD message would only be accessed after the target had passed. If auditory preemption did occur, it would be outside the safety-critical section of track for the HUD condition.

The results revealed problems with these predictions. One, the engineer in many cases did not delay the message but accessed the HUD message in the safety-critical section of track. Since the message in the HUD condition was now being played at or around the same time as the message in the radio condition, the likelihood of distraction because of auditory preemption is expected to be similar in both conditions. This is Strike one against the HUD. Sorkin (1988) suggested that providing information to operators indicates the relative urgency of an alarm improves attention allocation between tasks. A future study could code the dispatcher's messages by urgency based on the expected time before reaching the event, e.g., green for a distant threat and red for an imminent threat. Finally, future experiments should allow engineers to use the system for an extended period of time. One could then analyze the resulting eye movement behavior changes over time to investigate any novelty effects.

Furthermore, by reading the message on the screen and not listening to it as predicted, the engineer added a second visual task in addition to the visual tasks of train driving. The MRT predicts that the visual resources required of the engineer to read the message on the in-cab screen would interfere with the visual resources needed for operating the train. The result is poorer time-sharing performance in the HUD condition compared to the radio condition. This is Strike two against the HUD. A future study to examine alternative display design might include the dispatch message as synthetic audio only – the advantage here is that it could be repeated as needed. If text was desired, e.g., to replace the engineer writing the information down on paperwork, then summary versions of messages could be used, rather than full

text, which was the entire text of what the dispatcher would normally say over voice radio. The length and complexity of digitally-transmitted messages has been shown to impact performance (Masquelier, Sheridan, & Multer, 2004), so this is certainly worth pursuing.

## CONCLUSION

In summary, radio communications can potentially create distractions, especially in safety critical sections. More research needs to be undertaken in order to determine how best to reduce these distractions. It appears that training might be all that is needed. But alternative human-machine interfaces might be required as well.

## DISCLAIMER

The opinions expressed in this document are the author's own and do not reflect the view of the Federal Railroad Administration, the Department of Transportation, or the United States Government.

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