Driver behaviour and decision making at railway level crossings: an exploratory on-road case study

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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, along with the overall analysis undertaken, 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

Rail level crossings, driver behaviour, cognitive task analysis, verbal protocol analysis.

Introduction

In 2008 there were 58 collisions between trains and vehicles at rail level crossings in Australia, which led to 33 fatalities and serious injuries [1]. Although much research has been undertaken focussing on driver behaviour at rail level crossings [2], the problem has proved largely intractable. Recent advances in research methods for investigating driver behaviour, such as the provision of instrumented on-road test vehicles, now allow more accurate and unobtrusive collection of objective, real-time data regarding driver behaviour in range of contexts. Of particular utility is the ability to identify the factors, both related to the driver and the wider road transport system (e.g. road infrastructure, road rules and regulations, other road users) that influence driver behaviour in different contexts. This article presents the findings derived from a pilot study focussing on the assessment of driver behaviour at rail level crossings using an instrumented vehicle. The aims of the pilot study was first, to test a novel framework of methods for assessing driver behaviour at rail level crossings, and second, to describe driver behaviour, including the factors influencing it, within this context.

Driver behaviour at rail level crossings

Driver behaviour and rail level crossings have both received significant attention from the road safety research community [2]. For example, a range of rail level crossing models have been proposed, such as statistical models [e.g. 3,4], which, based on analyses of existing crash data, attempt to describe the safety benefits provided by specific countermeasures. Similarly, models of driver behaviour are rife in the literature [e.g. 5]; however, these have not yet been applied in the rail level crossing context. Additionally, although research has explored facets of driver behaviour at rail level crossings [e.g. 6, 7, 8, 9], the majority has focussed on specific issues in isolation (e.g. comparison of crash countermeasures, accident analysis) and has not specifically looked at behaviour from a systems-perspective. One particular aspect that currently remains ambiguous is the effect of wider road transport system conditions (e.g. road infrastructure design, road rules and regulations, other road user behaviour) on driver behaviour at level crossings. Further investigation regarding road user behaviour, and the factors influencing it, at rail level crossings is therefore required.

The main aim of this research was to conduct a pilot study focussing on the use of a novel framework of methods for evaluating driver behaviour at rail level crossings. For this purpose an on-road study, utilising a range of data collection approaches, and focussing on driver behaviour and decision making at rail level crossings, was undertaken. This article presents an overview of the study, including the methodology employed and extracts of the results obtained. The aim of this article is firstly to demonstrate the utility of the multi-method approach adopted, and secondly, to give insight into the driver and wider systems factors that shape behaviour at rail level crossings.

Methodology

The methodology employed during the on-road study utilised a range of different approaches for collecting detailed data on driver performance at rail level crossings. An overview of the methodology used is presented in Figure 1 and a brief description of the component methods follows.

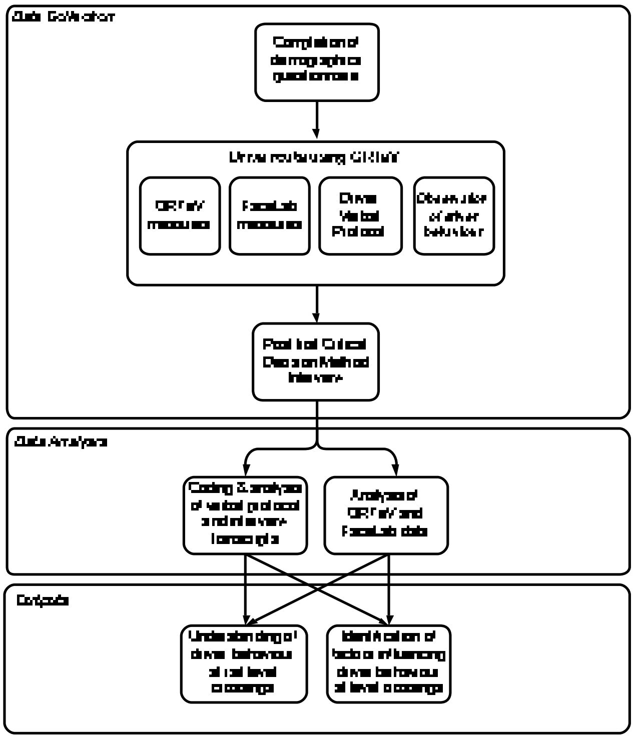

Figure 1. On-road study methodology.

On-Road Test Vehicle (ORTeV)

The MUARC ORTeV is a state-of-the-art instrumented vehicle for use in studies on driver behaviour. ORTeV has been equipped to collect data for both controlled and naturalistic studies and three main types of information can be continuously logged: vehicle-related data, driver-related physiological data, and eye tracking data. The vehicle data is acquired from the vehicle network and includes: 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, HVAC, 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 participants drove ORTeV around the pre-determined route.

Driver Verbal Protocols

Verbal Protocol Analysis (VPA), or 'think aloud' protocol analysis, was used to elicit data regarding the cognitive and physical processes undertaken by drivers whilst 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. situation awareness, decision making) in various domains, including the military, process control and road transport. In this case drivers provided verbal protocols as they drove the route. The verbal protocols were recorded using a Dictaphone, and transcribed 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 [10], which 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 [11]. Each interview focussed specifically on one of the rail level crossings negotiated by participants 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 activities during the incident in question. For this research a set of appropriate cognitive probes was adapted from the literature on previous CDM applications [12,13]. The set of CDM probes used are presented in Table 1.

Table 1. CDM probes used during on-road study.

Goal specification	What were you aiming to achieve during this activity?
Decisions	What decisions/actions did you make during the event?
Cue identification	What information/features did you look for/use when you made your decisions?
Influencing factors	What was the most important factor that influenced your decision making at this point?
Options	What other courses of action were available to you? Why was the chosen option selected?
Situation awareness	What sources did you use to gather this information? What prior experience or training was helpful in making the decisions?
Situation assessment	Did you use all of the information available to you when making decisions? Was there any other information that you could have used/would have been useful when making the decisions?
Information integration	What was the most important piece of information that you used to make your decisions?
Influence of uncertainty	At any stage, were you uncertain about the accuracy or relevance of the information that you were using?
Mental models	Did you run through in your head, the possible consequences of this decision/action?
Decision blocking - stress	At any stage during the decision making process did you found it difficult to understand and use the information? How much time pressure was involved in making the decisions/performing the task? How long did it take to make the decision? Did you, at any point, find it difficult to process and integrate the information?
Conceptual	Are there any situations in which your decisions/actions would have turned out differently?
Basis of choice	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? Were you confident at the time that you were making the right decision/performing the appropriate actions?
Analogy/ generalisation	If you could go back, would you do anything differently? If yes, what?
Interventions	Is there anything that you think could be done to prevent similar errors being made during similar situations?

Participants

Twenty-five drivers (15 males, 10 females) aged 19-59 years (mean = 28.9, SD = 11.9) took part in the study. Nine participants held a valid Full license while the remaining sixteen held a valid Victorian Probationary (P2) license. Participants were recruited through the weekly on-line Monash University newsletter and were compensated $50 for their time. Prior to commencing the study ethics approval was formally granted by the Monash Human Ethics Committee.

Materials

A demographic questionnaire was completed using pen and paper prior to the on-road study. An urban route incorporating 4 rail level crossings, all with boom gates, bells and flashing light controls, was used for the on-road study. A representation of the type of rail level crossings involved in the study is presented in Figure 2. For VPA practice and vehicle familiarisation purposes, the route used also incorporated a practice route, which included 4 intersections. Participants drove the route using ORTeV which utilised a range of data collection equipment including the FaceLab eye tracker system and the SceneCam video recording system (see ORTeV description above). A Dictaphone was used to record participant verbal transcripts during the drive, and the post drive CDM interviews. In-vehicle observers used pen and an error pro-forma to record the errors made during the drive. A series of cognitive probes (see Table 1) were used by the interviewer during the CDM interview, and participant responses were recorded on a CDM interview pro-forma.

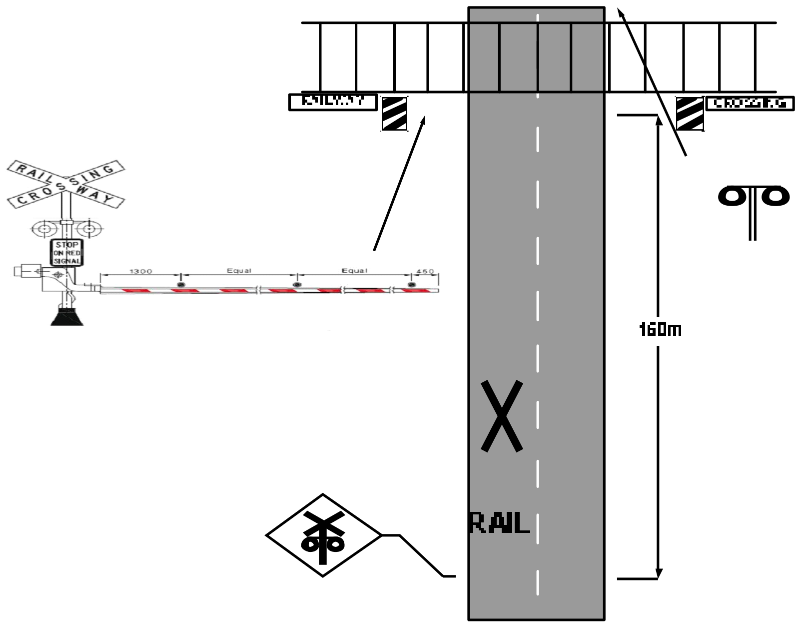

Figure 2. Representative schematic of rail level crossings used in study.

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. 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. Two observers were present in the vehicle throughout the drive. 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. 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.

Results

It is beyond the scope of this article to present the study results in their entirety; rather we focus specifically on the data derived from two participants at one of the level crossing encountered (hereafter referred to as level crossing 1). The examples presented are reflective of the findings from the wider analysis and demonstrate the utility of the multi-method approach. An overview of level crossing 1, including the participants' route through it (as represented by the bold white line with directional arrows), is presented in Figure 3. As demonstrated in Figure 3, participants encountered the level crossing 1 immediately after making a left turn into the roadway and had to move into the right lane (whilst negotiating the level crossing) in preparation for a right hand turn immediately after the level crossing.

Figure 3. Route through level crossing 1.

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

Participant 1, Barriers descending

Participant 1 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 driver only realised this whilst already located on the level 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 level 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 presented below.

An extract from participant 1's VPA transcript when entering and negotiating the level crossing is presented below:

"*Getting into the left lane watching out for the parked cars, the pedestrians, pedestrian crossing. Doing a head check making sure no ones going to get in the way. Getting in the right lane, getting out of the way from the boom gates*"

The CDM interview also gave insight into the driver's behaviour whilst negotiating the level crossing. The responses of interest are presented in Table 2.

Table 2. Participant 1 CDM extracts

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 b/c 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.
Why was the chosen option selected? Why were the other options rejected? It was easiest. It was the first decision that came into my head – snap decision was to get out of the way of the boom gates and easiest way to go.
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.
Was time pressure involved in making the decisions? Yes, absolutely. **How long did it take to make the decision?** Less than 2 seconds from time I heard signal to moving forward. **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.
If you could go back, would you do anything differently? If yes, what? Probably hesitated before entering level crossing rather than making decision in the level crossing – didn't do that because it took me by surprise too busy looking right.
What interventions do you think could be used to prevent inappropriate decisions here? Early warning or louder signal.

A graph showing participant 1's head rotation, gaze and vehicle lateral position is presented in Figure 4. A graph showing the participant 1's speed, brake, throttle and steering profiles whilst approaching and negotiating rail level crossing 1 is presented in Figure 5. As demonstrated in Figure 4, the vehicle lateral position shows the point at which the vehicle turns left onto the road containing the rail level 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 in Figure 4 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 in Figure 5 indicate how the driver sped up in order to get through the active 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.

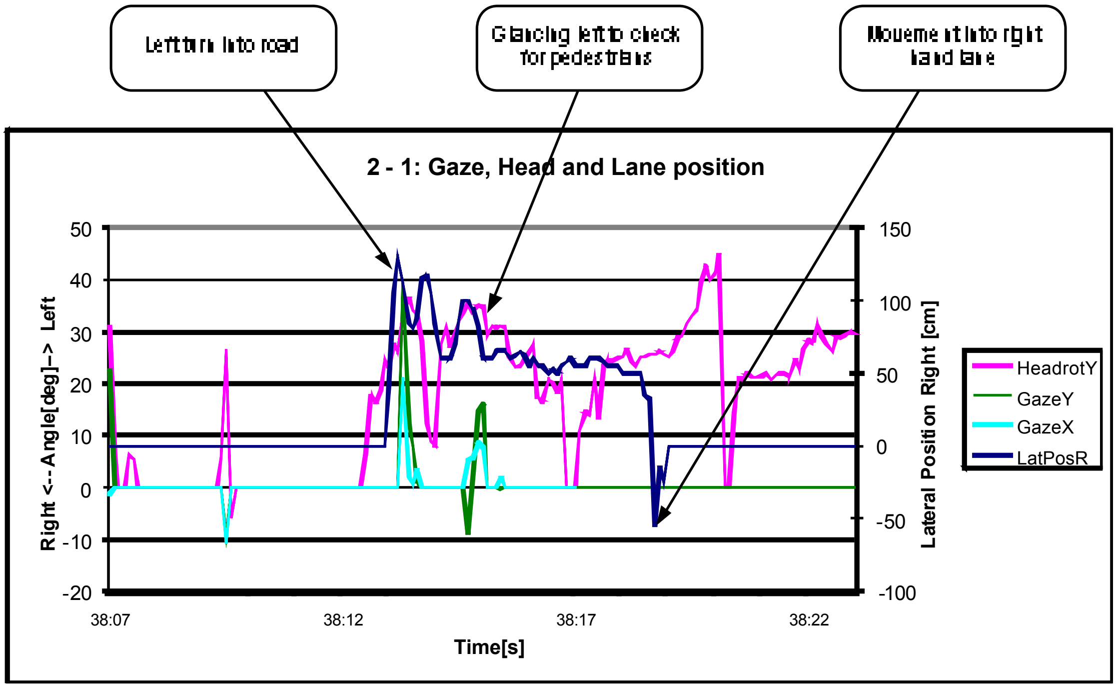

Figure 4. Participant 1's head rotation, gaze and lateral position.

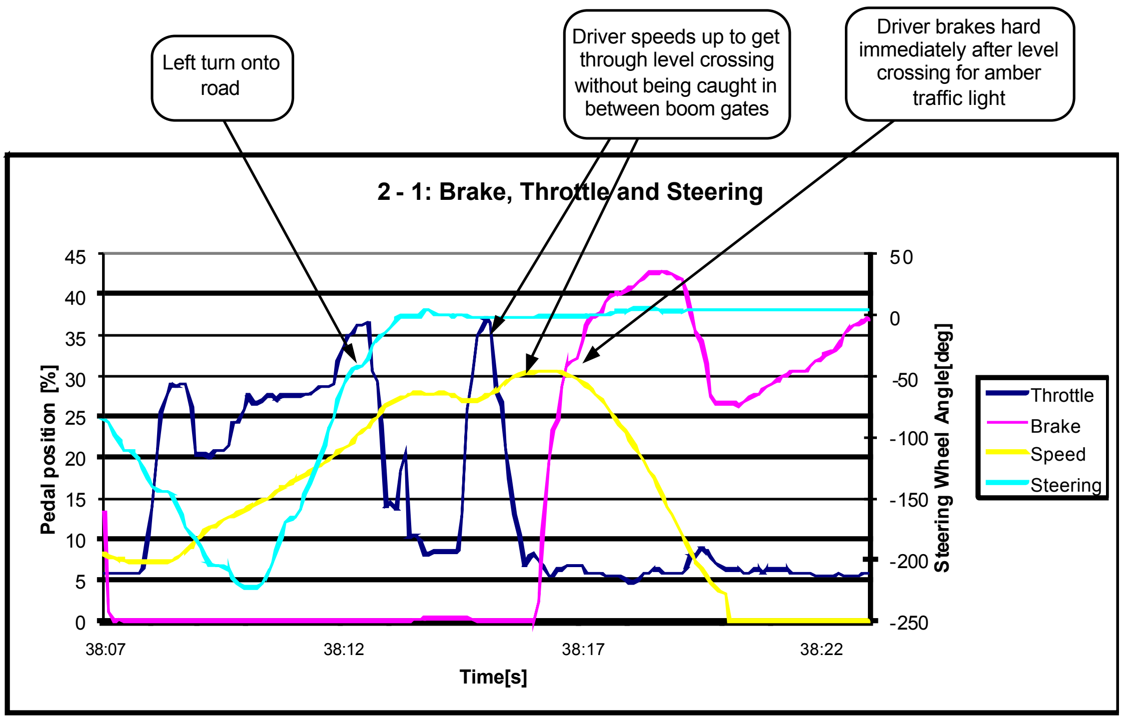

Figure 5. Participant 1's throttle, brake, speed and steering profiles.

Participant 2, Barriers descending

Participant 2 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 driver realised this and proceeded to pass through the level crossing. 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 below.

An extract from participant 2's VPA transcript when entering and negotiating the level crossing is presented below:

"*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*"

Extracts from participant 2's CDM interview transcript are presented in Table 3.

Table 3. Participant 2 CDM extracts

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.
Did you use all of the information available to you when making decisions? I was probably a bit delayed in noticing the gates and the lights. I probably only saw them a bit later than I should have. I saw them before I crossed the tracks, but could have been scanning a bit more, but the signals didn't go off until I had crossed.
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. **How long did it take to make the decision?** 2-3 seconds. Happened pretty quickly. **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 anew 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.

A graph showing participant 2's head rotation, gaze and vehicle lateral position is presented in Figure 6. 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 participant 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.

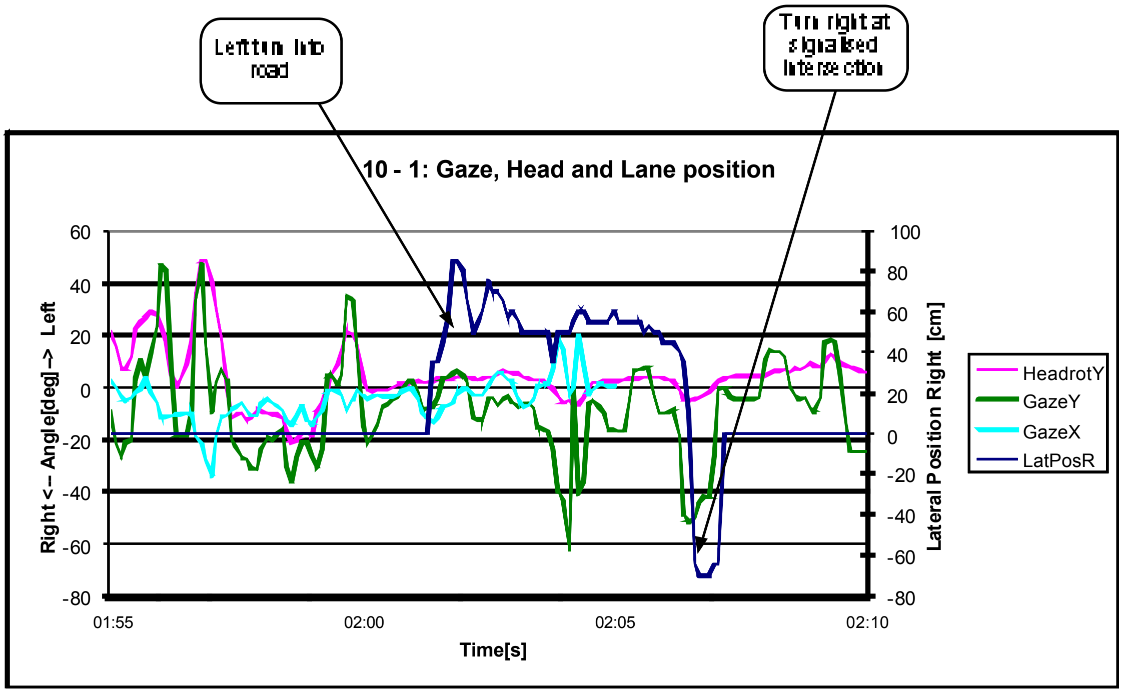

Figure 6. Participant 2's head rotation, gaze and lateral position.

Discussion

The aim of the study described was to investigate, using a novel framework of methods, driver behaviour at 4 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 level crossing context. As demonstrated by the analyses presented, there are various factors influencing driver behaviour at rail level crossings. Of particular interest in the context of this article is the influence of factors external to the driver that shape behaviour. For example, the two analyses presented, and the overall analysis focussing on all 25 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 rail level crossings. For example, the data indicates that participant 1, who entered the rail level crossing whilst the boom gates were descending, was distracted from the primary task of attending to the rail level 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, with participant 2 referring to the need to check for participants prior to the rail level 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 4 rail level crossings, more references were made to pedestrians and pedestrian crossings than to the level crossings themselves or elements associated with them (e.g. signage, signals, boom gates, trains etc). In the case of level crossing 1 (focussed on in this article), just over 50% of drivers referred to the level 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 level crossings, 24% of participants reported that pedestrians were the most influential, compared to 20% for boom gates, and 4% for the train itself. The findings therefore suggest that pedestrians situated in the vicinity of rail level 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 rail level crossing. The suitability of placing pedestrian crossings in the vicinity of rail level 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 participant 1 was focussed on the impending right hand turn required immediately after the rail level crossing, and also the traffic signals controlling this intersection, which are placed immediately after the rail level crossing. Participant 2, inexperienced on the road in question, reported that they did not expect a rail level 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 1 and 2 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 rail level crossing immediately after making the left turn.

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 rail level 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 rail level 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 rail level crossings.

As well as identifying influences on driver behaviour at rail level 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. Further, cross comparison of the data from these different sources can be used to validate the findings and the conclusions drawn. Finally, using a framework of methods in this manner overcomes the majority of the flaws associated with using approaches in isolation. For example, the flaws associated with the collection of subjective data regarding driver performance (e.g. correlation with performance on the driving task, drivers 'forgetting' portions of the task in which performance was substandard, and various biases) are mitigated through the collection of objective real-time performance-related data.

Conclusion

This article has presented a novel approach for studying driver behaviour, on the road, in different contexts. The study presented indicates that there are a range of factors which influence driver behaviour at rail level crossings, with evidence being found on the influence of road infrastructure and road way design, surrounding traffic, pedestrians, the actions required immediately after the rail level crossing, and the level crossing itself on the way in which drivers negotiate rail level crossings. In particular, the key role of infrastructure and roadway design and pedestrians on driver behaviour at rail level crossings is emphasised by these findings, 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 or pilot studies, the study did have 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 rail level crossing signal and signage placement, new rail level crossing infrastructure and roadway designs, lane markings and new warnings (e.g. traffic lights) would all benefit greatly from this form of analysis.

Acknowledgement

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