AN EXPLORATORY STUDY ASSESSING DRIVER BEHAVIOUR AT HIGHWAY-RAIL GRADE CROSSINGS USING ON-ROAD TEST VEHICLES

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ABSTRACT

Crashes at rail level crossings represent a significant problem, both in Australia and worldwide. Advances in driving assessment methods, such as the provision of on-road instrumented test vehicles, now provide researchers with the opportunity to further understand driver behaviour at rail level crossings in ways not previously possible. This paper gives an overview of a recent on-road pilot study of driver behaviour at rail level crossings in which 25 participants drove a pre-determined route, incorporating 4 rail level crossings, using MUARC’s instrumented On-Road Test Vehicle (ORTeV). Drivers provided verbal commentary whilst driving the route, and a range of other data were collected, including eye fixations, forward, cockpit and driver video, and vehicle data (speed, braking, steering wheel angle, lane tracking etc). Participants also completed a post trial cognitive task analysis interview. Extracts from the wider analyses are used to examine in depth driver behaviour at one of the rail level crossings encountered during the study. The analysis presented gives insight into the driver and wider systems factors that shape behaviour at rail level crossings, and highlights the utility of using a multi-method, instrumented vehicle approach for gathering data regarding driver behaviour in different contexts.

Keywords: highway-rail grade crossing, instrumented vehicle, cognitive task analysis, driver behaviour.
INTRODUCTION

The intersection of the railway system with the road transport system, through highway-rail grade crossings, represents one key area in which optimum efficient performance has not yet been achieved. Collisions at these crossings, such as collisions between trains and vehicles, impact both the efficiency and safety of the rail and road systems. As an example of the size of the problem, there were 2592 accidents and 892 fatalities at Rail Level Crossings (RLCs) in the European Union across 2006-7 (European Railway Agency, 2009). In the US in 2007 there were 2206 crashes and 229 deaths (U.S. Department of Transportation, 2009). Within Australia during 2009 there were 58 collisions at RLCs (Australian Transport Safety Bureau [ATSB], 2009). These crashes typically involve traumatic injury, and the economic impacts of disruption to the rail and road networks are significant. This is particularly so for heavy vehicle collisions as they have a much greater potential to derail the train.

Achieving acceptable levels of performance and safety at highway-rail grade crossings has proven difficult partly because they are not homogeneous. These crossings are typically classified as one of two types: those with active warnings (e.g., flashing red lights), or passive crossings (protected by stop or give way signs). Further, there are differences in the volume of rail and road traffic, the type and speed of traffic, overall crossing geometry, and so on. All of these factors influence fundamental aspects of human performance that shape road user behaviour and thus the appropriate solution. Across Australia there are approximately 9,400 highway-rail grade crossings, with 6,060 passive (60%), 2,650 (30%) active, and 690 (10%) having other forms of control (Australian Transport Council, 2003). Current solutions to the problem, such as grade separation and installation of boom barriers, provide significant safety improvements (Wigglesworth & Uber, 1991), but remain cost prohibitive. The effectiveness of lower cost countermeasures, such as education campaigns, speed limit reductions, rumble strips, train strobe lightings and in-vehicle warnings remains largely unknown, with the evaluations conducted to date being poorly designed and lacking a sound underpinning theoretical framework (Edquist, Stephan, Wigglesworth, & Lenné, 2009).

Key to developing effective crash countermeasures for these crossings is an in-depth understanding of the RLC system, including the performance of, and interactions between, its component parts (road users, vehicles, trains, train drivers, infrastructure, etc). Although a limited number of models have been developed, currently we do not possess this systemic understanding. For example, statistical models have been developed, based on analyses of existing crash data, to describe the safety benefits provided by specific countermeasures such as stop signs (Yan, Richards, & Su, 2009) and to predict effectiveness across a wider range of measures at RLCs (Austin & Carson, 2002; Saccomanno, Park, & Fu, 2007). Although these models do provide guidance to engineers and policy makers, they are not based upon, nor do they consider, models of human or system performance. Behaviour-based models have been developed to describe car driver performance (Cacciabue & Carsten, 2010; Michon, 1985), but these models are yet to be extended to the level crossing domain.

This paper reports on an exploratory study of driving behaviour at highway-rail grade crossings using our on-road test vehicle. The aim of this paper is to examine the types of factors influencing driver decision-making and behaviour at highway-rail grade crossings. Existing
knowledge of driver behaviour at these crossings, and the role of simulation, is considered in the following sections.

Understanding driver behaviour at highway-rail grade crossings

There have been a modest number of published studies that address aspects of driver behaviour at highway-road grade crossings. There are challenges to conducting research into driver behaviour at RLC, both in the field and using simulation, that no doubt contribute to this. While some studies focus on driver behaviour at crossings when no trains are present (Åberg, 1988; Ward & Wilde, 1995a, 1996), many focus on behaviour when a train is approaching and when warning signals for active crossings become activated. For this latter group of studies a primary obstacle is the low rate of exposure to on-coming trains. This presents practical challenges when trying to assess behaviour in the field as a very large number of testing hours are required to collect very modest numbers of observations, which does not make such studies cost-effective.

The majority of research conducted to date that has explored driver behaviour at highway-road grade crossings has employed observational methods, typically involving video-analysis of large traffic volumes or through the use of trained observers located on-site. The aim here is to understand driver behaviour on approach to a crossing when a train is approaching. If a driver responds appropriately to a level crossing control when a train is approaching then the chances of a safe interaction should be increased. For this reason driver compliance with warning signs and signals is the most common performance measure used in these observational studies. It is also straightforward to measure during on-site observation or video analysis as it is not necessary to stop and interview drivers to collect additional information. Compliance with level crossing controls in the field has been found to be variable; ranging from 10% - 67% with flashing lights (Meeker & Barr, 1989; Meeker, et al., 1997; Tenkink & Van der Horst, 1990) and from 14% - 38% with barrier gates and flashing lights (Meeker, et al., 1997; Witte & Donohue, 2000). Other measures used include speed on approach to a crossings and lateral head checks (Åberg, 1988; Ward & Wilde, 1995b).

While these on-road observational studies provide important findings, particularly with regard to driver compliance with crossing controls, they do not shed light into the underlying factors that shape a driver’s response to crossing controls. This remains significant because, as noted previously (e.g., Tenkink & Van der Horst, 1990), the various causes of level crossing crashes remain poorly understood, but fall into two broad classes. The first is unintentional error, encompassing situations where the drivers may fail to detect the warnings or to apprehend their meaning, even if the site is known and the warnings are clearly visible. According to the Federal investigation body in Australia, this type of error accounts for nearly half of fatal level crossing crashes in Australia (ATSB, 2002), compared to 22% for all other fatal road crashes. These drivers do not detect potential threats and therefore are at great risk. The second explanation may be that drivers see the lights and are fully aware of their meaning, but intentionally cross on their own judgment.

Driving simulation is also increasingly being used to study driver behaviour in a wide range of settings (e.g., Fischer, Rizzo, Caird & Lee, 2011). While it can be used to provide the controlled and increased exposure to on-coming trains that is missing in field studies (Triggs, 2002), this
must be balanced against the risk of measuring non-representative behaviour through exposure to a high number of low-frequency events within a short time period. Aside from being unrealistic it can result in heightened driver expectancy which can bias the results (Lenné et al., 2011). Nonetheless the increased control using simulation can provide a different approach to the analysis of driver behaviour at rail crossings. For example, in a recent study we examined driver responses to different forms of warnings at highway-rail grade crossings in rural areas including flashing red lights and traffic signals (Lenné et al., 2011). By carefully controlling the timing of train approach to the crossing and activation of warning signals, it was possible to measure driver reaction times and speed profiles on approach to the different crossing configurations, along with compliance to warnings, to assess the efficacy of each treatment. While simulation allows all participants to experience a similar scenario of a train approaching a crossing, and is suitable for in-depth hypothesis testing, it does provide a limited experience in terms of the range of signal timings, interaction with other road users, and so on, compared to that experienced on-road. While valuable for investigation of the how a given factor influences behaviour, it is problematic to extract the ‘why’ underlying the observed results.

The outstanding questions around the perceptual and motivational factors that influence crossing compliance remain and necessitate further exploration of this issue. That is, there is little understanding of why drivers behave as they do at highway-rail grade crossings. Recent developments in suites of technologies to instrument vehicles have seen a boom in the number of on-road in-vehicle studies being conducted. The study reported here aimed to capitalise on these developments by studying driver behaviour on-road, attempting to understand the factors that influence driver decision-making and behaviour at highway-rail grade crossings.

METHOD

Participants

Twenty-five participants completed the study, however data from the instrumented vehicle were available for 23 drivers (15 males, 8 females) aged 19-59 years (mean = 27.9, SD = 11.1). Participants were divided into an experienced driver group and a novice driver group. The experienced driver group comprised fourteen participants who held a valid Full license while the novice driver group comprised nine participants who held a valid Victorian Probationary (P2) license. The experienced driver group had a mean age of 32.7 yrs and had an average of 14.3 yrs solo driving experience (SD = 11.8 yrs) average. The novice driver group had a mean age of 19.8 and had an average of 1.8 years solo driving experience (SD = 0.8 yrs). Participants were recruited through the weekly on-line Monash University newsletter and were compensated for their time. Prior to commencing the study ethics approval was formally granted by the Monash Human Ethics Committee.

Data collection approaches

The methodology employed during the on-road study utilised a range of different approaches for collecting detailed data on driver performance at highway-rail grade crossings. An overview of the methodology used is presented in Figure 1 and a brief description of the component methods follows.
On-Road Test Vehicle (ORTeV)

The MUARC ORTeV is an instrumented vehicle equipped to collect two main types of data: vehicle-related and eye tracking data. The vehicle data are acquired from the vehicle network and include: vehicle speed, GPS location, accelerator and brake position (as well as vehicle lateral and longitudinal velocity and acceleration), steering wheel angle, lane tracking and headway logging, primary controls (windscreen wipers, turn indicators, headlights, etc.), and secondary controls (sat-nav system, entertainment system, etc.). Driver eye movements can be tracked and overlaid on a driver’s-eye camera view using the FaceLab eye tracking system. ORTeV is also equipped with seven unobtrusive cameras recording forward and peripheral views spanning 90° each respectively as well as three interior cameras and a rearward-looking camera. For the purposes of this study, vehicle-related data and eye tracking data were collected whilst drivers drove ORTeV around a pre-determined route.

Driver Verbal Protocols

Verbal Protocol Analysis (VPA), also commonly referred to as ‘think aloud’ protocol analysis, was used to elicit data regarding the cognitive and physical processes undertaken by drivers while driving the route. VPA is commonly used to investigate the cognitive processes associated with complex task performance and has been used to date to explore a range of concepts (e.g.,

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**Figure 1** On-road study methodology.
situation awareness, decision making) in various domains, including road transport (Walker et al., 2007). In the present study, participants provided verbal protocols continuously as they drove the instrumented vehicle around the test route. The verbal protocols were recorded using a digital Dictaphone, and transcribed verbatim post-trial using Microsoft Word.

**Critical Decision Method interviews**

Cognitive task analysis interviews were held post-drive with each participant using the Critical Decision Method (CDM; Klein, Calderwood & McGregor, 1989). The CDM is a semi-structured interview approach that has previously been used to investigate cognition and decision making in a range of domains, including road transport (Stanton et al., 2007; Walker et al., 2009). Each interview focussed specifically on one of the highway-rail grade crossings encountered by the participant during their drive. When using CDM, the interviewer uses a series of cognitive probes to interrogate the cognitive processes underlying the interviewee’s decision making and task performance during the activities in question. For this study, a set of appropriate cognitive probes was adapted from the literature on previous CDM applications (e.g., Crandall et al., 2006; O’Hare et al., 1998). The set of CDM probes used are presented in Table 1 on the following page.

**Procedure**

Upon completion of an informed consent form and demographic questionnaire, participants were briefed on the research and its aims, and informed what was required of them during data collection. Participants were informed that the study aimed to examine driver behaviour broadly in urban settings so as not to heighten participant expectancies around the crossings of interest.

After a short training session on the VPA method, participants were taken to the ORTeV and told to set themselves in a comfortable driving position. Once comfortable, the FaceLab eye tracking system was calibrated with the participant and the ORTeV data collection systems were initiated. Upon commencing the drive, participants completed a practice route and familiarised themselves with ORTeV and the VPA method. Upon reaching the end of the practice route, participants were informed that the test had begun and that data collection had now commenced. The route was a 21km urban route around the suburbs surrounding Monash University Campus, incorporating 4 active highway-rail grade crossings, all with boom barriers, bells and flashing light controls. Images of these four crossings, and the route selected to negotiate these crossings, are presented in Figure 2 on the following pages.

Two observers were present in the vehicle throughout the drive. On-route, the observer located in the front passenger seat provided directions, and a Dictaphone was used to record the driver verbal protocols. Upon completion of the drive, the two observers selected one of the rail level crossing negotiations for further analysis through CDM interview. The participant was then interviewed using the CDM probes. The CDM interview was recorded using a Dictaphone, and the interviewer also took written notes using a CDM interview pro-forma. For each of the rail level crossings negotiated, data of interest (e.g. FaceLab, speed, braking, lateral vehicle position, video data) was extracted from ORTeV for further more detailed analysis.
Table 1  CDM probes used during on-road study.

<table>
<thead>
<tr>
<th>Target Theme</th>
<th>Candidate probes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal specification</td>
<td>What were you aiming to achieve during this activity?</td>
</tr>
<tr>
<td>Decisions</td>
<td>What decisions/actions did you make during the event?</td>
</tr>
<tr>
<td>Cue identification</td>
<td>What information/features did you look for/use when you made your decisions?</td>
</tr>
<tr>
<td>Influencing factors</td>
<td>What was the most important factor that influenced your decision making at this point?</td>
</tr>
<tr>
<td>Options</td>
<td>What other courses of action were available to you?</td>
</tr>
<tr>
<td></td>
<td>Why was the chosen option selected?</td>
</tr>
<tr>
<td>Situation awareness</td>
<td>What sources did you use to gather this information?</td>
</tr>
<tr>
<td></td>
<td>What prior experience or training was helpful in making the decisions?</td>
</tr>
<tr>
<td>Situation assessment</td>
<td>Did you use all of the information available to you when making decisions?</td>
</tr>
<tr>
<td></td>
<td>Was there any other information that you could have used/would have been useful when making the decisions?</td>
</tr>
<tr>
<td>Information integration</td>
<td>What was the most important piece of information that you used to make your decisions?</td>
</tr>
<tr>
<td>Influence of uncertainty</td>
<td>At any stage, were you uncertain about the accuracy or relevance of the information that you were using?</td>
</tr>
<tr>
<td>Mental models</td>
<td>Did you run through in your head, the possible consequences of this decision/action?</td>
</tr>
<tr>
<td>Decision blocking - stress</td>
<td>At any stage during the decision making process did you found it difficult to understand and use the information?</td>
</tr>
<tr>
<td></td>
<td>How much time pressure was involved in making the decisions/performing the task?</td>
</tr>
<tr>
<td></td>
<td>How long did it take to make the decision?</td>
</tr>
<tr>
<td></td>
<td>Did you, at any point, find it difficult to process and integrate the information?</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Are there any situations in which your decisions/actions would have turned out differently?</td>
</tr>
<tr>
<td>Basis of choice</td>
<td>Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision/performing the same task successfully?</td>
</tr>
<tr>
<td></td>
<td>Were you confident at the time that you were making the right decision/performing the appropriate actions?</td>
</tr>
<tr>
<td>Analogy/Generalisation</td>
<td>If you could go back, would you do anything differently? If yes, what?</td>
</tr>
<tr>
<td>Interventions</td>
<td>Is there anything that you think could be done to prevent similar errors being made during similar situations?</td>
</tr>
</tbody>
</table>
Figure 2. Images and bird’s eye view of the four highway-rail grade crossings.
RESULTS

Cognitive task analysis interview data

A total of 25 CDM interviews were conducted, one for each participant focusing on one of the crossings encountered during the drive. The CDM interview transcripts were coded by one analyst. This involved identifying keywords from each interview question response, which in turn allowed key themes for each CDM probe to be identified from the data. The key themes were then analysed using frequency counts and the outputs are presented in Table 2.

Table 2 Frequency of responses (% in parentheses) from the CDM interviews and VPA

<table>
<thead>
<tr>
<th>Theme</th>
<th>Elements</th>
<th>CDM Data</th>
<th>VPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing elements</td>
<td>Crossing itself</td>
<td></td>
<td>18 (71)</td>
</tr>
<tr>
<td></td>
<td>Bells &amp; Lights</td>
<td>25 (100)</td>
<td>9 (36)</td>
</tr>
<tr>
<td></td>
<td>Boom gates</td>
<td>19 (76)</td>
<td>5 (20)</td>
</tr>
<tr>
<td></td>
<td>Train &amp; train line</td>
<td>8 (32)</td>
<td>1 (4)</td>
</tr>
<tr>
<td></td>
<td>Road markings</td>
<td>4 (16)</td>
<td></td>
</tr>
<tr>
<td>Road environment</td>
<td>Road ahead</td>
<td></td>
<td>5 (20)</td>
</tr>
<tr>
<td></td>
<td>Signage</td>
<td>2 (8)</td>
<td>3 (13)</td>
</tr>
<tr>
<td></td>
<td>Distance to get through safely</td>
<td>2 (8)</td>
<td>1 (4)</td>
</tr>
<tr>
<td>Road Users</td>
<td>Pedestrians</td>
<td>4 (16)</td>
<td>6 (24)</td>
</tr>
<tr>
<td></td>
<td>Traffic</td>
<td>24 (96)</td>
<td>16 (64)</td>
</tr>
<tr>
<td></td>
<td>Space in other lanes</td>
<td>2 (8)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>12 (48)</td>
<td></td>
</tr>
<tr>
<td>Experiential</td>
<td>Experience of this level crossing/area</td>
<td>12 (48)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experience of other similar level crossings</td>
<td>5 (20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>General driving experience</td>
<td>17 (68)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experience as a train passenger</td>
<td>1 (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Driver training</td>
<td>5 (20)</td>
<td></td>
</tr>
<tr>
<td>Knowledge-based</td>
<td>Knowledge of train times</td>
<td>1 (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge of road rules</td>
<td>3 (12)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge of level crossing accidents</td>
<td>2 (8)</td>
<td></td>
</tr>
</tbody>
</table>

In terms of the features that participants stated they looked for on approach to a crossing, all noted bells and flashing lights and 76% noted the boom barriers. All bar one participant (96%) also reported looking out for the behaviour of other road users. With regard to the elements that participants believed most influenced their behaviour, 64% noted that the presence of other road users in the immediate vicinity influenced their behaviour, followed by the crossing warning
signals. Participants also noted significant time pressure (n= 14, 56%) and very rapid decision-making (n – 16, 64%) with respect to choosing the appropriate behaviour.

To a large degree, the themes that emerged from the VPA, taken while driving, are similar. Participants verbalised the presence of the crossing itself (71%), trains and the train line (68%), and the crossing warnings. Interestingly the presence of other road users was not verbalised during the drive.

**Vehicle-based measures and scanning behaviour**

Measures of speed on approach to highway-rail grade crossings were sensitive to various types of active warning in our simulator research (Lenné et al., 2011; Rudin-Brown et al., Accepted for Publication), and so were included in this analysis. Measures of head rotation and gaze along x and y axes were also analysed to assess the degree of scanning of the crossing surrounds. A multi-variate analysis was conducted with the between-subject factor being driving experience (novice, experienced) and the within-subjects factor being crossing number (1 through 4). Each crossing was considered separately as it was hypothesised that the complex environments presented in crossings 1 and 3, which involve unsignalised turn manoeuvres and have increased pedestrian activity, may be more challenging for the inexperienced drivers.

The multivariate analysis confirmed an overall effect of driving experience (F(6,71) = 2.33, p < 0.05) and crossing number (F(18,219) = 4.21, p < 0.05), but no interaction between the two factors (F < 1). The univariate analysis confirmed that both mean and SD of speed varied significantly according the crossing number (F(3,84) = 13.01, p < 0.01; F(3,84) = 6.32, p < 0.01). Post-hoc tests confirmed that mean speed was lowest on approach to crossing 1 (p < 0.05) and SD was lower for crossings 1 and 2 than for crossing 3 (p < 0.05). The lower speeds, and reduced variability in speeds, at crossing 1 is most likely due to the presence of a pedestrian crossing immediately prior to the point at which the participant must turn left (illustrated in Figure 2, top left panel). Driving experience was not a significant factor for either mean or SD of speed (F(1,84) = 1.91, p > 0.05; F < 1).

![Figure 3. Mean Speed (left) and SD Speed (right) for novice and experienced drivers for each of the four crossings (km/h ±SE).](image)
The FaceLab system records gaze across both $x$ and $y$ axes. As illustrated in Figure 4, gaze variability across both $x$ and $y$ axes was found to be higher for novice than experienced drivers ($F(1,84) = 5.23, p < 0.05$; $F(1,84) = 5.20, p < 0.05$). There was no influence of crossing type for either $x$ or $y$ axes ($F<1$; $F(3,76) = 2.34, p > 0.05$), and the crossing by experience interaction was not significant for both axes.

![Figure 4. SD of gaze across $x$ (left) and $y$ (right) axes for novice and experienced drivers for each of the four crossings (degrees ±SE).](image)

Integration with on-road data

The route through crossing 1 involved both left and right turns in the immediate vicinity of the crossing, necessitating decisions be made concerning the presence of pedestrians on the pedestrian crossing, turning left into traffic, negotiating the crossing and changing lanes, followed by a right turn. Given the complexity of this crossing, and the significantly lower mean speeds observed, this crossing was chosen for more in-depth case study analysis to explore behaviour in more depth and to explore potential reasons for the increased scanning observed by inexperienced drivers.

Two such case studies are presented here where the CDM, VPA, vehicle and eye-movement data are considered together to build a picture of the factors shaping behaviour at the crossings. The examples presented are reflective of the findings from the wider analysis and demonstrate the utility of the multi-method approach.

The two participants were selected as they were inexperienced drivers and were involved in negotiating crossing 1 whilst it was in an active state (i.e., boom barriers beginning to descend, lights flashing and bells sounding). A summary of the results derived from each data source for each participant is presented below.

Case Study 1

This participant encountered the crossing just as the signals were active (i.e. lights flashing, warning bells sounding) and the boom barriers had started to descend. The driver only realised this whilst already located on the crossing and so sped up in order to get through the level
crossing without being trapped by the boom gates. Taken together the data indicate that the driver was unaware on approach to the crossing that it was in an active state. Further interrogation suggests that the driver was distracted, firstly by checking for pedestrians, and secondly by the need to change immediately into the right hand lane after turning left onto the road in preparation for the right hand turn immediately after the level crossing. As a result no check of the level crossing signage, signals or boom gates was made by the driver on approach to it. To demonstrate, extracts of the data are in Table 3.

The two figures within Table 3 show the participant’s head rotation, gaze and vehicle lateral position (top right), and the participant’s speed, brake, throttle and steering profiles whilst approaching and negotiating the crossing 1 (bottom right). The vehicle lateral position shows the point at which the vehicle turns left onto the road containing the crossing, and also the point at which the vehicle then moves across to the right hand lane in preparation for the right hand turn immediately after the rail level crossing. Also shown is the driver’s head rotation, which clearly shows a rotation to the left when approaching and negotiating the rail level crossing, which is indicative of the checking for pedestrians as reported by the participant in the VPA. The speed and throttle profiles presented indicate how the driver sped up in order to get through the activated rail level crossing without being trapped by the active boom gates, and the brake profiles show the hard braking required by the driver upon seeing the amber light immediately after the rail level crossing.

Case Study 2

This participant encountered the level crossing just as the signals were active (i.e. lights flashing, warning bells sounding) and the boom gates had started to descend. The data available indicates that the driver did not expect to encounter a rail level crossing immediately after making the left turn and also that the requirement to check for pedestrians prior to the rail level crossing was a significant source of distraction from the level crossing. Under time pressure having unexpectedly encountered the rail level crossing, the driver quickly made a decision to pass through the level crossing, and was unable to change this once the crossing became active. To demonstrate, extracts of the data are presented in Table 4.

A graph showing the participant’s head rotation, gaze and vehicle lateral position is presented within Table 4 (right). The lateral position of the vehicle highlights the point at which the vehicle turns left onto the road containing the rail level crossing and then again the point at which the vehicle turned right at the intersection following the rail level crossing. In contrast to case study 1, the head rotation data in this case indicates that the driver’s gaze was predominantly focussed straight ahead when approaching and passing through the level crossing.
Table 3. Verbal Protocol (top left), CDM Interview (middle left) and Vehicle Data (right panel) for Case Study 1

VPA - “Getting into the left lane watching out for the parked cars, the pedestrians, pedestrian crossing. Doing a head check making sure no one’s going to get in the way. Getting in the right lane, getting out of the way from the boom gates”

CDM - What were you aiming to achieve during this activity?
To get through before boom gates came down.

What decisions did you make during the event?
As soon as I heard it I decided to keep going through rather than reversing. It was split decision to keep going through. I made a decision to stay in the same lane as it was clear I didn’t need to move around.

What was the most important factor that influenced your decision making at this point?
The clear road ahead of me – had there been traffic there it would have influenced it a lot.

Did you use all of the information available to you when making decisions?
Probably could have looked around more, but made fast decision because of time constraints.

Was there any other information that you could have used/would have been useful when making the decisions?
An earlier sign saying there was a level crossing would have been useful because I wouldn’t have had to hurry through it. I would have had more time to consider the decision. Louder signals – I didn’t hear them until I was already there.

At any stage, were you uncertain about the accuracy or relevance of the information that you were using?
No. I was uncertain how long the signals had been on – if they’d just started or been on for a while as the boom gates were about to close. Knew I had enough time to get through.

Did you, at any point, find it difficult to process and integrate the information?
Took a second to notice that signals going off – took me by surprise. Instantly knew it was the boom gates.
**VPA** - “So at the lights we’re turning? So pedestrians on my left and right. Just better be careful because that man is going to run out. And it’s safe to go so. Just missed the train”

**CDM** - What were you aiming to achieve during this activity?  
The most important thing for me was safety so not getting stuck on the tracks or not running across them when the lights had gone – so safety was the first aim. It wasn’t really to try to beat the train. I didn’t want to get hit.

**What decisions did you make during the event?**  
Decision about whether to go or stop, but by the time I heard the ringing bells I had already made my decision, so then it was just to turn and go.  
It was clear to turn, then the lights sounded after (the crossing). I didn’t know the road so it only really hit me when I turned – it would have been different if I knew there was a crossing there.

**What information/features did you look for/use when you made your decisions?**  
Whether there was any traffic coming in either direction, the general traffic I suppose. Any signs and then I saw the level crossing lights flashing and the gates coming down. The sounds of the bells.

**At any stage during the decision making process did you found it difficult to understand and use the information?**  
Not really understand, but I would have liked a sign before I turn saying that there was a crossing around the corner.

**Did you, at any point, find it difficult to process and integrate the information?**  
Because I’m usually quite cautious and there was a lot going on because it was a new place. So I first had to scan that there was no one coming in either direction and then analyse where the lights were, where the road marking and then the boom gates and lights came, so there was a lot going on, and then I was like did I just run the red light at the boom gates. There was a lot of stuff to process.

**What interventions do you think could be used to prevent inappropriate decisions here?**  
A precautionary sign, because I would have known to start slowing. Just the sign – a bit more warning.

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**Table 4. Verbal Protocol (top left), CDM Interview (middle left) and Vehicle Data (right) for Case Study 2**

<table>
<thead>
<tr>
<th>Time</th>
<th>Lateral Position Right [cm]</th>
<th>Throttle position [%]</th>
<th>Speed [km/h]</th>
<th>Steering Wheel Angle [deg]</th>
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**Diagram 1:**
- **Left turn into road**
- **Turn right at signalised intersection**

**Diagram 2:**
- **Gaze, Head and Lane position**
- **Brake, Throttle and Steering**
DISCUSSION

The aim of the study described was to investigate, using a novel framework of methods, driver behaviour at four different rail level crossings. Extracts taken from the overall analysis involving 25 participants were presented. The aim of this was to demonstrate the utility of the multi-method framework and to draw some conclusions, also supported by the wider analysis, regarding driver behaviour in the highway-rail grade crossing context.

The crossing environments are clearly complex built up environments involving other road users, judgements about lane changes, turn manoeuvres, stopping distances, activated warning signals, all of which contribute to time pressure experienced by drivers in making stop-go decisions around highway-rail grade crossings. The cognitive task analysis interview data clearly illustrate the reliance of drivers on the active warnings provided at highway-rail grade crossings. Drivers reported looking for these features and, along with the presence of other traffic, using this information to inform stop-go decisions at crossings. An interesting finding was the novice drivers exhibited a wider scanning pattern than experienced drivers.

These findings were examined further through the case studies. For example, the two analyses presented, and the overall analysis focussing on all 23 participants, highlight the influence of the road infrastructure, roadway design, and also other road users (e.g., other drivers and pedestrians) on driver behaviour when negotiating highway-rail grade crossings. For example, in case study 1 the participant entered the crossing whilst the boom gates were descending, and was distracted from the primary task of attending to the crossing, firstly by the need to check for pedestrians in the vicinity, and secondly by the need to change immediately into the right hand lane after turning left onto the road in preparation for a right hand turn immediately after the level crossing. The influence of pedestrians was also apparent in the other analysis presented in case study 2 with the participant referring to the need to check for pedestrians prior to the crossing in their VPA. Further, pedestrians were also found to be a key influencing factor in the wider analysis. For example, based on a content analysis of the VPA transcripts from all 25 drivers, it was found that when approaching and negotiating the four highway-rail grade crossings, almost as many references were made to pedestrians and pedestrian crossings than to the crossings themselves or elements associated with them (e.g. signage, signals, boom gates, trains etc). In the case of level crossing 1 (focused on in these case studies), just over 50% of drivers referred to the crossing, whereas close to 70% referred to the need to check for pedestrians and to the pedestrian crossings themselves. Further, during the CDM interviews, in response to the question regarding what the most influential piece of information was with regard to their decision making prior to negotiating the crossings, 24% of participants reported that pedestrians were the most influential, compared to 20% for boom barriers, and 4% for the train itself. The findings therefore suggest that pedestrians situated in the vicinity of crossings have a key influence on driver behaviour in and around level crossings; moreover it is apparent that pedestrians have the effect of diverting drivers’ attention away from the primary driving task of negotiating the highway-rail grade crossing. The suitability of placing pedestrian crossings in the vicinity of highway-rail grade crossings therefore represents a key area for future investigation.

The influence of road infrastructure and roadway design was also highlighted by the analyses presented, and the wider analysis focussing on all 25 participants. For the analyses presented, the
data indicate that the participant in case study 1 was focussed on the impending right hand turn required immediately after the crossing, and also the traffic signals controlling this intersection, which are placed immediately after the crossing. In case study 2, the participant, inexperienced on the road in question, reported that they did not expect a crossing to be positioned immediately after turning onto the road, and indicated that this had an influence on their behaviour as their decision whether to stop or go was heavily rushed. The element of time pressure was a prominent theme in the analysis. Both participants reported that they felt time pressure and that their decision whether to stop or go was made very quickly (both under 3 seconds). Again, this finding was common in the wider analysis, with over half of all participants reporting that they felt time pressure when deciding whether to stop or go at the level crossings encountered, and, in response to the question regarding how long their decision making process took, 64% of participants suggested that their decision whether to stop or go was ‘immediate’. Ostensibly the time pressure reported was caused by the roadway design and lack of warning signage, since drivers did not expect to encounter a highway-rail grade crossing immediately after making the left turn.

Despite the participants’ stated reliance on the active warnings provided by the crossing controls, the in-depth case study analysis, using the in-vehicle data to contextualise and verify the subjective reports, suggested that drivers in certain crossing environments were not able to detect these warnings until literally on the crossing itself. The lack of an early warning sign for level crossing 1 (on the road from which participants turned) was also highlighted. Both participants in the analysis presented suggested the need for a sign warning drivers of the impending highway-rail grade crossing in response to the probe regarding any further information that would have been useful, and both identified early warning signs when questioned over interventions designed to improve driver behaviour and safety at these crossings. This finding was also prominent in the wider analysis, with 24% of the participants identifying such a sign in response to the probe regarding any further information that would have been useful, and over 70% of the participants identifying earlier warning signs as an intervention that could be used to enhance driver behaviour and safety at highway-rail grade crossings.

Indeed this finding is echoed in our simulator-based research in this area (Lenne et al., 2011) and highlights the complementary role of simulation and on-road methods in this area. The on-road approach provides a more naturalistic exposure to drivers, and places their subjective reports and observed behaviours in a real world context. It provides insights into what drivers actually do on the road and some of the factors and motivations that influence this. What it highlights quite clearly is the complexities often faced by drivers in the vicinity of highway-rail grade crossings and the time-critical nature of decision-making. Clearly it is great challenge to sensibly analyse streams of vehicle-based data collected, even at a limited number of crossings, given the varied states of warning signals and presence of other road users. In this sense the on-road method provides a rich context for more in-depth hypothesis testing using other approaches such as simulation. In the case of early warning signs, for example, more in-depth simulator testing can be conducted to design and evaluate an earlier warning signal that is effective in a complex crossing environment and can accommodate the drivers’ scanning of other road users and road infrastructure. While many studies have used simulation to measure driver responses to earlier warning signals, most rely on crash statistics to inform the appropriate scenario development. Enriching this scenario development process with the outcomes from on-road observation will
only lead to more appropriate scenarios and behavioural indices. This type of research is fundamental for the development and testing of theories and models in human factors psychology.

In this study novice drivers were found to have a wider scanning field than experienced drivers, a finding that is contradictory to most of the research in this area (see Underwood (2007) for a review). This may be related to the drivers’ situational models for RLCs. There is some evidence that novice drivers’ situational models are less connected in terms of linkage between different information elements and comprise more distinct information elements (Salmon, Lenné, Young, & Walker, submitted). Experienced drivers on the other hand extract less raw information from the driving situation, and are able to generate smaller, more connected situational models. Together these findings suggest that novice driver situation awareness is less efficient than for experienced drivers during the study. This requires further examination with a larger number of participants.

As well as identifying influences on driver behaviour at highway-rail grade crossings, the analyses presented also demonstrates the utility of using a multi-method approach for analysing driver behaviour on-road in different contexts. The collection of real-time, objective and subjective data in conjunction with qualitative cognitive task analysis interview data permits an exhaustive analysis of driver behaviour, allowing the key factors shaping behaviour to be identified.

CONCLUSION

This exploratory research aimed to reveal the range of factors that shape driver behaviour at highway-rail grade crossings. The study presented indicates that there are a range of factors which influence driver behaviour at highway-rail grade crossings, with evidence being found on the influence of road infrastructure and roadway design, surrounding traffic, pedestrians, the actions required immediately after the crossing, and the crossing itself, on the way in which drivers negotiate these crossings. In particular, the key role of infrastructure and roadway design and pedestrians on driver behaviour at crossings are revealed here, and further investigation in this context is recommended through on-road study. The study presented was unique in that it demonstrated the use of a novel framework of methods, not previously used together in this manner, for studying driver behaviour on the road. As with all exploratory studies, there are limitations, in particular the fact that only 25 participants took part in the study, which represents a limited participant pool, requires that caution be urged when generalising the findings from this study to the overall driving population. Whilst the study has demonstrated that the framework of methods adopted is well suited to the study of driver behaviour, it is recommended that future efforts adopting this approach utilise a much larger sample of drivers. Having demonstrated the richness that this multi-method framework approach provides, it is now possible to explore more specific issues in more detail. For example, investigations regarding the specific influence of highway-rail grade crossing signal and signage placement, new crossing infrastructure and roadway designs, lane markings and new warnings (e.g. traffic lights) would all benefit greatly from this form of analysis.
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REFERENCES


