



**MONASH** University

Accident Research Centre

DRIVER BEHAVIOUR IN RESPONSE TO  
FLASHING RED LIGHTS *VERSUS* TRAFFIC  
LIGHTS AT RAILWAY LEVEL CROSSINGS

FINAL REPORT

September 2009



MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE  
REPORT DOCUMENTATION PAGE

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Report No.	Date	ISBN	ISSN	Pages
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**Title and sub-title:**

Driver behaviour in response to flashing red lights *versus* traffic lights at railway level crossings.

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**Author(s):**

Michael G Lenné, Christina M Rudin-Brown, Jordan Navarro, Jessica Edquist, Margaret Trotter & Nebojsa Tomasevic

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**Sponsoring Organisation(s):**

This project was performed under contract for VicRoads and was funded by the Victorian Railway Level Crossing Safety Steering Committee.

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**Abstract:**

In an effort to improve road safety, Australian railway authorities have made a concerted effort to reduce the number of level road-rail crossings, particularly those protected by 'passive' devices such as 'give way' or 'stop' signs. However, there are still a significant number of passive-controlled level crossings (e.g. about 1400 in Victoria according to Ford and Matthews, 2002). To improve this situation, passive level crossings are often "upgraded" with active traffic controls devices. Consequently, the question arises as to which of the available options represents the most effective active traffic control device. Within this context, the primary purpose of the project was to compare driver behaviour at two active railway level crossing controls: red flashing lights *vs.* traffic lights. A secondary goal was to compare driver behaviour at level crossings controlled by traffic lights to their behaviour at another active level crossing control—red flashing lights with boom barriers—and to their behaviour at the current standard passive level crossing control—a stop sign. Fifty participants aged 20-50 years drove the MUARC advanced driving simulator for two separate 15-minute drives. Participants were exposed to a total of four level crossing scenarios, each controlled by different level crossing controls. Three of these controls signalled the approach of a train, while the last was in 'failure mode' (i.e., no train present). The results presented addressed changes in behaviour on approach to the crossings through analysis of speed and eye movements, along with measurement of violational behaviours and subjective experiences with the different crossing types. While traffic lights do not appear to offer clear safety benefits over and above flashing red lights, further avenues are proposed to reach more definitive conclusions.

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**Key Words:**

Passive level crossings, active crossing controls, driving simulator, driver behaviour.

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Monash University Accident Research Centre,  
Building 70, Clayton Campus, Victoria, 3800, Australia.  
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363



# Preface

This research was conducted by the Human Factors team at the Monash University Accident Research Centre.

**Human Factors Team Leader:**

Dr. Michael Lenné

**Project Manager:**

Dr. Christina (Missy) Rudin-Brown

**Research Team:**

- Dr. Jessica Edquist
- Dr. Jordan Navarro
- Nebojsa Tomasevic
- Margaret Trotter



## **Acknowledgements**

This research was performed under contract for VicRoads and funded by the Victorian Railway Level Crossing Safety Steering Committee. We would like to thank the members of the stakeholder advisory group for their inputs in project discussion. In particular we note the following members of the stakeholder group for their input to the development of the simulated level crossing scenarios: Mr. Colin Kosky; Mr. Ken Hall, VicRoads; Mr. Peter Upton, V/Line; and Mr. Jim Warwick, VicTrack.

We also thank VicTrack for providing detailed data for level crossings scheduled for future upgrades to help inform design of the simulator scenarios used.





## Executive Summary

### Research Aims:

Flashing red lights, alone and with boom barriers, are two of the primary countermeasures that are available in Victoria to upgrade passive level crossings to active crossings. Traffic lights represent another potential yet untested possibility in this regard.

This research aimed to examine driver behaviour associated with the use of active treatments (flashing red lights, flashing red lights with boom barriers, and traffic lights) applied to passive level crossings. This research was designed to address two research questions. Firstly, how does driver behaviour at level crossings with conventional flashing red lights compare with crossings fitted with traffic lights? Secondly, how does driver behaviour at crossings with flashing red lights and boom barriers compare with traffic lights?

### Research Design:

Two studies were conducted to address the research questions, with participants in each study being exposed to different crossing configurations to avoid over-exposure to a large number of level crossings within a short time period. A within-subjects design with level crossing control as a factor was used for both groups. All participants were exposed to the stop sign- and the traffic lights-controlled level crossings.

Study 1 addressed the first research question by examining driver responses to level crossings with flashing red lights and traffic lights. This group also experienced the flashing red lights operating in failure mode. Study 2 addressed the second research question by comparing driver behaviour at level crossings controlled by traffic lights versus flashing red lights with boom barriers. This group also experienced the traffic lights operating in failure mode at a level crossing.

### Methods:

*Participants:* Fifty participants aged 20-50 years drove the MUARC advanced driving simulator for two separate 15-minute drives. Participants were exposed to a total of four level crossing scenarios, each controlled by different level crossing controls. Three of these controls signalled the approach of a train, while the last was in 'failure mode' (i.e., no train present). Study 1 included 19 males and 6 females with an average age of 34.4 years, while Study 2 included 17 males and 8 females with an average age of 31.6 years.

*Equipment:* Driver testing was carried out using the MUARC advanced driving simulator. The simulator, located at MUARC, consists of a GM Holden VE Commodore sedan mounted on a three degrees-of-freedom motion base, and a curved projection screen (located in front of the vehicle) providing a 180° horizontal, and 40° vertical, field of view. Forward vision was produced by three image generators using seamless blended projection onto the cylindrical screen, while rear vision was provided by a separate projection screen at the rear of the vehicle. The simulator has been used extensively to study driver behaviour in a range of conditions. The FaceLab system was used to record driver eye movements, while interviews were conducted post-session to collect subject data.

*Scenario Design:* Simulator scenario design was informed by examination of level crossing data provided by VicTrack, the relevant Australian Standards, and stakeholder input. Crossing characteristics were extracted from the VicTrack database of 55 actual level crossings from across Victoria. These data included those passive crossings scheduled for upgrade to active status in the near future.

*Data Analysis:* Driving performance variables collected in the simulator included: number of violations (not stopping at a level crossing), vehicle speed, accelerator pedal release time and distance, brake pedal release time and distance, and latency to proceed after a level crossing 'event'. Speed profile data were analysed using two-way Analysis of Variance (ANOVA) with *level crossing type* and *distance* as the two factors. T-tests were used to analyse other measures of driving performance. In all analyses, an  $\alpha$ -level of 0.05 was used to determine statistical significance.

### Key Findings:

In Study 1 there is some evidence to suggest that drivers respond more rapidly to activated flashing red lights compared to traffic lights moving into amber phase. This is evidenced by a slightly more rapid decline in speed on approach to the crossing. The proportion of crossing violations was lower for flashing red lights than for traffic lights, and in the post-driver interviews, two-thirds of drivers said they preferred flashing red lights at level crossings over traffic lights, although a number of these participants commented that they would prefer flashing red lights and boom barriers even more. This preference for flashing red lights rather than traffic lights was because they indicate danger more actively, are more salient, and are strongly associated with rail level crossings. When experiencing the flashing red lights in failure mode, one-third of drivers waited for up to four minutes before driving through the crossing with flashing red lights activated. Nearly half of the drivers made a comment to the researchers that indicated that they realised that something was not quite right.

In Study 2 there was very little difference in behaviour as drivers approach crossings with traffic lights and crossings with flashing red lights and boom barriers. There was no difference in speed on approach for these two types of active level crossings, and no difference in the time to release the accelerator and apply the brake. The proportion of crossing violations was lower for traffic lights than for flashing red lights and boom barriers with flashing red lights. Drivers in Study 2 experienced the traffic lights at level crossings in failure mode. The pattern of results was very similar as for the flashing red light failure mode in Study 1. That is, about one-quarter of drivers waited patiently for five minutes at the crossing before being told to proceed through, and around one-third proceeded through the crossing against a red traffic light after approximately 4 minutes. While a similar number of drivers in studies 1 and 2 indicated to the researcher that they thought something was wrong with the simulation in the failure mode condition, those comments were made earlier for the traffic light failure mode (Study 2) compared to the flashing light failure mode (Study 1).

Across both studies 34 of the 50 drivers stated the correct response at a level crossing with stop signs only was to slow down and look for trains, but only 7 of 50 stated that coming to a complete stop was the required behaviour. All participants stated they would stop at a crossing that had flashing red lights activated or traffic lights with a red signal.

## Conclusion:

This study is not without limitations and there are several issues that should be explored further to provide definitive conclusions with regard to the safety benefits that may be provided through the use of traffic lights at level crossings. These relate primarily to the examination of responses in a wider range of crossing scenarios and examination of behaviour with repeated exposures to the crossing treatments over an extended period of time.

In addition to addressing some caveats with the current research, there are several new lines of inquiry that may lead to further safety benefits at level crossings. The benefits of advisory signs further in advance of active crossings should be established as there is strong evidence to support this from this study. Further, there is a large body of research to suggest that the utility of warnings can be further enhanced through the provision of both directional and multi-sensory cues to the driver. There is also a range of established human factors methods that can be used to identify in detail the specific user (driver) requirements to inform countermeasure design and integration. Finally, major programs such as the establishment of improved data systems are required to enable researchers and stakeholders to more accurately establish the causes of level crossing crashes. In other areas of injury prevention the establishment of crash factors and types is paramount to more effective countermeasure development and implementation.

While the primary purpose of this study was to examine driver behaviour at level crossings, it is interesting to address the question of risks associated with the use of traffic lights in the field. There are some issues that we believe need to be pursued to further address the issue of risk. Firstly, assessments of behaviour at level crossings with traffic lights need to be made across a wider range of environments, including more urban conditions, and with drivers experiencing traffic lights across different signal phases on approach to the crossing. It is important also that driver behaviour be assessed both when drivers have an expectation that they will encounter traffic lights at level crossings, and after repeated exposures. Finally, the violation issue needs to be explored with different signal timings to establish violation rates across a range of crossing experiences. This driver simulation study was designed so that drivers saw the flashing red lights activate and the traffic lights change from green to amber 6 seconds before reaching the crossing. As amber is interpreted as 'proceed with caution/stop if this can be done safely' this represents an additional level of decision making and could perhaps have contributed to the greater number of violations for traffic lights. All traffic light violations occurred within 2 seconds of the lights changing from amber to red, suggesting that an incorrect decision to proceed was made as opposed to a mid-phase deliberate violation. In contrast, drivers in this study appeared to have responded more immediately to the activation of flashing red lights.

In conclusion, this research intended to provide data to Victorian stakeholders regarding driver behaviour around level crossings with a range of active treatments, including the use of traffic lights, in a defined set of level crossing scenarios. This information was intended to inform stakeholder discussions regarding the potential further exploration of behaviour and risk associated with the use of traffic lights at level crossings. On the basis of these findings, and acknowledging the restricted range of road types (rural) and speed limits (80 km/h) evaluated, the use of traffic lights at level crossings does not appear to offer clear safety benefits over and above those provided by flashing red lights or flashing red lights with boom barriers.



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# 1. INTRODUCTION

Road-rail level crossings are present on all categories of road, and can be one of two types: those protected by active devices (i.e., that provide a signal to vehicle drivers of an approaching train), or those that are unprotected (referred to as ‘passive’ level crossings). The latter are characterised by signage only (usually a give-way or stop sign) and, as their name suggests, do not provide any active indication to drivers of the presence or absence of trains. While the overall number of level crossings in Victoria has decreased by about 30% in the quarter century from 1969-1974 to 1996-2000, there has been, in the same period, a much larger reduction of 73% in the number of collisions and an even larger reduction of 85% in the number of deaths at railway level crossings (Edquist et al. 2009). This is likely due, at least in part, to the upgrading of many level crossings from passive, to active, controls. For example, while there was a 48% decrease in the number of passive level crossings from 1969-1974 to 1996-2000, there was a corollary increase of 46% in the number of crossings controlled by red flashing lights, and a 295% increase in the number controlled by red flashing lights with boom barriers (Edquist et al. 2009). Despite these changes, however, safety at railway level crossings remains one of the top concerns amongst road and rail authorities.

## 1.1. WHY MIGHT VIOLATIONS OCCUR?

Understanding why drivers cross against active signals is important in order to devise appropriate countermeasures. An investigation of 87 fatal level crossing crashes by the Australian body responsible for investigating fatal transport accidents, found that unintentional error was a more common causal factor in level crossing crashes than for other fatal road crashes (Australian Transport Safety Bureau Transport Safety Statistics Unit 2002). Level crossing crashes also involved fewer cases where the driver was affected by drugs or alcohol, fewer cases involving excessive speed, and more cases where the road user concerned was an older driver. These findings suggest that issues of information perception and processing are more involved, while issues of deliberate risk-taking are less involved, in level crossing crashes than for other fatal crashes.

Pickett and Grayson (1996) examined witness statements and surveyed motorists who had violated active warning signals at various level crossings. To better understand the reasons for the violations, the authors classified drivers into three, not necessarily distinct, categories: those who were unaware of the signals, those who were unable to stop because they were too close to the level crossing or to the vehicle behind, and those who were unwilling to stop. While drivers may be unwilling to stop at a level crossing due to a broad range of motivational, dispositional and situational factors that are largely outside authorities’ control, the two other categories represent prospective areas of focus for treatments that might improve the effectiveness of level crossing controls. The following sections present three factors of interest that may contribute to the effectiveness of level crossing controls: driver expectancy, warning saliency, and warning credibility.

### 1.1.1. Driver expectancy

One of the most important considerations in the context of successful information processing is the phenomenon known as ‘inattention blindness’ (Mack 2003). Inattention blindness describes the failure to see highly visible objects we may be looking at directly when our attention is elsewhere. In terms of railway level crossings, a

driver's likelihood to experience inattention blindness is, in part, shaped by their expectancy of what is likely to happen at a given level crossing. In fact, several authors have commented on the importance of inattention blindness to level crossing safety (Henderson 1991; Raslear 1996; Eck 2002; Yeh and Multer 2007).

When the number of trains using a given level crossing is low, drivers and other road users may come to expect that the crossing will be clear when they encounter it. In addition to inattention blindness, this false expectation may result in a failure to perform appropriate actions such as visual checks of the track. In situations where the expectancy is violated, and a signal indicates an approaching train, a driver may not be able to respond in a safe time period, or may fail to respond at all. These situations often result in violations and near-misses, and can result in potentially fatal collisions. The second group of drivers identified by Pickett and Grayson (1996), those who fail to stop at a level crossing because they were either too close to the crossing or to the vehicle behind them, would be those who are able to perceive the warnings but, because of their expectations, are too late to respond.

### **1.1.2. Warning saliency**

Drivers may be unaware of signals because the signals are insufficiently salient to be noticed amongst extraneous visual information, or 'clutter'. Although warnings may be designed to be *physically* obvious to users, they do not always convey the intended *urgency*. In fact, Green (2002) noted that level crossing signal design is often not based on human factors knowledge regarding the most effective means of conveying information to the driver. Thus, signals may fail to be noticed due to features such as inappropriate colour for the conditions, restricted power output, or location within the environment. Drivers may not notice red flashing lights because of a number of factors, including visual obstructions (e.g., vegetation, parked cars), reflected sunlight, colour-blindness, or position on the road (e.g., past the point at which the signal lights' maximum intensity is directed). Further, drivers may not hear warning bells (which are not required under the Australian Standard AS 1742.7 Railway crossings, and are used primarily to warn pedestrians, not drivers, of an impending train) because of other competing noises within the vehicle. These physical limitations of warning signals can be alleviated by recent improvements in level crossing technology such as LED (light-emitting diode) lights that are more efficient and produce greater visibility, while at the same time being flexible in terms of power sources (e.g., can use battery power in the event of a power failure).

Other support for the notion that lack of level crossing signal saliency may contribute to level crossing violations comes from analyses of crash data. For example, Wigglesworth (Wigglesworth 1978; Wigglesworth and Uber 1991) noted that many crashes that occur at level crossings protected only by red flashing lights tend to be located near busy road intersections. He suggested that the visual and mental tasks of interacting with other traffic may overload drivers and prevent them from adequately perceiving the level crossing signal. Because of this possibility, it is recommended that level crossings be assessed on a regular basis (Davis Associates Limited 2005), as traffic often increases markedly from the time a crossing is first built.

### **1.1.3. Warning credibility**

Drivers may be unwilling to stop at a level crossing if they believe that the benefits of continuing through the crossing outweigh the costs associated with stopping. As such,

they may choose to violate a level crossing warning signal if they judge it to have a high likelihood of false positives, or warning signals when no train is present. This is particularly true for local drivers who are familiar with a known level crossing. They may incorrectly believe that they can accurately judge the length of time from the activation of the warning signals to the arrival of the train and, therefore, decide that they can cross safely when it is actually unsafe to do so.

The perceived credibility of a warning is critical for driver acceptance and compliance. False alarms, failure modes, and warning timings are key issues in this respect. For example, when crossing signals are frequently activated without a train being present, road users may lose faith in the warnings and begin to ignore them. Wilde et al. 1987 (cited in Yeh and Multer 2007) studied five level crossings and found that more violations occur at crossings with a high false alarm rate than at those that generate accurate warnings.

Another issue that can erode the credibility of a warning system is the nature of the failsafe mode for active warnings. Currently, when railway level crossing controls fail, the 'active' mode of the signal is triggered. The resultant situation means that there is no way for a driver to tell if the lights are flashing because a) there is a train approaching or b) there is a problem with the system. The configuration of the failsafe mode and anticipated driver responses, therefore, should be considered when designing a credible level crossing control.

Duration of the warning phase prior to the arrival of a train is another important factor that can affect level crossing warning signal credibility. The timing of this phase is normally adjusted so as to permit the slowest moving vehicles enough time to cross before the arrival of the fastest moving train. Compared to warning phases that are relatively short in duration, drivers are more likely to violate signal warnings at level crossings that use longer warning times (Richards and Heathington 1990). For this reason, Heathington and colleagues (1990) recommend using traffic lights as signals only at crossings where warning times are consistent and short in duration.

## **1.2. TRAFFIC LIGHTS AT LEVEL CROSSINGS**

A potential countermeasure to contend with the tendency of some drivers to violate level crossing controls is to install traffic lights at selected level crossings instead of either red flashing lights, or red flashing lights with boom barriers. The rationale behind this proposal involves the hypothesis that drivers may be more likely to comply with traffic lights. Compliance may be more likely because traffic lights are stimuli that produce a well-learned response in drivers, i.e. a sequence of behaviours that ultimately concludes with the driver bringing his or her vehicle to a full stop. In addition, failing to stop at a traffic light is a well-known, prosecutable offence under the Victorian Road Safety (Road Rules) Regulations (1999). While failing to stop at a level crossing controlled by active signals is also a prosecutable offence under the Regulations (with the same associated number [5] of penalty units), it is possible that drivers are better aware of, and thus more likely to comply with, the regulations that pertain to traffic lights.

Traffic lights may result in higher levels of driver compliance at level crossings than red flashing lights because of their familiar appearance. In fact, in an effort to make them more conspicuous, current railway level crossing signals such as red flashing lights were intentionally designed to be dissimilar to common road warnings (Henderson 1991). It is possible that this design philosophy may have inadvertently reduced their effectiveness by

making them more difficult for drivers to understand. Using standard traffic lights at level crossings *instead* of red flashing lights may improve drivers' decision making ability, and improve the level of warning compliance; however, this possibility remains untested.

Replacing normal crossing signals with standard traffic lights may make the signal more effective by increasing its salience. In addition, the use of standard traffic lights at railway level crossings will provide an additional warning phase (the amber phase) that may allow drivers to make safer judgements regarding whether to stop or continue through a level crossing. It is hoped that this additional warning phase will also eliminate the dilemma currently perceived by drivers when they are required to react both safely and *legally* to current level crossing controls such as red flashing lights.

To-date, limited published evaluations of traffic lights at level crossings have been conducted. One study, carried out in the United States, consisted of a before-and-after field trial that compared the effectiveness of red flashing lights activated by train predictors (to enable consistent warning time) to the effectiveness of standard traffic lights at the same level crossing (Fambro et al. 1989). Two months of data were collected before and after the installation of the traffic lights. Observations of red flashing lights included those from 45 drivers during the passage of 50 trains, while observations of traffic lights included those from 78 drivers during the passage of 92 trains. Compared to the number of vehicles crossing during the red flashing lights, the number of vehicles crossing during the red traffic light was reduced by 80 percent. There was also a significant decrease in the number of vehicles crossing less than 20 seconds in front of the train. Other results, however, were not as compelling. For example, there was no significant difference found in overall clearance time (the time between a vehicle clearing the crossing and a train arriving at the crossing), and no significant difference in perception-brake response time (measured as the time from the warning or traffic lights being activated/turning red until the vehicle's brake lights came on), as this was highly variable across drivers. Further, decelerations did not differ between the two signal types.

Two recent conference papers also demonstrate the safety potential of traffic lights at level crossings. Level crossings in Germany have traffic lights, although these are most commonly used in conjunction with boom barriers. Only red and amber lights are used at level crossings. Level crossings with traffic lights and half barriers (that cover a single lane) are slightly more effective in terms of reducing crash rates than those with flashing red lights and half barriers (Schwarz, 2006). In fact, the use of traffic lights with half barriers is not the preferred treatment, and flashing red lights with barriers are no longer manufactured. The rationale for this change was to capitalise on road users familiarity with traffic lights. A second study in Israel examined driver behaviour at level crossings before and after the installation of traffic lights placed 24 m in advance of the crossing (Becker, Zemach, Gellert, Ben-Shabat, & Ben-Dor, 2008). Following the installation of the traffic lights, they reported a relative drop of 57% in the number of vehicles who crossing the crossing while the flashing red lights were activated.

### 1.3. THE CURRENT RESEARCH

The present project was initiated in early 2008 by the Victorian Level Crossing Safety Steering Committee, which comprises representatives from a variety of Victorian road and rail stakeholders. It represents a 'first step' to inform debate surrounding the utility of traffic lights as a measure to improve rail safety in Victoria

The overall aim of the present study was to compare driver behaviour at two active level railway crossing controls: red flashing lights *vs.* traffic lights. A secondary goal was to compare driver behaviour at level crossings controlled by traffic lights to their behaviour at another active level crossing control, red flashing lights with boom barriers, and to their behaviour at the current standard passive level crossing control, a stop sign.



## 2. METHOD

### 2.1. RESEARCH DESIGN

To avoid individual overexposure to a large number of rail level crossings within a short time period, two groups of participants were exposed to different crossing configurations. A within-subjects design with level crossing control (four levels) as a factor was used for both groups. All participants were exposed to the stop sign- and the traffic lights-controlled level crossings.

Participant Study 1 (first group of participants) addressed the first research question comparing driver behaviour at level crossings controlled by traffic lights *vs.* red flashing lights. Study 2 (second group of participants) addressed the second research question by comparing driver behaviour at level crossings controlled by traffic lights *vs.* red flashing lights with boom barriers. Driver behaviour at level crossings controlled by either red flashing lights (Study 1) or traffic lights (Study 2) in ‘failure’ mode was also assessed. Table 1 presents the four different level crossing configurations used for each study.

**Table 1. Level crossing configurations.**

Study 1	Study 2
Stop sign	Stop sign
Traffic lights	Traffic lights
Flashing red lights	Flashing red lights with boom barriers
Flashing red light controls in failure mode	Traffic light controls in failure mode

### 2.2. PARTICIPANTS

Twenty-five fully-licensed drivers took part to each study.

The first study included 19 males and 6 females with an average age of 34.4 years ( $SD \pm 9.5$ ). On average, participants reported driving 258 km per week ( $SD \pm 159.3$ ).

The second study included 17 males and 8 females with an average aged of 31.6 years ( $SD \pm 10$ ). On average, these participants reported driving 235 km per week ( $SD \pm 215.1$ ).

For both studies participants were recruited by means of notices posted within the local community, the MUARC potential participant database, and advertisements in a local community newspaper (the Waverley Leader), and were compensated \$20 for their participation. The study was approved by the Monash human ethics committee.

### 2.3. EQUIPMENT

#### 2.3.1. Driving simulator

Driver testing was carried out using the MUARC advanced driving simulator. The simulator, located at MUARC, consists of a GM Holden VE Commodore sedan mounted on a three degrees-of-freedom motion base, and a curved projection screen (located in front

of the vehicle) providing a 180° horizontal, and 40° vertical, field of view. Forward vision was produced by three image generators using seamless blended projection onto the cylindrical screen, while rear vision was provided by a separate projection screen at the rear of the vehicle. Eight-inch, widescreen liquid crystal display (LCD) monitors displaying side-mirror views were mounted within the vehicle’s side mirror housing.

A 7.1 surround sound audio system produced the simulated audio environment, and an acoustic shaker produced realistic vibration cues to the driver. The simulator used a high fidelity, real-time dynamics model, CarSim, developed for vehicle design and testing. The model has been adapted to run in real time, and is fully integrated with the virtual environment.

An experimenter controlled all driving simulations remotely from a control room located adjacent to the simulation room.

### 2.3.2. Eye tracking

FaceLab was used to measure visual scanning behaviour. This system comprises two unobtrusive cameras set on the dashboard that are calibrated for angles and depth of the seated driver in order to establish movement parameters of the eyes and head in three dimensions. Camera images and recordings are linked to a user-operated computer interface for various custom and default set-up procedures. The system is designed to recognise and track facial features and markers (small stickers) placed on the driver’s face. For example, a “face model” can be seen in the left panel of Figure 1. The system also recognises the iris, pupil and eyelids, and the experimenter is able to manually adjust size and shape parameters to achieve optimal recordings of the gaze direction (see right panel of Figure 1). A model of the vehicle and screen surrounds (a world model) can also be built so that the system records “hits” at various locations within the vehicle and in the road environment.

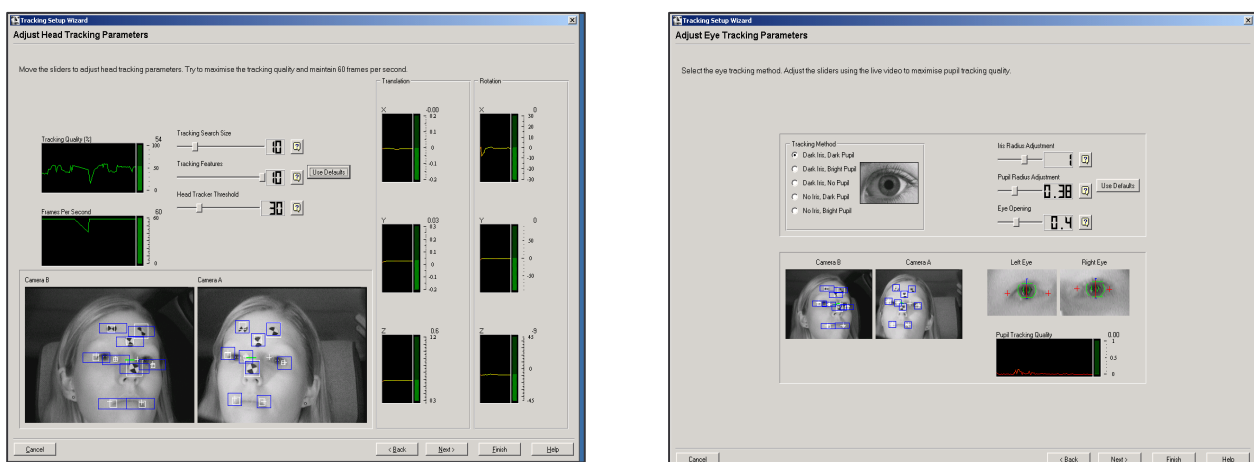


Figure 1. A head model (left panel) and eye tracking parameters (right panel) in the FaceLAB system.

To correlate the data produced by faceLAB with the dynamic environment, the software tool SceneCamera (Seeing Machines Inc.) was used. Designed to work in combination with faceLAB to overlay head direction and gaze direction onto a video of the surroundings, it computes head direction and gaze point that can be overlaid onto a video stream to indicate the point a subject was looking at in the three dimensional space. The



gaze vector intersection with a screen is represented with a circle (see Figure 2). The dynamic environment video was captured using a wide-angle lens USB (universal serial bus) camera that was mounted on the vehicle dashboard.



Figure 2. Gaze point overlaid onto video stream of approach to level crossing controlled by traffic lights.

## 2.4. PROCEDURE

Twenty-five subjects participated in each study. Upon their arrival at the simulator laboratory, participants were briefed on the general nature of the study, signed an informed consent form, and filled out demographics and general driving questionnaires (see Appendix for copies of all questionnaires and study instructions). By not specifically identifying level crossing controls as the focus of the study, the likelihood of observing realistic driver reactions to all events encountered during the test scenarios was maximised. Participants also completed a ‘Current Well-Being’ questionnaire (which they again completed *after* testing was concluded) that was designed to determine if a participant suffered any motion sickness during the driving portion of the study.

The first exposure to the driving simulator was a 5-minute *familiarisation drive*. This drive allowed participants to experience the virtual driving environment and the control dynamics of the simulated vehicle. Participants were instructed to practise accelerating and braking gently.

Once the participant was familiar with the driving simulator, calibration of the eye tracker took place. To do this, the participant was instructed to hold their gaze steady while looking into one of two cameras. The experimenter calibrated the system remotely, using the FaceLAB software for that purpose. Once all eye-tracking calibrations were complete, a screen shot of four points labelled from A to D was projected onto the centre of the

simulator's projection screen, and the participant was asked to look at each point sequentially. The accuracy of the software to track the participant's gaze was confirmed before moving on to the next phase of the experiment.

Once the eye-tracking calibration was complete, the participant was instructed to drive a second 5-minute *familiarisation drive*. This drive was similar to the first; however, the participant was now instructed to try and drive at a consistent speed of 80 km/h. The purpose of this drive was for the participant to get a better sense of speed estimation in the driving simulator.

After the second *Familiarisation drive*, the simulator was configured for the first of two 15-minute *test drives*. Each *test drive* consisted of a two-lane highway, with gentle curves and dips. Scenario road geometry was designed according to the VicRoads Traffic Engineering Manual (VicRoads 2006) as well as from video data of typical Victorian roads. Each participant encountered a total of four level crossing scenarios during the test trial, two in each *test drive*. The level crossing scenarios are described in more detail in the following section of this report.

The order of presentation of the level crossings was counterbalanced across participants; however, for validity reasons, the level crossing control in failure mode always occurred last in the second *Test drive*. Study 1 drivers encountered: one level crossing with stop signs ('Stop'), one level crossing with red flashing lights ('FlashL'), one level crossing with traffic lights ('TrafficL'), and one level crossing with red flashing lights in failure mode. Study 2 drivers encountered: one level crossing with stop signs ('Stop'), one level crossing with traffic lights ('TrafficL'), one level crossing with red flashing lights and boom barriers (Active Control), and one level crossing with traffic lights in failure mode. On average, participants encountered a level crossing approximately every 7.5 minutes. In addition, drivers encountered three other road-road intersections during each *test drive*, one controlled by traffic lights, and two with stop signs on the secondary road. Oncoming traffic (approximately 3-4 vehicles per km, on average) was present during each *test drive*, but was not present at any of the level crossings. In between the two *test drives*, participants were given the opportunity to take a short break.

Upon completion of the second *test drive*, the experimenter brought participants to the simulator control room where they completed a face-to-face *post-drive interview*. Interview questions were designed to investigate participants' subjective perceptions of the different level crossing controls used in the study, as well as the acceptability and perceived convenience of each. Questions also related to the participants' typical behaviour at traffic control devices, and what they believed was the appropriate behaviour at various level crossing, and traffic, controls. The *post-drive interview* took approximately 10 minutes to complete.

#### **2.4.1. Simulated Level crossing controls**

Four different types of level crossing controls were used across the two Studies. These included stop signs ('Stop'), red flashing lights ('FlashL'), red flashing lights with boom barriers ('Boom'), and traffic lights ('TrafficL'). Scenarios were designed so that an approaching train was encountered at each level crossing, except when the control was in 'failure mode'. As a result, drivers were expected to stop at all level crossings.

The design of the level crossing scenarios was informed by examination of data held by VicTrack, the relevant Australian Standards, and stakeholder input. Crossing characteristics were extracted from a VicTrack database of 55 actual level crossings from across Victoria. These data included those passive crossings scheduled for upgrade to active status in the near future.

All level crossings encountered during the scenarios appeared in good physical condition (including written text on signs and pavement markings), and had similar road and environmental characteristics. These included: a two-lane sealed pavement surface that was level in grade, a single railway track, no adjacent distractions (including other vehicles), a speed limit of 80 km/h, and a road-rail angle of 90 degrees. The approaching train, which included an engine and five carriages, was 150 m in length, and travelled at a speed of 80 km/h.

Four different types of level crossing control were assessed. Each was designed according to the specifications set out in Australian Standard 1742.7 – Manual of uniform traffic control devices, Part 7: Railway crossings. In addition, each crossing included level crossing width markers, which is the current practice in the state of Victoria.

#### 1. Level crossings with passive (stop sign) control ('Stop').

This type of control (see Figures 3a, 3b and 3c), used as a baseline condition across both groups, included two pre-warning signs (road sign with a train picture) located on each side of the road 210 m prior to the level crossing. Other signs included one indicating 'stop sign ahead' located 150 m prior to the crossing on the left side of the road, and a composite sign positioned 3.5 m in front of and to the left of the crossing that included a rail cross buck, stop sign, and the text "LOOK FOR TRAINS". In addition, in the 60 m following the pre-warning signs, the text "RAIL X" appeared as road pavement markings.

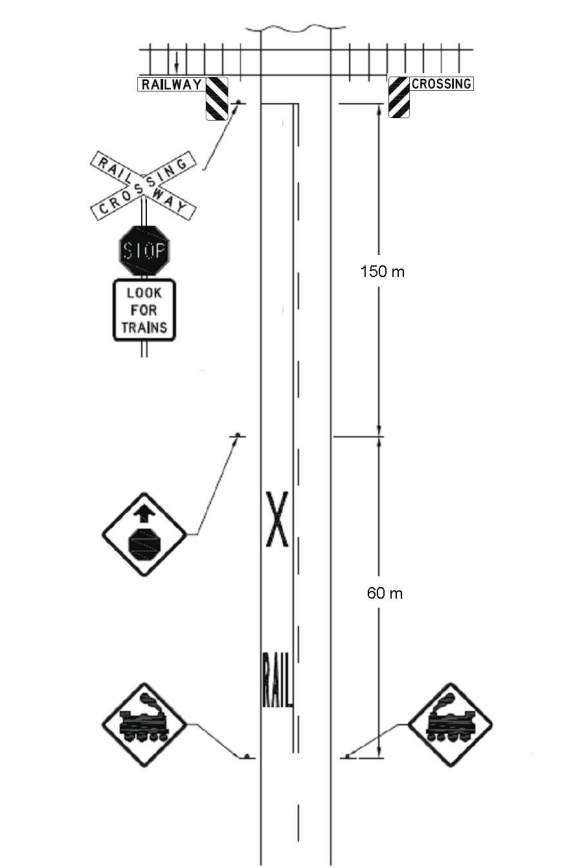


Figure 3a. Simulated level crossing with stop sign control ('Stop'). Location of signage.



Figure 3b. Screen image of approach to level crossing with stop sign control ('Stop').



Figure 3c. Screen image of approach to level crossing with stop sign control ('Stop').

## 2. Level crossings with standard Australian red flashing light controls ('FlashL').

This scenario (see Figures 4a, 4b and 4c) comprised one primary set of red flashing lights on the left hand side of the road on the approach side of the level crossing, and an additional set of lights on the right of the departure side of the crossing. The primary set of red flashing lights was positioned 3.5 m in front of the crossing, within a composite sign that also included a rail cross buck above, and a sign with the text "STOP ON RED SIGNAL", below. A pre-warning sign indicating the presence of a level crossing with active controls (road sign with picture of cross buck and flashing lights) was positioned on the left side of the road 150 metres prior to the level crossing. In addition, in the 60 metres following this pre-warning sign, the text "RAIL X" appeared as road pavement markings in the left hand lane.

When activated, the red lights flashed alternatively at a rate of 45 per minute. Audible warning bells (60 dB) accompanied the red flashing lights at a rate of approximately 60 bells per minute. The bells only became audible to a participant when the subject vehicle was within 20 metres of the level crossing.

Activation of the red flashing light controls was dependent on the speed of the subject vehicle. The flashing red lights would be activated 4 seconds ( $t=4$ ) after the subject vehicle passed trigger point ( $t=0$ ), which occurred when the subject vehicle was 10 seconds from the level crossing. The train was programmed to arrive at the level crossing approximately 20 seconds after the subject vehicle. Just prior to the train arriving at the level crossing, a train horn sounded. The red lights would continue to flash, and the bells would continue to ring, until approximately three seconds after the train cleared the level crossing. The entire sequence took 37 seconds.

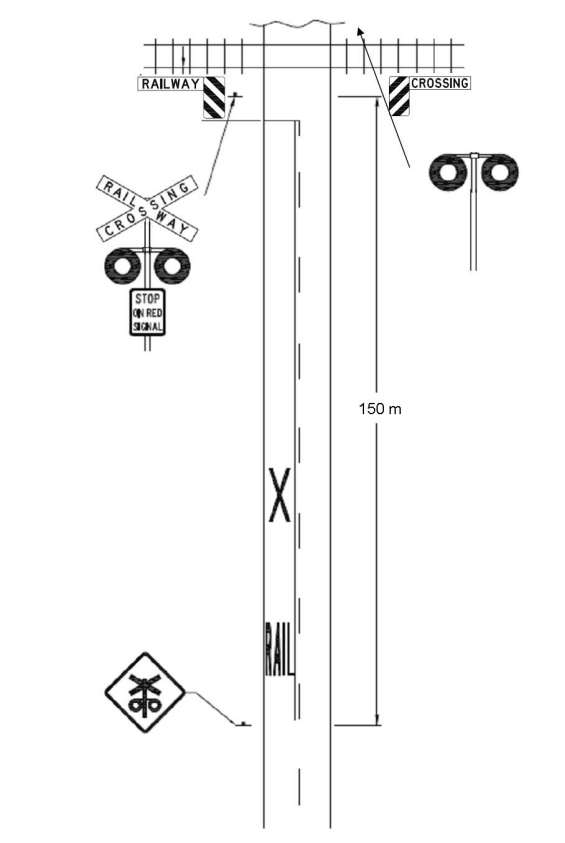


Figure 4a. Simulated level crossing with standard Australian red flashing light controls ('FlashL'). Location of controls and signage.



Figure 4b. Screen image of approach to level crossing with standard Australian red flashing light controls ('FlashL').



Figure 4c. Screen image of level crossing with standard Australian red flashing light controls ('FlashL').

### 3. Level crossings with standard Australian traffic light controls ('TrafficL').

This scenario (see Figures 5a, 5b and 5c) comprised two primary sets of traffic lights on the left and right hand sides of the road on the approach side of the level crossing, and two additional sets of traffic lights on both sides of the departure side of the crossing. The two primary sets of traffic lights were positioned 3.5 m in front of the crossing, within a composite sign that also included a rail cross buck above, and a sign with the text "STOP ON RED SIGNAL", below. A pre-warning sign indicating the presence of a level crossing with active controls (road sign with picture of cross buck and traffic lights) was positioned on the left side of the road 150 metres prior to the level crossing. In addition, in the 60 metres following this pre-warning sign, the text "RAIL X" appeared as road pavement markings in the left hand lane.

When activated, the traffic lights cycled from green to amber for 4.5 seconds, and then to red. Audible warning bells (60 dB) accompanied the amber and red traffic lights at a rate of approximately 60 bells per minute. The bells only became audible to a participant when the subject vehicle was within 20 metres of the level crossing. Activation of the traffic light controls was dependent on the speed of the subject vehicle. The trigger point (time = 0) was activated when the subject's vehicle was ten seconds from the level crossing if they continued at their current speed. Four seconds after the trigger point ( $t = 4$ ), regardless of the vehicle's speed, the traffic lights changed from green to amber. After a further 4.5 seconds ( $t = 8.5$ ), again regardless of the vehicle's speed, the traffic lights changed from amber to red. The train was programmed to arrive at the level crossing approximately 20 seconds after the subject vehicle. Just prior to the train arriving at the level crossing, a train horn sounded. The traffic light would remain red, and the bells would continue to

ring, until approximately three seconds after the train cleared the level crossing, at which point the traffic light changed to green. The entire sequence took 37 seconds.

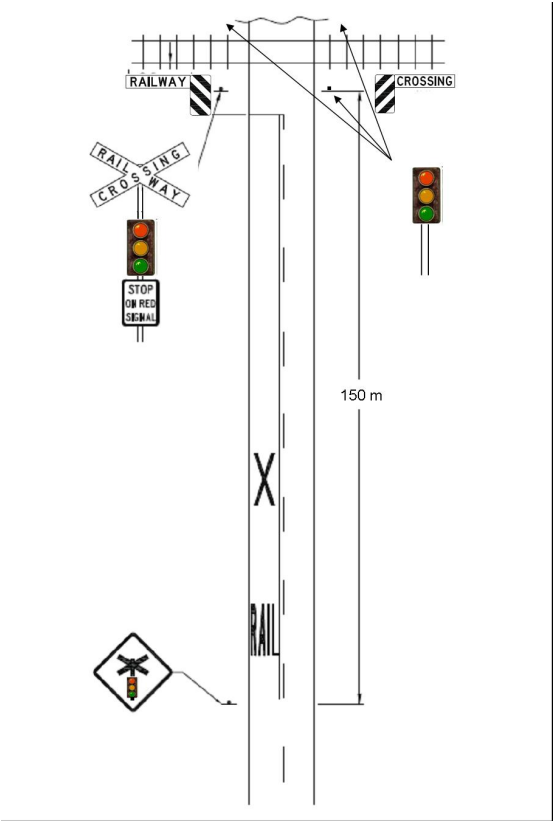


Figure 5a. Simulated level crossing with traffic light controls ('TrafficL'). Location of controls and signage.



Figure 5b. Simulator screen image of approach to level crossing with traffic light controls ('TrafficL').





Figure 5c. Screen image of level crossing with traffic light controls ('TrafficL').

#### 4. Level crossing with standard Australian red flashing light controls PLUS boom barriers ('Boom').

Like the FlashL scenario, this scenario (see Figures 6a, 6b, 6c and 6d) comprised one primary set of red flashing lights located 3.5 m in front of the level crossing, on the left hand side of the road on the approach side, and an additional set of lights on the right of the departure side of the crossing. The primary set of red flashing lights was positioned within a composite sign that also included a rail cross buck above, and a sign with the text "STOP ON RED SIGNAL", below. In addition to the red flashing lights, active boom barriers completely blocked the left and right hand lanes. A pre-warning sign indicating the presence of a level crossing with active controls (road sign with picture of cross buck and flashing lights) was positioned on the left side of the road 150 metres prior to the level crossing. In addition, in the 60 metres following this pre-warning sign, the text "RAIL X" appeared as road pavement markings in the left hand lane.

When activated, the red lights flashed alternatively at a rate of 45 per minute. Audible warning bells (60dB) accompanied the red flashing lights at a rate of approximately 60 bells per minute. The bells only became audible to a participant when the subject vehicle was within 20 metres of the level crossing.

Activation of the red flashing light PLUS boom barriers controls was dependent on the speed of the subject vehicle. The subject vehicle crossed the trigger point ( $t=0$ ) when it was 10 seconds from the level crossing. Four seconds after the vehicle crossed the trigger point ( $t=4$ ) the red flashing lights were activated. After flashing for seven seconds ( $t=11$ ), the boom barriers on both side of the level crossing would begin to lower. The lowering sequence took 13 seconds in total. The train was programmed to arrive at the level crossing approximately 26 seconds after the subject vehicle. Just prior to the train arriving

at the level crossing, a train horn sounded. The boom barriers would remain in the lowered position, the red lights would continue to flash, and the bells would continue to ring, until approximately three seconds after the train cleared the level crossing. At that point, the bells ceased ringing; however, the lights continued to flash until the boom barrier was raised completely. The raising sequence took 13 seconds in total. The entire sequence from start to finish took 50 seconds.

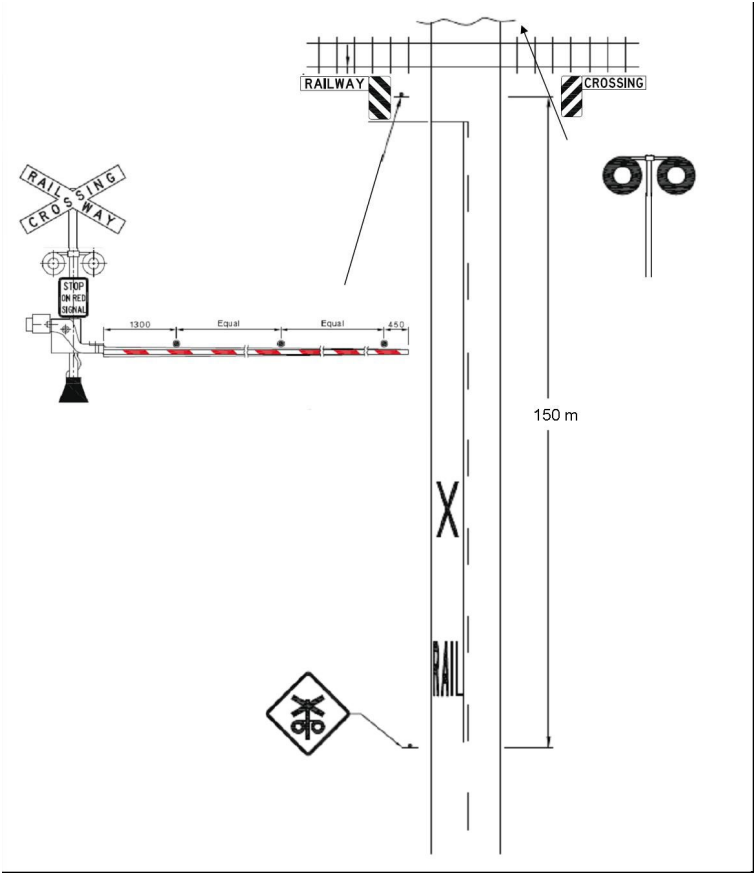


Figure 6a. Simulated level crossing with red flashing light controls PLUS boom barrier ('Boom'). Location of controls and signage



Figure 6b. Screen shot of approach to level crossing with red flashing light controls PLUS boom barrier ('Boom').



Figure 6c. Screen shot of approach to level crossing with red flashing light controls PLUS boom barrier ('Boom'). Barriers raised.



Figure 6d. Screen shot of approach to level crossing with red flashing light controls PLUS boom barrier ('Boom'). Barriers lowered.

### 5. Level crossing controls in failure mode.

For the FlashL (Study 1) and TrafficL (Study 2) scenarios, a 'failure mode' was introduced at the end of the second test drive so as to observe participants' behaviour in the case of device failure. In current practice, an active level crossing control enters into this mode when no information regarding the presence (or absence) of an approaching train is available, normal power supply is interrupted etc., and it becomes necessary to warn approaching motorists to use caution. For technical reasons, current level crossing systems are not able to distinguish between normal operation and a failure; therefore, the failure mode is the same as for when an approaching train has been detected. In the present study, the Australian standard default configuration was adopted for the FlashL failure mode condition (i.e., red flashing lights activated). To be consistent with the current configuration for red flashing lights, it was agreed by the stakeholders that the failure mode for the TrafficL condition would be a steady state red light (in other words, the same cue that is present when a train is in fact approaching the level crossing).

The FlashL and TrafficL level crossings in failure mode were not associated with the arrival of a train; however, activation of the signals occurred in the same manner as the FlashL and TrafficL scenarios (see above). As no train was present, the respective signal at both scenarios (red traffic light or red flashing lights) did not stop or change. The *test drive* ended when the participant either began to accelerate through the level crossing, or commented that something did not appear to be working correctly.

## 2.5. DATA ANALYSIS

Driving performance variables collected in the driving simulator included: number of violations (not stopping at a level crossing), vehicle speed, accelerator pedal release time and distance, brake pedal release time and distance, and latency to proceed after a level crossing 'event'. Speed profile data were analysed using two-way Analysis of Variance (ANOVA) with *level crossing type* and *distance* as the two factors. T-tests were used to analyse other measures of driving performance. In all analyses, an  $\alpha$ -level of 0.05 was used to determine statistical significance.



## 3. RESULTS

### 3.1. DRIVING DATA

#### 3.1.1. Study 1 – Flashing Red Lights vs Traffic Lights

The data presented in the following section focuses on those drivers who came to a stop at level crossings in normal operation. Data for those drivers who violated the crossing, and who experienced crossings in failure mode, are presented in separate sections following. The data presented in the following section include level crossings controlled by stop signs, by flashing red lights and by traffic lights. Statistics analyses, however, only focus on the comparison between flashing red lights and traffic lights.

#### *Measures of Speed*

Speed profiles for each approach to each level crossing were calculated. These profiles represent the speed of the subject vehicle from 280 m before a crossing to 8 m after the same level crossing. The maximum value 280 m was chosen because the first warning or signage relating to any of the level crossing controls occurred at 210 m before a level crossing for the stop-sign condition, and at 150 prior to the crossing for the other level crossing conditions. Therefore, 280 m from the level crossing, drivers were considered not to have started to react to the upcoming signs/road pavement markings/active level controls.

Average speed profiles for all three level crossing controls of the first study (Stop, FlashL and TrafficL) are presented in Figure 7 for all drivers who came to a complete stop at the crossing. It is important to note here the reason why the speed profile curves do not attain a zero speed value. These curves represent an average speed profile, taken across participants, and do not account for the fact that individual stopping points differed by participant. For example, some participants stopped in advance of the crossing while others stopped on the stop line. Therefore, the curves give the impression that participants did not ever come to a complete stop, however this is not, in actuality, the case.

It is apparent, from this Figure, that there is a difference in speed profile shape between the Stop condition and the two active controls (flashing red lights and traffic lights). The reason for this difference is likely to be because, in the Stop condition, the first warning sign pertaining to the level crossing appears at -210m from the crossing, further away from the crossing than that associated with the active crossing controls where the first signage appears at -150 m.

The speed profiles observed for the FlashL and TrafficL conditions look rather similar. The participants kept an almost identical speed in FlashL and TrafficL conditions until they reached a position of about 80 meters from the level crossing. This was confirmed by a significant interaction between level crossing condition and distance ( $F(1, 9) = 2.82, p < .05$ ). *Post-hoc* analyses showed that the significant difference between the FlashL and TrafficL conditions from 100 to 10 meters of the crossing is mainly due to the 50 and 60 meters points. After people reached their minimal speed, no differences were observed between conditions in terms of speed profiles.

A one way ANOVA performed on the speed recorded at 140m from the level crossing, the point at which the road sign appears, revealed a significant difference between the three

level crossing controls ( $F(2,49) = 4.03, p < .05$ ). *Post hoc* analyses showed that drivers' speed in the Stop condition was significantly lower than for both FlashL and TrafficL conditions ( $p < .05$ ).

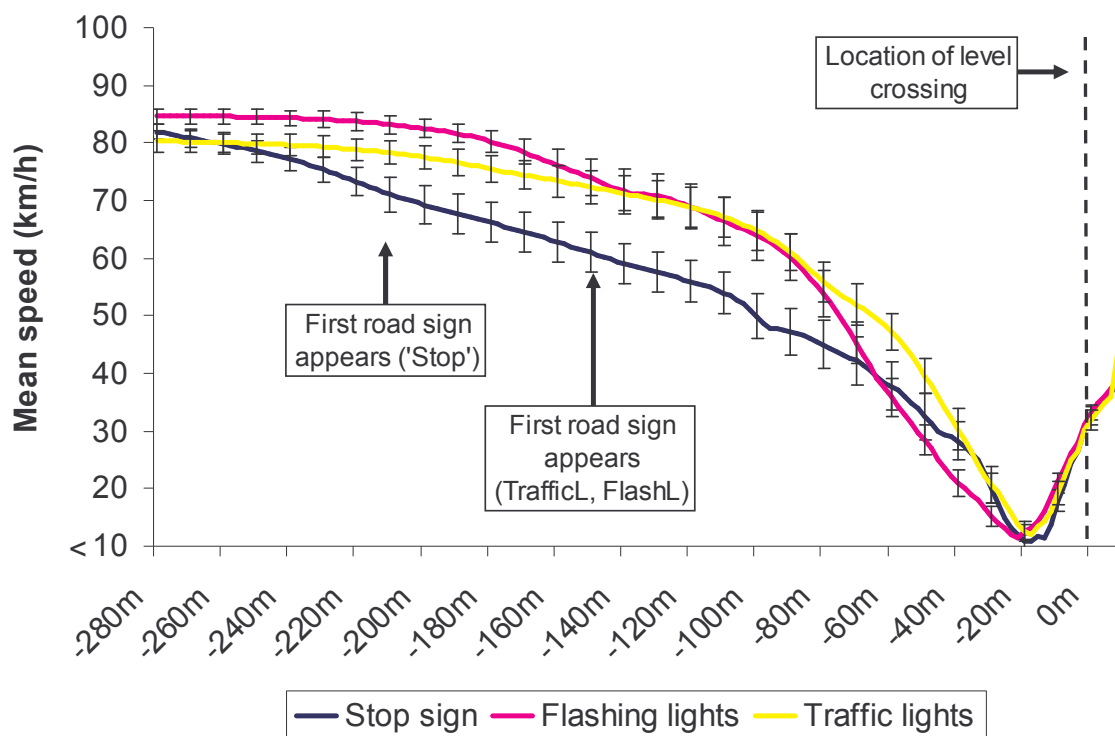


Figure 7. Mean speed profiles (km/h) on approach to level crossings with a stop sign, flashing light, and traffic lights

### Response time (to level crossing signal)

#### Accelerator release time

Accelerator release time was measured from the time at which the subject vehicle triggered a train crossing 'event' to the time at which the participant first released the accelerator pedal. Despite a trend suggesting that release time was faster in the flashing light condition, statistics did not revealed a significant effect between FlashL and TrafficL conditions ( $t(16) = .69, p > .05$ ). Average accelerator release times of each level crossing type are presented in Figure 8.



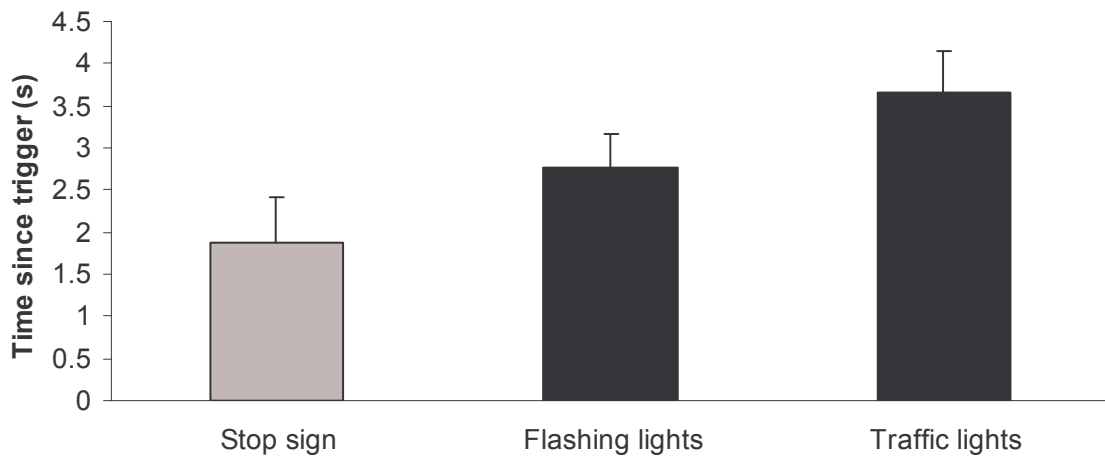


Figure 8. Mean accelerator release time at each level crossing type.

#### Foot on brake time

Foot on brake time was measured from the time at which the subject vehicle triggered a train crossing ‘event’ to the time at which the participant first depressed the brake pedal. Although mean time to apply the brake was around 1 sec faster in the flashing light condition, there were no significant statistical difference between FlashL and TrafficL conditions,  $t(16) = 1.53, p > .05$  (see Figure 9).

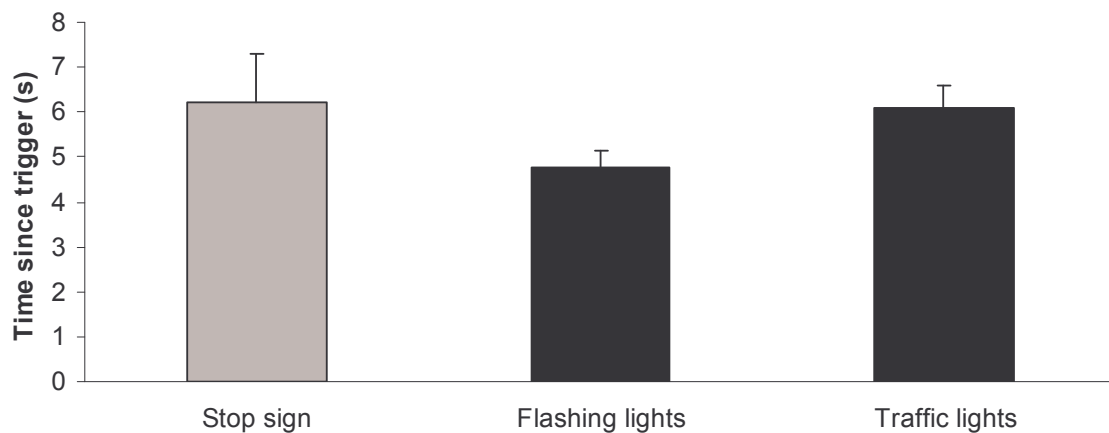


Figure 9. Average ‘foot on brake’ time for each level crossing type.

#### ***Behaviours after stopping at the crossing***

##### Latency to proceed

Latency to proceed was defined as the time from when the level crossing signals ended (or when the train had passed, in the case of the stop sign-controlled level crossing) to when a participant first depressed the accelerator pedal. A t-test revealed a significant effect between FlashL and TrafficL conditions on latency to proceed,  $t(16) = 3.05, p < .05$ , with the FlashL condition resulting in significantly longer latencies to proceed after the signals ended than the TrafficL condition (see Figure 10).

Due to the occurrence of several unusually high values (>8 s) in the FlashL condition, where participants didn't realise that the light had stopped flashing and that they were allowed to proceed, caution should be used at this point regarding interpretation of these results.

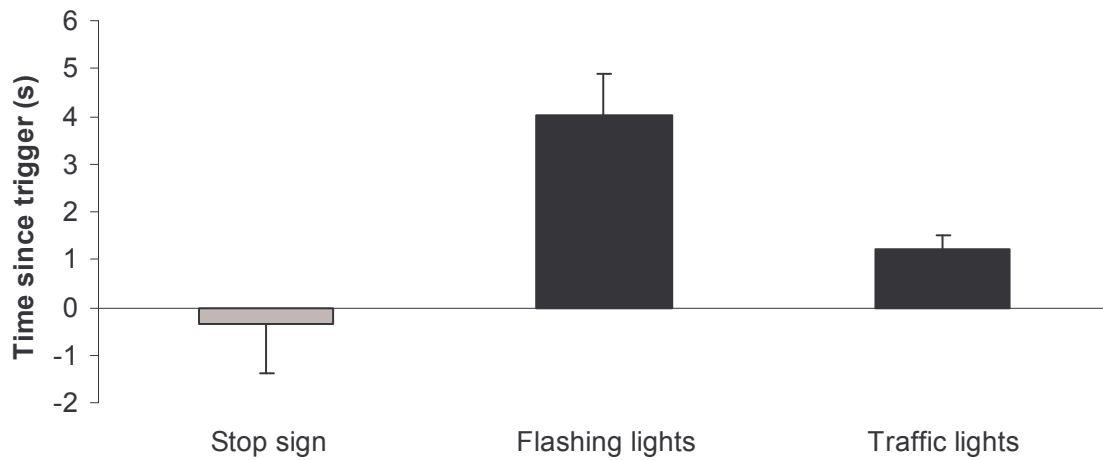


Figure 10. Mean 'latency to proceed' time for each level crossing type.

### Crossing speed

After stopping and waiting for the train, no significant differences were found between FlashL and TrafficL ( $t(16) = .67, p > .05$ ) when looking at the speed at which participants drove through the level crossing (see Figure 11).

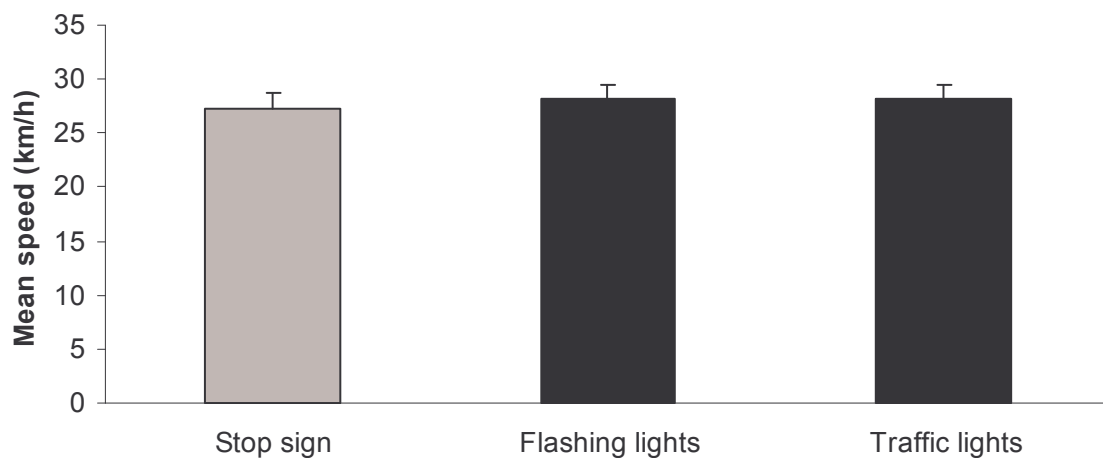


Figure 11. Subject vehicle speed at level crossing.

### Violations

To determine whether a driver violated a level crossing control (i.e., drove through the crossing before the train arrived) two sources of data were consulted. First, minimum speed within the 280 m before each level crossing was determined. If this speed was less than 10 km/h, then the driver was deemed to have stopped before that particular crossing. If the minimum speed was above 10 km/h, the driver was deemed to have driven through that

particular crossing and this was defined as a ‘VIOLATION’. This data was then compared to the experimenter’s notes that were taken during testing and, in cases where there was a discrepancy between the two, further investigations of the crossing’s speed profile was made. Only one case was identified where a violation had occurred even though the minimum speed was less than 10 km/h (at stop sign-controlled crossings, where the subject vehicle slowed and then continued, despite the presence of a train; see the individual speed profile including this participant in Figure 13).

The number of completed stops *vs.* violations across each of the three level crossing controls is presented in Figure 12.

Respectively 36%, 4% and 24% of the drivers violated the level crossings in the Stop, FlashL and TrafficL conditions. There are clearly fewer violations in the FlashL condition than in the Stop and TrafficL conditions.

This driver simulation study was designed so that drivers saw the flashing red lights activate and the traffic lights change from green to amber 6 seconds before reaching the crossing.. As amber is interpreted as ‘proceed with caution/stop if this can be done safely’ this represents an additional level of decision making and could perhaps have contributed to the greater number of violations for traffic lights. All traffic light violations occurred within 2 seconds of the lights changing from amber to red, suggesting that an incorrect decision to proceed was made as opposed to a mid-phase deliberate violation. In contrast, drivers in this study appeared to have responded more immediately to the activation of flashing red lights.

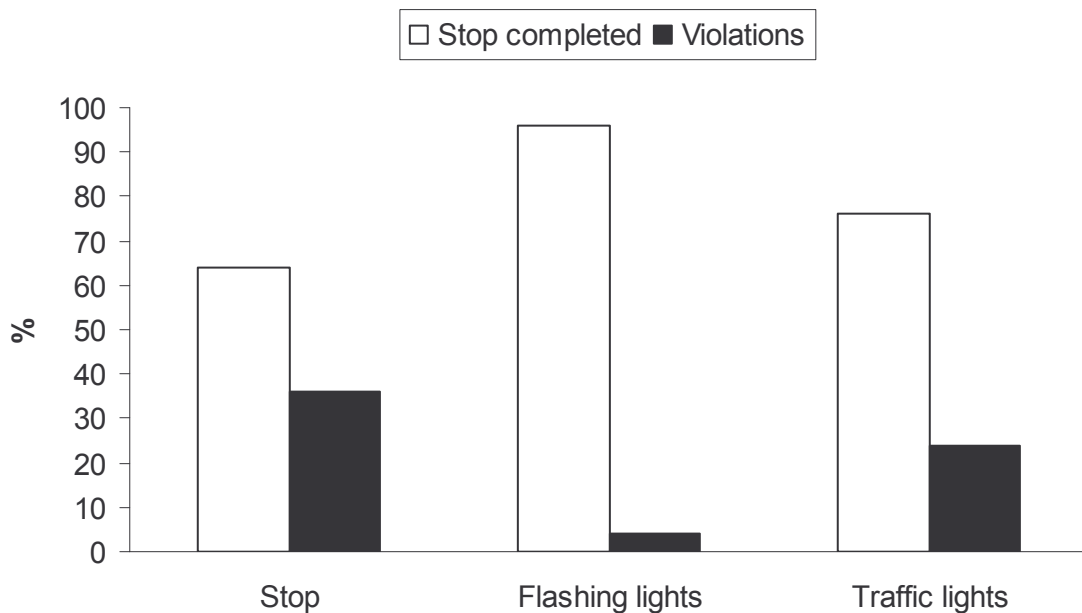


Figure 12. Proportion of drivers who violated the crossings across each condition

### Speed profiles for violations

Individual speed profiles were plotted to better understand the behaviour of those drivers who violated the crossing signals. Nine drivers did not stop at the stop sign in Study 1. Of

those nine drivers, six did not decrease speed at all and maintained a speed of over 70 km/h while proceeding through the stop sign and over the crossing.

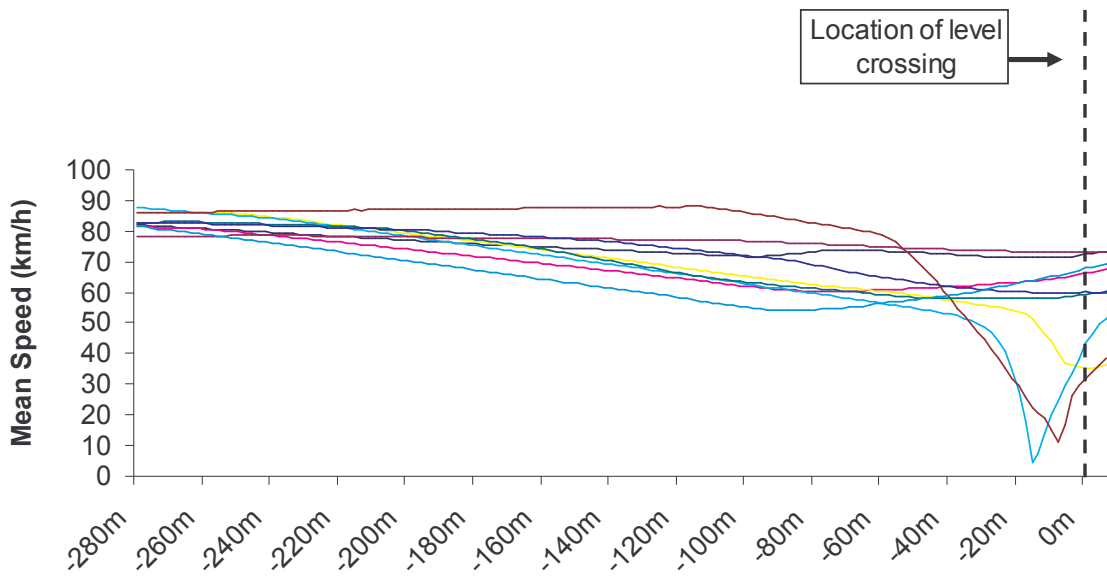


Figure 13. Individual speed profiles for those drivers who did not stop at the stop sign.

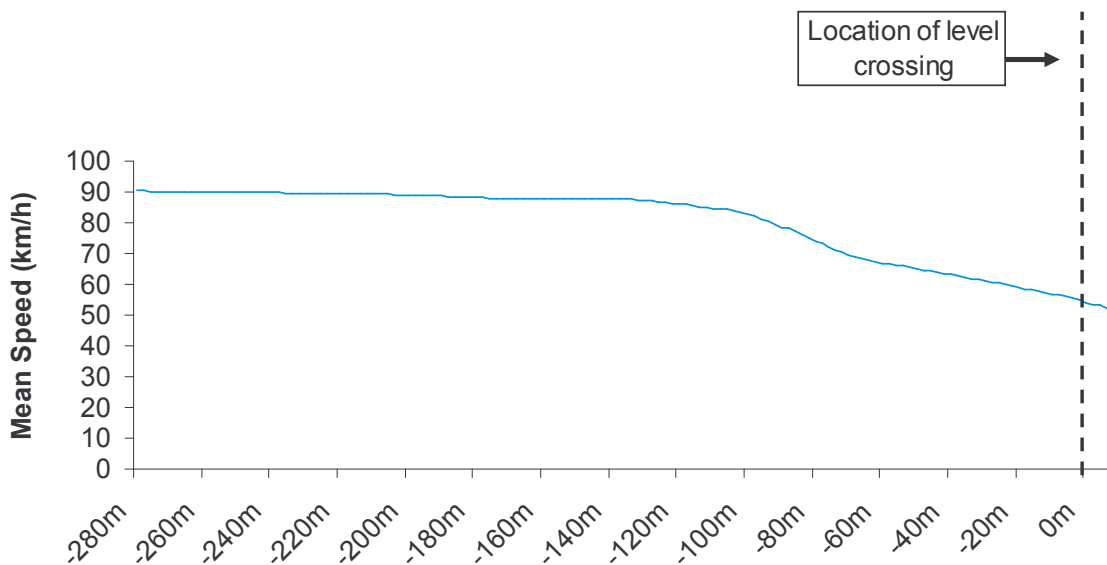


Figure 14. Individual speed profiles for those drivers who did not stop at the flashing red lights.

Only 1 driver did not stop at the flashing red lights (see Figure 14). It is probable that this driver was aware of the crossing given that there was some attempt to reduce speed from 90 km/h to 60 km/h at the crossing. However, the driver did not engage in heavy braking and presumably made the decision to proceed through the crossing.

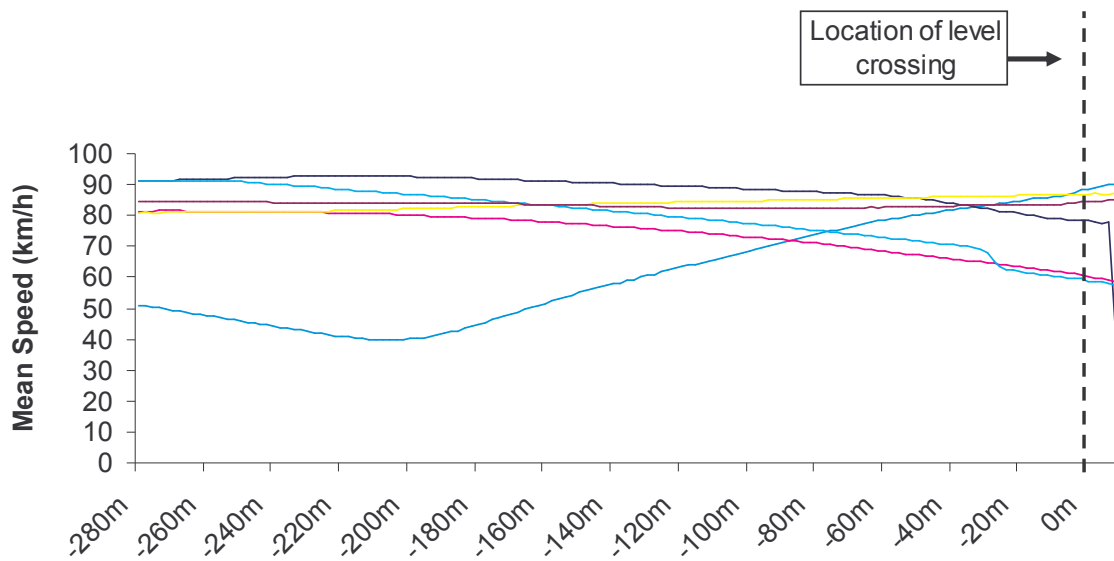


Figure 15. Individual speed profiles for those drivers who did not stop at the traffic lights.

Six drivers proceeded through the level crossing with traffic signals activated an indicating the need to stop (see Figure 16). None of these six drivers made any serious attempt to stop at the crossing, which could be due to drivers either feeling they could not stop safely, not detecting the crossing, or ignoring it.

The eye movement and subjective data will shed more light on these possibilities and will be explored in the Discussion.

### Visual behaviours

To assess drivers' visual strategies, the percentage of time they have spent looking at five different regions was computed. The regions are represented in Figure 16. The region from -10 degrees to 10 degrees collects all the gaze positions when the drivers look straight ahead. The two regions of 20 degrees (from -30 to -10 degrees and from 10 to 30 degrees) on each side collect all the peripheral gaze positions, either on the left or on the right of the central region. Finally the two extreme categories (<-30 and >30 degrees) collect very eccentric gaze positions.

The gaze data have been analysed according to the percentage of time drivers spent looking at these different visual regions. These data are discussed separately for drivers who did and did not stop at the different level crossings.

Two distinct distance regions have been used to assess the gaze position while approaching the different level crossings - from 280m to 160m from the level crossing, and from 160m to 60m from the level crossing. The first region (280m – 160m) was defined to evaluate drivers' visual behaviours on approach of the road signs. The second region (160m – 60m) was defined to evaluate drivers' visual behaviours on approach of the level crossing.

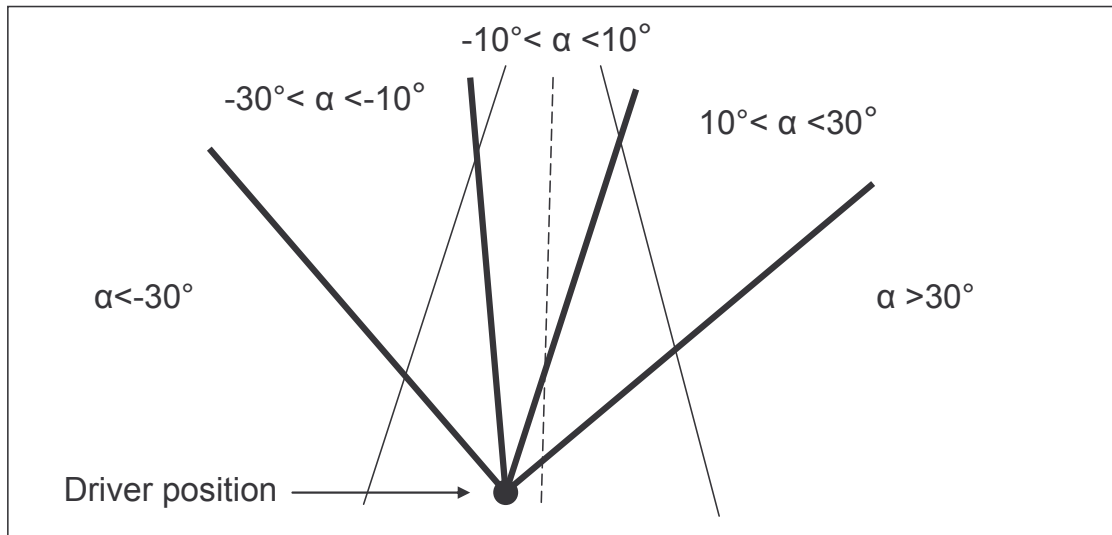


Figure 16. Schematic representation of the five regions of interest for gaze position.

For those drivers who did stop at the different level crossings

As shown in Figure 17, for each type of level crossing control, the drivers who *did* stop spent most of the time looking straight ahead from 280m to 160m of the level crossing. A few glances were also recorded on the left side of the road, especially for the stop sign condition.

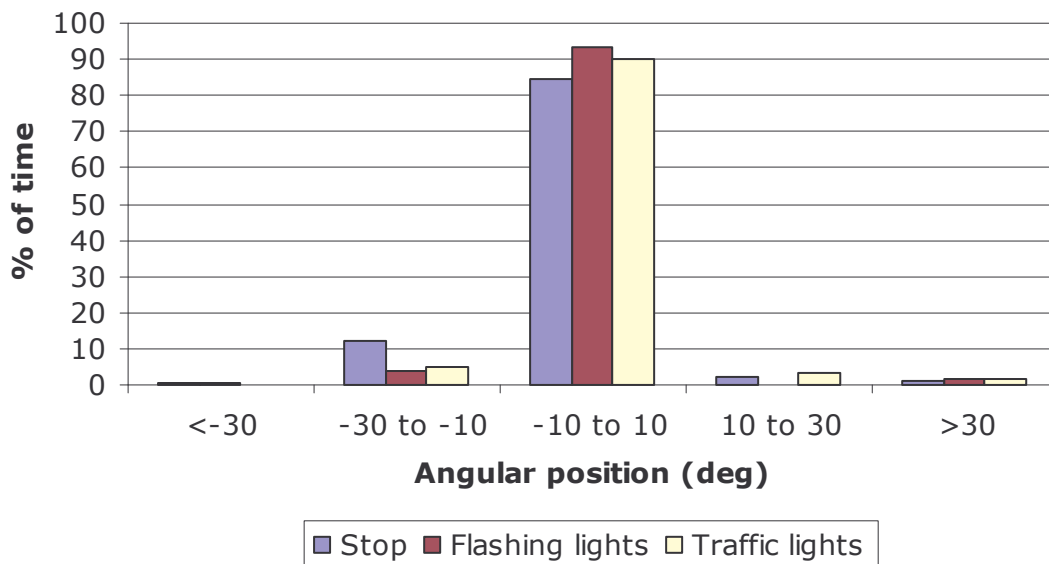


Figure 17. Percentage of time spent by the drivers who did stop at the level crossings in five different visual regions from 280 to 160 meters of the level crossing, depending on the level crossing control.

Very similar results were observed from 160m to 60 meters of the level crossing (see Figure 18). Most of the time participants look straight ahead and a few glances were also made to the left side of the road.

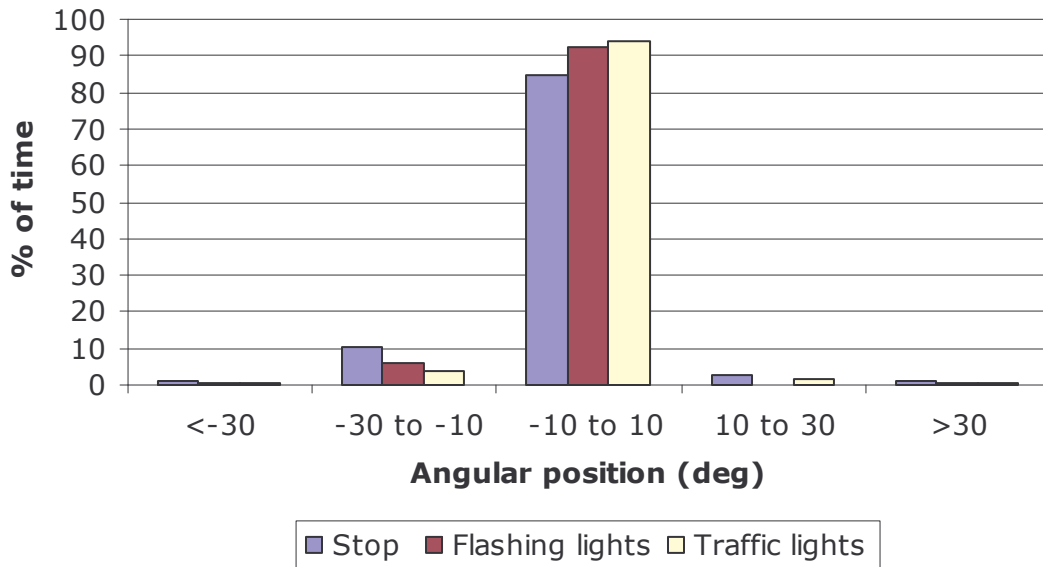


Figure 18. Percentage of time spend by the drivers who did stop at the level crossings in five different visual regions from 160 to 60 meters of the level crossing, depending on the level crossing control.

For those drivers who did not stop at the different level crossings

As can be seen in Figure 19, for each type of level crossing control, those drivers who did *not* stop before the level crossing spent most of their time looking straight ahead from 280m to 160m from the level crossing. However, the few glances toward the left of the road that were observed for drivers who *did* stop before the level crossing were not observed in case of those who were in violation of the level crossing.

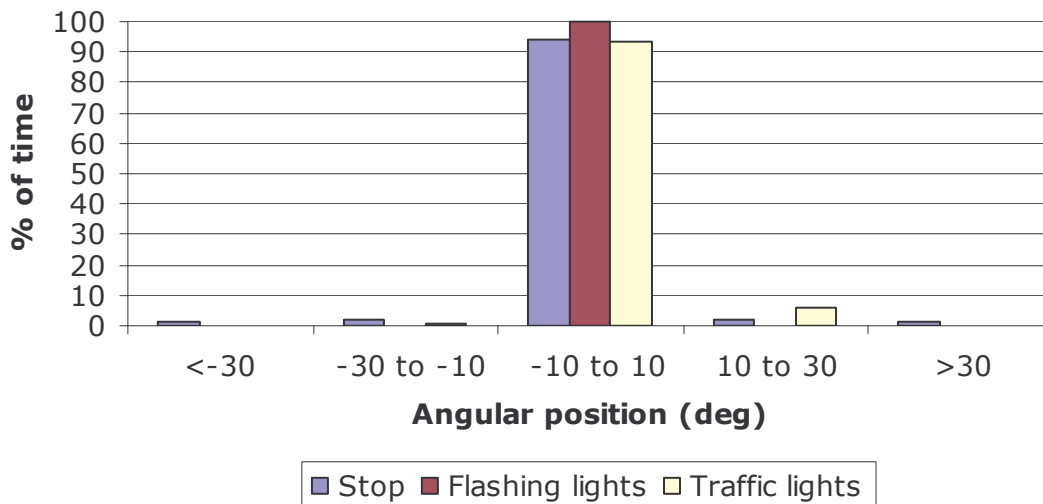


Figure 19. Percentage of time spent by the drivers who did not stop at the level crossings in five different visual regions from 280 to 160 meters of the level crossing, depending on the level crossing control.

From 160m to 60m of the level crossing drivers spent most of their time scanning the central region and made a few glances on the left side of the road (see Figure 20).

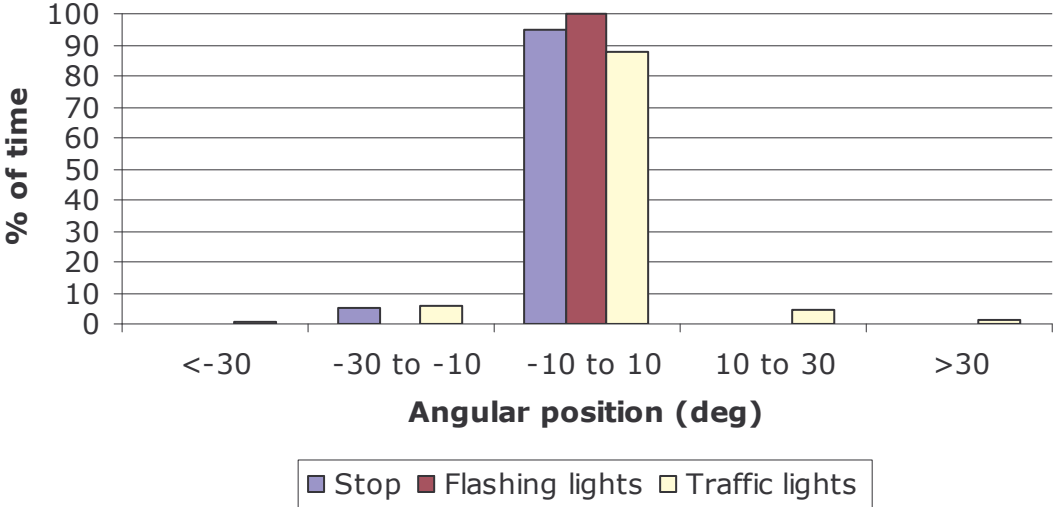


Figure 20. Percentage of time spend by the drivers who did not stop at the level crossings in five different visual regions from 160 to 60 meters of the level crossing, depending on the level crossing control.

**Failure mode**

Participants in the first study were exposed to a flashing red light level crossing in ‘failure’ mode, a condition that was not associated with the arrival of a train. Activation of the flashing red lights occurred in the same manner as the FlashL scenarios; however, as no train was present, the flashing red lights did not cease. The maximum amount of time that a participant could wait at a crossing in failure mode was five minutes. If, at this point, the participant had not driven through the level crossing or said anything, the experimenter would terminate the scenario.

Figure 21 presents the participant responses to the failure mode. Eight drivers proceeded through the level crossing in violation of the active signal within the 5 minutes, with five of these eight waiting over 2 minutes before making this decision. Ten drivers made a comment to the experiment indicating they believed there was something wrong with the simulation. Of these ten, five drivers made a comment within the first 2 minutes, while the other five waited between 2-4 minutes to speak up. Finally, six drivers sat at the crossing, for 5 minutes before being told by the experimenter to proceed through. One of the participants did not face the FlashL in failure condition because of a technical problem during the simulation, hence n = 24 for these data.



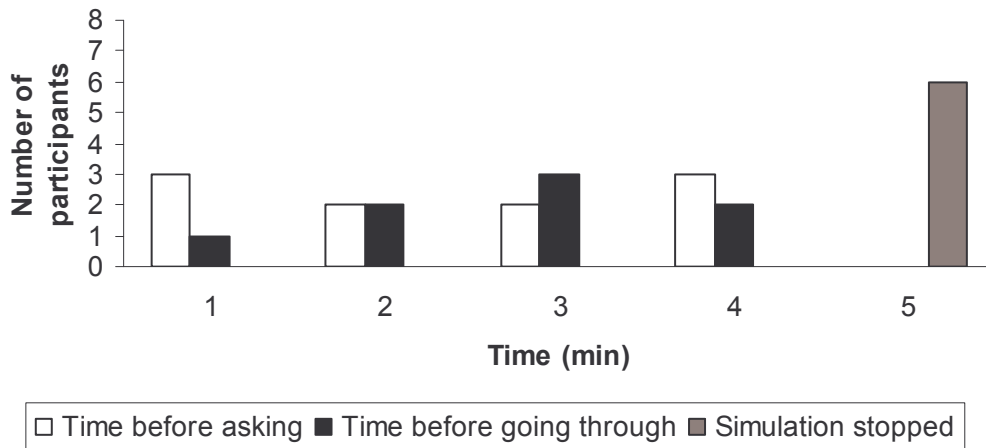


Figure 21. Participants' behaviours in FlashL failure mode.

All the participants stopped before the level crossings in failure mode (no direct violation were observed).

### 3.1.2. Study 2 – Flashing Red Lights + Boom Barriers vs Traffic lights

The data presented in the following section excludes the level crossings that were violated and the level crossing in failure mode. The data presented in this section include level crossings controlled by stop signs, by flashing red lights plus boom barriers and by traffic lights. Statistics analyses, however, only focus on the comparison between flashing red lights plus boom barriers and traffic lights.

#### Measures of Speed

Average speed profiles for all three level crossing controls in the second study (Stop, Boom and TrafficL) are presented in Figure 22.

As observed in the Study 1, there is a clear difference in speed profile shape between the Stop condition and the two active controls (Flashing red lights plus boom barriers and traffic lights).

The speed profiles observed for the Boom and TrafficL conditions look rather similar until participants reach a position of about 130 meters from the level crossing. While there appears to be a small difference between Boom and TrafficL conditions, the absence of a warning condition by distance interaction suggest that the rate of speed reduction was not different between the Boom and TrafficL conditions ( $F(1, 9) = .46, p > .05$ ).

While speed at the point at which advisory signs appeared (140m) appeared lower in the stop sign condition, this difference just failed to reach statistical significance ( $F(2,49) = 3.08, p = .055$ ).

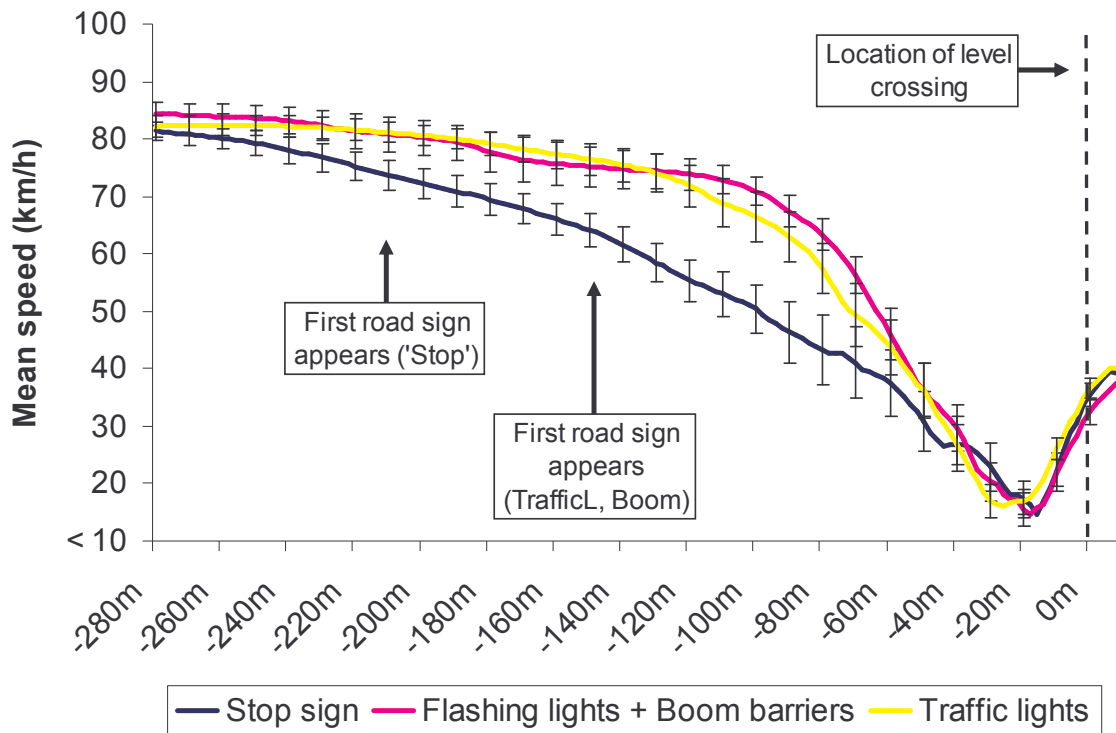


Figure 22. Profile of mean speed on approach to the level crossings.

### Response time (to level crossing signal)

#### Accelerator release time

No significant differences were recorded between Boom and TrafficL ( $t(14) = 1.41, p > .05$ , see Figure 23).

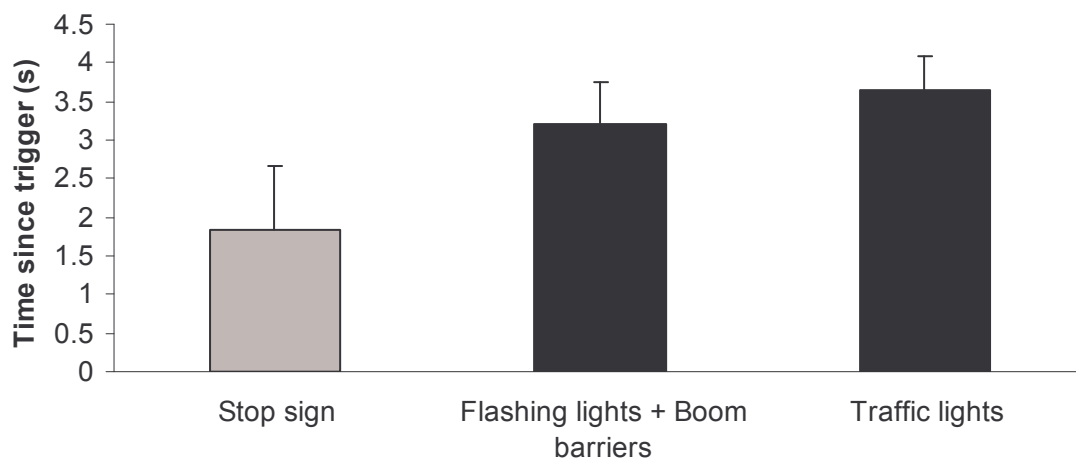


Figure 23. Average accelerator release time at each level crossing type.

### Foot on brake time

There were no significant differences between Boom and TrafficL ( $t(14) = 1.62, p > .05$ , see Figure 24).

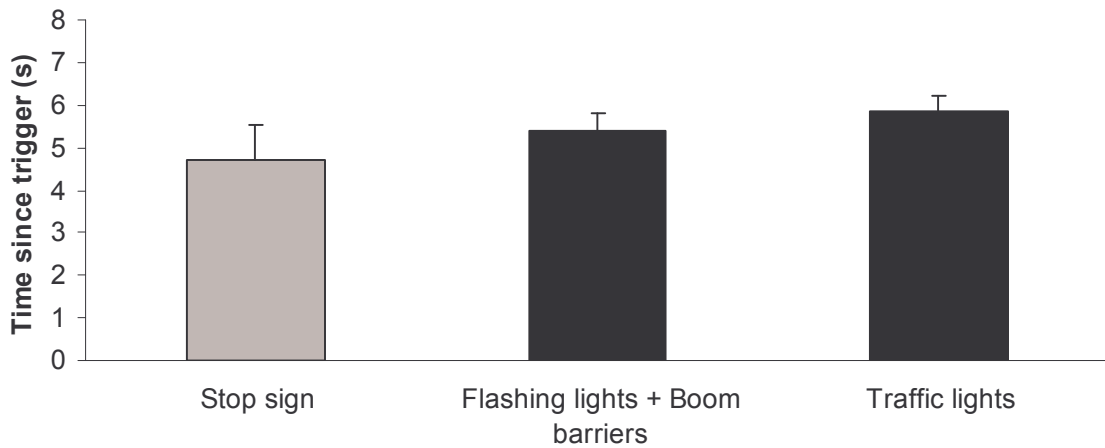


Figure 24. Average 'foot on brake' time for each level crossing type.

### *Behaviours after stop*

#### Latency to proceed

No significant differences were recorded between Boom and TrafficL ( $t(14) = .36, p > .05$ , see Figure 25).

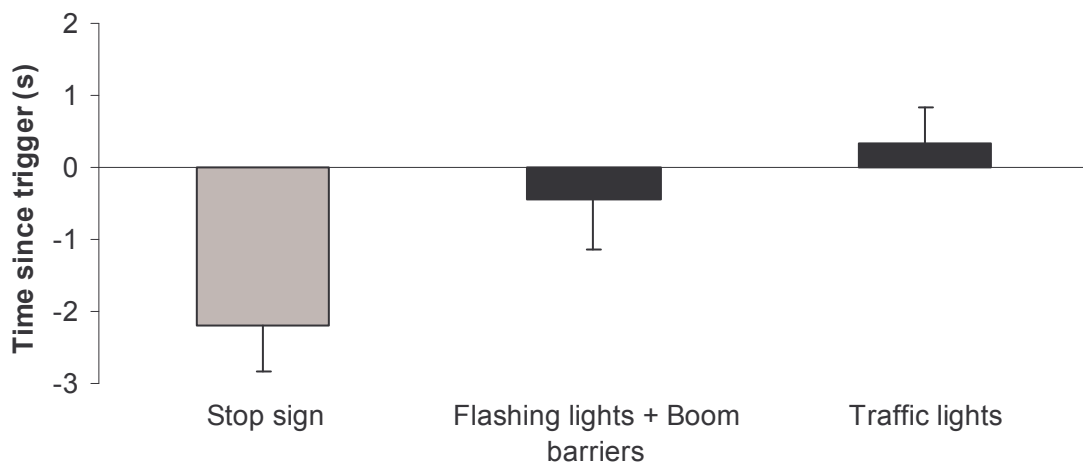


Figure 25. Average 'latency to proceed' time for each level crossing type (violations removed).

### Crossing speed

There was no significant difference between Boom and TrafficL conditions in the speed at which drivers moved away from the crossing ( $t(14) = .51, p > .05$ , see Figure 26).

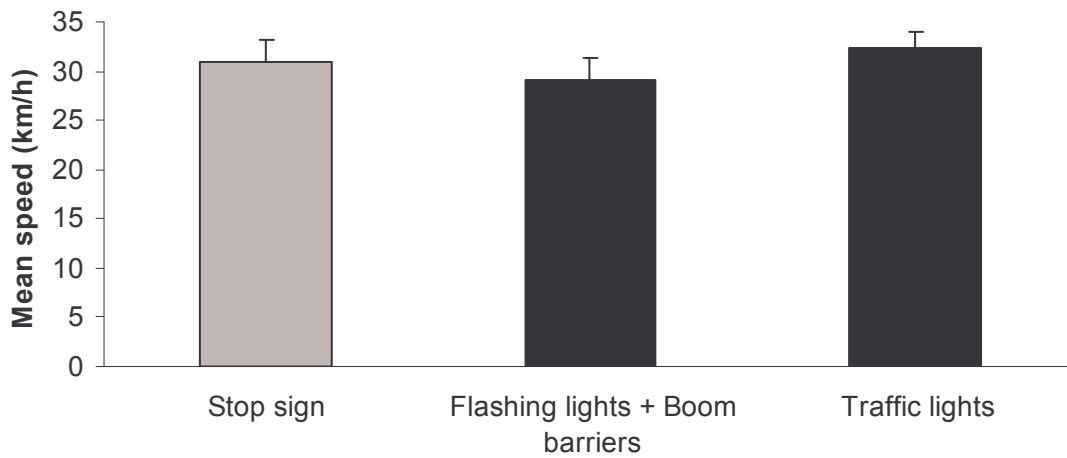


Figure 26. Vehicle speed at level crossing.

### *Violations*

In Study 2 the lowest proportion of violations was seen in the traffic light condition, whereas just over half of the participants in this study did not stop at the crossing in the stop sign condition. The proportion of drivers who violated the traffic lights (around 20%) was almost identical to that observed for traffic lights in Study 1.

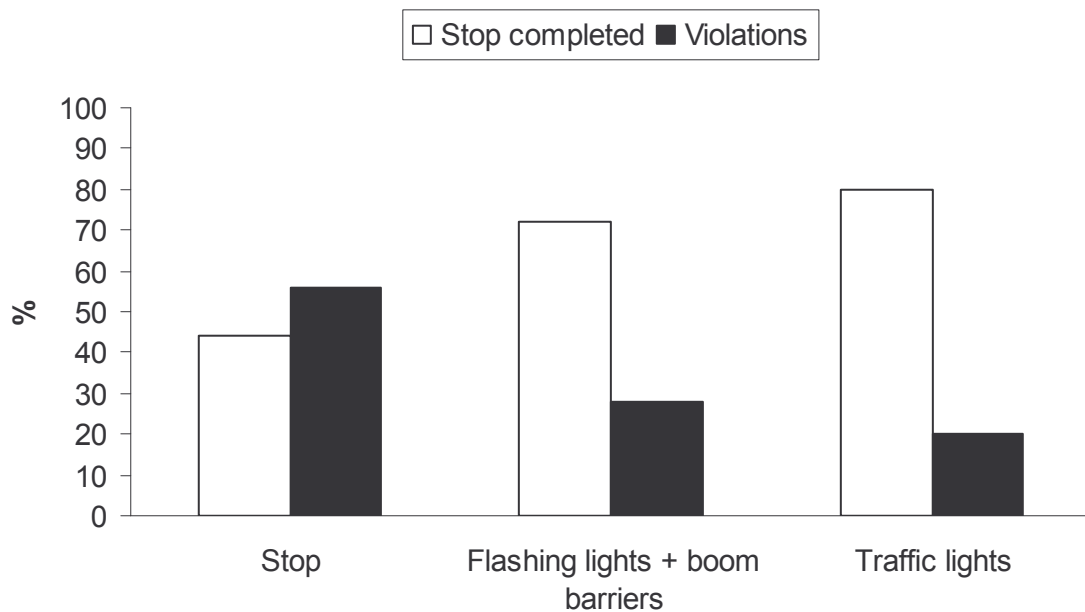


Figure 27. Percentage of crossing violations for the three crossing configurations

### Speed profiles for violations

Individual speed profiles were again plotted to better understand the behaviour of those drivers who violated the crossing signals. As can be seen in Figure 27, 14 of the 25 drivers in this study did not stop at the stop sign. Of those 14 drivers, eight did not decrease speed at all, and maintained a speed of over 70 km/h while proceeding through the stop sign and over the crossing (see Figure 28).

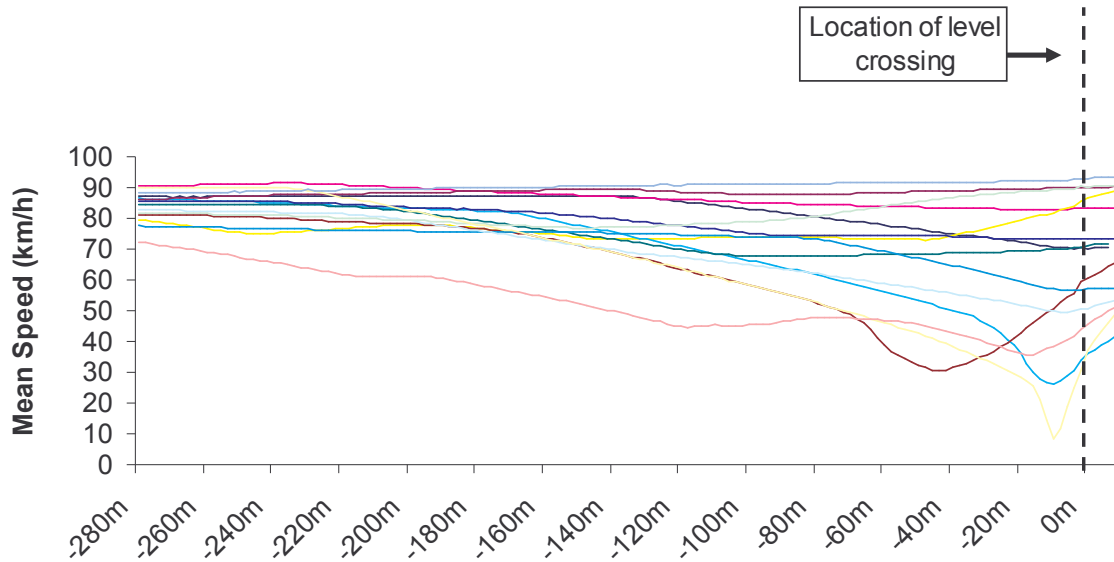


Figure 28. Individual speed profiles for those drivers who did not stop at the stop sign.

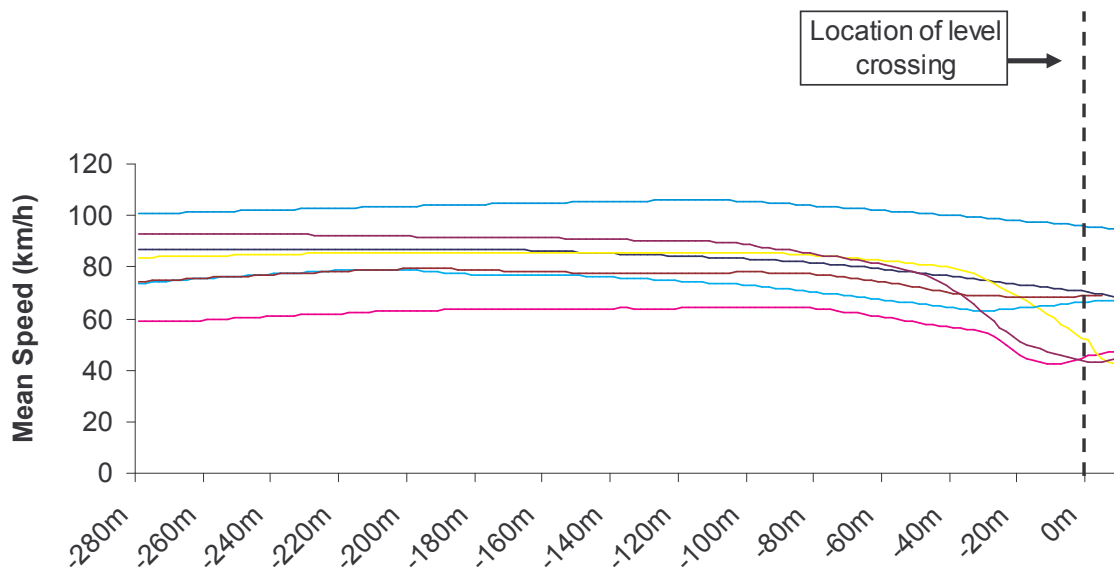


Figure 29. Individual speed profiles for those drivers who did not stop at the flashing red lights with boom barriers.

Four of the seven drivers who proceeded through the activated flashing red lights with boom barriers appeared to make very little effort to reduce speed and stop at the crossing (see Figure 29). It should be noted that all seven drivers drove through the crossing while the flashing red lights were activated but the boom barriers had not yet descended.

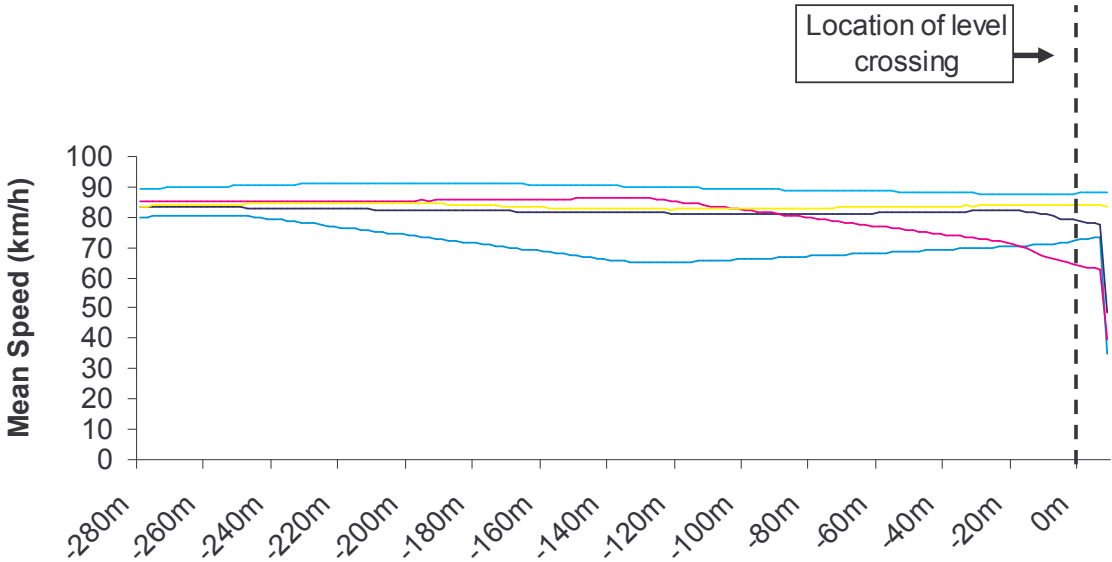


Figure 30. Individual speed profiles for those drivers who did not stop at the traffic lights.

As can be seen in Figure 30, none of the five drivers who proceeded through the crossing against the traffic lights reduced speed on approach to the crossing.

**Visual behaviours**

For those drivers who did stop at the different level crossings

As can be seen in Figure 31, for each type of crossing control, drivers spent most of their time looking straight ahead from 280m to 160m from the level crossing. A few glances were also recorded on both sides of the road, especially for the traffic light and flashing red light plus boom barriers conditions.

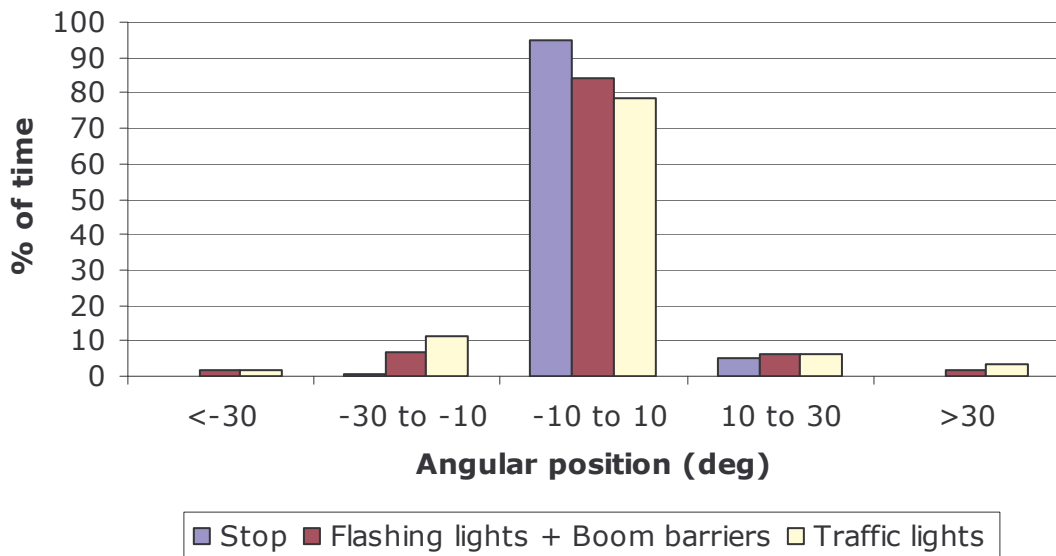


Figure 31. Percentage of time spent by the drivers who did stop at the level crossings in five different visual regions from 280 to 160 meters of the level crossing, depending on the level crossing control.

Figure 32 shows that a very similar pattern of results to the above were observed from 160m to 60 meters of the level crossing.

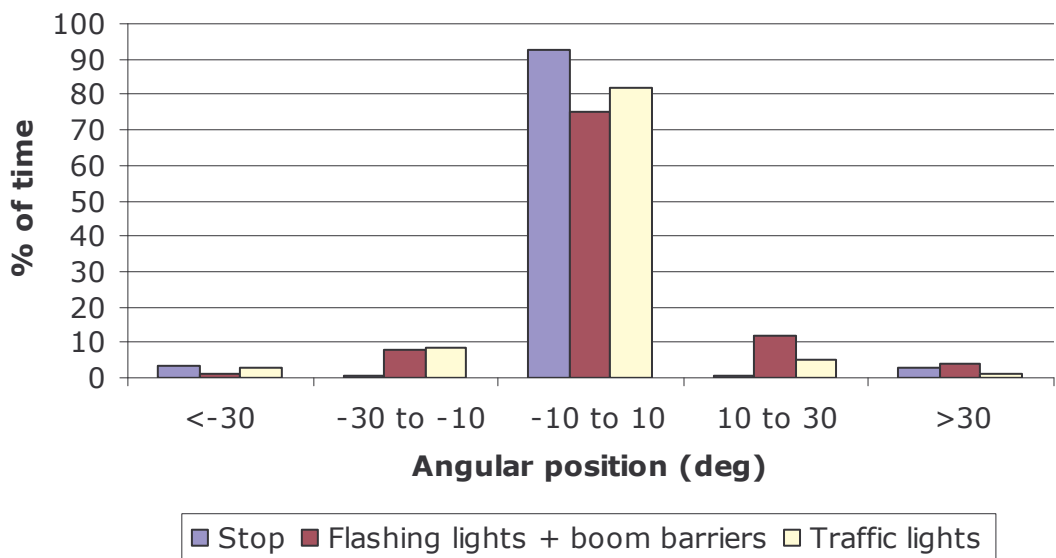


Figure 32. Percentage of time spent by the drivers who did stop at the level crossings in five different visual regions from 160 to 60 meters of the level crossing, depending on the level crossing control.

For those drivers who did not stop at the different level crossings

From 280m to 160m of the level crossing participants who did not stop at the level crossing were also looking straight ahead for the majority of their time (see Figure 33). But contrary to what was observed in the Study 1, those drivers who did not stop also scanned

on the left side of the road, especially when approaching a level crossing controlled by flashing red lights plus boom barriers.

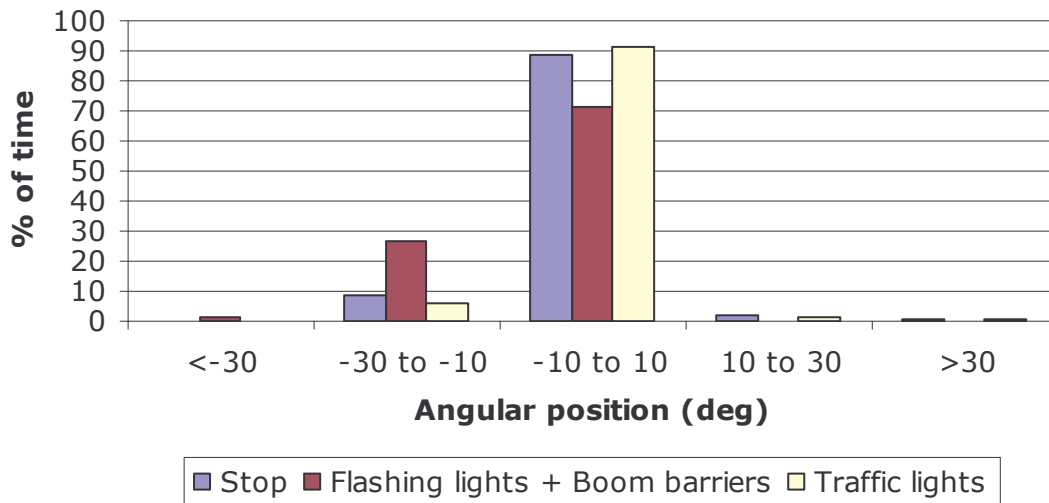


Figure 33. Percentage of time spent by the drivers who did not stop at the level crossings in five different visual regions from 280 to 160 meters of the level crossing, depending on the level crossing control.

A very similar pattern of results to the above were observed from 160m to 60 meters of the level crossing (see Figure 34).

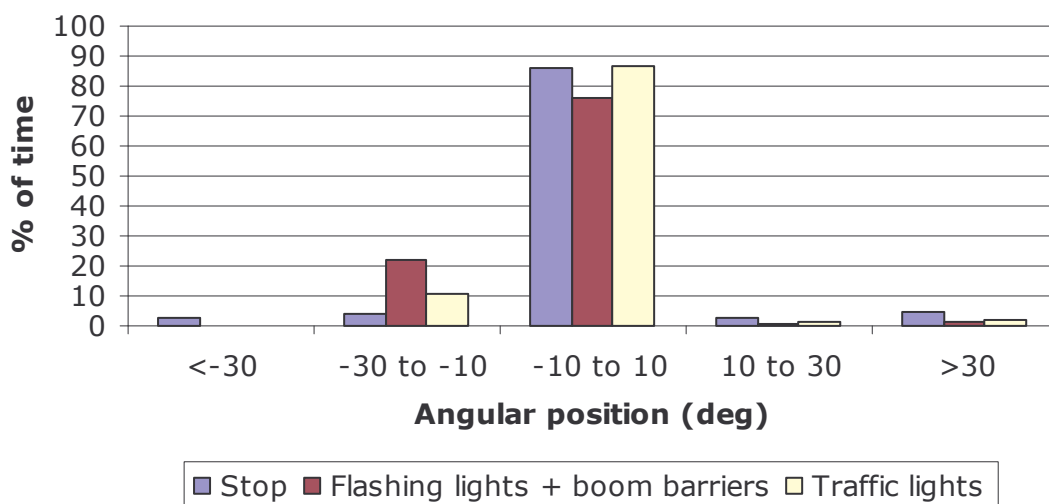


Figure 34. Percentage of time spend by the drivers in five different visual regions from 160 to 60 meters of the level crossing, depending on the level crossing control.

### Failure mode

All the participants of the Study 2 were exposed to the traffic lights level crossing in ‘failure’ mode, a condition that was not associated with the arrival of a train. Activation of the traffic lights occurred in the same manner as the TrafficL scenarios; however, as no



train was present, the traffic lights remained red. Similar to Study 1, the maximum amount of time that a participant could wait at the crossing in failure mode was five minutes. If, at this point, the participant still had not said anything or proceeded through the level crossing, the experimenter terminated the scenario.

Figure 35 presents participant responses to the failure mode. Seven drivers proceeded through the level crossing against a red traffic light within 4 minutes, with four of these seven waiting over 2 minutes before making this decision. Eleven drivers made a comment to the experiment indicating they believed there was something wrong with the simulation. Of these 11, nine drivers made a comment within the first 2 minutes, while the other 2 waited between 2-4 minutes to speak up. Finally, seven drivers sat at the crossing for 5 minutes before being told by the experimenter to proceed through.

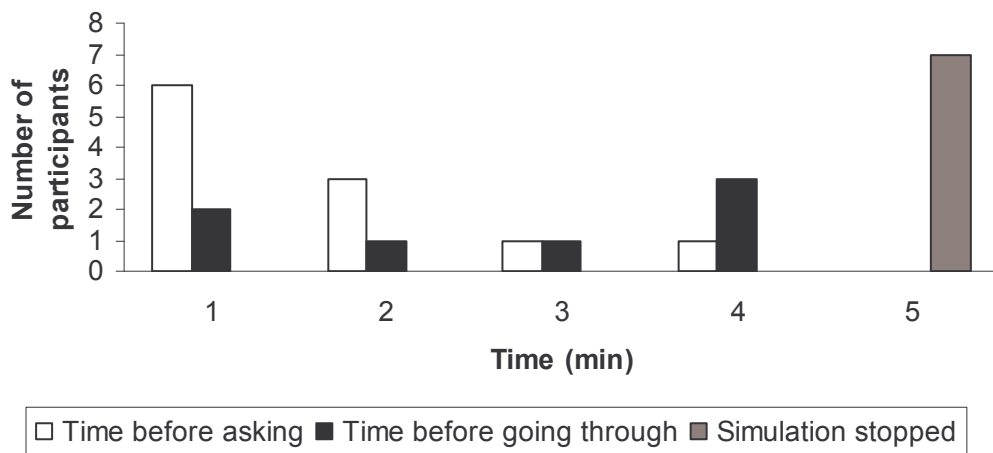


Figure 35. Participants' behaviours in TrafficL failure mode.

All the participants stopped before the level crossings in failure mode (no direct violation were observed).

### 3.2. SUBJECTIVE DATA

At the conclusion of testing, participants were asked a series of short questions relating to the level crossings, as well as what they believe to be the appropriate behaviours at level crossings and at traditional traffic control devices. As the questions were similar for both studies, the combined Study 1 and 2 data are presented here.

#### 3.2.1. Preferred level crossing control

In response to the question “What do you think is the best form of traffic control device for level crossings—flashing red lights or traffic lights?”, 32 participants (64%) reported preferring flashing red lights, while 18 (36%) reported that they preferred traffic lights. A number of those participants who preferred flashing red lights commented that they would prefer flashing red lights and boom barriers even more.

Reasons offered for the preference of flashing red lights included:

- The flashing red lights represent trains, while traffic lights represent intersections (“historical presence”);
- They “grab your attention”, are more “obvious”, better visibility, more “salient”;
- They indicate danger more “actively”
- They “always mean stop”

Reasons offered for preferring traffic lights included:

- They always mean the same thing;
- Their purpose is more clear (than red flashing lights—these may just indicate a warning);
- They provide a warning (amber light);
- People are “more used to them”, and are certain that they are working.

### **3.2.2. Confusion regarding level crossing controls**

Participants were asked whether there were “any railway crossings in the simulated drives at which they were confused about what to do”. Fifteen of 50 drivers (30%) reported being confused at the crossing controls that were in failure mode. Ten drivers (20%) reported confusion at the stop sign-controlled crossing; the most common reason provided for this confusion being that they could not adequately identify the stop sign in sufficient time to respond. Only two drivers reported confusion at each of the boom barrier-controlled and the red flashing lights-controlled level crossings.

Ten drivers (20%) reported some confusion at the traffic lights-controlled level crossing. One reported that they felt confused until they saw the amber light change to red. Another reported that the traffic lights made sense, but seemed to be “out of context”. This driver also stated that he did not expect to see a traffic lights-controlled level crossing out in the country, and that he thought this situation could be potentially dangerous. Other reasons offered for the confusion at the traffic lights-controlled level crossings included that the red light was not visible or “didn’t look red”, that its activation was “too late”, and that the bells seemed quieter (than the other controls).

### **3.2.3. Understanding of level crossing controls**

Participants were asked to indicate what they believed to be the appropriate driving behaviour when approaching level crossings with various types of controls. All but one driver reported that the correct behaviour is to stop if approaching a level crossing where the flashing red lights and bells were operating.

When asked about the appropriate driving behaviour when approaching a level crossing with lights off and no bells ringing, 28 participants reported that the correct behaviour was to slow down and/or look and check for trains before proceeding. Three participants reported that it was correct to stop completely before proceeding, and 12 reported that it was correct to proceed with caution. Six participants simply reported that it was correct to proceed and did not make any further comments.

All but one participant reported that the correct behaviour if they approached a level crossing with the boom barrier down across the road was to stop.

When asked about the correct driving behaviour when approaching a crossing at which the boom barriers were descending, all but three participants reported that the correct behaviour was to stop. The remaining three participants believed the correct behaviour was to stop if it was possible to do so safely and, if not, to continue. One of these three participants further commented that this situation was “like an amber traffic light”.

When asked about approaching a level crossing with no lights or bells, only stop signs, 34 participants reported that the correct behaviour was to slow down and/or look for trains. Seven participants reported that it was correct to come to a complete stop before looking and proceeding across the level crossing. Four participants simply reported that it was correct to obey the signs. Five participants reported that the correct behaviour was to proceed with caution, while one participant reported that it was correct to proceed and did not make any further comments.

When approaching a level crossing with a regular traffic light showing green, 26 participants reported that the correct driving behaviour was to proceed and did not make any further comments. The remaining 24 participants reported that the correct driving behaviour was to proceed with caution, either slowing down, checking for trains, or both.

All participants reported that the correct driving behaviour when approaching a level crossing with a normal traffic light showing red was to stop.

Finally, participants were asked to indicate what they believed to be the correct driving behaviour when approaching a level crossing with a regular traffic light showing amber. Nineteen participants reported that the correct driving behaviour was to stop, while 28 reported that the correct driving behaviour was to stop if it was safe to do so and, if not, (such as when the drivers considered themselves to be too close to the crossing) to proceed across the level crossing. One participant reported that the correct driving behaviour was to slow down, while two reported that the correct behaviour was to proceed.

### **3.2.4. Timings at level crossings**

#### ***3.2.4.1. Flashing red lights***

All but three drivers reported that they would stop at a level crossing if the red lights were flashing and the bells were ringing. When asked to estimate how much time it would take for a train to arrive once the lights began flashing, participants estimated that it would take approximately 49 s (SD=55). Likewise, they estimated that it would take approximately 24 s (SD=30) for the lights to stop flashing once a train had passed.

#### ***3.2.4.2. Traffic lights***

When asked “How did you interpret the traffic light at the level crossing?” all participants reported that they interpreted the traffic lights to have the same meaning as any other traffic lights, although several commented that traffic lights at a railway crossing were “confusing” and “a bit weird because they are not expected”. Several participants said that, compared with traffic lights at a normal intersection, they would be less likely to proceed on the amber light, as they would not want to “risk as much” on it, or they would not “trust the train”. Every participant reported that they would stop if the traffic light was red, and 48 said that they would stop if it was safe to do so when the light was amber. Only two out of 50 reported that they would “proceed” if the traffic light was amber.

When asked how much time they would expect it to take before an (amber) traffic light turns red, participants estimated that it would take 5.8 s (SD=5.7).

#### **3.2.4.3. Failure mode**

Overall, participants stated that they would wait an average of 158 s (SD=109) at a traffic lights-controlled level crossing, and 170 s (SD=112) at a red flashing lights-controlled level crossing, before assuming that something was wrong with the signals.

Most (44 out of 50) participants reported that, once they had assessed that no train was coming (either visually or by using auditory clues as well as visual) they would proceed with caution if they encountered either a red flashing lights- or a traffic lights-controlled level crossing in failure mode. Four participants added that, before proceeding, they would first attempt to ask someone else (either another driver or by calling an emergency phone number if one was available) regarding whether there was a fault. Two participants said that they would not cross the crossing and would seek an alternative route.

## 4. DISCUSSION

Flashing red lights, alone and with boom barriers, are two of the primary countermeasures that are available in Victoria to upgrade passive level crossings to active crossings. The current approved standard for upgrading a level crossing from passive to active control is to fit the crossing with flashing red lights and boom barriers. Traffic lights represent another potential yet untested possibility in this regard. This research aimed to examine driver behaviour associated with the use of active treatments (flashing red lights, flashing red lights with boom barriers, and traffic lights) applied to passive level crossings. This research was designed to address two research questions. Firstly, how does driver behaviour at level crossings with conventional flashing red lights compared with crossings fitted with traffic lights? Secondly, how does driver behaviour at crossings with flashing red lights and boom barriers compare with traffic lights? The following discussion provides an overview of the results found, interpretation of the results, and avenues for further exploration.

### Results overview

In Study 1 there is some evidence to suggest that drivers respond more rapidly to activated flashing red lights compared to traffic lights moving into amber phase. This is evidenced by a slightly more rapid decline in speed on approach to the crossing. The proportion of crossing violations was lower for flashing red lights than for traffic lights. In the post-drive interviews, two-thirds of drivers said they preferred flashing red lights at level crossings over traffic lights, although a number of these participants commented they would prefer flashing red lights and boom barriers even more. This preference for flashing red lights rather than traffic lights was related to the perception that they indicate danger more actively, are more salient, and are strongly associated with rail level crossings.

In study 2 there was very little difference in behaviour as drivers approached crossings with traffic lights and those with flashing red lights and boom barriers. There was no difference in speed on approach in the two conditions, and no difference in the time to release the accelerator and apply the brake. The proportion of crossing violations was lower for traffic lights than for boom barriers with flashing red lights.

Across both studies in the post-drive interviews, 34 of the 50 drivers stated the correct response at a level crossing with stop signs only was to slow down and look for trains, but only 7 of 50 stated the coming to a complete stop was the required behaviour. All participants stated they would stop at a crossing that had flashing red lights activated or traffic lights with a red signal.

### Driving behaviour on approach to crossings

In study 1 the speed profile data show that drivers slow down at a slightly more rapid rate in the flashing red light condition than the traffic light condition. More gradual reductions in speed over a longer time period were observed in the stop sign condition, which can be explained by considering the level of information provided to drivers in this condition. Drivers in the stop sign, traffic light, and flashing red light conditions all received the standard warning sign 150 m in advance of the level crossing. Drivers in the stop condition received an additional warning sign 210 m in advance of the crossing. The speed profile data for the stop sign condition clearly suggest that the earlier advisory warning sign resulted in a reduction in speed further in advance of the crossing compared to the two active conditions in Study 1. This was confirmed from the analyses that showed that speed

140 m in advance of the crossing was significantly lower for the stop sign condition than for flashing red light and traffic light conditions.

Study 2 examined the differences between traffic lights and the current active standard, flashing red lights and boom barriers. There were no differences in performance on approach to operational crossings in these two conditions, as measured by speed, and accelerator and brake inputs. As above, there are some interesting observations that can be made with these data given that both treatments provide a 2-stage warning. In the stop sign condition drivers tend to reduce speed earlier and more gradually. This is not the case with the traffic light condition or the flashing red light and boom barrier condition.

Visual scanning data for those drivers who stopped at the crossings show that drivers in all conditions spent well over 80% of the time scanning the central region of the driving environment. It is interesting to note that, in Study 1, peripheral scanning of the environment was slightly higher in the stop sign condition, a finding that may be due to drivers' slower approach speed to the stop sign-controlled level crossing and which, parenthetically, also supports the suggestion to install advanced warning signs at 210 m for level crossing treatments other than stop signs. Alternatively, the limited scanning at crossings with flashing red lights and traffic lights may have resulted from drivers looking at the lights themselves, rather than scanning for trains. Scanning on approach to the crossing appeared very similar for traffic light and flashing red light conditions. For drivers that did not stop at the crossing, well over 90% of time was spent looking centrally with virtually no scanning of the peripheral environment. Drivers in Study 2 had a different pattern. There was a reduced amount of scanning the wider visual scene, but interestingly, drivers who violated the crossings with flashing red lights and boom barriers spent significant time scanning the periphery, suggesting that they may have been looking for the approaching train in making their decision to cross.

From a theoretical perspective these results may be explained by considering issues such as expectancy and priming, for which there is an established body of literature (see Lenné & Triggs, 2009) that has been invoked in other road safety settings that address the timing of warnings providing to drivers (Lenné et al., 2008). That is, upon seeing the first advisory sign at 210 m, drivers may have heightened expectancies that may facilitate a more rapid response to the subsequent warning sign at 150 m. In isolation, this earlier sign at 210 m is not enough to produce the optimum safety benefit as the number of violations observed was significantly higher for the stop sign condition. What this result does show, however, is the potential safety benefits that could be gained from considering the use of an earlier warning sign in other settings that also provide information on the presence of an oncoming train. This is potentially a very promising avenue for further exploration that could provide further safety benefits for minimal installation costs relative to other treatments. These data could also potentially be validated against on-road driving performance through the use of purpose-built vehicles that collect on-line driving data, such as MUARCs on-road test vehicle.

Another interesting theoretical interpretation can be gleaned by considering the staged warnings provided by the traffic light condition. Drivers were marginally faster to respond to the activated flashing red lights than the amber traffic light. This could be for several reasons, including the conspicuity of the two treatments, but more likely could be indicative of a slight delay in driver decision making. Amber traffic signals are routinely interpreted as a signal to stop if safe or continue through the intersection if not possible to stop safely. Flashing red lights on the other hand have a binary operation – they are either

on or off. In the range of scenarios used in this study, where a split second decision to stop or cross was required, perhaps a 2-stage warning is not optimum, or could be enhanced with earlier signage as noted above.

### Violations

In Study 1, violations were highest for stop signs (35%), followed by traffic lights (20%) and then flashing red lights ( $\leq 5\%$ ). In Study 2 stop signs again had the highest proportion of violations (55%), followed by flashing red lights and boom barriers (30%) and traffic lights (20%). It should be noted that while drivers did violate the flash lights and boom barriers, no drivers drove around the boom barriers or into lowered booms.

While it was expected that some drivers would violate the crossings, either intentionally or unintentionally, the large number of violations observed in this study was surprising. Descriptive analysis of the speed profile data for those drivers who violated the crossings shows that the majority of drivers made little or no attempt to slow down on approach to the crossing. There are several potential reasons for this. Firstly, the scenarios for this driver simulation study were designed such that the driver would encounter a level crossing being activated 6 seconds before reaching it and be forced to make a decision whether to stop safely or proceed through the crossing. It is therefore possible that some drivers felt they could not stop safely and thus proceeded through. It is also possible that these drivers either did not see the crossing or were not clear that vehicle slowing was the appropriate behaviour. Finally, it is possible that some drivers made a deliberate decision at the outset not to stop as they could not see a train.

The most likely explanation however for the violation data we believe is related to the timing of the events presented in this study. In study 1 the point on approach to the level crossing where the flashing red lights activated (for flashing red light crossings), and where the traffic light moved from green to amber (for traffic light crossings) was the same. As amber is interpreted as 'proceed with caution/stop' this represents an additional level of decision making and could perhaps have contributed to the greater number of violations in this condition. All traffic light violations occurred within 2 seconds into the red signal phase, suggesting that an incorrect decision to cross was made as opposed to a mid-phase deliberate violation. In contrast, drivers in this study appeared to have responded more immediately to the activation of flashing red lights.

Similarly for study 2 this can be considered in the context of the timings of the flashing red lights activating and boom barriers descending, versus the timing of the amber and red traffic light phases. In the traffic light condition the red traffic signal occurred several seconds before the boom barrier descended (for crossings with flashing red lights and boom barriers). Drivers in this study appeared to use the descending boom barrier as the cue to stop rather than the activation of the flashing red lights. As such it is not unexpected that violations were slightly higher in this condition.

While the violation data are inherently interesting, these results should be interpreted with some caution. The violation rate for the failure mode conditions in Studies 1 and 2 was lower than for the three crossings previously experienced in normal operation. The experimental design dictated that participants always experienced three crossings in normal operation before the crossing operating in failure mode. It is therefore possible that, with further exposure to level crossings in the simulator, the violation rate for all crossings may

be decreased. This could be established using a larger number of longer driving sessions. The large number of violations in the stop sign condition does underscore the importance of upgrading crossings to active status.

### Failure mode

The failure mode data are also quite interesting. In an observed laboratory environment it was not expected that drivers would proceed through the crossing against an active warning. One-third of drivers in Study 1 waited for up to four minutes before driving through the crossing with flashing red lights activated. Nearly half of the drivers made a comment to the researchers that indicated that the driver realised that something was not quite right.

Drivers in Study 2 experienced the traffic lights at level crossings in failure mode. The pattern of results was very similar as for the flashing red light failure mode in Study 1. That is, about one-quarter of drivers waited patiently for five minutes at the crossing before being told to proceed through, and around one-third proceeded through the crossing against a red traffic light. While a similar number of drivers in studies 1 and 2 indicated to the researcher that they thought something was wrong with the simulation in the failure mode condition, those comments were made earlier for the traffic light failure mode (Study 2) compared to the flashing light failure mode (Study 1). The traffic light in failure mode was however confusing for a small proportion of drivers.

### Study limitations

This study is not without limitations. We examined driver responses to active level crossing treatments where an immediate decision was required to brake and stop safely or to proceed through the crossing. This design was deliberate, and while representative of safety-critical situations where an immediate decision to cross/not to cross was required, represents only a restricted set of level crossing experiences. It is unclear whether the proportion of violations would decrease in the active warning conditions if the active level crossing treatments had been activated several seconds earlier.

Another aspect of this design was that the oncoming trains were deliberately kept out of view of the approaching car driver. This was done to ensure that decisions to stop safely or proceed through the crossing were based upon the crossing characteristics and not confounded by potential detection of the oncoming train itself. Any cues based on train detection that drivers would use in the real world to make crossing decisions were therefore not available in this study.

Finally, the use of simulation, rather than real-world performance measurement, is also seen by some to be a limitation. While the simulator has been validated against real-world driving, a quick comparison with some real world data collected at crossings with stop signs, flashing red lights, and/or flashing red lights and boom barriers would put at end to such debate.

Acknowledging the limitations above, we believe that the study design and conclusions are both defensible and scientifically robust.



## Conclusion

There are outstanding questions arising from this research that should be addressed. Participants in this study were exposed to a select range of scenarios that required a time-critical decision to stop at an activated level crossing or to proceed through ahead of the train. Line of sight was restricted such that cues originating from the train itself were not available to the driver to inform this decision. Drivers in this study indicated that the correct response at crossings with flashing red lights activated, or traffic lights in the red phase, is to stop. This should be confirmed by examining driver behaviour in a wide range crossing situations where the treatments become active at different points on the drivers approach to a crossing.

Secondly, drivers in this study experienced crossings operating in failure mode at the end of their drive. No drivers violated the crossing in the failure mode. This raises the possibility that the number of violations observed in the simulator might reduce with repeated exposure to level crossings, meaning that the violation data should be interpreted with some caution. This underscores the importance of further examining the effects of repeated crossing exposure on rates of violations.

Thirdly, drivers in this study at the post-drive interviews expressed a preference for the use of flashing red lights at crossings over and above traffic lights, partly because they strongly associate flashing red lights with level crossings and traffic lights with conventional road-road intersections. Drivers also expressed some confusion at seeing traffic lights at crossings without prior exposure or expectation that this may occur. It is possible that prior information about the presence of traffic lights at level crossings, and repeated exposures to this scenario, might improve both objective and subjective responses to traffic lights at level crossings. These are areas that are straightforward to address in any subsequent work in this area.

In addition to addressing some caveats with the current research, there are several new lines of inquiry that may lead to further safety benefits at level crossings. Firstly, examining a broader range of warning times, as well as distances, may provide a more accurate understanding of driver behaviour, particularly in the amber phase of traffic lights at level crossings. Secondly, the current studies examined level crossings in a rural environment, however, driver behaviour at level crossings may alter in more urban environments. Lower speed limits, as well as increased visual clutter and greater potential for distraction in urban environments, may all impact on driver behaviour. Drivers may also be more used to experiencing traffic lights in urban environments and, therefore, the confusion indicated in this study by some participants at the presence of traffic lights at a level crossing maybe reduced. Subsequent research into the use of traffic lights at level crossings should, therefore, also involve the examination of driver behaviour at urban level crossings. Thirdly, the extent to which a driver is distracted may interact with the saliency of certain level crossing controls. Given that the saliency of flashing red lights was one of the reasons commonly given in these studies for the preference of flashing red lights over traffic lights, it is important that future studies look at the effect of distraction on level crossing control saliency in order to determine whether crossing controls deemed salient and effective at low levels of distraction remain effective at high levels of distraction. Relating to the issue of distraction, future studies could also examine the potential benefits of in-vehicle train warning systems, which, along with other low-cost devices that warn drivers of approaching trains at level crossings, were previously identified as a high priority recommendation for research (Edquist et al., 2009).

Finally, the benefits of earlier advisory signs for active crossings should be established as there is strong evidence to support this from this study. Further, there is a large body of research to suggest that the utility of warnings can be further enhanced through the provision of both directional and multi-sensory cues to the driver (Ho & Spence, 2008). The incorporation of directional cues could be incorporated into dynamic warnings signs at crossings and into the design of potential in-vehicle solutions, while multi-sensory cues also have great potential for in-vehicle applications. There is also a range of established human factors methods that can be used to identify in detail the specific user (driver) requirements to inform countermeasure design and integration (Stanton, Salmon, Walker, Baber, & Jenkins, 2005). Finally, major programs such as the establishment of improved data systems are required to enable researchers and stakeholders to more accurately establish the causes of level crossing crashes (Edquist, Stephan, Wigglesworth & Lenné, 2009). In other areas of injury prevention the establishment of crash factors and types is paramount to more effective countermeasure development and implementation.

While the primary purpose of this study was to examine driver behaviour at level crossings, it is interesting to address the question of risks associated with the use of traffic lights in the field. There are some issues that we believe need to be pursued to further address the issue of risk. Firstly, assessments of behaviour at levels crossings with traffic lights need to be made across a wider range of environments, including more urban conditions, and with drivers experiencing traffic lights across different signal phases on approach to the crossing. It is important also that driver behaviour be assessed both when drivers have an expectation that they will encounter traffic lights at level crossings, and after repeated exposures. Finally, the violation issue needs to be explored with different signal timings to establish violation rates across a range of crossing experiences.

In conclusion, this research intended to provide data to Victorian stakeholders regarding driver behaviour around level crossings with a range of active treatments, including the use of traffic lights, in a defined set of level crossing scenarios. This information was intended to inform stakeholder discussions regarding the potential further exploration of behaviour and risk associated with the use of traffic lights at level crossings. On the basis of these findings, and acknowledging the restricted range of road types (rural) and speed limits (80 km/h) evaluated, the use of traffic lights at level crossings does not appear to offer clear safety benefits over and above those provided by flashing red lights or flashing red lights with boom barriers.

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# APPENDIX – FORMS AND INSTRUCTIONS

## Traffic control devices study instructions

### 1. When participant arrives:

Introductions, overview of experiment, pre-drive questionnaire & current well-being (see below)  
Walk participant to car

**Please sit in the car and adjust the seat to suit you. I will go back to the control room, but we can still talk to each other through the intercom.**

**The controls work exactly like a normal car, but may feel a bit odd.**

**The motion platform under car will give you the feel of the road.**

**But you won't get normal acceleration and braking feelings – this can make some people feel a bit uncomfortable.**

**If you feel uncomfortable at any time, don't worry about finishing the drive, just let me know and you can stop the car and get out.**

**Do you have any questions?**

### 2. Familiarisation drive #1:

**The purpose of this drive is for you to get used handling the simulator.  
When you are ready, turn ignition on, put shift into drive, and start driving.  
You may notice – screen is a bit blurry**

- weird feeling when accelerating and braking
- Practice braking when ready: start GENTLY

**How are you feeling?  
Any questions?**

### 3. Gaze calibration (see process described in methods section)

### 4. Familiarisation drive #2:

**This drive is for you to get the feel of driving at 80km/hr in the simulator.  
Try to stay at 80, and I will tell you if you are going too slow or too fast.**

### 5. First main drive:

**You will drive on a semi-rural road with a number of different traffic controls.  
Please drive as you normally would on a real highway.  
The speed limit is 80km/hr – it's important that you drive as close to the speed limit as possible.**

After each drive:

**How are you feeling? (Offer break, water, mints if necessary)**

### 6. Second main drive:

As for first

### 7. Post-drive questionnaires

Current Wellbeing questionnaire  
Post-drive interview (see below)



**Pre-drive questionnaire**

Participant code:

Date:



Thank you for coming along today. Your involvement is greatly appreciated. For research purposes, it is important that we obtain some information concerning your background. Please answer each question as fully and as accurately as possible, and remember, all of the information that you provide will be kept confidential.

**Part A - Personal Details**

1. Are you:      Male       Female

2. How old are you?

3. Do you suffer from any form of colour blindness?

Yes       No

4. Do you suffer from any eye diseases that affect your visual acuity and/or visual field?

Yes       No

5. Do you have any neck problems that severely restrict our head movements?

Yes       No

**Part B – Driving experience**

6. Do you hold a current Victorian driver’s licence?

Yes       No

7. How old were you when you were first licensed to drive a car?

8. Are there any conditions on your licence?

- A (Automatic only)
- S (Glasses or corrective lenses)
- V (Driver aids or vehicle modifications)

9. On average, how many hours do you spend driving a car each week?

10. On average, how many kilometres do you drive each week?

11. In which environment do you drive the most:

- Metropolitan/urban (city)
- Residential
- Rural

Thank you.



Code: \_\_\_\_\_ Administration: **Pre** Date: \_\_\_\_\_

## Current Well-Being Questionnaire

Please indicate the extent to which each of the symptoms listed below is affecting you **now**.

- |                                     |                               |                                 |                                   |                                 |
|-------------------------------------|-------------------------------|---------------------------------|-----------------------------------|---------------------------------|
| 1. General discomfort:              | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 2. Fatigue:                         | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 3. Headache:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 4. Eye strain:                      | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 5. Difficulty focusing:             | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 6. Increased salivation:            | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 7. Sweating:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 8. Nausea:                          | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 9. Difficulty concentrating:        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 10. Fullness of head <sup>1</sup> : | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 11. Blurred vision:                 | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 12. Dizzy (eyes open):              | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 13. Dizzy (eyes closed):            | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 14. Vertigo <sup>2</sup> :          | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 15. Stomach discomfort:             | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 16. Burping:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |

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<sup>1</sup> Fullness of head = awareness of pressure within the head

<sup>2</sup> Vertigo = feeling of a loss of orientation with respond to vertical upright

Code: \_\_\_\_\_ Administration: **Post** Date: \_\_\_\_\_

## Current Well-Being Questionnaire

Please indicate the extent to which each of the symptoms listed below is affecting you **now**.

- |                                     |                               |                                 |                                   |                                 |
|-------------------------------------|-------------------------------|---------------------------------|-----------------------------------|---------------------------------|
| 1. General discomfort:              | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 2. Fatigue:                         | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 3. Headache:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 4. Eye strain:                      | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 5. Difficulty focusing:             | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 6. Increased salivation:            | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 7. Sweating:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 8. Nausea:                          | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 9. Difficulty concentrating:        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 10. Fullness of head <sup>1</sup> : | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 11. Blurred vision:                 | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 12. Dizzy (eyes open):              | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 13. Dizzy (eyes closed):            | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 14. Vertigo <sup>2</sup> :          | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 15. Stomach discomfort:             | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |
| 16. Burping:                        | <input type="checkbox"/> None | <input type="checkbox"/> Slight | <input type="checkbox"/> Moderate | <input type="checkbox"/> Severe |

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<sup>1</sup> Fullness of head = awareness of pressure within the head

<sup>2</sup> Vertigo = feeling of a loss of orientation with respond to vertical upright

## **Driver responses to traffic control devices - Interview guide for post-drive interview**

**(to be read out by experimenter)**

Thank you for your participation in the simulator experiment today. The last part of the experiment involves some questions concerning behaviour at traffic control devices. Please answer each question as fully and as accurately as possible, and remember that all of the information you provide will be kept confidential.

1. What is your understanding of the appropriate driving behaviour when approaching a railway crossing with:

- flashing lights and bells operating?
- lights off and no bells?
- a boom barrier down across the road?
- a boom barrier descending (going down)?
- no lights or barriers, just signs?
- a standard traffic signal showing green?
- a standard traffic signal showing red?
- a standard traffic signal showing amber?

2. a) Were there any railway crossings in the simulated drives at which you were confused about what to do?

b) The last level crossing you saw in the simulation today is what happens when the crossing control is not working properly. (If not mentioned in response to previous question: How did you interpret this situation?)

c) (If not mentioned in response to 2a:) How did you interpret the traffic light at the level crossing?

3. a) If you are approaching a railway crossing and the lights begin flashing, how much time do you expect it to take before a train arrives?

b). After a train has passed through a railway crossing, how much time do you expect it to take before the lights stop flashing and you are permitted to cross?

4. a) When driving in your own car, how much time would you wait at a flashing railway crossing light before assuming something must be wrong with the signals?

b) What action would you take in such a situation?

5. a) How much time would you wait at a railway crossing with a traffic light before assuming something must be wrong with the signals?

b) What action would you take in such a situation?

6. a) What do you think is the best form of traffic control device for level crossings, flashing lights or traffic lights?

b) Why?

7. What is your understanding of the appropriate driving behaviour when approaching a road intersection with:

a) a green traffic signal?

b) an amber traffic signal?

c) a red traffic signal?

d) a stop sign?

e) a give way sign?

8. If you are approaching a traffic signal and the light turns amber, how much time do you expect it to take before the light turns red?

9. When a traffic signal turns red, how much time would you expect it to take before:

- traffic on the intersecting road gets a green light?

- you get a green light again?

10. a) How much time would you wait at a red light before assuming something must be wrong with the traffic signal?

b) What action would you take in such a situation?

That is the end of the questions. Thank you for your time.