Applying Ecological Interface Design principles to the design of rural highway-rail grade crossing infrastructure

Link to publication record in USC Research Bank:
http://research.usc.edu.au/vital/access/manager/Repository/usc:24221

Document Version:
Author accepted manuscript (postprint)

Citation for published version:
Beanland, Vanessa; Grant, Eryn L; Read, Gemma J M; Stevens, N J; Thomas, Miles; Lenne, Michael G; Stanton, Neville A; Salmon, P M (2017) Applying Ecological Interface Design principles to the design of rural highway-rail grade crossing infrastructure. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* pp.1887-1891.

Applying Ecological Interface Design principles to the design of rural highway-rail grade crossing infrastructure

Vanessa Beanland[a], Eryn Grant[a], Gemma J. M. Read[a], Nicholas Stevens[a], Miles Thomas[a],
Michael G. Lenné[b], Neville A. Stanton[c] & Paul M. Salmon[a]

[a] Centre for Human Factors and Sociotechnical Systems, University of the Sunshine Coast, Maroochydore, QLD, Australia; [b] Monash University Accident Research Centre, Monash University, Clayton, VIC, Australia; [c] Transportation Research Group, Civil, Maritime, Environmental Engineering and Science, Faculty of Engineering and the Environment, University of Southampton, Southampton, UK.

Countries such as Australia and USA have many rail level crossings (a.k.a. highway-rail grade crossings) with limited protection (e.g., static signs only or flashing lights but no physical barriers). Lower cost design solutions are required as upgrading crossings using current infrastructure treatments is cost-prohibitive. Here we applied Ecological Interface Design (EID) principles to develop a novel rail level crossing design for high-speed rural roads, and then evaluated the design via two driving simulator studies. Experiment 1 provided an initial concept evaluation of the crossing, then Experiment 2 evaluated the crossing in safety-critical situations, including when a distractor was present and when crossing infrastructure was damaged through vandalism. Driving performance, subjective workload, and usability were compared against existing rural crossing designs. Findings suggest the EID crossing provides a feasible alternative to existing designs, with the potential to encourage safer decision-making by road users and thus reduce collisions.

INTRODUCTION

Collisions at *rail level crossings* (a.k.a. *highway-rail grade crossings*) are an enduring problem. The most effective countermeasure for reducing collisions is to install boom barriers or gates that close to prevent road users entering the tracks when a train is approaching (Saccomanno, Park, & Fu, 2007). However, in countries such as Australia and USA most rail level crossings, especially in rural areas, have only passive protection (e.g., static signs instructing the road user to stop, yield or look for trains), or active controls with no boom gates (e.g., red flashing lights only). Due to the high cost, installing gates at all crossings is not feasible in many jurisdictions, so lower-cost design solutions are required to improve safety.

There are various issues associated with these existing passive treatments. They have low compliance (e.g., drivers do not stop) and high error rates (i.e., drivers fail to look for or detect trains), especially at low-traffic crossings on high-speed roads (Read, Beanland, Lenné, Stanton, & Salmon, 2017). Drivers may become complacent when trains are rare, as they implicitly assume they will not encounter a train, and therefore approach rural rail level crossings with a different mindset to urban crossings (Salmon, Read, Stanton, & Lenné, 2013). New rural rail level crossing designs are required to improve safety, which should allow for high travel speeds by road vehicles, and should also ensure that drivers search for trains, detect them when present, and ultimately make safe decisions.

One design approach that has been used with some success in transportation is the Ecological Interface Design (EID) philosophy (Vicente & Rasmussen, 1992). To generate a novel design intended to satisfy these requirements, we applied EID principles to the Australian rural rail level crossing environment. EID is a “top-down” approach that bases design requirements on an understanding of the system constraints that limit behavior, coupled with an understanding of human capabilities and limitations. EID is intended to support users in both familiar and unfamiliar situations, with emphasis on supporting users to make appropriate decisions in unanticipated situations (Vicente & Rasmussen, 1992). This is achieved through making constraints explicit to design end-users. An example situation could be a driver encountering a train unexpectedly on a train line they assumed was not operational. EID employs the skills, rules, knowledge taxonomy, which postulates that people use three mechanisms for information processing: skill-, rule- and knowledge-based behavior. Skill- and rule-based behaviors are based on immediate perception of a situation, whereas knowledge-based behavior requires deeper analytical processing (McIlroy & Stanton, 2015). The principles of EID dictate that a design should support all three mechanisms, but should not require its user to activate a higher level of cognitive control than the task inherently demands. That is, EID allows direct perception and action, but also supports analytical problem-solving. The abstraction hierarchy tool from the initial phase of Cognitive Work Analysis, Work Domain Analysis (WDA) is used to identify the constraints of the system, and becomes the basis for EID (Vicente & Rasmussen, 1992).

The EID philosophy has been applied to diverse domains, such as healthcare (Watson & Sanderson, 2007) and transport (Young & Birrell, 2012). Evaluations indicate that EID interfaces outperform traditional interfaces (Burns & Hajdukiewicz, 2004; Vicente, 2002). Previous applications focused on human-machine interfaces; here we extended the application of EID by considering the rail level crossing environment as a physical interface that mediates interactions between road users and trains.

To generate the EID rail level crossing, human factors researchers participated in a design workshop where they were instructed to generate a new design for a specific rural environment. The workshop was aimed at generating an innovative design rather than incremental revision of existing designs (Read et al., 2017). Workshop participants reviewed WDA outputs to identify key constraints on road users’ behavior at rural level crossings, and considered what would happen if constraints were removed, strengthened, or made more explicit to users. Consideration was given to how skill-, rule- and knowledge-based behavior could be supported.

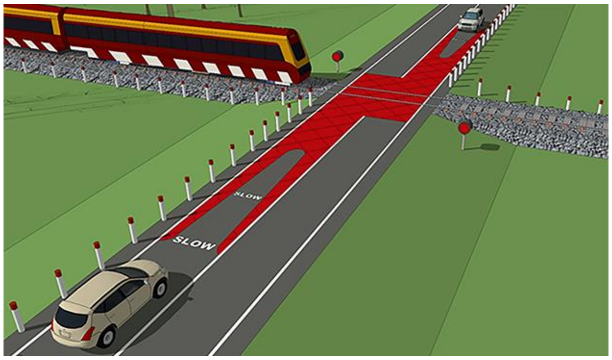

Figure 1. Design concept for the EID rail level crossing.

The workshop process resulted in the generation of a new EID rail level crossing, shown in Figure 1, which incorporated design features intended to make key constraints visible to road users. A colored area across the tracks emphasizes the danger zone, with colored markings extending back along the approach road and forming a ‘tongue’ intended to represent a static field of safe travel (Gibson & Crooks, 1938) that ends at just before the crossing. Poles are placed along both the road and train tracks, with intervals decreasing on approach to the crossing, to provide a reference point for road vehicle drivers and train drivers to judge the speed of the approaching traffic, and to emphasize the constraint of speed by increasing self-perceived travel speed. Large mirrors at the crossing reflect the image of an approaching train to represent its relative distance, shifting this constraint from the track to the roadway directly in front of road users. The mirrors also reflect the sound of the train horn toward the roadway. The train appearance is altered to increase its visual saliency. Finally, train speed is slowed to 20 km/h (12 mph) through the crossing to provide the train driver with more control to stop if they perceive a potential collision with a road vehicle.

We conducted two driving simulator studies to evaluate how the proposed EID rail level crossing design influenced drivers’ behavior, compared against two existing designs.

GENERAL METHOD

Participants

Experiment 1 included 30 fully-licensed drivers (21 male) with an average of 14.8 years’ driving experience (*SD* = 12.3). Experiment 2 included 25 fully-licensed drivers (8 male) with an average of 15.0 years’ driving experience (*SD* = 11.2).

Ethical aspects of the research were approved by the University of the Sunshine Coast Human Research Ethics Committee. All participants provided written informed consent and received financial reimbursement for their time.

Apparatus

A medium-fidelity fixed-base driving simulator was used, comprising an adjustable driver’s seat, automatic transmission, Logitech G27 vehicle controls (brake, accelerator, steering wheel), and three 40” LCD monitors representing a 135° field of view. The vehicle instrument panel was displayed on a 9.7” tablet screen. Oktal SCANeR™ studio v1.5 was used to program the scenarios and collect performance measures.

Questionnaires

Participants provided demographic information including driving experience and habits. Subjective workload was assessed using the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), which incorporates six subscales: mental demand, physical demand, temporal demand, performance, effort and frustration. Perceived usability was assessed via an adapted version of the System Usability Scale (SUS; Brooke, 1996), in which participants rated each crossing’s likability, complexity, ease of use, and need for technical support.

Procedure

Prior to commencing the study, participants were given an overview of the research methods and provided written informed consent. Participants then completed a brief demographic questionnaire, before being seated comfortably in the driving simulator for a brief familiarization drive, followed by five experimental drives.

After each drive, participants completed the NASA-TLX twice: once thinking about rail level crossing encounters when a train was present, and once thinking about rail level crossing encounters when no train was present. Finally, participants completed the SUS considering their overall experiences with the rail level crossing design, and were asked to indicate what they liked and disliked about the crossing.

Data Analysis

In Experiment 1, EID was compared with both a standard active and standard passive crossing. In Experiment 2, EID was compared with a standard active crossing only. This paper presents analysis of mean speeds only, which were compared using repeated-measures analysis of variance (RM-ANOVA). Greenhouse-Geisser corrections were applied where Mauchly’s test was significant.

Wilcoxon Signed Rank Tests were used to compare NASA-TLX and SUS scores between EID and the standard crossings. NASA-TLX subscales were rated 0-20, where higher scores indicate higher subjective workload. SUS scores were 0-4 for individual attributes and 0-100 for overall usability, where higher scores represent greater usability.

Wilcoxon Signed Rank Tests were also used to compare response times (RTs) in Experiment 2, as Shapiro-Wilks tests indicated RTs were not normally distributed. RTs >4s were considered lapses and removed before analysis.

EXPERIMENT 1

Experiment 1 was designed to provide an initial concept evaluation for the EID crossing. Participants experienced five rail level crossing designs: two existing standard designs and three novel designs (EID and two others). The current paper focuses the comparison between EID and existing standards. Each crossing design was encountered multiple times both with and without a train present. The two existing standard designs included one active crossing featuring flashing lights and bells but no boom barriers, and one passive crossing featuring only a Give Way (yield) sign. Both conformed to contemporary Australian design standards (AS 1742.7–2007) and were selected as they represent the types of existing crossings that would likely be prioritised for upgrade.

Method

Participants completed five simulated drives, with each drive featuring a different rail level crossing design (see Figure 2) but matched in terms of road environment and traffic conditions. The default speed limit was 100 km/h (62 mph), but reduced to 80 km/h (50 mph) on approach to each rail level crossing, reflecting real-world conditions. Within each drive, the participant drove continuously through a rural setting and encountered five rail level crossings: two with a train present and three with no train. All rail level crossings were situated on a straight stretch of road with good sight distance. The first rail level crossing was always in an inactive (train-absent) state, with the order of subsequent train-present and train-absent exposures counterbalanced between drives. Drive order was fully counterbalanced between participants.

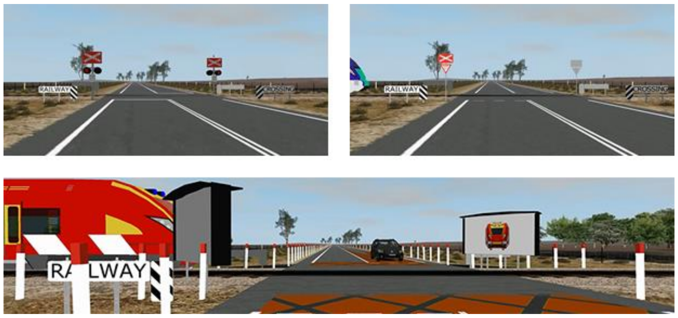

Figure 2. Screen captures of the standard active (top left), standard passive (top right) and EID (bottom) rail level crossing designs as rendered in the driving simulator.

Results and Discussion

Approach speeds. The RM-ANOVA included 3 factors: crossing type (EID, active, passive); train (present, absent) and approach zone (zone 1: 250-150m away, zone 2: 150-50m away, zone 3: 50-0m away). Mean speed significantly decreased across zones, $F_{1.6,46.3} = 59.08$, $p < .001$, $\eta_p^2 = .67$, from 67.8 km/h ($SE = 1.7$) in zone 1, to 52.9 km/h ($SE = 1.5$) in zone 2, and 50.0 km/h ($SE = 1.3$) in zone 3. Speed was significantly slower for train-present ($M = 51.0$ km/h, SE = 0.8) versus train-absent ($M = 62.8$, $SE = 1.5$) encounters, $F_{1,29} = 157.14$, $p < .001$, $\eta_p^2 = .84$. There was no main effect of crossing type on speed, $F_{2,58} = 0.96$, $p = .388$, $\eta_p^2 = .03$, but there was a significant 3-way interaction between crossing, train and zone, $F_{2.6,75.5} = 19.09$, $p < .001$, $\eta_p^2 = .40$ (see Figure 4). Interestingly, at the standard active crossing drivers reduced speeds to the same extent regardless of whether a train was present. In contrast, for the EID and standard passive crossing, drivers showed minimal reduction when trains were absent but large speed reductions when a train was present. All crossings had good sight distance, so one possibility is that drivers were scanning for trains on approach to the EID and passive crossings, and proceeded without slowing when they determined there was no train, whereas for the active crossing they focused on the flashing light assembly and needed to slow to adequately assess whether it was activated.

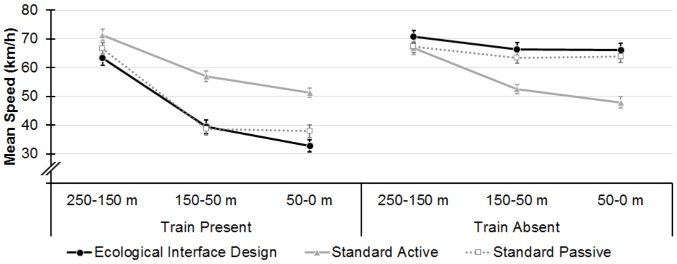

Figure 3. Mean speeds on approach to each crossing type (Exp 1), comparing train-present and train-absent encounters.

Mean speeds were similar on approach to EID and the standard passive crossing, but were significantly slower on approach to EID when a train was present and non-significantly higher when no train was present (see Figure 3). This suggests EID effectively highlights relevant constraints to drivers; that is, the design encouraging drivers to look for trains and slow when necessary, but did not compromise travel efficiency when no train was present.

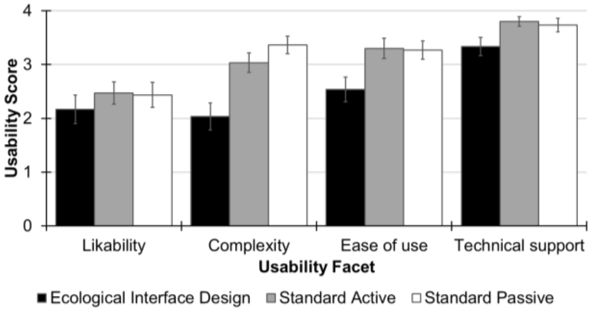

Figure 4. Comparison of usability scores (Exp 1) between EID, standard active and standard passive rail level crossings.

Usability. The EID crossing was rated as having significantly lower overall usability ($Mdn = 65.6$) compared with both the standard active crossing ($Mdn = 81.3$, $Z = -2.726$, $p = .006$) and the standard passive crossing ($Mdn = 81.3$, $SD = 18.4$, $Z = -2.973$, $p = .003$). Analysis of individual items revealed that EID was rated as significantly worse than existing designs with respect to complexity (higher), ease of use (lower), and requirement for technical support (higher), but not likeability (see Figure 4).

Subjective workload. Several aspects of workload were elevated for EID compared with the standard active crossing. Participants reported higher physical demands when a train was approaching (EID: $Mdn = 3.0$; active: $Mdn = 1.0$; $Z = -2.772$, $p = .006$), higher temporal demands when no train was approaching (EID: $Mdn = 3.5$; active: $Mdn = 2.0$; $Z = -1.994$, $p = .046$), and higher frustration both with (EID: $Mdn = 4.5$; active: $Mdn = 2.0$; $Z = -2.270$, $p = .023$) and without a train (EID: $Mdn = 4.0$; active: $Mdn = 2.0$; $Z = -2.143$, $p = .032$). When comparing EID with the standard passive crossing, the only significant difference was that participants reported higher effort when no train was present (EID: $Mdn = 4.0$; passive: $Mdn = 3.5$; $Z = -2.098$, $p = .036$). This suggests elevated workload relative to the active crossing stemmed largely from the omission of active controls. Note that even where comparisons were statistically significant, the difference was small and most workload ratings were at the extreme lower end of the scale (<5; possible range 0-20).

Overall impressions. Participants' open-ended responses indicated that they liked the train color and salience. Some drivers liked the road markings and roadside reflector poles, which encouraged slower approach speeds, but some found the infrastructure overwhelming. The mirrors generated confusion for some participants, due to graphical fidelity of the simulation: the driver-facing mirror was rendered as a flat grey sign (see Figure 2), so some participants did not recognize it as a mirror.

EXPERIMENT 2

Experiment 2 was designed to assess drivers' responses to the EID crossing in safety-critical situations. Two safety issues were identified based on previous research (Read et al., 2017) and through consultation with rail and road industry stakeholders: *driver distraction* and *system reliability*. Regarding distraction, stakeholders expressed concern that new in-vehicle technology (both driving- and non-driving-related) could distract drivers on approach to rail level crossings, impacting their ability to identify critical cues. This could be especially problematic at passive crossings where there are active warnings to divert drivers' attention back to the crossing. Regarding system reliability, participants in a previous study expressed concern that signals may fail in rural areas (Read et al., 2017). Because existing passive crossings do not have technology that can fail, Experiment 2 compared EID with the standard active crossing only.

Method

Participants completed five simulated drives, based on the designs from Experiment 1. Each drive included four rail level crossings encounters with different approach conditions:

- No train approaching, normal conditions.
- Train approaching, normal conditions.
- No train approaching, in-vehicle distraction.
- Train approaching, system failure state.

The first crossing in each drive was the normal train-present condition, to expose participants to the design in its normal active state. The order of other encounters was counterbalanced between conditions. The drive featuring the standard passive crossing had only three crossings, as no system failure state was included. The order of experimental drives was counterbalanced between participants, except the third drive which was always the standard passive crossing, included to "reset" participants' expectations about the drive duration and format (i.e., that all will include four crossings, with one technology failure).

In-vehicle distraction. A visual detection task was used to evaluate the influence of in-vehicle distraction in three contexts: on a straight road; on a corner; and approaching a rail level crossing. The distractor task required participants to immediately press a button on the steering wheel, whenever they detected a small red dot that appeared at the bottom of the center screen of the simulator at pseudo-random intervals. This task has been found to induce distraction-related errors in real driving (e.g., Young, Salmon, & Cornelissen 2013). The current analysis focused on performance on approach to rail level crossings. Systematic differences in RTs would suggest EID either increases or decreases attentional demands (i.e., fast RTs indicate low attentional demands).

System failure state. The system failure state involved participants experiencing each rail level crossing design in a situation where there was a train approaching and warnings were unavailable or functioning in a suboptimal manner. Because each design included unique warnings, each had a unique failure state, based on plausible real-world problems.

Rail industry stakeholders indicated that technical issues can involve complete failure (i.e., no warning), but more commonly involve delayed or mistimed warnings (i.e., full warning time not provided), so for the standard active crossing, the failure state involved delayed warning activation, with the flashing lights and bells triggered 15s later than normal. (Australian standards specify a minimum warning time of 25s, so this represents a substantial delay.)

During the design process, it was noted that the EID crossing mirrors may be subject to vandalism, so the EID fail state involved vandalism, with the mirrors depicting the approaching train being defaced by graffiti (thus obscuring vision of approaching trains).

Results and Discussion

Distraction task. Effects of distraction on mean speed during train-absent level crossing encounters were assessed using RM-ANOVA with 3 factors: crossing (EID, active), approach zone (1, 2, 3), and distraction (none, distracted). The only statistically significant effect was the main effect of zone, $F_{1.1,26.0} = 22.04$, $p < .001$, $\eta_p^2 = .48$. Mean speed reduced significantly from zone 1 ($M = 70.6$, $SE = 2.1$) to zone 2 ($M = 62.8$, $SE = 2.4$) and zone 3 ($M = 57.0$, $SE = 3.7$). The crossing*zone interaction approached significance, $F_{1.5,36.4} = 3.30$, $p = .061$, $\eta_p^2 = .12$:, drivers showed larger speed reductions for EID compared with the standard active crossing. The distractor task did not influence mean speed or interact with other variables (all Fs < 1, ps > .45).

RTs to the distractor task were systematically longer for EID ($M = 1.38$s, $SD = 0.77$, $Mdn = 1.25$) compared with the standard active crossing ($M = 1.11$s, $SD = 0.43$, $Mdn = 1.05$), $Z = -2.148$, $p = .032$. Consistent with this, temporal workload for train-absent encounters was rated significantly higher for EID ($Mdn = 3.0$) versus the standard active crossing ($Mdn = 1.0$), $Z = -2.222$, $p = .026$. No other aspects of workload differed significantly between crossings.

System failure. Effects of system failure on mean speed were assessed using RM-ANOVA with 3 factors: crossing, approach zone, and failure state (normal, failure). This revealed a significant main effect of crossing, $F_{1,24} = 45.67$, $p < .001$, $\eta_p^2 = .66$. Approach speeds were slower for EID ($M = 38.7$, $SE = 1.4$) compared with the standard active crossing ($M = 44.1$, $SE = 1.3$). There was also a significant main effect of zone, $F_{1.2,28.8} = 55.38$, $p < .001$, $\eta_p^2 = .70$. Mean speed reduced significantly from zone 1 ($M = 62.5$, $SE = 2.8$) to zone 2 ($M = 37.2$, $SE = 2.5$) and zone 3 ($M = 24.6$, $SE = 2.1$). Finally, there was a significant crossing*zone interaction, $F_{2,48} = 3.40$, $p =$

.042, η_p^2 = .12. As shown in Figure 5, the decrease in speed across zones was larger for EID than for the standard active crossing. The crossing*failure state interaction approached statistical significance, $F_{1,24}$ = 3.73, p = .065, η_p^2 = .14. In the system failure state drivers exhibited reduced speed on approach to EID, but not the standard active crossing.

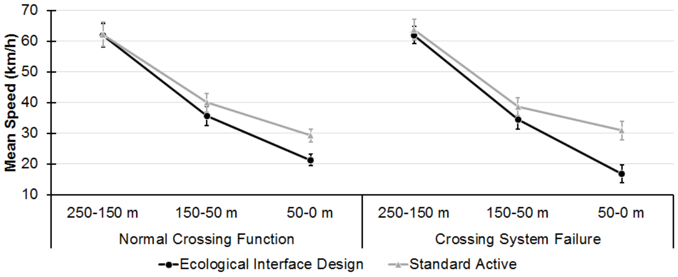

Figure 5. Mean speeds during train-present encounters (Exp 2) by crossing type and system failure state.

Subjective workload ratings were similar (and very low) for EID and the standard active crossing. However, when a train was present performance ratings were significantly *lower* (i.e., better performance) for EID compared with the standard active crossing, Z = -2.663, p = .008, although the difference was very small (Mdn = 2.0 for both designs).

Usability. Overall usability scores were not significantly lower for EID (Mdn = 75.0) compared with the standard active crossing (Mdn = 87.5), Z = 1.403, p = .161, and none of the individual aspects of usability were significantly different.

GENERAL DISCUSSION

This study presented a novel rail level crossing design for rural environments, based on EID principles, and evaluated it using two driving simulator studies. When a train was present and/or when they were distracted, participants showed greater speed reductions at the EID crossing compared with the standard active crossing. This suggests the design encouraged more cautious behavior as intended; that is, drivers slowed when necessary to look for trains or deal with secondary tasks. As the design was driven by EID principles, these findings suggest that the explicit representation of constraints within road environments can potentially improve road user behavior.

Importantly, however, drivers did not slow unnecessarily, as approach speeds for EID train-absent encounters in Experiment 1 were higher than for the standard active crossing. This indicates that the design increases safety without unduly compromising efficiency. Participants commented positively on several aspects of the design, particularly the salient train and road markings.

Interestingly, experiencing the EID crossing under safety-critical situations seemed to improve participants' perceptions of its usability and impact on workload. In Experiment 1, where the crossings were encountered repeatedly under optimal functioning conditions, EID was generally rated as having lower usability and higher workload compared with the standard designs, whereas Experiment 2 showed minimal differences on these measures. One possibility is that the optimal conditions in Experiment 1 reinforced participants' positive experiences with existing designs, so the novel EID design was perceived as comparatively more difficult to negotiate. In Experiment 2, exposure to unreliable warnings highlighted the relative advantages of the EID design; namely, that relevant constraints were available to participants to assist them to respond appropriately to an approaching train.

While the findings provide promising evidence regarding EID for road environment design, the studies presented here represent only the first step in the evaluation process. The simulator studies, although useful for experimentally testing novel infrastructure, had inherent limitations (e.g., sample sizes are typically small and may not be representative). The most notable limitation of the study was its inability to fully simulate all intended design features, especially the mirrors. This highlights the fact that some crucial design aspects may only be meaningfully evaluated in field trials.

Overall the studies presented here demonstrate the potential utility of applying EID principles to transport infrastructure design, which to our knowledge is a novel application of EID that could prove useful in other domains (e.g., intersection designs).

ACKNOWLEDGEMENTS

This research was funded by Australian Research Council (ARC) Linkage Grant LP100200387 in partnership with VicTrack, Transport Safety Victoria, Public Transport Victoria, Transport Accident Commission, VicRoads and V/Line. VB is supported by ARC Discovery Early Career Researcher Award DE150100083, and PS is supported by ARC Future Fellowship FT140100681.

REFERENCES

Burns, C. M., & Hajdukiewicz, J. R. (2004). *Ecological interface design*. Boca Raton, FL: CRC Press.

Gibson, J. J., & Crooks, L. E. (1938). A theoretical field-analysis of automobile-driving. *The American Journal of Psychology*, *51*, 453-471.

McIlroy, R. C., & Stanton, N. A. (2015). Ecological interface design two decades on: whatever happened to the SRK taxonomy? *IEEE Transactions on Human-Machine Systems*, *45*(2), 145-163.

Read, G. J. M., Beanland, V., Lenné, M. G., Stanton, N. A., & Salmon, P. M. (2017). *Integrating Human Factors Methods and Systems Thinking for Transport Analysis and Design*. Boca Raton, FL: CRC Press.

Read, G., Salmon P. M., & Lenné, M. G. (2016). When paradigms collide at road and rail interface: Evaluation of a sociotechnical systems theory design toolkit for cognitive work analysis. *Ergonomics*, *11*, 1-23.

Saccomanno, F. F., Park, P. Y.-J., & Fu, L. (2007). Estimating countermeasure effects for reducing collisions at highway–railway grade crossings. *Accident Analysis & Prevention*, *39*(2), 406-416.

Salmon, P. M., Read, G. J. M., Stanton, N. A., & Lenné, M. G. (2013). The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. *Accident Analysis & Prevention*, *50*, 1278-1288.

Vicente, K. J. (2002). Ecological interface design: Process and challenges. *Human Factors*, *44*, 62-78.

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics*, *22*(4), 589-606.

Watson, M. O., & Sanderson, P. M. (2007). Designing for attention with sound: Challenges and extensions to ecological interface design. *Human Factors*, *49*, 331-346.

Young, K. L., Salmon, P. M., & Cornelissen, M. (2013). Distraction-induced driving error: An on-road examination of the errors made by distracted and undistracted drivers. *Accident Analysis & Prevention*, *58*, 218-225.

Young, M. S., & Birrell, S. A. (2012). Ecological IVIS design: Using EID to develop a novel in-vehicle information system. *Theoretical Issues in Ergonomics Science*, *13*, 225-239.