

# PRELIMINARY EVALUATION OF LEAD TIME VARIATION FOR RAIL CROSSING IN-VEHICLE ALERTS

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## ABSTRACT

In-Vehicle Auditory Alert (IVAA) effectiveness depends on several auditory factors. Lead time has been shown to significantly influence IVAA effectiveness for automotive displays, although applications for Highway-Rail Grade Crossings (HRGCs) have yet to modulate and determine an appropriate lead time. To address this research gap, we conducted a small-scale driving simulator study to investigate the effect of lead time variation on driving performance and gaze behavior at rail crossings. We recruited 11 participants who drove through three experimental drives with different alert state conditions. Preliminary results show that a seven second lead time led to statistically higher temporal demand, a slower approach speed to crossings, and better gaze behavior than the no IVAA condition. The seven second lead time condition had similar higher values than the advanced warning condition, although they were not statistically significant. Findings of the current study offer insight into auditory display guidance for HRGCs, although future work involving a larger recruitment pool is needed to confirm study findings.

## 1. INTRODUCTION

The use of In-Vehicle Auditory Alerts (IVAA) has been shown to improve driving performance in various driving contexts. IVAA have been successfully used for rear and forward collision warnings [1, 2], intersections [3, 4], and take-over alerts in automated vehicles [5].

In the field of rail crossings, IVAA have been suggested as a method to control and reduce the incidence of Highway-Rail Grade Crossing (HRGC) accidents [6, 7]. As these locations present increased risk to drivers due to the lethality of accidents [8] and the incidence of inattentive driving [9], IVAA present many benefits in increasing safety and alerting drivers on-time for responding to the crossing [10].

While the design of IVAA for HRGCs has been shown to improve driving performance at rail crossings [11], IVAA have been designed following guidelines in related automotive research fields. As HRGCs have different risk and approach profiles than other road features, there is a need to evaluate and determine whether past auditory display guidelines should be used or improved based on the HRGC context. Lead time is one such variable requiring evaluation, as it represents one of the first considerations when designing an IVAA, and should vary depending on the purpose of the

display. Existing research on lead time selection points to varying lead times for safety applications, such as take-over requests [12] and forward collision warnings [13], further suggesting the need for an evaluation for HRGCs. Performance at HRGCs can also be considered as distinct from other automotive applications, as appropriate behavior at crossings also involves visually monitoring the crossing for a train and existing warning displays present at crossings. Based on these considerations, we conducted our study to determine the influence of lead time variation on driving performance, gaze behavior, and workload for HRGC situations. To further contribute to existing literature in the field, three auditory display types were defined, and variables within each type were modulated for further analysis.

## 2. RELATED WORKS

### 2.1. Rail crossing displays

Various research groups and teams have started testing IVAA for HRGC situations. The “SAFER Level Crossing” multiagency research project in the European Union has evaluated the use of auditory alerts that would play when vehicles approach crossings in participating countries such as Italy [14]. In Greece, the use of auditory alerts has been evaluated with taxi drivers in the city of Thessaloniki [15], showing the benefit of the alerts and factors to include based on driver feedback. However, the design of the auditory alert was not thoroughly investigated for rail-crossing applications, using past guidance in automotive displays.

A recent initiative using a connected multimodal alert for Rail Crossing Violation Warnings (RCVW) has also shown promise [16]. The vehicle is connected to the wider network of sensors at active rail crossings. The RCVW system warns drivers if they do not seem to take appropriate actions near the crossing, if the crossing they stopped at is currently active, and the likely presence of trains around.

Finally, our research group has also conducted a systemic design of auditory alerts for HRGCs [6, 7], showing that hybrid auditory alerts using both speech and non-speech components are preferred for the rail crossing situation.

### 2.2. Lead time

Researchers reported a lead time of six to seven seconds as appropriate for take-over requests in highly automated vehicles [5, 12]. Higher lead times did not match driver

expectations, whereas a shorter lead time gave drivers too little time to respond to the incoming threat. In forward collision applications, a lead time of four seconds has been used and recommended by other researchers [13], who indicated that this lead time would match with the driving situation and restrictions with regards to the forward collision situation. Further pointing to the need to consider the driving context, researchers reviewing past automotive applications and research also indicate that contextual factors influence lead time selection [17], though in general a seven second lead time was deemed appropriate for high urgency safety IVAAAs [18].

### 3. METHOD

#### 3.1. Participants

Eleven college-aged ( $M = 22.4$  yrs,  $SD = 3.0$ ; 6 male, 5 female) participants completed the study. Each participant received ten dollars at the end of the study. All participants had a driver's license and reported normal hearing ability. Informed consent was obtained at the start of each session.

#### 3.2. Apparatus

Participants drove through simulated driving scenarios and wore eyetracker glasses to record their gaze. The driving simulator used in the current study, was a medium-fidelity National Advanced Driving Simulator (NADS). The eyetracker used was the Tobii Eyetracker Pro Glasses 2.

#### 3.3. Stimuli

The candidate In-Vehicle Auditory Alert (IVAA) consisted of two earcon dings of medium urgency and a speech section voiced by a male native English speaker. The speech alert component consisted of the following statements: "Slow down. Rail crossing ahead. Look left and right at crossing". The IVAA sound level was 15dB above background noise, following previous research guidelines on IVAA design [19].

#### 3.4. Experimental Design

The study conducted used a within-subjects design, manipulating the following variables:

- Alert state: Participants experienced three experimental drives with different alert states. A control condition with no IVAA was present, as well as two alert states that differed based on lead time. For one state, the alert would play 7 seconds before the crossing, which was determined based on the prevailing speed limit at each section (35mph in urban settings, 65mph in rural settings). For the other state, the alert would play at the advanced warning location, a location determined by guidelines for the design of rail crossings [20]. This alert would play before the seven second lead time condition.
- Crossing location: Each drive included crossing two urban and two rural crossings.
- Crossing type: Each drive included two passive crossings, using a crossbuck and yield or a crossbuck and stop sign, and two active crossings

that were turned off, a crossbuck and lights and a crossbuck, lights, and an open gate.

The order of alert states shown was counterbalanced across participants through a balanced Latin-Square design across three experimental drives. Variables that were collected consisted of workload scores from the NASA-TLX questionnaire, gaze behavior scores based on binary coding regarding whether participants looked left or right at the crossing (a score of 1 given for each score if a participant looked left and right at a crossing), and vehicle speed values near the crossing. The interval of data that was used for this value started at a seven second lead time location from each crossing until the crossing itself.

#### 3.5. Procedure

Participants provided informed consent at the start of the study and then, completed a demographic questionnaire that collected their age, gender, and their number of years with a driving license.

Participants were first asked to drive through a scenario meant to determine driving simulator sickness. The driving scenario consisted of a five-minute drive through a rural road containing sharp turns and stopping at a designated area to the side of the road. Participants filled out a questionnaire before and after the short driving scenario and could indicate if they felt dizzy or nauseous, at which point the experiment would be stopped and participants would still be compensated. No participant needed the experiment to conclude at this stage, and all drove through the experimental scenarios.

After the driving simulator sickness test, participants wore Tobii Eyetracker 2 glasses to detect gaze behavior near HRGCs. The glasses were calibrated before each lap to ensure accurate gaze collection. Participants drove one lap through a simulated driving scenario (Figure 1) which included four HRGCs.



Figure 1: Simulated driving scenario at an urban crossing

After crossing all HRGCs, which took around 10 minutes on average to complete, participants took five minutes to answer the NASA-TLX workload questionnaire before driving through another lap and scenario. After the completion of all three experimental drives, which had a counterbalanced design for experiencing all alert states, participants were compensated for their participation and left the test site.

## 4. RESULTS

#### 4.1. Workload scores

A repeated-measures ANOVA was used to analyze the effect of the alert state and the driving scenario on NASA-TLX subscale scores.

The alert condition had a statistically significant main effect on temporal demand  $F(2, 18) = 3.59, p = 0.0487$ . We ran post-hoc paired-samples t-tests using a Bonferroni correction (with an adjusted  $\alpha = 0.05/3 = 0.0167$ ) for pairwise comparisons. The alert condition with a 7s Lead Time ( $M = 32.27, SD = 21.72$ ) was perceived as more demanding than the No IVAA condition ( $M = 17.27, SD = 8.17$ ), although it did not reach a statistically significant level  $p = 0.0180$  (Figure 2). No statistically significant difference was found with the advanced warning alert state ( $M = 17.27, SD = 9.84$ ).

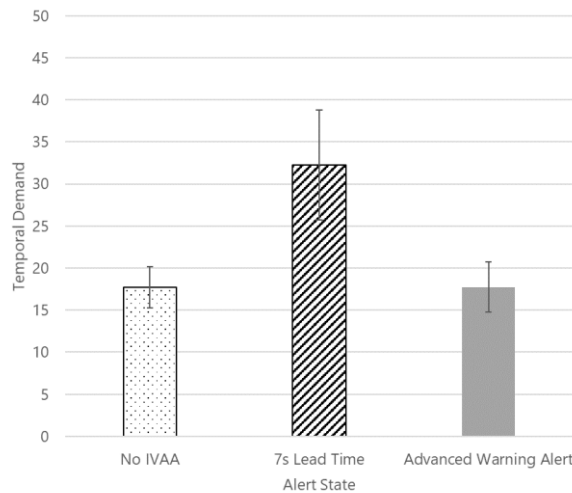


Figure 2: Temporal demand workload scores for different alert states.

No other statistically significant main effect was found for other workload subscales.

#### 4.2. Vehicle speed

A repeated-measures ANOVA was used to analyze the effect of the alert state and the driving scenario on average and minimum vehicle speed metrics reached for the approach to the crossing. We ran post-hoc paired-samples t-tests using a Bonferroni correction (with an adjusted  $\alpha = 0.05/3 = 0.0167$ ) for pairwise comparisons.

We found a main effect of alert state on average vehicle speeds  $F(2, 110) = 4.62, p = 0.0118$ . Pairwise comparisons showed that vehicle speed was significantly higher for the no alert condition ( $M = 35.91, SD = 15.49$ ) than for the 7 second lead time condition ( $M = 31.36, SD = 14.23, p = 0.0095$ ) and the advanced warning alert condition ( $M = 29.86, SD = 12.60, p = 0.0053$ ) (Figure 3).

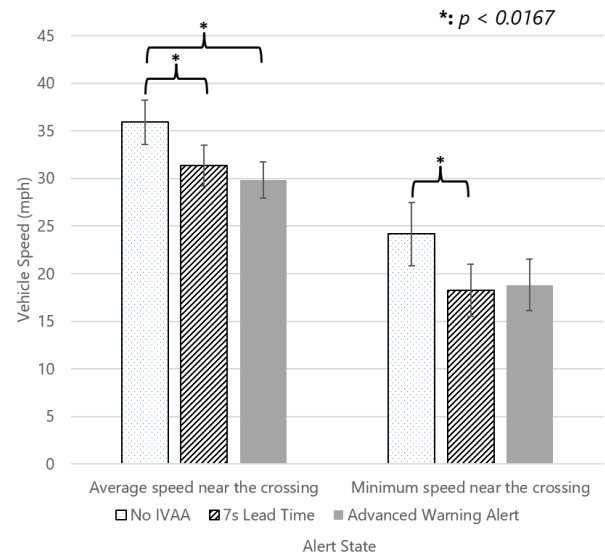


Figure 3: Influence of alert state on average and minimum vehicle speeds near the crossing

We found a main effect of crossing location on average vehicle speeds  $F(1, 110) = 252.55, p < 0.0001$ . Vehicle speed was significantly higher for the rural condition ( $M = 42.82, SD = 10.35$ ) than for the urban condition ( $M = 21.93, SD = 9.09$ ).

We found a main effect of crossing type on average vehicle speeds  $F(1, 110) = 4.73, p = 0.0318$ . Vehicle speed was significantly higher for the active condition ( $M = 33.80, SD = 13.18$ ) than for the passive condition ( $M = 30.95, SD = 15.28$ ).

We found a main effect of alert state on minimum vehicle speeds  $F(2, 110) = 3.16, p = 0.0463$ . Pairwise comparisons showed that vehicle speed was significantly higher for the no alert condition ( $M = 24.16, SD = 21.89$ ) than for the 7 second lead time condition ( $M = 18.23, SD = 18.31, p = 0.0135$ ). No statistically significant difference was found for the advanced warning alert condition with the other alert states ( $M = 18.81, SD = 18.07$ ) (Figure 3).

We found a main effect of crossing location on minimum vehicle speeds  $F(1, 110) = 137.98, p < 0.0001$ . Vehicle speed was significantly higher for the rural condition ( $M = 32.42, SD = 17.42$ ) than for the urban condition ( $M = 8.38, SD = 13.14$ ).

#### 4.3. Gaze behavior

A repeated-measures ANOVA was used to analyze the effect of the alert state and the driving scenario on gaze behavior metrics. We ran post-hoc paired-samples t-tests using a Bonferroni correction (with an adjusted  $\alpha = 0.05/3 = 0.0167$ ) for pairwise comparisons.

We found a main effect of crossing type on the likelihood of looking left at the crossing  $F(1, 110) = 4.07, p = 0.0461$ . The likelihood of looking left was significantly higher for the passive condition ( $M = 89.39\%, SD = 31.03\%$ ) than for the active condition ( $M = 78.79\%, SD = 41.19\%$ ).

We found a main effect of alert state on the likelihood of looking left  $F(2, 110) = 5.53, p = 0.0052$ . Pairwise comparisons showed that the likelihood of looking left was significantly lower for the no alert condition ( $M = 63.64\%$ ,  $SD = 48.67\%$ ) than for the 7 second lead time condition ( $M = 95.45\%$ ,  $SD = 21.07\%$ ,  $p = 0.0027$ ) and the advanced warning alert condition ( $M = 93.18\%$ ,  $SD = 25.50\%$ ,  $p = 0.0041$ ) (Figure 4).

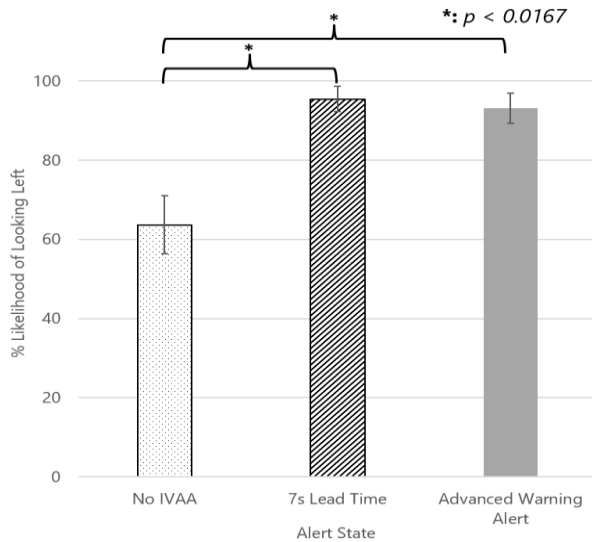


Figure 4: Influence of alert state on likelihood of looking left at the crossing

We found a main effect of alert state on the likelihood of looking right  $F(2, 110) = 4.52, p = 0.0130$ . Pairwise comparisons showed that the likelihood of looking right was significantly lower for the no alert condition ( $M = 61.36\%$ ,  $SD = 49.25\%$ ) than for the 7 second lead time condition ( $M = 93.18\%$ ,  $SD = 25.50\%$ ,  $p = 0.0035$ ). No statistically significant difference to the adjusted alpha level was found for the advanced warning alert condition with other alert states ( $M = 86.36\%$ ,  $SD = 34.71\%$ ) (Figure 5).

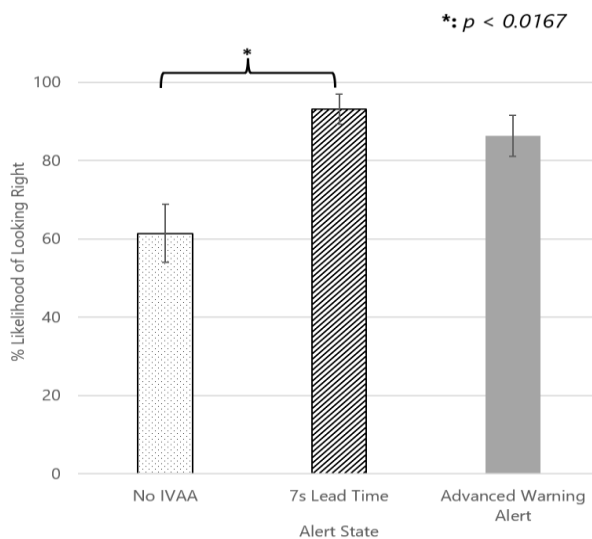


Figure 5: Influence of alert state on likelihood of looking right at the crossing

## 5. DISCUSSION

To determine the effect of lead time variations on driving performance at HRGCs, we conducted a driving simulator study with college-aged participants driving through three simulated scenarios containing rail crossings. The results of the experiment showed the effect of lead time variations on driver behavior when compared to the no IVAA condition, as well as numerical differences between a seven second lead time with an alert playing at advanced warning alerts.

First, workload scores indicate that the seven second lead time condition led to a statistically higher temporal workload when compared to the other alert states. The effect reflects other research in the automotive field [21, 22] regarding increased workload in more complex driving situations, but could also indicate increased awareness to the crossing threat due to the short timeframe between the alert location and the crossing, and a compensatory strategy to respond to it [23].

Vehicle speed results indicate that the presence of alerts significantly decreased average vehicle speed near the crossing. This result seems to indicate that vehicle drivers drove carefully around the crossing. Minimum vehicle speed at the crossing was significantly smaller for the seven second lead time condition than the no IVAA condition. These results indicate slight differences between the seven second lead time and advanced warning alert states, as pairwise comparisons did not show differences between the advanced warning alert and both the no IVAA and the seven second lead time alert states. These results might indicate the alert at the advanced warning location occurred too early, with results like longer lead times observed in previous studies [5, 24].

The effect of crossing location on average and minimum vehicle speed was observed and reflected differences in speed limits between the rural and urban crossings.

Results indicate the effect of alert state on gaze behavior at rail crossings. The presence of an alert significantly increased the likelihood of looking left at crossings, reflecting the benefits of using IVAAs [3]. Additionally, similarly to minimum speed reached at crossings, no statistical difference was found between the no IVAA condition and the advanced warning alert, with a higher numerical value for the seven second lead time alert. This furthers previous findings regarding speed and workload score differences associated with this alert state. Though the results are not statistically different than the advanced warning alert state, the results seem to indicate improved performance for a seven second lead time alert at HRGCs, although more work is needed to clarify this effect.

The effect of crossing location on gaze behavior was observed, with a higher likelihood of looking left at crossings for passive crossings. As the active crossings were deactivated, results likely indicate drivers assumed the active crossings meant no threat was present, leading to inattentive behavior, as previous research has shown [9]. Further confirming this effect, the effect of crossing type on average vehicle speed was found, with speed at active crossing being statistically higher than speed at passive crossings.

## 6. LIMITATIONS

The results of this study are limited due to the small pool of participants recruited. In future research, we plan to investigate the effect of alert lead time variation. Additionally, we also seek to evaluate driving performance under driving conditions with higher workload demands, such

as nighttime driving, as the lack of statistically significant differences between alert states may indicate a ceiling effect.

## 7. CONCLUSION & FUTURE WORK

We conducted a driving simulation study evaluating the effect of different lead times on driving performance. Though results did not show a statistically significant difference between the two lead time conditions, the results confirm the benefit of IVAAs in improving driving performance and gaze behavior. Additionally, numerical differences between the seven second and advanced warning conditions may indicate the possibility of the seven second lead time being the most appropriate for the rail crossing situation. We plan to conduct an expanded driving simulator study with a larger pool of participants to determine whether this effect can be statistically significant in more demanding conditions.

## 8. ACKNOWLEDGEMENTS

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project is made possible through Federal Railroad Administration, BAA Contract 693JJ6-18-C-000027 Effects of In-Vehicle Auditory Alerts on Driver Behaviors at Highway Rail Grade Crossing–PHASE 1.

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