THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR2004

The Use of Red Flashing Lamps by Road Recovery Operators

Off-road trials and other research

M Palmer, M Bell, C Baverstock, A Holcombe, A Avis, J Hitchings, J Radcliffe, J Kamat, N Studdard, S Helman

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Executive Summary

The UK's breakdown and road recovery industry employs nearly 500,000 roadside recovery operators, who often work in the high-risk environment of beside or on the carriageway. The industry has proposed that regulations are changed to allow fitting and use of rear-facing red flashing lamps while stationary attending accidents and breakdowns on the hard shoulder or on other roads, suggesting that these could help approaching drivers identify the recovery vehicle as a hazard, so exercising greater caution.

Previous work by TRL for the DfT (Geitner et al, 2020) recognised general stakeholder support for their use, but acknowledged the lack of evidence for the effects of different lamp colours on road user understanding and behaviour, so recommended that an off-road trial should be undertaken to understand how naïve participants (i.e. ordinary road users with no prior knowledge) perceive stationary vehicles displaying amber, red, and combined amber and red flashing warning lamps.

This project was commissioned by the DfT's International Vehicle Standards (IVS) division. IVS has responsibility for developing and implementing the DfT's policy for safer road vehicles. The main purpose of the project was to investigate the issues of whether extending the use of rear-facing flashing red lamps to the road recovery industry would provide road safety benefits or whether they might introduce disbenefits, affecting both recovery operators and other road users.

The main requirement from this project was to generate robust evidence to inform a decision on whether the use of red flashing lamps should be extended to road recovery operators. Evidence was gathered by carrying out research using a range of research techniques.

There are two main outputs from the work, a final report, and a conspicuity guidance document, each supported and informed by the research activities:

- Answering main research questions: Final Report (understanding how drivers react, understanding public perceptions):
    - Track Trials: Participants – Rural environment
    - Simulator trials: Participants – Motorway with hard shoulder, high speed dual carriageway, urban
    - Online anonymous survey – Participants – Perceptions of lighting
    - Expert review
- Additional requirements within the Final Report: Potential proliferation
    - Stakeholder consultation
    - Online anonymous survey – Technicians – intentions to follow guidance
- Guidance document (with industry review)
    - Literature review of pedestrians near conspicuous vehicles (some content included in Final Report)
    - Review of conspicuity aids and 'horizon scanning' (some content included in Final Report)

- Regulations review

The track trials, undertaken in daytime and darkness, in a rural environment, recorded naïve participants' stated time to demerge, i.e. leave the obstructed lane to pass the recovery vehicle. The results showed no statistically significant impact on this behaviour in response to the variations of lighting colour. There is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of time to demerge in either daytime or night-time.

Simulator trials were undertaken in three environments: urban, high-speed dual carriageway and motorway with hard shoulder, in daytime and darkness. Data were recorded to identify change of speed in response to the recovery vehicle (all three environments) and distance from the recovery vehicle for demerge (urban and high-speed dual carriageway environments) or lateral movement (motorway environment, with the recovery vehicle on the hard shoulder). In all three environments (urban, high-speed dual carriageway, motorway with hard shoulder), there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of change in speed, lateral movement or distance of lane demerge.

From the trials behavioural data we found no evidence to support any change to regulations on safety grounds, when safety is measured in terms of the behaviour of road users approaching stopped recovery vehicles. Additionally, results from post-trial questionnaires and the online survey do not show a clear understanding of any lighting by naïve participants (especially for amber and red together) although the colour red seems to be associated with a slightly higher likelihood of being perceived as meaning 'danger' and 'prepare to stop', and are slightly more highly rated as attention grabbing.

The observations and recommendations given provide evidence for the DfT of the effects on driver behaviour of rear-facing red flashing lamps and our two recommendations suggest potential actions to improve roadside safety for the road recovery industry.

From the combination of trials and survey data, we make the observation:

There is no evidence in the current research trials that red flashing lamps or amber plus red flashing lamps result in any discernible change to the response of drivers approaching a vehicle displaying them, when compared with amber lamps. Surveys suggest that they do seem to lead to a slight increase in perceiving the meaning of 'danger' or 'prepare to stop', compared with amber. Any decision to change regulations to allow the use of red flashing lamps by road recovery industry vehicles should be supported by extensive engagement with the industry to ensure that recovery operators are not led to expect direct safety benefits from this change alone.

Aside from the main trials and survey findings, research outcomes demonstrated that there are several actions, all permitted within current regulations, the industry could take that have the potential to improve approaching drivers' identification of vehicles in high-risk locations and so improve safety for their technicians and other road users. This could be undertaken and developed as a co-operative ongoing action by the industry, creating and implementing an industry-wide vehicle safety improvement strategy. This leads to our first recommendation:

The breakdown and recovery industry should work together to develop an improvement strategy incorporating various actions to improve safety. This should include how any legally permitted technologies, colours and flash patterns should be used.

This strategy would identify:

- A common industry definition of 'high-risk location'
- A common 'urgent' flash rate (using the permitted 4 Hz and findings from this and other research) for use in high-risk locations only
- A common, slower, lighting flash pattern (likely based on 1 Hz and research findings) to be used consistently in all other locations

Development of systems capable of controlling and displaying appropriate flash patterns and lighting intensity, complying with GB regulations and aligning with research findings, is likely to entail working with lighting system designers and suppliers. With these lighting patterns confirmed, the industry should then ensure that all technicians are aware of the purpose of these flash rates and patterns and the safety benefits from maintaining a clear differentiation in use between higher- and lower-risk locations.

A common theme from numerous submissions was that current amber beacons are heavily over-used, with this not limited to the road recovery industry. An additional task for the industry could be to forge relationships with other authorised amber beacons users to encourage responsible and appropriate use of beacons.

Implementation of appropriate, risk-related, flash patterns may need to be accompanied by changes to conditions of membership of industry groups, with provision of updates to guidance and training on beacon use, potentially with monitoring and reporting.

The guidance document developed in Work Package 1 can also form part of improved conspicuity training for technicians.

Two other actions with potential long-term benefits are to:

- Review additional conspicuity equipment and recommend to the industry those which are proven beneficial
- Record, investigate and report, on a common database, all collisions involving industry vehicles and personnel. This incident recording may inform improvements to working practices and development of targeted safety advice and equipment

Our second recommendation is that **any change in the lighting or other technologies permitted should be supported by public education on the meanings of different conspicuity technologies. This could include related elements within the Hazard Perception Test and Theory Test for new drivers, and changes to the Highway Code.**

This project has identified several aspects where, should authorisation be granted for the road recovery industry to display rear-facing red flashing lamps, their more widespread use might potentially have adverse effects on other road users and other industries authorised only to use amber warning lighting. Some of these potential disbenefits could arise from increased glare (if the total amount of light output increases, i.e. red being added to current amber) that could reduce drivers' ability to identify pedestrians in the area around the recovery vehicle.

Also, should red flashing lamps, or red and amber flashing lamps, be routinely displayed on vehicles on the hard shoulder, this could reduce drivers' expectation of red light having the meaning that a live lane is obstructed by that vehicle.

A further potential disbenefit could be for the safety of other users of other vehicles that amber warning lamps and undertake stops, or move slowly, in live lanes for their work activities. This could include vehicles used for traffic management and roads maintenance. Thus, any change to permissions should consider the potential impacts on other users. For context on these potential disbenefits, estimates were made in Work Package 2 for potential proliferation of red flashing lamp use, should authorisation be given for their use the by the road recovery industry. Depending on the locations (i.e. within a live lane, off the carriageway, or both), then there could be between 2.75 and 5.5 million additional instances each year where recovery industry vehicles might display red flashing lamps

Finally, several contributing industry stakeholders expressed the view that the Health and Safety Executive (HSE) should be considered a key stakeholder and involved with consultation regarding any decision on authorisation of red flashing lamp use by the industry.

The Use of Red Flashing Lamps by Road Recovery Operators

Off-road trials and other research

M Palmer, M Bell, C Baverstock, A Holcombe, A Avis, J Hitchings, J Radcliffe, J Kamat, N Studdard, S Helman (2022)

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Technical report

Full details can be found at:

Project report PPR2004

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Road recovery technicians work near high-speed traffic. The industry has suggested that red flashing lamps could improve safety and has proposed that regulations are changed to allow use. More recently, following several collisions, this campaign has gained momentum.

Previous work recognised **general stakeholder support** but acknowledged the **lack of direct evidence**. The current project was carried out for the DfT, to investigate potential benefits and any unintended effects, and to provide evidence to inform the DfT's decision-making.

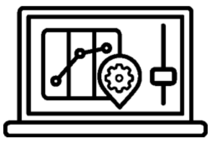
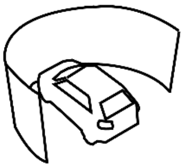
The **main requirements** from this project were to:

- **Generate evidence to inform a decision,** including from off-road trials

Other work included:

- Assess the risks associated with potential proliferation of use of red flashing lamps
- Development of a conspicuity guidance document

Research methods used:

	**Industry stakeholder consultation**	Stakeholders were asked about their views on current guidance on the use of warning lamps and incident numbers
	**Literature review, innovation search, review of lighting regulations**	These activities supported writing the guidance document
	**Online surveys: stakeholders, technicians, public**	Online surveys allowed large amounts of data to be collected
	**Participant trials: test track (rural) and simulator (urban, motorway with hard shoulder, high-speed dual carriageway)**	Trials, with members of the public, identified stated and actual driver behaviour

The Use of Red Flashing Lamps by Road Recovery Operators. Off-road trials and other research

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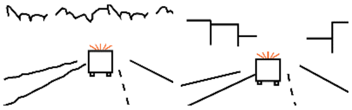
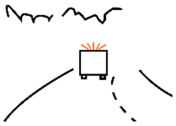
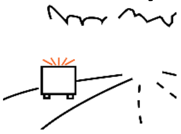
Rural **Urban**



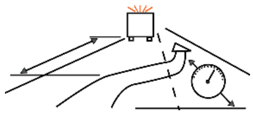
Dual carriageway



Motorway



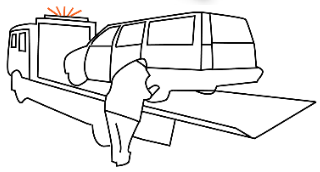
Distance, speed, and movement data recorded



Track trials (rural) recorded participants' stated point at which they would leave the obstructed lane. Results showed **no statistically significant differences in this for red, amber, and red/amber lamps during night or daytime**

Simulator trials (urban, high-speed dual carriageway, motorway) found **no evidence that colour of flashing lamps (red, amber, red/amber) changes driver responses** in terms of change in speed, lateral movement, or distance of lane change

The guidance document gives advice on equipment that can be fitted to vehicles and gives safety advice for technicians. The draft was reviewed by industry, including the IVR.



Post-trial and online surveys suggested that drivers' understanding of all lighting colours is variable, especially for red and amber together. Red flashing lamps were more likely to be perceived as meaning 'danger' or 'prepare to stop' while amber lamps were more likely to be perceived as meaning 'caution'. Red flashing lamps, and red and amber flashing lamps together, were rated as slightly more attention grabbing when compared with amber, although again there was variability in responses across all lighting colours.

Observation and recommendations

1. There is no evidence in the current trials that red, or red plus amber, flashing lamps result in any discernible change to the response of drivers approaching a vehicle displaying them, when compared with amber. Surveys suggest that they seem to lead to a slight increase in perceiving the meaning of 'danger' or 'prepare to stop', compared with amber. Any decision to change regulations to allow the use of red flashing lamps by road recovery industry vehicles should be supported by extensive engagement to ensure that recovery operators are not led to expect direct safety benefits from this change alone.
2. The breakdown and recovery industry should work together to develop an improvement strategy incorporating various actions to improve safety. This should include how any permitted technologies, colours and flash patterns should be used.
3. Any changes should be supported by public education on the meanings of different conspicuity technologies. This could include related elements within the Hazard Perception Test and Theory Test for new drivers, and changes to the Highway Code.

1 Introduction

1.1 Background

The UK's breakdown and road recovery industry employs nearly 500,000 roadside recovery operators, who work near approaching and passing traffic when assisting motorists beside or on the carriageway. This is a high-risk environment. The industry has suggested that displaying red flashing lamps could help approaching drivers identify the recovery vehicle as a hazard, so exercising greater caution, and has proposed that regulations are changed to allow the industry to fit and use additional red flashing lamps. This campaign has gained momentum in light of some recent fatal collisions involving recovery industry operators.

Previous work by TRL for the DfT (Geitner et al, 2020) asked whether there might be a demonstrable road safety benefit from the display of red flashing lamps. It recognised general stakeholder support for their use but acknowledged the lack of evidence comparing different light colours for their effects on road user understanding and behaviour. The work recommended that an off-road trial should be undertaken to understand how naïve participants perceive stationary vehicles displaying amber, red, and combined amber and red warning lamps.

1.2 Purpose

The DfT's International Vehicle Standards (IVS) division has responsibility for developing and implementing the DfT's policy for safer road vehicles. Before any change to regulations is considered further, it is essential that the DfT fully understands whether extending the use of rear-facing flashing red lamps to the road recovery industry would provide road safety benefits and, in addition, whether they might introduce disbenefits that may affect both recovery operators and other road users. This project was commissioned by the DfT to investigate these issues, so as to provide robust data to inform the DfT's decision-making.

The main requirement from this project was to:

- Generate evidence to inform a decision on whether the use of red flashing lamps should be extended to road recovery operators. Evidence must be gathered by undertaking three Work Packages, including off-road trials

The project scope was also developed to provide the DfT with a better understanding of several additional factors relating to warning lamps:

- Configuration requirements for different combinations and positions of warning lamps on different recovery vehicle types
- An assessment of the risks associated with proliferation of red flashing lamps on UK roads
- Development of a vehicle warning lamp guidance document, highlighting to operators the broad range of lighting functions that are currently available under existing laws to help improve the conspicuity of recovery vehicles

1.3 Previous work

In 2020, the Department for Transport's International Vehicle Standards (IVS) Division commissioned a review of evidence to see if a more flexible approach to the use of red flashing lamps by road recovery operators might be appropriate, taking account of their impact on the behaviour of other road users and crucially, whether there is expected to be an overarching and demonstrable road safety benefit. The project used three methods to assess evidence:

- A literature review, building on previous work in the area related to Traffic Officer Vehicles and red warning lamps (unpublished, 2009)
- Consultation with representatives from the roadside recovery industry, and wider stakeholders and academics
- A trawl of social media and an internet search to identify further literature, data and case studies, and public sentiment around the issue

The literature and web searches found little evidence to suggest that red flashing lamps would help with conspicuity; there is a dearth of research specifically into the topic. The findings did suggest, however, that drivers approaching a recovery vehicle would be helped in their understanding by seeing red warning lamps, since people have an association between the colour 'red' and the concept of danger. However, the scientific evidence identified only related to that colour-meaning association. No new UK-based research was found relating to comparative trials of vehicle lamp colours.

Stakeholder interviews (including from the road recovery industry and authorised red flashing lamp users) revealed a general support for the use of red flashing lamps on recovery vehicles, if managed properly to avoid over-use (for example, not used when emergency vehicles are also present and displaying red flashing lamps, or when a recovery vehicle is not attending to an incident). Other concerns identified related to the potential over-use of warning lamps, and the possibility that increased use of warning lamps could cause either discomfort or disability glare for approaching drivers. The possibility of causing confusion for drivers, should red warning lamps be used in different circumstances from existing permitted users, was also identified. The following two quotes illustrate these points.

> *"Best practice highlights that amber lights should only be used when you are causing a hazard to other road users. Many vehicles now travel with amber lights permanently…"*

> *"Negative is if they are not used correctly, over used or used irresponsibly, they will confuse the public and undermine their purpose - they may also confuse the public that it is an emergency vehicle, which is why I believe they should only ever be used along with and not instead of orange lights."*

The Regulatory Impact Assessment recommended, from five options communicated by the Department for Transport, proceeding with the option to allow rear-facing red flashing lamps on all roads (non-live running lane) when a road recovery vehicle is stationary. This took into consideration the potential benefits and disbenefits of having a red warning signal to alert upcoming traffic. However, that option did not reflect the industry's concerns regarding operations in live lanes on non-motorway high-speed dual carriageways. Also, it is inconsistent with the current usage of red flashing lamps by National Highways Traffic Officers.

Based on the evidence on light colour association and general stakeholder support regarding suitability of use, but acknowledging the lack of evidence comparing different light colours, the report (Geitner et al. 2020) made three recommendations:

1. An off-road comparative trial should be undertaken to gain understanding of how naïve participants perceive stationary vehicles displaying amber and amber and red warning lamps. The outcome of this trial can feed into implementation, including driver awareness campaigns.
2. Subject to the outcome from that trial, recovery vehicles should be allowed to use rear-facing red flashing lamps in such a manner that their use does not cause confusion with current permitted use, e.g. Highways England Traffic Officers. Any implementation should be accompanied by:
    a. Dedicated stakeholder consultation with relevant industry representatives to focus on the procedures for implementation, including aspects such as: locations permitted (live lanes or off the carriageway), whether permitted only when stationary or when arriving/leaving, management of over-use and avoidance of glare.
    b. A driver awareness campaign to educate the driving public on what to do when approaching and passing recovery vehicles displaying red flashing lamps.
3. Over the longer term, research should be undertaken to establish the boundary conditions for detectability of vehicles and people around them, and driver understanding, when vehicles are displaying different lighting combinations. This research should focus on optimising the combinations of vehicle lighting and Personal Protective Equipment (PPE).

1.3.1 Project elements

The current project's plan required research to be delivered across three Work Packages. Within these Work Packages a range of research techniques were used. Where possible, individual research activities were used to support data gathering across the Work Packages. The main research activities within the Work Packages are shown in Figure 1.

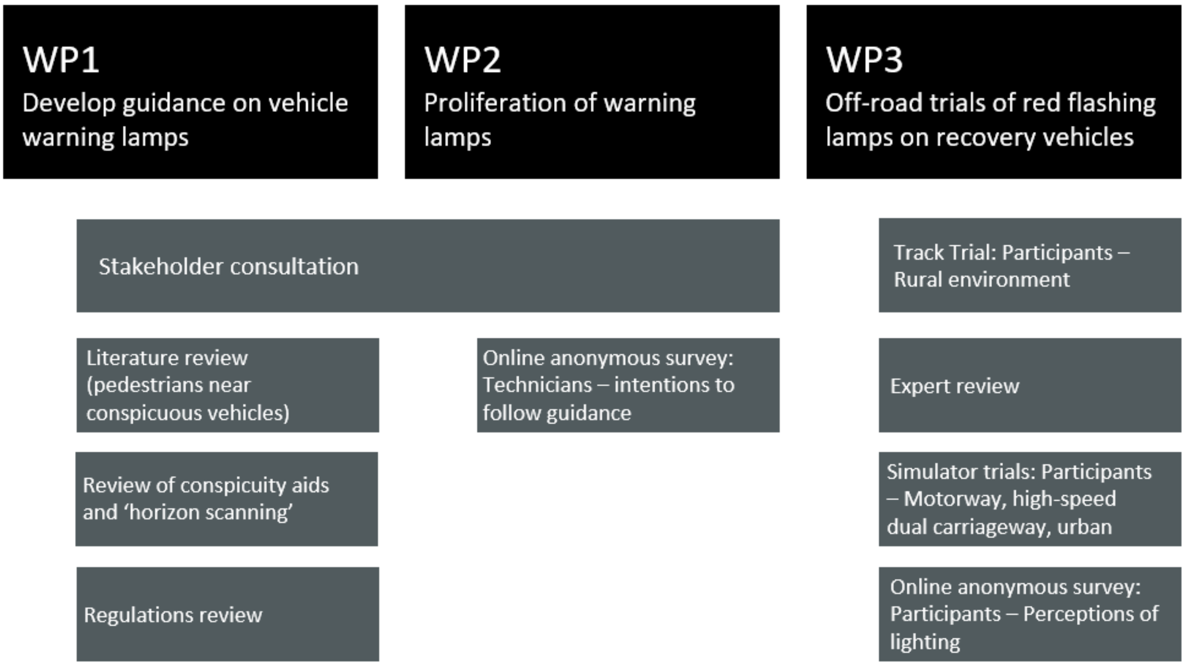


Figure 1: Three Work Packages, identifying main research activities

Completion of the two main deliverables (a final report, and the guidance document) required that outputs from the research activities were used in different areas, with some contributing to both deliverables:

- Answering main questions: **Final Report** (understanding how drivers react, understanding public perceptions):
    - Track Trial 1: Participants – Rural environment
    - Simulator trials: Participants – Motorway with hard shoulder, high speed dual carriageway, urban
    - Online anonymous survey – Participants – Perceptions of lighting
    - Track Trial 2: Expert review
- Additional requirements: **Final Report**: Potential proliferation
    - Stakeholder consultation
    - Online anonymous survey – Technicians – intentions to follow guidance
- **Guidance document** (with industry review)
    - Literature review of pedestrians near conspicuous vehicles (some content included in Final Report)
    - Review of conspicuity aids and 'horizon scanning' (some content included in Final Report)
    - Regulations review

The remainder of this final report is structured as follows:

Section 2 presents background research on visibility and conspicuity.

Section 3 describes the work to develop the guidance document.

Section 4 presents findings from the literature review on the identification of pedestrians around vehicles displaying lamps.

Section 5 discusses the work to examine the potential for proliferation of red flashing lamp use should the recovery industry be granted their use.

Section 6 introduces the main empirical work in the project – the off-road trials with naïve participants. Section 7 then describes the track trial and Section 8 the simulator trial.

Section 9 discusses the engagement with experts in a track event and Section 10 details further engagement undertaken as an online seminar.

Section 11 discusses the findings from questionnaires completed by participants in the track and simulation trials, and Section 12 the findings from an online survey.

Sections 13 and 14 then discuss the findings from across the project and provide an observation and recommendations.

The appendices then cover more detailed content from these activities and are referenced in the respective sections.

2 Conspicuity

2.1 What are 'visibility' and 'conspicuity'?

Conspicuity and *visibility* are terms that are often confused. They each have a specific meaning, and there are several types of conspicuity.

- *Visibility* is usually defined as how easily you can see something when you know its location
- *Conspicuity,* defined by Lesley (1995, cited in Langham & Moberly, 2003), is how well something stands out from its surroundings

It is generally acknowledged that the most important aspect which determine an object's conspicuity/visibility is its contrast with its surroundings. In real-world situations such as when a recovery technician is working at the roadside, the two most important aspects of personal and vehicle conspicuity (Cole and Hughes (1984)) are:

- *Attention conspicuity*, the extent to which something 'grabs' someone's attention when they are not actively looking for it (this is known as *search conspicuity*)
- *Cognitive conspicuity*, the extent to which an object is expected by the observer

Another important concept is how well understood something is by an observer, such as an approaching driver.

When a recovery vehicle is at the roadside attending a breakdown, it is unlikely that approaching drivers will expect to see it or that they will actively be looking for it. Conspicuity 'aids', such as warning lamps and fluorescent and retroreflective materials, can make the vehicle stand out from its surroundings and 'grab' the driver's attention. Typically, these are used to make the recovery vehicle brighter than its surroundings.

Recovery vehicles are relatively rare on the road, so drivers will not usually be expecting to see them. When a recovery vehicle is present, drivers may not understand what they are seeing or how they should react. Conspicuity equipment may help drivers to identify the vehicle and help them understand what they need to do.

Conspicuity equipment, such as retroreflective and fluorescent markings and warning lamps, can only help approaching drivers if they have a clear line of sight to the recovery vehicle. If their view is obstructed, for example by the recovery taking place around a bend, or by other traffic, then drivers may not identify the recovery vehicle and be able to react to it in time.

The time of day may affect how easily a driver can identify the recovery vehicle. Low sun, at sunrise and sunset, may affect drivers' vision. Very bright sunlight, or reflections, may prevent drivers from identifying the recovery vehicle.

If the recovery vehicle is in the driver's line of sight, but does not stand out from its surroundings, the driver may not be able to identify it. And, if they are not expecting the recovery vehicle, then their reaction to it may be delayed.

Novelty

New markings or lighting schemes may sometimes seem successful through being ‘novel’, i.e. different to what a road user is used to seeing. However, there is a risk that novel schemes might be confusing and could increase the time taken for a driver to respond.

Brighter, or different colours?

Making an object brighter will potentially help approaching drivers see something, but it may not help them understand what they are seeing. Different colour might make a small difference to visibility if the light is difficult to see, but the main purpose and advantage is to help distinguish between types of vehicles or hazards, for example blue lamps on emergency vehicles. However, this requires that the driver understands the meaning of the colour being used.

2.2 Best practice conspicuity research

When delivering conspicuity research the study will, ideally, use participants who are unaware of the purpose of the trials. This recognises the fact that the reactions of participants will be more realistic if they are surprised by the scenario ahead of them rather than expecting it. This ideal was described by Langham and Rillie (2001):

> *“However, often the biggest problem is that subjects are instructed to search for a particular type of vehicle, for example ‘press the button when a motorcycle appears’. This lacks any reflection of reality (or ‘ecological validity’) as when we drive we don’t generally look for any one type of road users.*
>
> *“More importantly, if we suspect expectancy has got something to do with these accidents then the very last thing we should do is instruct subjects this way.”*

As far as possible, the participant track and simulator trials undertaken in this project were designed to identify road users’ reactions to variations in warning lamps. Participants were not informed of the purpose of the research and not given any indication of what they should be looking for or reacting to.

2.3 How drivers react

When looking at a scene, what drivers “see” is partly influenced by what they expect to see. This means that approaching drivers are often not actively looking for vehicles, such as breakdown and recovery vehicles, stopped in live lanes. This is one version of the “looked, but failed to see” error, where the driver looks directly at a vehicle but then subconsciously dismisses it as a hazard or threat because it does not fit with their expectations.

If drivers are aware of the recovery vehicle (potentially because their attention has been ‘grabbed’ by the vehicle’s warning lamps and conspicuity markings), they must be able to:

- Identify what the hazard is
- Understand what action they need to take and decide whether they have a reasonable time to do so

- Carry out the manoeuvre
- Ensure their vehicle is steady and stable, then pass the obstruction

To achieve this requires early recognition of whether the hazard is in a live lane (particularly if obstructing the lane in which the driver is travelling) or on another location such as the hard shoulder and emphasises that the importance of conspicuity is not just to attract attention but is also about enhancing understanding. This sequence is shown in Figure 2 as a series of zones.

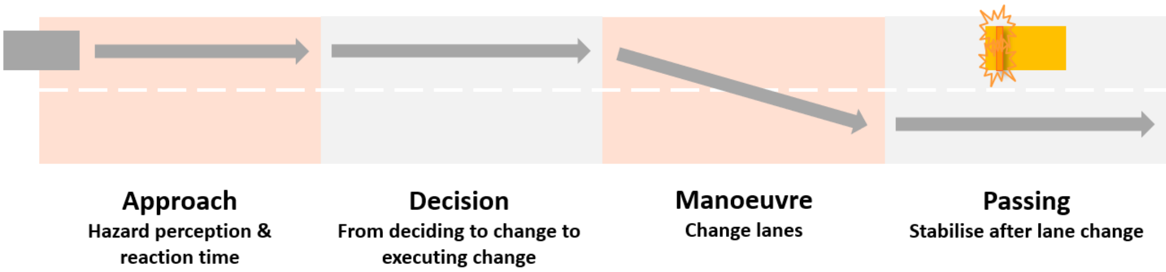


Figure 2: Approaching an obstruction

An unpublished 2009 TRL report on the conspicuity of abnormal loads reviewed research to produce this driver behaviour model and identified potential durations for each 'zone':

1. Hazard perception and reaction time (understanding) – 3 seconds
2. Time from deciding to change lanes to executing a lane change – 5 seconds
3. Time to change lanes – 5 seconds
4. Time to stabilise after lane change – 5 seconds

Note that it is not intended that the zones identified in this model should map across directly to results from either the participant track or simulator trials.

During discussions as part of the technology Horizon Scanning, an innovator commented that illumination on the vehicle should be considered as 'messaging'. This emphasises that, whatever is implemented onto the vehicle, the most important aspect after detection is what the approaching drivers understand – what is the message that they perceive? Comments received from a reviewer of this report did note that this 'understanding', while likely to be helpful, may not be essential, the most important thing for safety being the behaviour that people execute reliably to the signal. The research covers both reaction and understanding.

Therefore, any interventions introduced to improve safety of recovery vehicles should aid earlier understanding for approaching drivers to improve their decisions and actions.

3 Work Package 1: Development of a guidance document

The DfT had originally intended that Work Package 1 should generate a guidance document for roadside recovery operators on vehicle warning lamps that provides a reference for roadside recovery operators to better understand the broad range of lighting functions that are currently available to road recovery operators under existing laws, and to help improve the conspicuity of both the recovery vehicle and the recovery technicians.

Subsequently, it was agreed to widen the scope of the document to include an introduction to conspicuity (based on known conspicuity science and research), both of vehicles and technicians working around their vehicles. This would include basic information on benefits and potential difficulties.

During development of the draft, the intention was that it could be used by:

- Recovery industry technicians, to improve their understanding of the benefits and limitations of conspicuity aids
- Recovery industry trainers, so that technicians are aware of how safety may be improved by the correct use of conspicuity aids
- Recovery industry managers, when specifying conspicuity aids for vehicles

To support development of the document, a wide range of research was undertaken, including:

- Online survey, views from a wide group of industry and other experts, see Appendix A.2.1
- Stakeholder consultation (nine from the recovery industry, one from the roadworks traffic management industry, three from authorised red flashing lamp users), to understand the views that industry experts have of their current conspicuity guidance, see Appendix A
- Review of GB road vehicle lighting regulations
- Literature review, focussed on obscuration and identification of pedestrians near conspicuous vehicles (detailed findings from this review are given in Appendix C, with a summary in Section 4)
- Search for conspicuity equipment, technology and innovation, including ‘horizon scanning’ for potential new developments which could improve recovery vehicle conspicuity. Innovations which were considered to fall outside of GB road vehicle lighting regulations were not included in the guidance document but are given in Appendix D.

The first draft of the guidance document was offered to sections of the recovery industry for review, any comments returned were logged, reviewed, and considered for inclusion.

Content of the guidance document includes:

- What visibility and conspicuity are
- How conspicuity aids may improve safety for technicians, customers, and other drivers

- Potential adverse effects and how they may be reduced or allowed for
- How drivers must react when approaching an incident
- What conspicuity equipment can be fitted to vehicles (and where to find further information)
- Things to consider before using warning beacons
- Risks of working around conspicuous vehicles
- Additional conspicuity equipment, permitted by regulations, that can be fitted

Use of warning beacons in specific situations is covered thoroughly in the SURVIVE Best Practice Guidelines (SURVIVE 2018), so was not duplicated in the guidance document. The guidance document (TRL Ltd, 2022) will be published separately. All pages of the document are shown in Appendix K.

4 Literature review – identification of pedestrians

A desktop literature review was undertaken to identify any existing research evidence relating to drivers' ability to identify pedestrians when approaching vehicles displaying beacons. This section provides a summary of findings. Detailed method and findings are available in Appendix C.

The review identified research relating to two particular aspects of using additional lamps:

- The visibility and conspicuity of both recovery vehicles and recovery operators; and
- Whether, if red and amber lamps are displayed alternately, there will a sufficient duration when beacons are 'off' to allow approaching drivers to identify any pedestrians who are adjacent to the recovery vehicle.

This review did not replicate the literature review undertaken in the previous project, which related to lighting colour (and partly led to the track and simulation trials in this work) rather than to pedestrian safety.

The review was undertaken across a range of sources, applying a set of search terms. In total, 44 articles were identified and considered for review. Each was systematically scored using a set of inclusion criteria (relevance, quality, and timeliness). From this, seven articles (four academic articles and three industry reports) were shortlisted and reviewed in full.

Based on the papers reviewed, the main factor (or at least the most investigated) would appear to be the intensity of the flashing. There is a need to determine a balance between intensities that are high enough to allow drivers to spot the vehicles, but not so high as to cause glare and impair identification of pedestrians.

1. Peak intensity – Factors that may assist in determining optimal peak intensities include:
    - Time of day – Peak intensities need to be lower at night-time. Bullough and Rea (2016c) suggest peak intensities of 600 cd during the day and 200 cd during night-time.
    - Weather – Peak intensities need to be lower in cases where the weather may cause reduced visibility (e.g., fog) and scattering of light. Bullough and Rea (2016b) recommend peak intensities around 150 cd in such conditions.
    - Pedestrian features – Where possible, workers and other personnel should be encouraged to use high visibility retroreflective safety clothing. Peak intensities may need to be lower in areas where pedestrians are less likely to have such safety clothing on (e.g., in cities).
2. Minimum intensity – Rea and Bullough (2016a) suggest that minimum flash intensities need to be at least 10% of the associated peak intensities.

While the frequency of the flashing did not make a substantial difference in pedestrian visibility, some observations related to for the pattern of the flashing can be made:

1. To allow drivers to effectively spot the vehicles as well as the pedestrians around it, a high-low flash pattern is recommended (Bullough & Rea, 2016c)

2. Where a high-low flashing pattern is adopted, the flashing should maintain its intensity to at least 10% of the lamp's peak intensity at all times (Bullough & Rea, 2016c)
3. Where an on-off flashing pattern is adopted, a 'full on' - 'full off' sequence is better suited to pedestrian visibility than a 'half on' - 'half off' sequence (Flannagan & Devonshire, 2007)

These observations suggest that further work on developing suitable flash patterns and limiting lighting intensity could provide benefits for approaching drivers, technicians and, potentially, other pedestrians around the recovery vehicle. Provision of conspicuous clothing for occupants from casualty vehicles could be considered.

5 Work Package 2: Potential proliferation of red flashing lamps

Throughout the consultation activities with the industry, one point consistently raised has been the desire to have approaching drivers see road recovery vehicles and understand clearly how to behave. Should authorisation be given for use of red flashing lamps by the recovery industry, this could lead to a substantial increase in the use of red flashing lamps on GB roads over the current levels of use by the emergency services and National Highways' Traffic Officers. Concerns had been raised, including during industry stakeholder calls, that current use of amber flashing lamps may result in 'dilution' of their effectiveness for giving warning to approaching drivers and that substantially increased use of red flashing lamps might suffer a similar effect.

Work was undertaken in Work Package 2 to determine how many times red flashing lamps would be likely to be used, if their use were permitted by recovery vehicles, to help understand the scale of increased exposure to red flashing lamps for the driving public. To identify this, two sets of data were used:

- Online survey of the recovery industry and current authorised users; this survey, carried out to identify views on several issues, asked for data on:
    - Current use of red flashing lamps (authorised users)
    - Numbers of incidents attended and their locations
- Online survey of recovery industry technicians; this asked whether they would be likely to conform to guidance, should use of red flashing lamps be authorised.

This section provides a summary of findings. Detailed method and findings are available in Appendix A and Appendix B.

5.1 Industry experts online survey.

Fifteen experts completed an online questionnaire to determine what authorisations they have regarding the colour of lamps on their vehicles and how many incidents their organisation attends. Key findings from the online survey which relate to proliferation were:

- The majority of the experts (12/15) believed that their current guidance on the use of warning lamps could be improved
- Combined responses from experts, were able to choose multiple options for each colour scenario, stated that:
    - Amber lamps should be used when slowing down to stop off the carriageway and live lanes, when stationary off the carriageway and/or in live lanes, and when leaving the hard shoulder
        - The majority of experts thought amber lamps should be used in the situations stated above (12/15)
    - Red flashing lamps should be displayed when stationary off the carriageway and in live lanes

        - The majority of experts thought red flashing lamps should be used predominately when stationary off carriageways (9/15) and when stationary in live lanes (10/15)
    - Amber and red flashing lamps should be used in conjunction when stationary off the carriageway and in live lanes
        - The majority of experts thought amber and red flashing lamps together should be used predominately in the same situations as above (12/15)
- The majority of the experts (9/15) were not permitted to use red flashing lamps on their organisation's vehicles
- The single organisation that is permitted to use red flashing lamps and provided data reported that 100 incidents are attended annually, 75 where red flashing lamps are displayed

Views on the potential use of red flashing lamps were investigated further during consultation calls with industry experts. These are detailed in Appendix A.

However, only two smaller recovery organisations provided detailed information on the numbers of incidents attended, separated into road types. This information is shown in Table 1. No responses were received to indicate the extent of use by organisations authorised to display rear-facing red flashing lamps. Together, this shortage of information severely limited the opportunity to produce estimates of potential increases in red flashing lamp use.

Table 1: Numbers and locations of incidents

Org.	Type of road and numbers and locations of incidents						Total	% in 50mph+ live lanes	% on hard shoulders
	50mph+ live lanes	50mph+ hard shoulder	Off road	Rural	Urban	Residential			
1	5000	5000	2500	5000	500	2500	20500	25%	25%
2	3700	4475	11500	3700	4775	5500	33650	11%	13%

Note: 50mph roads and above are considered to be ‘high speed’

It should be noted that, as smaller organisations, both are likely to work within smaller geographic areas, so the number of live lane incidents attended is likely to be affected by their working areas. It is known that some of the larger organisations sub-contract some incident attendances to other organisations, which might also affect the types and locations of incidents attended.

However, the figures provided give a indicative range of incidents that are in live lanes on 50mph+ roads and on hard shoulders, for use in subsequent estimations.

5.2 Technicians online survey

The link to this online survey was provided to industry experts, for subsequent distribution to technicians. The survey was anonymous to encourage accurate self-reporting, with the opportunity for those responding to enter a prize draw.

The purpose of the survey was to identify the views of individual technicians on whether they would be likely to conform to guidance (in whatever form that took), should wider use of red flashing lamps be authorised. Participants were also asked about whether they would expect to use red flashing lamps in defined scenarios. 94 responses were received, results are given in full in Appendix B. Key points are that most technicians stated they:

- Would use red flashing lamps in some working situations, after conducting a risk assessment of the dangers and risks of the recovery situation
- Would not use red flashing lamps in urban areas such as housing estates, when parked either on or off the road
- Would use red flashing lamps on high-speed roads with no hard shoulder
- Would not use red flashing lamps when their vehicle is moving at normal traffic speeds

Most technicians reported that they would be very likely to follow the guidance, stating that red flashing lamps would only be used in certain circumstances, see Figure 3.

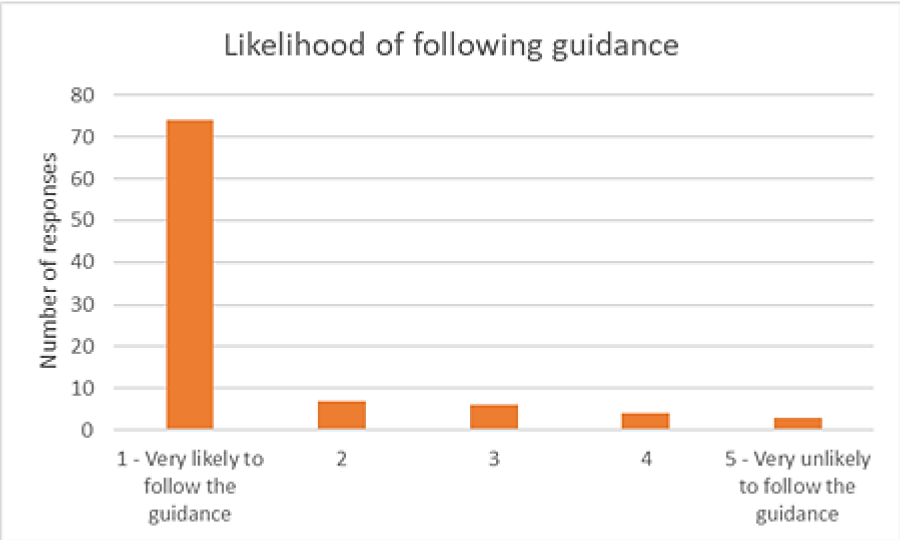


Figure 3: Likelihood that technicians would follow guidance

For the purposes of estimating the compliance with guidance element of potential proliferation, columns 4 (four responses) and 5 (three responses) were combined, to give a likely non-compliance of about 8%. However, it is acknowledged that actual compliance might vary according to the detailed content of any guidance and on the outcomes of individual, site-specific, dynamic risk assessments.

5.3 Estimation method

It had been intended that data on current and potential use of red flashing lamps would be used to inform an estimation of potential proliferation should authorisation be given for the recovery industry to use red flashing lamps. This data would have been used, with adjustment according to the overall responses from technicians, to quantify the process shown in Figure 4.

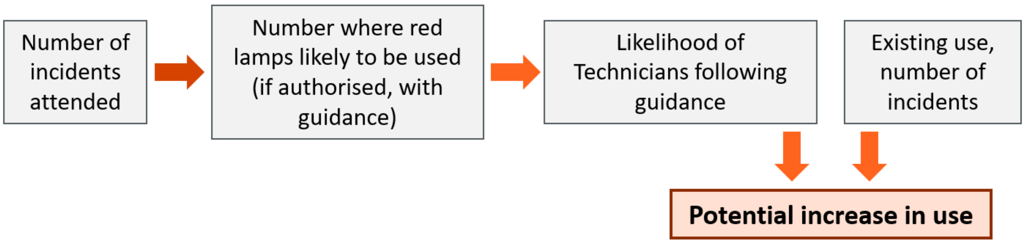


Figure 4: Intended process for estimating potential proliferation

However, as the detailed data obtained from the online survey was solely from two smaller recovery organisations, and none was received from existing authorised red flashing lamps user organisations, it was not possible to establish a baseline for current red flashing lamp use. Therefore, to produce estimates of potential increase in red flashing lamp use, it was necessary to identify an initial estimation of the number of breakdowns and recoveries attended annually by the industry. Publicly available data was used for this initial estimation.

- Statista reported that, in 2015, the RAC had a 27% share of the UK breakdown market[1]
- In 2006, the RAC stated: “Each year, patrols attend to 2.5million motorists at the scene of a breakdown”[2]

From these figures, an approximate figure of 10 million UK breakdowns each year can be estimated. However, this will include a wide range of incidents in lower-risk scenarios, such as car parks and residential roads.

For subsequent estimation of how many industry incidents might result in display of red flashing lamps, the guidance and procedures for National Highways Traffic Officers (see Appendix J) were used as a template. These maintain a distinction between amber and red, with ‘red’ to be displayed only when the vehicle is stationary and obstructing a live lane.

[1] “Breakdown Recovery: market share in the UK” https://www.statista.com/statistics/680793/breakdown-recovery-market-share/

[2] “Breakdown Britain” https://www.rac.co.uk/pdfs/report-on-motoring/breakdown-britain-report-2006

Transitory instances of a recovery vehicle arriving and departing from an incident scene have not been included.

Consultation with stakeholders showed that there is no clear, single, agreement on the locations where red flashing lamps should be used. When the use of red flashing lamps by the industry was debated in the House of Commons (Hansard, 2019), Tracey Crouch, MP, stated that:

> *" … the roadside recovery industry is not calling for the use of red lights in live carriageways, nor is it calling for the operation of red lights while its vehicles are moving."*

Several industry experts who completed the online survey on the use of warning lamps seemed to support this view, with nine (of 15) stating that they believed red flashing lamps should be used when the recovery vehicle is stationary off the carriageway or on the hard shoulder. However, 10 (of 15) stated that red flashing lamps should be used when the recovery vehicle is stationary in a live lane. Thus, the statements from industry experts are not always consistent with the statement by Tracey Crouch, MP, and with the work instructions for National Highways Traffic Officers which, generally, maintain a distinction with rear red flashing lamps being used only in live lanes. If authorisation is given for red flashing lamps to be used by the recovery industry it will be important that the industry agrees a clear set of rules for when and how they are used, assuming that the industry wishes red flashing lamps to communicate a clear meaning to approaching drivers. Presumably these rules would be most effective if they are designed to consider any usage of red flashing lamps by other organisations operating at the roadside, so that a consistent experience and understanding can be achieved for approaching drivers. Two sets of potential increases were developed, for incidents where the recovery vehicle is in a live lane, and on a hard shoulder.

5.4 Conclusion: potential increase in red flashing lamps displayed

From the data available and depending on whether authorisation was given but limited use of rear-racing red flashing lamps to certain locations, it is estimated that there could be:

- Between 1.2 million and 2.75 million additional instances each year where, should authorisation be given, recovery industry vehicles might display red flashing lamps in live lanes on high-speed roads
- Between 1.5 million and 2.75 million additional instances each year where, should authorisation be given, recovery industry vehicles might display red flashing lamps while stationary on hard shoulders.

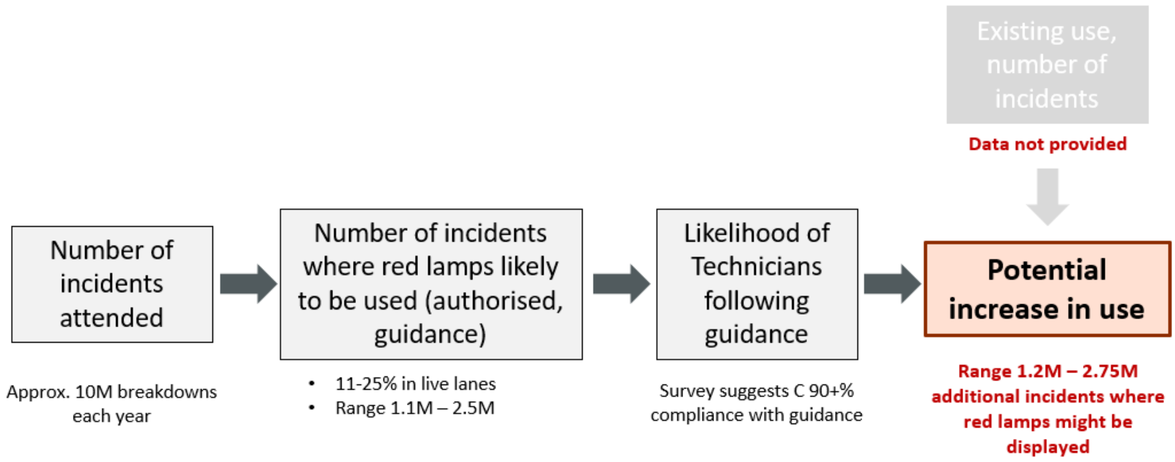


Figure 5: Estimated potential increase in red flashing lamps displayed in 50+ mph roads in live lanes

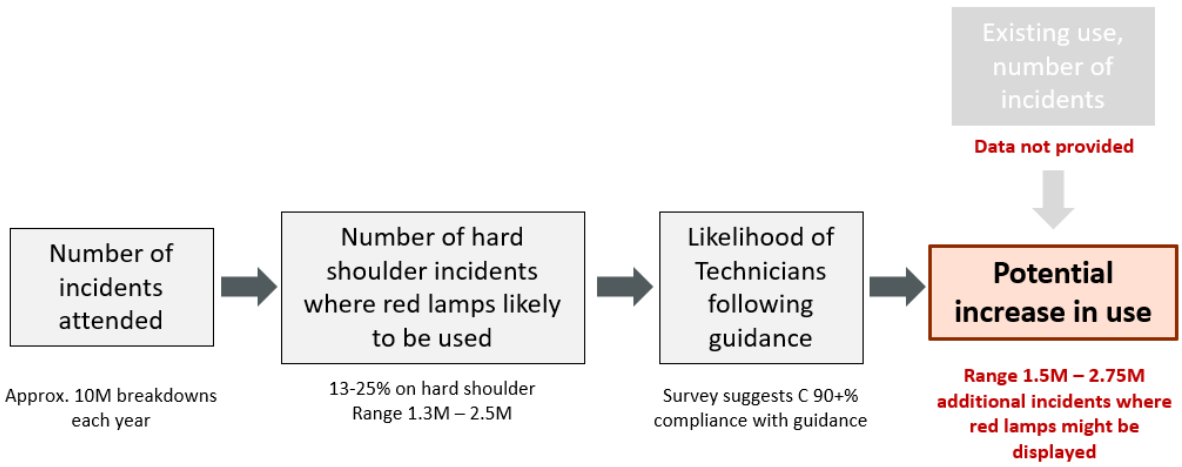


Figure 6: Estimated potential increase in red flashing lamps displayed on hard shoulders

6 Work Package 3: Off-road trials – introduction

The main requirement from the project was to generate evidence to inform a decision by the DfT on whether the use of red flashing lamps should be extended to road recovery operators. Work Package 3 involved delivery of off-road trials (track, and simulation) of red, and red plus amber, flashing lamps on recovery vehicles.

Table 2: Work Package 3 research activities

Requirement	Research Method	Benefit
Views and opinions from industry stakeholders	Expert review event[3]	Viewing warning lamps from extended distances (as would drivers)
Driving behaviour from physical lighting	Track study: Participant trials, naturalistic rural environment	The off-highway track provides a close to real-world experience for participants. Viewing physical lighting in both daytime and night-time provides subjective data
Driving behaviour data (speed, position) from participants driving in simulated environment	Simulator scenario 1: Motorway, with static vehicle on hard shoulder	The simulated environment facilitates extremely accurate data gathering, using repeatable and consistent scenarios (in both daytime and night-time) which are not affected by ambient weather or traffic conditions
	Simulator scenario 2: Dual carriageway, static vehicle in live lane	
	Simulator scenario 3: Urban road, static vehicle in live lane	
Identify perceptions and understanding of lighting colour and flash patterns	Online study, displaying a range of computer animated lighting	Separating lighting displays from actual and simulator driving trials allows understanding to be obtained from large number of participants

[3] This session was originally intended to be the first research activity, in March 2022. Due to external events beyond TRL's control, it was postponed until September 2022.

Delivery of Work Package 3 involved a range of research activities involving members of the public and industry stakeholders. These activities, identifying the benefits to be gained from each, are shown in Table 2.

6.1 Trials variables

The following variables were tested within the trialling as a whole:

- **Vehicle lighting**; three colour variations: rear-facing flashing red lamps only, amber warning beacons plus rear-facing flashing red lamps, amber warning beacons only. For research purposes, this would be the main independent variable
    - Note that, although roof-mounted beacons should be visible from around the vehicle, all participant trials and the Expert Review involved viewing the rear of the vehicle only
- **Ambient lighting**; two ambient lighting conditions (day, night)
- **Road types**; the DfT's scope required three road types (SRN, urban, rural). However, as it is acknowledged that the industry consider attendance at live lane incidents on high-speed roads to be the highest risk locations, this variable was expanded to four road types: motorway with hard shoulder, high-speed dual carriageway, urban, rural
- **Flash patterns**; a small set of alternative (outside of current regulations) lighting flash patterns were displayed at the industry Expert Review track event only. Using this set of variables resulted in a manageable set of trials which would maintain participant engagement. Also, it would allow use of methods which balanced answering the research questions, statistical robustness and representativeness, and efficiency of delivery within the project timeline, with minimal risks.

No single dedicated UK test track facility could provide a complete range of suitable, naturalistic, road environments to cover the conditions requested. Even if one had been available, it would have required extended and exclusive access for long periods to enable trialling with a sufficiently large number of participants; this would have been highly impractical. Using a range of test track facilities was also impractical, would have reduced efficiency of project delivery and added risk.

TRL's 'DigiCar' driving simulator offered a highly configurable option. The nature of the simulated environment, due to its ability to allow careful and precise control and measurement of variables, provided a lower risk and efficient approach for trials delivery. Ambient lighting and weather conditions can be controlled, which is not possible at test tracks.

Therefore, we developed a hybrid method incorporating use of both a secure off-road test track (rural environment) and TRL's DigiCar simulator (motorway with hard shoulder, high-speed dual carriageway and urban environments), along with some online surveys.

6.2 Developing trials research questions

An important part of the trials design process is to develop specific research questions (RQs). These must focus on the issue being specific enough to ensure that sufficient data can be collected within the time available and within the constraints of manageable trials.

The DfT's Statement of Requirements[4] set out the questions that the project's trials should answer:

> 8.1 The basic research question for the vehicle off-road trials relates to road safety benefit to both recovery operators and other road users: Is there a difference in the road safety benefit to all road users if road recovery vehicles are fitted with rear-flashing red lamps only, and rear-facing flashing red lamps plus amber warning beacons compared to the current usage of amber warning beacons only?
>
> 8.2 One of the reported benefits of road-recovery vehicles fitted with red flashing lamps is an implicit association between the colour red and the concept of danger. It has been suggested that this association of red with danger could benefit road recovery operators if it causes drivers approaching a scene to take more care. Therefore, a key objective for the off-road trials is to generate sufficient data to statistically quantify this association under "real road" conditions and determine whether there is expected to be demonstrable road safety benefits to recovery operators and other road users.

For this project's trials' design, it was necessary to identify driver behaviours that could be recorded and analysed to determine whether any differences were solely as a result of the different lighting colours. 'Safety' cannot be measured in such a trial directly, so it was necessary to adopt appropriate measures:

- Track trial: 'time to demerge' (i.e. the time from contact with the static vehicle)
- Simulator trial: (as appropriate for the road environment), time to demerge, speed change, lateral movement.

To undertake the subsequent analysis, a set of specific questions was developed for each type of trial, also including the ambient lighting (daytime and night-time) condition. These RQs formed the basis of the analysis and reporting and are referenced in the relevant sections of this report.

Track Trials

- RQ1: Is there a statistically significant effect of colour of flashing lamps on the participants' time to demerge?
- RQ2: Is there a statistically significant effect of lighting condition (daytime and night-time) on the participants' time to demerge?
- RQ3: Is any effect of colour of flashing lamps on the participants' time to demerge different for daytime and night-time conditions?

Simulator trials

- RQ1: Is there a significant effect of colour of flashing lamps on the participants' responses?

[4] Department for Transport (2021) Statement of Requirements. Contract Title: The use of red flashing lamps by road recovery operators – Phase 2. Contract Reference: TETI1027.

- RQ2: Is any effect of colour of flashing lamps on the participants' responses different for daytime and night-time conditions?
- RQ3: Is any effect of colour of flashing lamps on the participants' responses different for the different road types?

6.3 Development of lighting used during participant trials

The lighting system used during the track trial was representative of those currently in use by the industry. The light bar used was equipped with certain modules (not across the full width of the light bar) capable of displaying either amber or red light. Any variations in light level displayed between amber and red are representative of how lighting would be displayed should authorisation be granted, and red flashing lamps integrated into lightbars. Figure 7 shows a comparison of the track and simulator lighting against a National Highways Traffic Officer vehicle. The simulator images are screenshots from video recordings outputted from the simulator.

The lighting patterns displayed were designed to show the ‘amber only’ and ‘red only’ lighting colour clearly and used single flash rather than use ‘multiple strike’ flash patterns. Both used an alternating left-right single flash pattern commonly used on recovery industry vehicles. The ‘amber + red’ pattern was simplified from that used on National Highways’ Traffic Officer vehicles, where both amber and red are displayed concurrently. The flash pattern used displayed amber and red together, alternating left-right. Flash patterns were timed to provide participants with sufficient lighting ‘on’ time to identify the colour differences. All other aspects of the recovery vehicle (e.g. rear chevron markings as described in Parts 2 and 3 of the Traffic Signs Manual Chapter 8 (Department for Transport, 2009)) remained consistent during the track trial.

The three flash patterns were replicated for the simulator trials. However, due to the rendering of lighting in the simulator, the area of light bar illuminated was increased from representing two modules to being displayed on half of the light bar width. The 3D model of the recovery service van replicated the markings of the van used during track trials.

Due to the concurrent display of both colour lamps in the amber + red condition, there was a higher light level displayed. This was considered during data analysis, allowing the following comparisons in the research:

1. Direct comparison of driver responses to lighting colour between amber only and red only, where similar light levels and (alternating side-to-side) flash patterns were displayed, and
2. Comparison of driver responses to the amber + red pattern where both colours were displayed simultaneously (i.e. where a higher level of light was displayed) against the amber only and red only alternating flash patterns.

These comparisons are consistent across both types of trial. Behavioural responses are comparable within each trial type but should not be directly compared between the two trial types as they are different.

Figure 7: Comparison of: (top) Traffic Officer vehicle displaying alternating amber and red, (centre) van used during track trials, shown displaying the alternating amber and red lighting condition, (lower) simulated van used during simulator trials, shown displaying the alternating amber and red lighting condition

All trial participants, in both track and simulator trials, completed a post-trial questionnaire which sought to determine their understanding of the light colours displayed and the actions which they understood that they should take in response to seeing them. This was further explored in a short online survey of a larger participant sample.

None of the participant trials or the Expert Review were intended to determine optimum flash patterns or flash rates.

During the Expert Review event, a wide range of flash patterns were displayed. These were not limited to amber light or to flash patterns permitted by vehicle lighting regulations. Participants were asked to report their perceptions of the lighting, for example: ‘was it attention grabbing?’, ‘did the vehicle look like it was static or moving?’, with the intention that these could guide selection of flash rates within those currently permitted and inform potential future lighting development.

7 Participant track trials

The track trial was the first activity where naïve participants were involved. Carried out over two days, the main purpose was to establish, in a realistic setting, for the scenario of interest (a recovery vehicle stopped in a live lane on a rural road), what drivers' stated responses were when presented with the various lighting options in both daytime and night-time conditions, while in a vehicle driving towards the stopped vehicle.

The perceptual judgements required of a driver in this situation are likely to be the same as those that are experienced on a public road and so the data collected during this off-road track trial provided a realistic initial test of the impact of the different light colours.

7.1 Method

72 participants (36 daytime, 36 night-time), recruited from TRL's participant register and targeted Facebook advertising, were invited to attend the site. Participants were offered a voucher to cover their costs and inconvenience. A power analysis was conducted and established that this sample (in both the track and simulator trials) would be sufficient to detect a medium effect size on the variable of interest (distance of lane change), with 80% power.

After a short briefing, they were driven at approximately 30mph, and as if on a public road, by researchers along three loops of the track. During the drive, on each lap, they encountered a service van, obstructing the nearside lane on a straight section of track. The van was displaying flashing lamps: these were amber only, red and amber, or red only. The order in which the colours were displayed was counterbalanced across participants to control for order effects.

Trees obscured participants' views towards the parked van until the trial cars turned onto the long straight.

Participants were asked to indicate, by raising their hand, when they would change lane ['demerge'] to avoid the obstructing vehicle, with each drive being video recorded. These points were analysed later to determine whether the lighting colour displayed on the recovery vehicle affected drivers' demerge decisions.

Post-drive, each participant was given a questionnaire to complete on their awareness and understanding of the lighting conditions, including their interpretation of the action they felt would be expected.

7.2 Trials process

Trial drives, with three cars operating, synchronised, on the track, followed the following process:

1. Participants were given an indicative colour vision test. The intention was to identify any issues, and no participants were excluded on the outcome from this test
2. Participants were given a short briefing on what was required. They were not informed of the purpose of the research

3. At the start of the first drive, participants were given a basic distance vision test, reading a number plate (participants had been asked to wear glasses or contact lenses if they needed them for driving)
4. Participants completed three drives past the scenario, each drive with a different lighting colour variation
5. After the third drive, participants were asked to complete a short survey

7.3 Trials set-up

Trials took place on a section of track at Wroughton airfield. This is a secure site, with controlled access. The research team had sole use of the trials area.

All trials drives followed the same route, as shown in Figure **8**. The key locations were:

- Red circle (left); start point for trials drives
- Blue arrows; direction of trial car travel during trial drives
- Red rectangle; location of van
- Dark blue arrow; measurement and demerge zone (see section 7.4 and Figure 10)
- Red circle (right); collection area. Trials cars passed the van individually (only one car travelling at any time) then returned in convoy to the start point

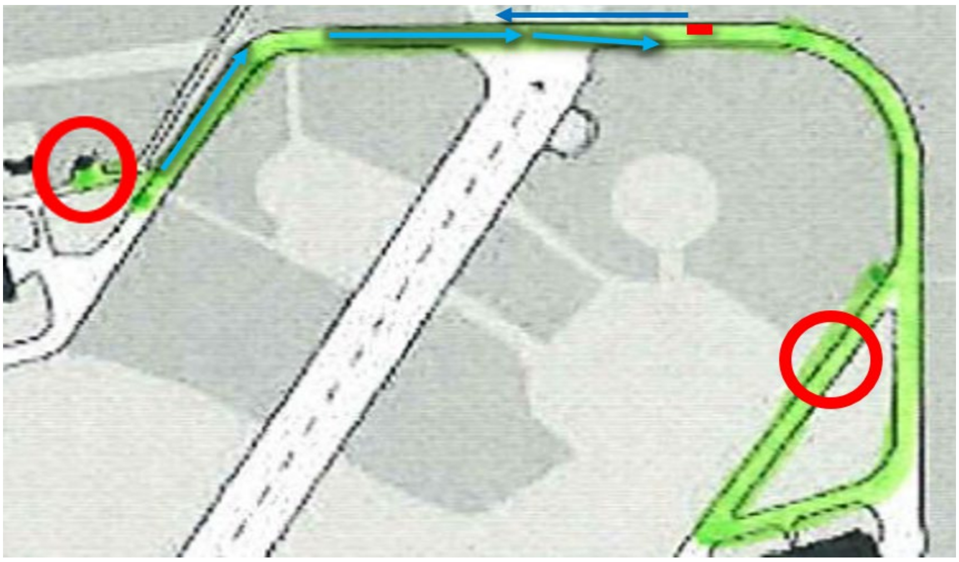


Figure 8: Trials elements and locations (original image © Science Museum Group)

Figure 9: Low aerial view of straight section and van location (image © Science Museum Group)

7.4 Trials equipment and video analysis

Each trials car was fitted with dual video cameras. These provided the following views:

- Camera 1, forward-facing, showing the 'road' ahead towards the breakdown van
- Camera 2, towards the participant, to identify when any hand signal is given

Trials cars were driven towards the van, maintaining a speed of about 30 mph.

For subsequent data analysis of participants' stated demerge location, marker cones were placed at measured distances along the verge upstream from the van (i.e. towards approaching trials cars). The marker cones were placed along the verge at distances equalling that travelled in one second at 30 mph.

These marker cones (see Figure 10 and Figure 11) extended to 14 seconds travel time (at 30 mph) from the rear of the van. A safety zone was identified at two seconds travel time from the van. If participants had not indicated to demerge by this point, the researcher would demerge to avoid a collision. Prior to entering the measurement zone, the van was visible to participants for approximately five seconds.

Figure 10: Measurement cones along the verge

Researchers undertaking analysis of video recordings located the trials cars' positions to 0.5 seconds travel accuracy. During the analysis they checked that the correct colour had been displayed according to the randomisation.

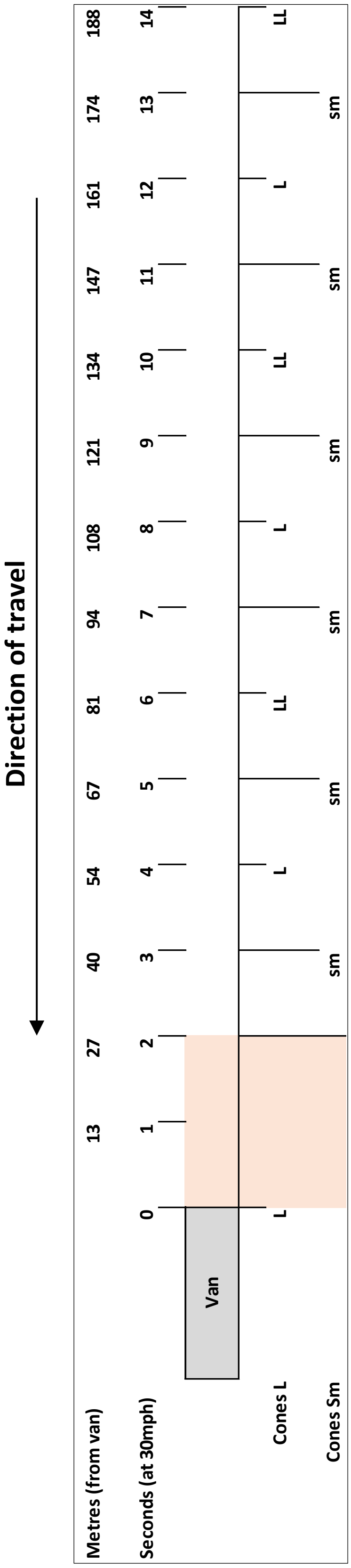


Figure 11: Placement of measurement cones (the van was visible to participants for approximately five seconds prior to the measurement zone)

7.5 Counterbalancing of lighting

Participants encountered the van three times, during which it was displaying (operated by the lighting technician) one of three lighting configurations:

- Control, amber only (alternating flash 75 flashes per minute)
- Red flashing lamps and amber (alternating single flash 75fpm)
- Red flashing lamps only (alternating flash 75fpm)

To control for order effects, the order in which the different beacon colours were displayed was counterbalanced across participants, see Table 3.

Table 3: Counterbalancing of lighting by participants

Participants	Drive 1	Drive 2	Drive 3
1-6, Light Order 1	Amber	Red	Amber and Red
7-12, Light Order 2	Amber	Amber and Red	Red
13-18, Light Order 3	Red	Amber	Amber and Red
19-24, Light Order 4	Red	Amber and Red	Amber
25-30, Light Order 5	Amber and Red	Red	Amber
31-36, Light Order 6	Amber and Red	Amber	Red

7.6 Video analysis

Post-trial video analysis involved matching the two video streams to identify the trial car's location at the point where the participant indicated that, if driving, they would demerge. Participants' views of the track were as shown in Figure 12. A participant indicating their preferred demerge location is shown in Figure 13.

Figure 12: Participant's first view of van, note distance from start of measurement zone

Figure 13: Anonymised image showing a participant indicating their preferred demerge location

7.7 Statistical analysis

7.7.1 Research questions

In this section we analyse the results from the track trial and answer the following research questions (RQs):

- RQ1: Is there a statistically significant effect of colour of flashing lamps on the participants' time to demerge?
- RQ2: Is there a statistically significant effect of lighting condition (daytime and night-time) on the participants' time to demerge?
- RQ3: Is any effect of colour of flashing lamps on the participants' time to demerge different for daytime and night-time conditions?

See Section 6.2 for information on development of research questions.

We begin with an exploratory analysis of the data in section 7.7.2, prior to a more formal statistical analysis in section 7.7.3.

7.7.2 Exploratory analysis

72 participants were originally recruited for the trial. However, after a number of dropouts on the trial days, only 64 participants completed the trial. Due to malfunctions with the recording equipment, data for four participants was not recorded at all, and data for a further two participants were removed due to an incomplete record of their responses being recorded. Data for a further three participants were removed due to an incorrect light order sequence being displayed; all three participants observed red flashing lamps twice. A further participant's data was removed for two reasons. Firstly, this was identified as an outlier in the statistical analysis of section 7.7.3. Secondly, this participant's data was non-informative; they provided the exact same responses (14 seconds) to all three colours of flashing lamps, responding at the earliest possible time they could respond – as soon as they rounded the

corner. Note, however, that the results of the statistical analysis are unaffected by the inclusion or exclusion of this participant's data.

After the removal of this data, the final dataset available for the statistical analysis consisted of 54 participants. The dataset available for analysis of 54 participants was less than the 72 participants that were originally intended. Therefore, the following checks were performed in order to investigate the balance of the data available:

- Table 4 presents the frequency of participants in each of the 'day' and 'night' groups. This demonstrates a minor imbalance between the day and night lighting conditions
- Table 5 presents the frequency of participants in each of the light order groups, and the split of these participants by lighting condition. The frequency of participants column demonstrates a more major imbalance in terms of the light orders that were observed; light order 1 was only observed by a single participant, with the remaining light orders being experienced by between 9 and 13 participants. The day and night columns demonstrate major imbalances for light orders 2 and 3 for the different lighting conditions, and minor imbalances for the remaining light orders

Table 4: Balance of data for lighting condition

Lighting Condition	Day	Night
Frequency of participants	28	26

Table 5: Balance of data for light order and lighting condition

Light Order	Day	Night	Frequency of participants
1	1	0	1
2	8	2	10
3	3	8	11
4	6	4	10
5	4	5	9
6	6	7	13

In section 7.7.3, following the statistical analysis, checks were performed to ensure that the results from statistical modelling were robust to these imbalances. These checks are explained in more detail in section 7.7.3.

Figure 14 presents a boxplot of the response times (time to demerge) for the participants in the trial. Note that the time to demerge is the estimated time based on the distance that the trial vehicle is away from reaching the van when the participant responds – hence a larger time to demerge means that a participant responded to the van earlier. The data for the day lighting condition is represented by orange boxes, the data for the night lighting condition is represented by grey boxes. Each box represents data from a unique combination of lighting condition and flashing lamp. The dark lines represent the median of each group, and the coloured boxes show the interquartile range of the data – that is, the middle 50% of the data for each group. From a visual inspection, it is clear that at night, the participants' demerge time is greater on average than for daytime. Participants responded earlier to the flashing lamps at night, with the difference between the two groups on average being almost a whole second; 7.12 seconds for day participants and 8.10 seconds for night participants. For each lighting condition, differences in responses to the three colours of flashing lamps appear relatively minor, although the night participants responded earlier to the red flashing lamps. This will be investigated more formally through the statistical analysis in section 7.7.3 however and cannot be taken as evidence for any effect of lighting colour until the statistical analysis is considered.

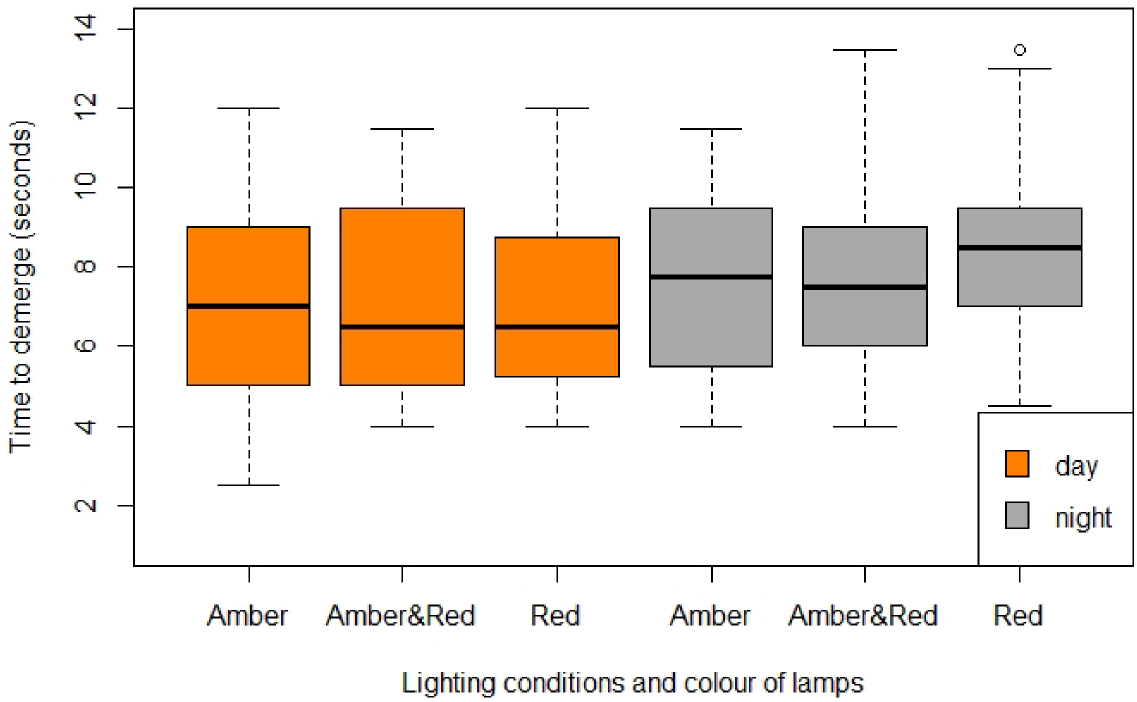


Figure 14: Participants' responses – time to demerge

7.7.3 Statistical analysis

In terms of statistical modelling, we have two factors; a *within-subjects* factor (colour of flashing lamp), where all participants experienced each of the colours during the trial, and a *between-subjects* factor (lighting conditions), where participants experienced only one of daytime or night-time conditions. This resulted in the six experimental conditions presented in Table 6. Each 'day' participant experienced experimental conditions 1-3, and each 'night' participant experienced conditions 4-6.

We wished to understand the effect of each of these factors on participants' responses – their time to demerge. We also had multiple responses (referred to as repeated measures) for each participant (one for each colour of flashing lamp), hence we required a suitable approach that could accommodate all of these considerations appropriately. The appropriate statistical model for this is a two-way mixed-model analysis of variance (ANOVA).

Table 6: Experimental conditions for the track trial

Experimental Condition	Lighting Conditions	Vehicle lighting
1	Day	Amber
2	Day	Amber & Red
3	Day	Red
4	Night	Amber
5	Night	Amber & Red
6	Night	Red

The ANOVA compared the effect of three colours of flashing lamp, under two different lighting conditions, on participants' response times. Results revealed the following:

1. Colour of flashing lamp did not have a statistically significant effect on participants' time to demerge ($p = 0.288$)
2. Lighting condition did not have a statistically significant effect on participants' time to demerge ($p = 0.182$)
3. Interaction effect: There was not a statistically significant interaction between the effects of colour of flashing lamp and lighting condition ($p = 0.068$)

None of the effects were significant at the 5% level, which is the conventional threshold for statistical significance.

As noted in section 7.7.2, various imbalances existed in the dataset. In order to further ensure the robustness of the results, multiple sets of balanced data were created at random from the full (unbalanced) dataset, and a two-way mixed-model ANOVA was performed each time on the resulting balanced datasets. This process involved the following:

- The balanced dataset was created each time by removing participants' data such that each row of Table 5 was equal. That is, each balanced dataset contained equal totals of day and night participants for each of the six light orders
- When selecting which of the participants' data to remove in order to obtain equal totals of day and night participants, participants were selected at random
- In total ten sets of balanced data were created

For all ten balanced datasets, the key findings from the ANOVA results were unchanged from the main analysis. This means that the results above have demonstrated a robustness to the lack of balance in the data.

A potential caveat of these results are the limited sample sizes involved for the trial. The intended sample sizes of 36 participants in each day and night group were reduced to 28 and 26 participants respectively, following dropouts and malfunctions. Since participant numbers were lower than the desired sample sizes, the analysis had less power than was originally planned. A visual inspection of Figure 14 shows only marginal differences in participants' responses between the three colours for the day group. Based on this evidence, even a considerably larger sample size would be unlikely to impact the results. For the night group, these differences are slightly more noticeable, although have not been found to be statistically significant. Based on this evidence, it is possible that a larger sample size could have some impact on the results. With the objective of informing the required sample sizes for a future trial, an additional power analysis was conducted, based on the results from this trial. This is discussed in section 13.6.

In terms of the research questions, the results above mean that we can draw the following conclusions from the statistical modelling:

- RQ1: Colour of flashing lamps was not statistically significant as a main effect. This means that based on the results of this track trial, there is no evidence to support the hypothesis that colour of flashing lamps has an effect on driver's responses in terms of time to demerge
- RQ2: Lighting condition was not statistically significant as a main effect. This means that based on the results of this track trial, there is no evidence to support the hypothesis that lighting condition has an effect on driver's responses in terms of time to demerge
- RQ3: The interaction between colour of flashing lamps and lighting condition was not statistically significant. This means that based on the results of this track trial, there is no evidence to support the hypothesis that the effect of colour of flashing lamp on participants' time to demerge is different for daytime and night-time conditions

7.8 Conclusions from track trial

Based on the data from the track trial, colour of flashing lamps was not statistically significant as a main effect. In addition, there was no significant interaction between colour and lighting condition. Hence there is no evidence from the track trial to support the hypothesis that colour of flashing lamps has an effect on driver's responses in terms of time to demerge.

8 Participant simulator trials

The participant track study was complemented by a simulator trial. This enabled inclusion of a wider set of variables into the study and permitted a degree of control over these variables that would simply not be possible in a study held fully at an off-road test track. Delivering physical trials relies on favourable ambient weather and lighting conditions, all of which can be managed or adjusted within the simulated environments.

Existing environments for the three additional road types (motorway with hard shoulder, high-speed dual carriageway, urban) were modified to include a static van, either on the hard shoulder (motorway environment) or obstructing a live lane (high-speed dual carriageway and urban environments). All three environments reflect accurately real-world driving environments that participants were likely to have encountered.

The simulated environments were implemented in DigiCar, TRL's advanced driving simulator. DigiCar consists of a production vehicle (Peugeot 3008), with fully operational controls, surrounded by curved front screens and a rear screen for a 300˚ field of view. The screens enable normal rear and wing mirror use. It recreates high fidelity test environments that accurately reflect real-world driving conditions. The car has electric actuators which supply motion with 3 degrees of freedom (heave, pitch, and roll). Engine noise, external road noise, and traffic sounds are provided by a stereo sound system. Driver interaction with the vehicle controls was captured directly from the vehicle CAN BUS at a frequency of 20 Hz. Figure 15 shows the driving simulator used.

Figure 15: TRL's DigiCar driving simulator

8.1 Trial design

A mixed design with repeated measures (all participants experience all road types and vehicle lighting conditions) and independent samples (participants experience only one of daytime or night-time ambient lighting conditions) was implemented. The following independent variables (IVs) were included:

1. Vehicle lighting configuration (red vs. red + amber vs. amber)
2. Ambient lighting (day vs. night)
3. Road type (motorway vs. dual carriageway vs. urban road)

The three road environments used are shown in Figure 16.

This set of variables gives a 2 x 3 x 3 design, resulting in a total of 18 experimental conditions to be tested. To answer the key research questions, the key dependent variables measured (to identify the effects of the independent variables, IVs) were:

1. The degree to which a driver adjusts their speed in response to the van (all environments)
2. Whether or not a driver changes lane (or moves within their lane) in response to the van (motorway environment)
3. The distance at which a driver changes lane (or moves within their lane) in response to the van (high-speed dual carriageway and urban environments)

These measures allowed evaluation of whether a change in lighting on the van (IV1) affects drivers' speed choice, lane keeping behaviour or lane choice, and to what extent speed choice, lane keeping choice and lane choice are influenced by different ambient lighting conditions (IV2) or between different road types (IV3).

A participant sample of 72 drivers (36 'day' and 36 'night') was recruited from TRL's participant database, with a general (though not representative) split of age, sex, driving experience and motorway driving. Separate cohorts of participants experienced daylight and darkness conditions.

Figure 16: Simulated environments used: urban (top image), high speed dual carriageway (centre) and motorway with hard shoulder (lower)

8.2 Simulated environments design

The three simulated road environment models selected from TRL's environments library accurately reflect current road design regulations and principles. This meant that all lane widths, road markings and other visual characteristics were as a participant would experience them in the real world.

If other, simulator system-controlled, traffic is introduced into an environment, it is critical that its behaviour is realistic to provide confidence when generalising from participant behaviours observed. While driving in the high-speed roads and urban environments, participants needed to be free to select their individual preferred demerge (lane change) locations. Therefore, no system-controlled traffic was included in those two environments. For the urban environment, demerge could involve crossing the road's centreline, so no oncoming traffic was introduced.

In the motorway environment, light traffic was introduced. This traffic reacted according to each participant's driving. No HGVs were included as these would have remained in lanes 1 and 2, and might have obstructed participants' forward views towards the van. The light, car only, traffic volume meant that there was little potential for obstruction of view.

Also, traffic lights systems within the urban environment were switched off so that participants were continuously able to choose their own speed and participants were briefed accordingly.

Each environment was arranged to allow the following sequence of driving:

1. Settling-in period, to become accustomed to driving in a simulated road environment
2. Three encounters with the stationary van, with normal driving between
3. End of trials scenarios

8.3 Trials process

All trials followed the same process:

- On arrival, participants were given two indicative eyesight tests: distance vision to a number plate and a basic colour vision test. These tests were as used during the participant track trials, no participants were excluded on the basis of their test results. Participants had been asked to wear glasses or contact lenses if they needed them for driving.
- Participants received a short briefing but were not informed of the purpose of the research or that recovery vehicles and lighting variations were involved.
- When taken to the simulator, participants completed a familiarisation session in a non-complex environment, with no other traffic, and were encouraged to practice changing lanes, braking and accelerating. This session allowed ample opportunity for participants to become familiar with the vehicle controls and relax before the trial began. Without this stage, any simulator study is likely to result in sickness or discomfort in some participants.
- Participants completed a series of short scenario drives. They were instructed to drive as they normally would on a real road or motorway. Specifically, they were asked not to treat the simulator as if it was a game, nor to try especially hard to drive their very best; they were advised that their driving was not being judged. This helped ensure that participants' behaviour in the simulator is representative of their real-world driving. During each drive they encountered vans displaying all three colour alternatives. The participant vehicle (car) had no maximum speed limit restriction.

- At the end of the driving element, each participant was asked to complete a post-trial questionnaire to capture subjective responses to the warning lamps, as well as exploring their comprehension of the various scenarios. The content of this questionnaire was similar to that given to the track trial participants.

8.4 Simulator data

Through the trial, the simulator recorded data for elapsed time, the vehicle's speed, position and distance. Collection of these data allowed for statistical comparisons to be made of the impact of the different variables on driver's response and behaviour. This level of consistent and comparable data gathering would be difficult to collect from a full set of trials conducted on off-road test tracks.

8.5 Counterbalancing of lighting and road environment

The order in which participants completed the scenarios and experienced the lighting variations was counterbalanced. This was necessary to reduce any potential effects on the participants' behaviour from the order of presentation. The road environment orders are shown in Table 7. Within each drive, the first participant in each Road Order saw Light Order 1, the second saw Light Order 2, etc. (repeated for day and night), see Table 8.

36 participants experienced the 'day' condition and 36 different participants experienced the 'night' condition. Within each set of 36 participants, the order in which they experienced the three road environments was as shown in Table 7.

Table 7: Counterbalancing for simulator drives (repeated for daytime and night-time drives)

	Participants	Drive 1	Drive 2	Drive 3
6 x Road Order 1	1, 2, 3, 4, 5, 6	Motorway	High speed road	Urban
6 x Road Order 2	7, 8, 9, 10, 11, 12	Motorway	Urban	High speed road
6 x Road Order 3	13, 14, 15, 16, 17, 18	High speed road	Motorway	Urban
6 x Road Order 4	19, 20, 21, 22, 23 ,24	High speed road	Urban	Motorway
6 x Road Order 5	25, 26, 27, 28, 29, 30	Urban	High speed road	Motorway
6 x Road Order 6	31, 32, 33, 34, 35, 36	Urban	Motorway	High speed road

Table 8: Lighting order viewed by participants (repeated for daytime and night-time drives)

Participant	Light Order	Loop 1	Loop 2	Loop 3
1, 7, 13, 19, 25, 31	1	Amber	Red	Amber and Red
2, 8, 14, 20, 26, 32	2	Amber	Amber and Red	Red
3, 9, 15, 21, 27, 33	3	Red	Amber	Amber and Red
4, 10, 16, 22, 28, 34	4	Red	Amber and Red	Amber
5, 11, 17, 23, 29, 35	5	Amber and Red	Red	Amber
6, 12, 18, 24, 30, 36	6	Amber and Red	Amber	Red

This resulted in the following sequences:

- Participant One drove the motorway first, then high speed road, then urban. During each of the three road types, they saw amber, then red, finally amber & red
- Participant Two drove the same order for the roads as Participant One, but saw amber, then amber and red, finally red

Through to Participant Seven, who had a new sequence of road types:

- Participant Seven drove the motorway first, then urban, then high speed road. During each of the three road types, they will saw amber, then red, finally amber & red
- Participant Eight drove the same order for the roads as Participant Seven, but saw amber, then amber and red, finally red

Through to Participant 13.

This sequence was used through to Participant 36. The sequence was repeated for daylight and darkness conditions. During trials delivery, 'day' and 'night' conditions were alternated.

8.6 Method

8.6.1 Research questions

The trial aimed to answer the following research questions (RQs):

- RQ1: Is there a significant effect of colour of flashing lamps on the participants' responses?
- RQ2: Is any effect of colour of flashing lamps on the participants' responses different for daytime and night-time conditions?
- RQ3: Is any effect of colour of flashing lamps on the participants' responses different for the different road types?

See Section 6.2 for information on development of research questions.

8.6.2 Independent variables and the experiment design

Data from the simulator trial consisted of 36 participants completing daytime drives, and 36 participants completing night drives. Each participant completed three separate trial drives – one for each road type (motorway, high speed road & urban). Each drive contained three scenarios for vehicle lighting, consisting of different colours of flashing lamps (amber, red & amber, red). Each participant completed all three drives in either day or night conditions. This means that we have the factors (independent variables) defined below. All participants experienced all road types and all vehicle lighting conditions (and hence these factors are defined as within-subject factors or repeated measures), whereas participants experienced only one of daytime or night-time lighting conditions (and hence this is a between-subject factor).

Within-subject factors (all participants experienced all scenarios):

- Vehicle lighting configuration (amber, red and amber, red)
- Road type (motorway, dual carriageway, urban road)

Between-subject factor (each participant experienced only one scenario):

- Lighting conditions (day, night)

This results in a 2 x 3 x 3 design resulting in a total of 18 experimental conditions that were tested; these are outlined in Table 9. Each participant experienced nine of these. That is, each ‘day’ participant experienced experimental conditions 1-9 and each ‘night’ participant experienced experimental conditions 10-18.

Table 9: The 18 experimental conditions

Experimental Condition	Road Type	Lighting Conditions	Vehicle lighting
1	Motorway with hard shoulder	Day	Amber
2	High-speed road without hard shoulder	Day	Amber
3	Urban road	Day	Amber
4	Motorway with hard shoulder	Day	Amber & Red
5	High-speed road without hard shoulder	Day	Amber & Red
6	Urban road	Day	Amber & Red
7	Motorway with hard shoulder	Day	Red
8	High-speed road without hard shoulder	Day	Red
9	Urban road	Day	Red
10	Motorway with hard shoulder	Night	Amber
11	High-speed road without hard shoulder	Night	Amber
12	Urban road	Night	Amber
13	Motorway with hard shoulder	Night	Amber & Red
14	High-speed road without hard shoulder	Night	Amber & Red
15	Urban road	Night	Amber & Red
16	High-speed road with hard shoulder	Night	Red
17	High-speed road without hard shoulder	Night	Red
18	Urban road	Night	Red

8.6.3 Dependent variables

Dependent variables for the trial are metrics that were devised in order to meaningfully capture participants' behaviour in their approach to the van, and to determine how they responded. Prior to defining these, we noted the following relevant points:

- For the motorway with hard shoulder, the van was stationary on the hard shoulder, and hence participants were not forced to change lanes in order to avoid impact. For the dual carriageways and urban environment, the van was stationary in a live lane, and hence participants were required to change lanes in order to avoid impact. This means that some dependent variables are only relevant for certain road types. Lateral movement distance is only relevant for the motorway, since for the high speed and urban roads, drivers are forced to move into the next lane. Distance of lane change is only relevant for the high speed and urban roads, since on the motorway the drivers may choose not to change lanes.

- We refer to the 'van interval' as the interval prior to the van where we investigate the responses of participants. This interval commences at the point where the recovery vehicle enters the line of sight of the participant and ceases when the participant passes the van.

See Section 6.2 for information on development of research questions.

We define below the dependent variables for the trial and the corresponding relevant road types:

1. **Speed change:** *(all road types).* The degree to which a driver adjusted their speed in response to the static recovery vehicle. This is the difference between their baseline speed at the start of the van interval, and the lowest speed reached within the interval.
2. **Lateral movement distance:** *(only for road type motorway with hard shoulder).* The maximum lateral movement recorded within the van interval. This may or may not include a lane change – the driver was not forced to change lane as the van is on the hard shoulder.
3. **Distance of lane change:** *(only for road types high speed road and urban road).* For these road types, the driver was forced to change lanes in order to avoid impact with the van. We measured the distance from the van at which a driver changes lane in response to the static recovery vehicle – so a shorter distance indicated that the driver changed lane later (i.e. closer to the van). The driver was determined to have changed lane when the centre of the vehicle crossed the lane marking.

These measures enabled us to evaluate whether a change in lighting on the static recovery vehicle impacted the drivers' speed choice, lane keeping behaviour or lane choice, and to what extent speed choice, lane keeping choice and lane choice are influenced by different lighting conditions or different road types.

8.7 Exploratory Analysis

Prior to conducting the statistical analysis of section 8.8, in this section we perform an exploratory analysis of the data – that is, some initial investigations and visual inspections of the data.

8.7.1 Part 1 – high frequency simulator data

Data were recorded in the simulator at a high frequency: 20 Hertz. That is, 20 measurements per second. Using these high frequency data, we can visually inspect the responses of participants by producing plots of both the speed and lateral movement throughout the van interval. Examples of these plots are shown in Figure 17. These show the lateral movement (upper row) and speed (lower row) on the high-speed road in daytime (left) and night-time (right) conditions. The units for lateral movement are metres, and for speed the units are miles per hour. Each point on the plot is an average, taken every 40 metres and over all relevant participants, of the lateral movement and speed – with a different colour for each set of flashing lamps.

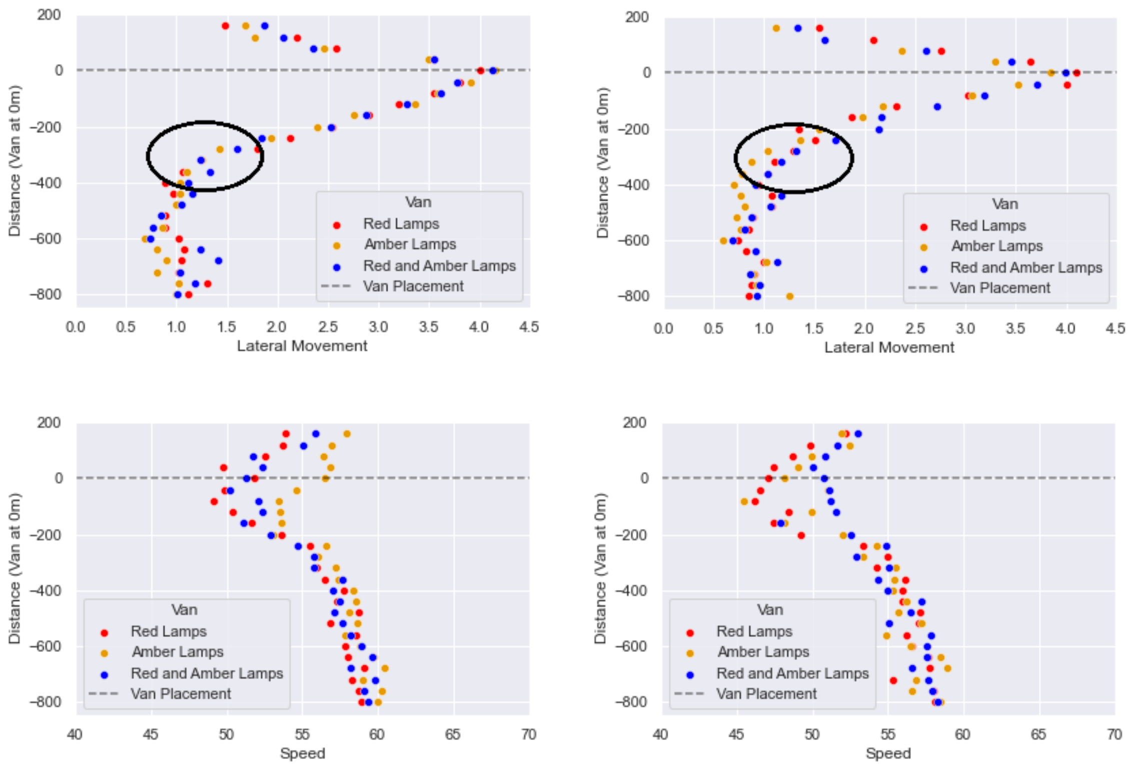


Figure 17: High-speed road in daytime (left), and night-time (right) conditions; lateral movement (upper row) and speed (lower row).

In all four plots, we see that the effect of colour of flashing lamp appears to be relatively minor, although for the speed plots there are some noticeable differences between the colours. The effect is also not consistent – for example amber lamps appear to result in the greatest decrease in speed at night, but the smallest decrease in speed in the daytime. For lateral movement, comparing the day and night conditions and focussing on the points within the black circles, we can see that at night, participants appear to start moving into the next lane slightly later (closer to the van) than the participants in the day. However, for all of these comparisons, we can draw clearer conclusions when we inspect boxplots of participants' responses in section 8.7.2. The points in Figure 17 are an average across all relevant participants, whereas the boxplots of section 8.7.2 are more revealing, in that they display aspects of the whole distribution of participants' data for each response variable.

Visual inspection of plots such as those in Figure 17 were highly informative in setting appropriate lengths of the van interval for calculating the dependent variables in section 8.6.3. For some dependent variables, the length of this interval was adjusted for the different road types in order to capture the relevant behaviour.

8.7.2 Part 2 – boxplots of participants' responses

In order to conduct the statistical analysis of section 8.8, appropriate summaries of each of the participants' responses (dependent variables) were produced from the high frequency data for each participant, for each of the relevant experimental conditions outlined in Table 9. From these summaries we present boxplots of the participants' responses in this section.

8.7.2.1 Outlier detection and removal

Initial boxplots were inspected for the presence of outliers and the following were found by visual inspection:

- For the dependent variable change in speed, one participant for the motorway had an extreme decrease in speed relative to the other participants. Data for this participant were removed from the analysis of this dependent variable.
- For the dependent variable distance of lane change, 10 participants were deemed to have changed lanes considerably earlier than it was possible to even observe the recovery vehicle, hence these were removed from the analysis of distance of lane change. Seven of these were 'night' participants, and three were 'day' participants.

Results for the statistical analysis of section 8.8 were checked for robustness in terms of comparing results for the presence and absence of these outliers – the results were unchanged.

8.7.2.2 Dependent variable 1 – change in speed

Figure 18, Figure 19 and Figure 20 are boxplots for participants' change in speed for the high-speed road, motorway and urban road respectively. Here a positive change in speed is a speed *reduction*, as drivers lower their speed as they approach the van. Therefore, a greater value is a greater reduction in speed.

- For the high-speed road (Figure 18), there is more variability across the inter-quartile range (the range of the coloured boxes that constitutes the middle 50% of the data) in the results for 'night' participants compared to 'day' participants. In terms of colour, there are only marginal differences between the responses.
- For the motorway (Figure 19), the effect of colour appears to be slightly less marginal, although still minor. In addition, this effect is not consistent. For example, red flashing lamps result in the smallest change in speed in the day, but the largest change in speed at night.
- For the urban road (Figure 20), the effect of colour again appears to be only slight. However, for this data the effect is a little more consistent – in the day, amber lamps result in the smallest speed reduction with red flashing lamps resulting in the greatest speed reduction. This is similar for the night participants, although due to the two negative extreme values for red at night, the average for red is slightly lower than amber and red, but greater than amber.

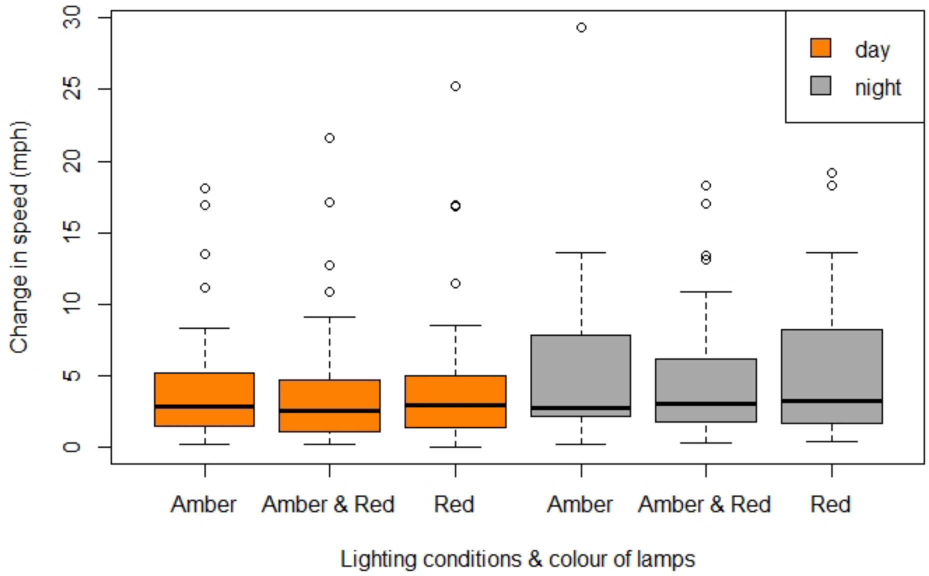


Figure 18: High-speed road – reduction in speed

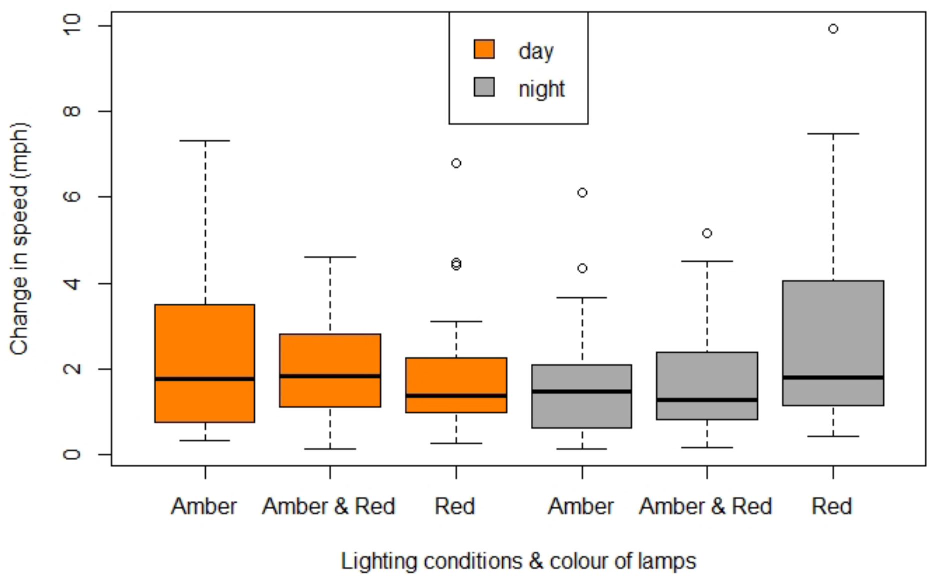


Figure 19: Motorway – reduction in speed

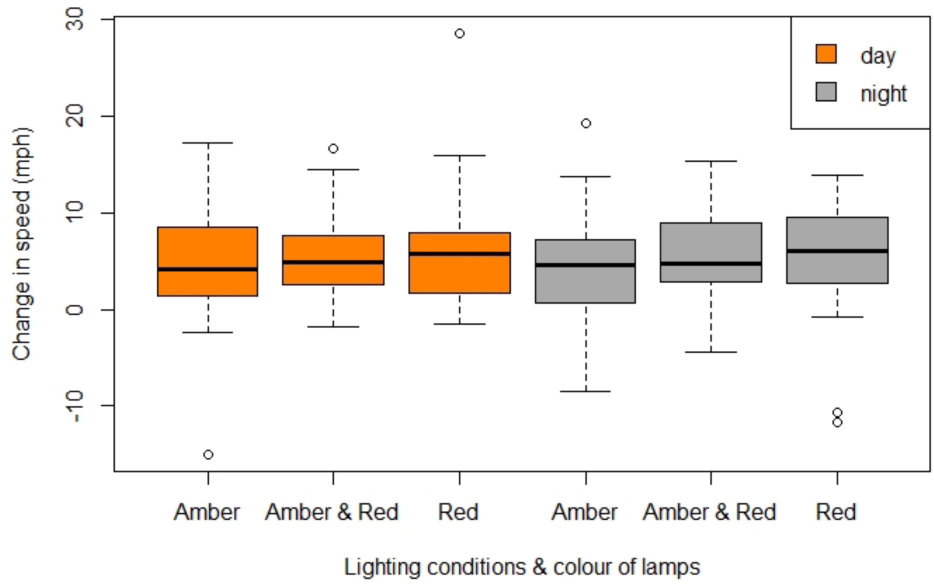


Figure 20: Urban road – reduction in speed

8.7.2.3 Dependent variable 2 – lateral movement

Figure 21 is a boxplot for participants' lateral movement on the motorway. A positive lateral movement is a movement to the right. The effect of colour is, again, minimal for both day and night participants, although in the day amber and red flashing lamps appear to result in slightly less lateral movement. The night responses appear to have more variability than the day responses. Assuming that a car is travelling in the centre of the lane, then a lateral movement of 1.85 metres would take the car into the next lane (marked by the horizontal dotted red line on the plot). From Figure 21 we see that only a small number of participants crossed into the next lane.

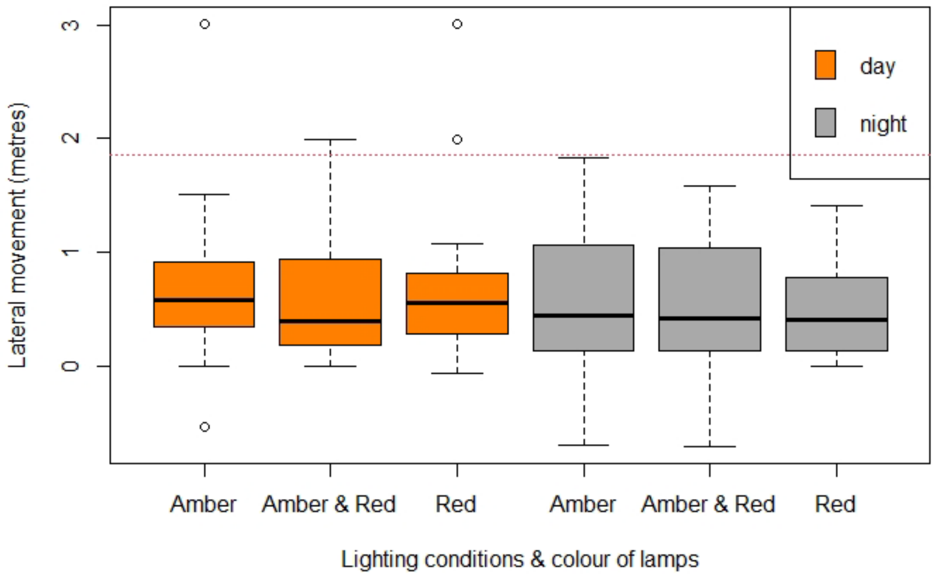


Figure 21: Motorway – lateral movement

8.7.2.4 Dependent variable 3 – distance of lane change

Figure 22 and Figure 23 are boxplots for participants' distance of lane change for the high-speed and urban roads respectively. This is the distance away from the van where a participant changes lane – so a greater value means that a participant changed lanes earlier.

For the high-speed road (Figure 22), we see that there appears to be a slight effect of colour, although this is not consistent. For example, at night, of the three colours red flashing lamps result in lane changes that are nearest to the van, whereas in the daytime these result in lane changes that are on average earlier than amber lamps. However, the most noticeable observation is that participants change lane later (closer to the van) at night compared with daytime conditions.

For the urban road (Figure 23) we see that, as for the high-speed road, participants change lane nearer to the van at night, although this effect is less noticeable than for the high-speed road. For the urban road, of the three colours, red flashing lamps result in the latest lane changes, for both day and night conditions.

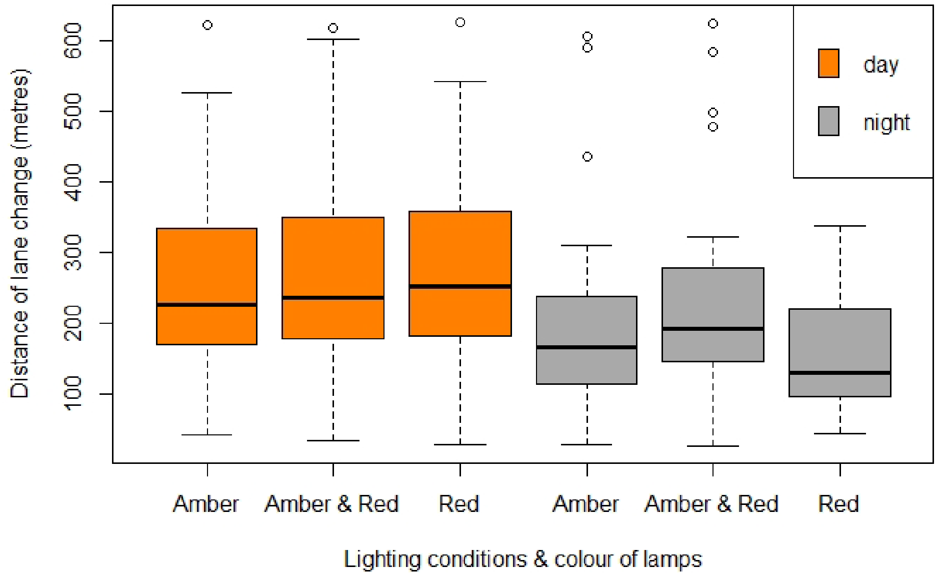


Figure 22: High-speed road – distance of lane change

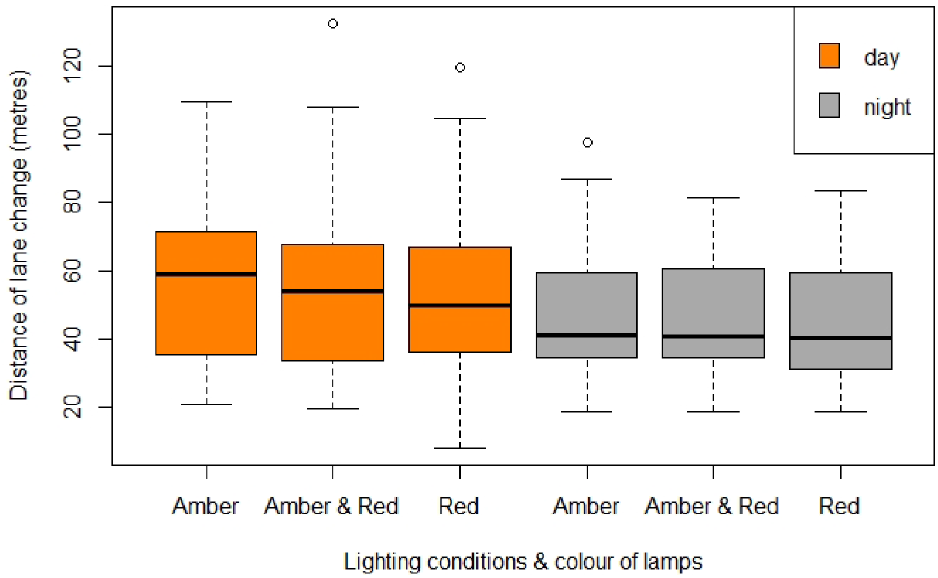


Figure 23: Urban road – distance of lane change

8.7.3 Summary of exploratory analysis

The exploratory analysis has revealed some interesting patterns in participants' responses. However, a key finding is that, from a visual inspection of these plots, there appears to be no clear and consistent overall effect of colour of flashing lamps on any of the three dependent variables. This is investigated more formally in the statistical analysis in section 8.8, where firmer conclusions are drawn.

8.8 Statistical analysis

As we explain in section 8.6.2, we have two within-subject factors, and one between-subject factor. Based on these factors, a three-way mixed model ANOVA was performed in order to analyse the effect of colour, lighting condition and road type on the dependent variables. The results from the ANOVAs for the three models (one for each dependent variable) are summarised in Table 10.

Table 10: Summary of ANOVA results

Model	Dependent Variable	Independent Variables	Summary Of Results
Model 1	Change in speed	Colour of flashing lamps Lighting conditions Road type	**No statistically significant main effect of colour on change in speed** (*p* = 0.162) No statistically significant main effect of light on change in speed (*p* = 0.658) Significant effect of road type: Simple main effects analysis showed that road type did have a statistically significant effect on change in speed (*p* < 0.001). A greater change in speed was observed for the high speed and urban roads, compared to the motorway. No significant interactions: interaction between colour and light (p = 0.773), interaction between colour and road type (p = 0.458), interaction between light and road type (p = 0.567) and interaction between colour, light and road type (p = 0.515).
Model 2	Lateral movement	Colour of flashing lamps Lighting conditions	**No statistically significant main effect of colour on lateral movement** (*p* = 0.712) No statistically significant main effect of light on lateral movement (*p* = 0.496) No significant interactions: interaction between colour and light (p = 0.857).
Model 3	Distance of lane change	Colour of flashing lamps	**No statistically significant main effect of colour on distance of lane change** (*p* = 0.382) Significant effect of lighting conditions: Simple main effects analysis showed that lighting conditions did have a statistically significant effect on distance of lane change (*p* = 0.005) –

		Lighting conditions	participants changed lane later (closer to the van) at night compared with day
		Road type	Significant effect of road type: Simple main effects analysis showed that road type did have a statistically significant effect on distance of lane change ($p < 0.001$). Distance of lane change occurred earlier (at a greater distance away from the van) for the high-speed road, than the urban road. No significant interactions involving colour: interaction between colour and light (p = 0.591), interaction between colour and road type (p = 0.422), and interaction between colour, light and road type (p = 0.585). Significant interaction between light and road type ($p = 0.018$). This means that the effect of lighting condition on distance of lane change depends on the road type. The effect was greater for the high-speed road, than for the urban road.

We state below the key conclusions from Table 10 and address the research questions stated in section 8.6.1:

- RQ1: For all three models, colour of flashing lamps was not statistically significant as a main effect. This means that, based on the results of this trial, there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of change in speed, lateral movement or distance of lane change.
- RQ2: For all three models, the lack of any effect of colour of flashing lamps on the participants' responses was not significantly different for daytime and night-time conditions.
- RQ3: For all three models, the lack of any effect of colour of flashing lamps on the participants' responses did not differ for the different road types.

Other notable results:

- Lighting conditions (daytime or night-time): For model 3 (distance of lane change), lighting conditions did have a statistically significant effect on distance of lane change – participants changed lane later (closer to the van) at night compared with day participants. For model 1 and model 2, lighting condition was not statistically significant as a main effect. This means that there is no evidence from this trial to support the hypothesis that lighting condition has an effect on driver's responses in terms of change in speed or lateral movement.

- Road type: For all three models, road type had a significant effect on participants' responses. This is unsurprising; different roads have different conditions, such as lane width and speed limits, which affect participants' responses. For example, for the motorway and the urban road, both the lane width and speed limit are considerably different.

One of the key assumptions that an ANOVA requires is that the dependent variable is normally distributed. When grouping data into the 18 experimental conditions (see Table 9 for more details), this assumption was violated for a number of groups for all three models. In order to ensure robustness of the analysis, the following additional analyses were conducted:

- Nonparametric alternative methods to ANOVA (which do not require such assumptions) were investigated and an additional analysis was performed.
- Transforms of the dependent variables were implemented, with the result that they were closer to being normally distributed – and ANOVAs were performed on the transformed data.

The results from both additional analyses were unchanged compared with the main results in Table 10.

8.9 Conclusions from simulator trial

For all three models, colour of flashing lamps was not statistically significant as a main effect. In addition, there were no significant interactions involving colour. Hence, there was no evidence from the simulator trial to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of change in speed, lateral movement or distance of lane change.

Another notable result was that participants changed lane later (closer to the van) at night compared with daytime lighting conditions. This was most apparent for the high-speed road. Implications of this finding are examined in Section 13.

9 Expert Review

An Expert Review event was undertaken to obtain the views of industry experts on a range of lighting patterns. It was originally intended that this would be held in early March, ahead of the participant track trial, and that the attending experts would have advised on design of the lighting pattern to be displayed during the trials and replicated for the participant simulator trials.

However, due to unforeseen circumstances, the intended test track became unavailable at short notice, so the event was cancelled and rearranged for later in the year.

The format for the event was that experts would view the lighting from two distances, 300m and 200m, in daylight and darkness. The venue selected allowed direct line of sight from those distances. Sixteen experts, from a range of companies, industry representative organisations, and National Highways, attended the event.

Ahead of the first, daylight, session, attendees received a briefing. This covered information on other activities within the project, basics of conspicuity and delivery of conspicuity research, and details of the questions that attendees would be asked for each of the lighting patterns. The patterns displayed were not limited to amber light or to flash patterns permitted by GB vehicle lighting regulations. The intention was that responses could guide selection of flash rates within those currently permitted and inform potential future lighting development. Also, certain patterns were similar to those displayed in the inline participant survey.

Figure 24: Viewing arrangements

Attendees were asked, for each pattern:

- Whether the lighting was attention grabbing
- Did the vehicle look like it was static or moving
- Did it look as if it was likely to be alongside the road (e.g., in a layby) or in the carriageway

- Whether the lighting was 'too bright', too distracting', or 'uncomfortable to look at'
- To what extent the lighting would prevent them from seeing around the vehicle (e.g. pedestrians)

The first six patterns displayed (see Appendix G for a full list of lighting patterns displayed) were based on beacon flash patterns permitted by current UK vehicle lighting regulations. That is with a flash rate between 60 – 240 flashes per minute (fpm) and with even intervals between the flashes being displayed.

Patterns 1, 3 and 5 were displayed at 75fpm, 120 fpm and 240 fpm, using the full width of the roof-mounted beacon bar. Patterns P2, P4 and P6 were displayed at 75 fpm, 120 fpm and 240 fpm, using half of the beacon bar alternately (see Figure 25). UNECE Regulation No. 65 (United Nations, 2011) allows a flash rate between 120 – 240 fpm.

GB vehicle lighting regulations require that the light from the beacon flash is visible from 360° around the vehicle. The alternating flash pattern, although in common use within the industry, may not meet that requirement.

Figure 25: Full width of beacon bar (left), half width (right)

However, due to two technical issues during the daytime session, it has been necessary to remove data for:

- 300m location, patterns 7 – 12
- 200m location, patterns 13 – 16

One issue was the brightness that patterns 13 – 16 were displayed during daytime at both distances. However, this was corrected for the night-time session and the opportunity was taken to display the four affected patterns, whilst still in daylight, at the 300m location. The combinations of patterns, distances and ambient lighting are detailed in Appendix G. Details of the responses that attendees gave to the patterns are given in Appendix H.

The main findings for the expert review are summarised below.

9.1.1 Amber patterns P1-P6

1. The 120 fpm alternating, 240 fpm flashing and 240 fpm alternating attracted more attention across the day and night, at 300 metres

2. All lighting patterns except the 75 fpm flashing pattern (which made the vehicle appear static) were reported to make the vehicle appear to be moving at 200 metres at night, compared with 300 metres at night
3. Attendees reported that the 75 fpm and 120 fpm flashing patterns represented the vehicle being alongside the road the most across the 200 metres and 300 metres night data
4. Attendees disagreed with the statement that the 75 fpm pattern was distracting, when viewed in the day
5. Attendees agreed that the 120 fpm flashing pattern and 240 fpm flashing pattern were too bright at night, from a distance of 200 metres
6. Disagreement towards the statement that the lighting patterns were distracting was noted for the 75 fpm and 120 fpm patterns was reported when comparing day versus night at 300 metres
7. Agreement towards the statement that the lighting pattern is uncomfortable to look at was reported for the 240 fpm flash and 240 fpm alternating lighting patterns when viewed at 300 metres at night
8. Disagreement towards the statement that the lighting pattern would prevent the attendee from seeing around the vehicle was noted in the both the day and night data; more strong disagreement was noted in the 300 metres day data
9. Agreement with the statement was noticeable in the night data for the 240 fpm flash data

9.1.2 Red patterns P7-P12

1. The red patterns displayed at 75 fpm, 120 fpm and 240 fpm were reported as particularly attention grabbing at night, compared with the day, and at 200 metres compared with 300 metres
2. The 75 fpm flash and 75 fpm alternating patterns appeared to make the vehicle seem to be moving more at 300 metres compared with 200 metres in the day
3. The 75 fpm pattern was perceived to represent the vehicle being alongside the road in the day 300 metres data, though the ratings for live lane were still higher
4. More agreement and neutral responses were noted regarding the statement that the lighting is too distracting, for the 240 fpm flash and 240 fpm alternating lighting patterns, when viewed at 200 metres at night
5. More strong disagreement regarding the statement that the lighting would prevent the attendee seeing around the vehicle was noticeable in the night data for the 240 fpm flash pattern

9.1.3 Patterns P13-P16

1. In the night data taken at 200 metres, agreement with the statement that the lighting was too bright was noted when attendees viewed the in-out amber flashing reds pattern.
2. Agreement with the statement that the lighting was too distracting was noted at 300 metres in the day and night particularly for the in out amber with flashing reds pattern.
    A. In the 300 metres night data, nearly half of the attendees agreed with the statement. This may suggest that this pattern was distracting for the attendees.
3. Attendees were either neutral or agreed with the statement that the lighting was uncomfortable to look at when presented with the in-out amber with flashing reds lighting pattern.

9.1.4 Summary

Considered together, the following conclusions can be reached (although note a full psychophysical test design would be needed to confirm such findings):

- Patterns displayed with a faster flashes per minute are attention grabbing but also potentially too bright, depending on the distance and time of day.
- Whilst rated as attention grabbing, patterns displayed with a faster rate of flashes per minute may also be rated as distracting.
- No patterns were viewed as particularly likely to prevent an attendee viewing around the vehicle.

When considered alongside the results from the online survey detailed in F.2.2, some consistent findings are noted:

- The online survey found a good proportion of respondents stated that the vehicle was parked, rather than moving for FP1. This is mirrored by the findings around the 75 fpm flashing pattern (pattern 1) in the Expert Review.
- The online survey found that respondents expected the vehicle to be moving, rather than parked for FP2, FP4 and FP6, this is mirrored by the expert review findings around the lighting patterns P2-P6.

10 Expert Seminar

As concerns were raised that the Expert Review event had not provided sufficient opportunity for industry representatives to provide additional input, an Expert Seminar for industry representatives, and other experts, was held online (using Microsoft Teams) on Tuesday, November 22nd, 2022. Invitations were sent to over 50 people, some of whom had been identified (and were contacted) by the industry. Twenty-two people attended the session, including 12 from the road recovery industry. Other stakeholders included representatives from organisations currently authorised to display red flashing lamps.

Authorised red flashing lamp user organisations represented were:

- National Highways
- Police (two representatives)
- Driver & Vehicle Standards Agency (DVSA)

The Seminar agenda included:

- Section 1
    - Context – 2020 & 2022 projects
    - Debrief of Newbury event
    - Outline of 2022 research project activities
- Section 2: Comments from industry (discussion)

Within Section 2, discussion was focussed on three questions that had been supplied to attendees ahead of the event:

- If: recommendation is to grant authorisation for the use of red lamps, what are your priorities on maximising their effectiveness?
    - e.g.: In consultation, views were expressed about over-use of red lamps, how could this be managed?
- If: recommendation is to not grant authorisation, what else could the industry pursue to improve safety?
- If: no firm evidence either way, how would the industry make the decision about what to do next?

Attendees were offered the opportunity to submit comments within the meeting 'chat' log, and to submit additional comments up to a week after the event (Tuesday 29th November; this deadline was subsequently extended to Friday 2nd December following a request from some industry stakeholders). Other comments were submitted ahead of the call. These comments are compiled in Appendix I, in four sections:

- 'Chat' Log. This has been anonymised
- Questions were asked relating to project delivery against the DfT's ITT document.
    - These are answered separately, with TRL responses in blue
- Submitted comments, anonymous

  - Where the comment raised a point or question relating to project delivery, these are answered in blue
- Submitted comments, attributed
  - Where the comment raised a point or question relating to project delivery, these are answered in blue

Within all submissions, if an individual, or group within an organisation, was identifiable by name or role within the submission, this information has been redacted.

11 Post-trials questionnaires

Immediately after completing their trials session, participants were asked to complete a post-trial questionnaire. For track trial participants, this was while still in the trial car, after responding to the three colour variations. For simulator participants, this was immediately after leaving the car simulator and moving to an adjacent office. The questionnaires that participants completed were similar; those completed after the track trial drives were on paper, those after the simulator trials were completed using a tablet computer. Questions in both questionnaires related to participants':

- Recall of the scenarios that they had experienced
- Understanding of the meaning of vehicle warning lighting colour and the actions that they understood that they should take

Compiled responses are presented in Appendix E.1 (track trials) and Appendix E.2 (simulator).

11.1 Key findings from track trial participants:

1. Only 55% of track trial participants were able to correctly identify colours of lamps that were displayed
2. Approximately 50% of participants reported that the red and amber lamps combination were 'very attention grabbing' compared with approximately 40% for red alone and fewer than 25% for amber lamps alone
3. Almost all participants reported that the van appeared static in daytime (all colour variations). However, in night conditions 16% of participants reported that it looked like it was moving
4. The largest proportion of participants in each condition stated that a vehicle was likely to be in a live lane when displaying red flashing, or red and amber flashing, lamps, and alongside the carriageway when displaying amber lamps
5. The largest proportion of participants stated that amber meant 'caution', red meant 'stop' and 'danger' and red /amber combined meant 'caution' 'danger' in both day and night, and 'slow down' in day conditions

11.2 Key findings from simulator trial participants:

1. Only 50% of participants correctly identified colours that were displayed
2. The largest proportion of participants perceived red and amber flashing lamps to be more attention grabbing when displayed in combination than when displayed separately
3. The largest proportion of participants perceived that the vehicles appeared static in both day and night conditions, and for all lighting conditions
4. The largest proportion of participants perceived that the vehicle was likely to be in a live lane when red flashing lamps were displayed either separately or in combination with amber lamps

5. The largest proportion of participants stated that, if they were on-road and saw amber lamps it would mean caution, red flashing lamps would mean danger and stop, and amber and red flashing lamps in combination would mean caution, danger, and stop

12 Online participant survey

An online, anonymous, questionnaire asked participants (from TRL's participants register) about their understanding of certain colour lamps and flashing patterns when displayed on vehicles.

Respondents were incentivised to take part in the questionnaire with a chance to win a £25 Amazon gift voucher. Exclusion criteria to take part in the questionnaire were if respondents had colour vision issues or if flashing images caused them difficulties.

The online participant survey presented a range of flash patterns, using a simulation of a roof-mounted light bar. This was arranged to show either two blocks (left and right of the bar) flashing either together or alternately. The flash patterns shown included those permitted by current regulations, with both blocks on together at 1 Hz (flash per second), 2 Hz, 3 Hz and 4 Hz. Interspersed were other flash patterns where the blocks alternated left-right on-off, again showing the same flash rates.

Participants were asked a range of questions (they had already answered questions about their understanding of lighting colour) relating to: type of vehicle, location (on or alongside the carriageway), whether the vehicle would be static or moving, and what action the flash pattern meant they should take.

Details of the survey method and compiled responses are given in Appendix F.

Key findings were that:

1. Red light is most associated with emergency vehicles, amber lamps are most associated with breakdown/ recovery vehicles, and red and amber lamps together are not well known enough by respondents to make a judgement.
2. The majority of respondents expect vehicles displaying amber lamps to be either parked or moving and to be in a live lane (*N*=266). There was no conclusive finding regarding whether respondents expect vehicles displaying red flashing lamps to be parked or moving or whether they expect the vehicle to be in a live lane.
3. Amber lamps are most associated with meaning 'caution needed' (*N*=295), red flashing lamps are most associated with meaning 'danger' (*N*=161), and amber and red flashing lamps together are most associated with meaning 'caution needed' (*N*=158).
4. Quicker flash patterns are more associated with respondents expecting to see an emergency vehicle rather than a service vehicle (i.e., at roadworks, or breakdown and recovery vehicles), and respondents are more likely to stop or prepare to stop.
5. When shown a video of a red 'X' with alternative flashing lamps, the majority of respondents think this means that the lane is closed (*N*=220), and they would not drive in the lane (*N*=272).

For the purposes of the survey, two 'types' of vehicle description were used: 'emergency' and 'service', with breakdown and recovery vehicles included within the 'service' category. The question relating to this was repeated, both times participants stated that they associated the slower (1 Hz, all on and alternate) with 'service' vehicles than the other flash patterns, with the faster flash patterns more likely to be associated with emergency vehicles. This aligns with Turner, et al (2014) who found that, compared to 1 Hz, 4 Hz was rated as ‘more urgent’ and they suggested the development of ‘high urgency mode’ lighting for emergency vehicles.

Considered together, these results on colour and flash rate show current driver understanding and expectation but, in particular for colour, run counter to the views expressed by some industry experts during interviews, that red and amber together would be beneficial to improve safety for technicians and other road users. The research identified on lighting intensity (see Section 4), with results from the survey on flash rates, runs counter to common fitment of warning lighting which includes multiple beacons and lamps, with unsynchronised flashing, resulting in what often appears as fast, almost random, flashing.

Faster flash patterns were associated with respondents being more likely to stop or prepare to stop. This might imply that flash rate should be adjusted according to the relative risk of where the recovery vehicle is located (i.e. in a live lane, or off the carriageway).

13 Summary of findings and discussion

This section will review the project's main research and findings, covering the following areas:

- Background to the research
- Potential limitations in the research methods used and how they were addressed
- Trials results and understanding of colour

13.1 Background to this research

As part of the breakdown and recovery industry's campaign towards gaining authorisation for the use of red flashing lamps, the Campaign for Safer Roadside Rescue and Recovery group and the All-Party Parliamentary Group for Roadside Rescue and Recovery were formed to improve safety for technicians. The use of red flashing lamps by the industry was debated in the House of Commons (Hansard, 2019). As part of that debate, aspects such as the use of red light for giving warning were covered. Psychological effects and responses, such as the association of red with 'stop' and 'danger' were also covered. As well as authorised use of red flashing lamps, for example by police and National Highways Traffic Officers, other current on-road use of flashing red lamps includes at railway level crossings and on overhead 'Red X' signals.

The main request for research within this project was to generate evidence to inform a decision on whether the use of red flashing lamps will be extended to road recovery operators, and that the evidence gathering must include off-road trials. These trials would inform the Department for Transport of potential road safety benefits for the road recovery industry and other road users, or of any potential disbenefits.

The opportunity was also taken to examine psychological effects by replicating questioning that was undertaken in previous studies (unpublished, 2009) to determine participants' understanding of the meaning of different colours of warning lamps and the actions that they would expect to take on seeing them.

The approach taken for gathering evidence was to gain understanding from the viewpoint of approaching drivers. For them, encountering a recovery vehicle, particularly when it is stationary in a live lane, is an unusual event, so could take time for them to understand what they are seeing and decide what action is required, then manoeuvre around the recovery vehicle. Therefore, ensuring that drivers' understanding is correct is vitally important, so research has included:

- What drivers say they understand, and how they would react
- How drivers actually react
- How drivers can be helped (e.g. to understand sooner where the vehicle is and what it is doing, to see pedestrians near the recovery vehicle if any are present)

Alongside that research, a guidance document was developed. Initially intended to provide guidance on the use of warning lamps, its scope was expanded to include information on conspicuity (of the recovery vehicle and the technician) and on what additional conspicuity aids can be fitted to the vehicle within current regulations.

13.2 Findings related to driver response and understanding

Extensive trials were undertaken in Work Package 3, using naïve participant samples, to determine whether driver behaviour varied with lighting colour. Trials were undertaken on a closed track which represented a rural environment, in daytime and darkness. Trials in TRL's DigiSim simulator were undertaken on three further environments.

Outcomes from both the track and simulator trials showed that there were no statistically significant differences in driver response to the different lamp colours:

- From the track trial (rural environment), there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of stated **time to demerge** in either daytime or night-time.
- From the simulator trials, in all three environments (urban, high-speed dual carriageway, motorway with hard shoulder), there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of **change in speed, lateral movement or distance of lane demerge**.

It was noted during analysis of the simulator trials data that night participants generally changed lane later (closer to the van) compared with daytime participants. This was more prominent for the high-speed road than for the urban road. There could be several reasons for this difference, including:

- Difficulty determining the location of the static vehicle, i.e. whether it was alongside the carriageway or obstructing a live lane
- Difficulty identifying that the vehicle was static rather than moving
- Difficulty determining distance from the static vehicle

Each of these might be addressed by specific interventions, such as:

- Driver understanding of 'location' might be improved by implementing lighting flash rates / patterns that differentiate between higher and lower risk locations, or by localised work scene lighting that illuminates the area around the recovery vehicle (both subject to lighting regulations)
- Driver understanding of static or moving vehicles might also be addressed by different flash rates. Also, during consultation, stakeholders expressed concerns about over-use of amber lighting. If this included lighting being displayed by vehicles moving at normal traffic speeds, then other drivers' expectations might be that all, or most, vehicles displaying amber lighting would be moving.
- Identification of distance to a static (or slower moving) vehicle might be improved by conspicuity aids that emphasise the width of the vehicle, potentially aiding drivers to perceive how quickly they are approaching.

Identifying and implementing appropriate interventions is part of an industry strategy suggested in 13.5.

As mentioned above, the opportunity was taken to use post-trial questionnaires and an anonymous online survey to replicate the driver understanding of lighting colour work that was carried out as part of the 2009 research. Full details, and comparisons with the 2009 outcomes, are given in Appendix E. However, the main comparison results are:

- For recovery vehicles displaying **amber flashing lamps**, the results from the current project and the study conducted in 2009 were relatively similar. The most common response (over 50%) was 'caution' in both projects, followed by 'slow down'.
- For the **red flashing lamps** condition, the most common answer in the current project was 'danger' (33%), compared with around 25% in the 2009 study. The most prevalent response of what participants thought red flashing lights meant in the 2009 study was 'stop or prepare to stop' (approximately 40%), compared with the current study which indicated a response rate of 27%. This suggests that 'danger' and 'stop or prepare to stop' are the two most common perceptions of red flashing lights when displayed on vehicles.
- When displaying **amber plus red flashing lamps together**, the most prevalent answer in the current project was that participants thought it meant 'caution needed' (36%), which was also one of the most prevalent responses in the 2009 study (approximately 25%). The next most common responses in the current study were 'slow down' (26%) and 'danger' (24%), while the next most frequent responses in the 2009 study were 'stop or prepare to stop' (approximately 25%), 'danger', and 'slow down' (both approximately 15%).

This suggested that the level of understanding of light colour, and the actions that drivers should take, has not altered substantially between the two studies. Understanding is also variable for all lighting colours. To examine this further, an online questionnaire was used, with 349 participants completing responses, although again in an indicative (rather than fully representative) sample. This expanded the range of lighting colours, and combinations of colours, to include those used by a range of vehicles.

The main findings for the meaning of lighting colours were:

- The most common light conditions associated with meaning 'caution needed' were amber lights (26%) and blue lights (21%)
- For the meaning 'danger', the light conditions most associated were red lights (29%), blue lights (21%), and red and blue lights in conjunction (20%)
- 'Slow down' was most associated with blue lights (23%), followed by amber lights (19%) and blue and red lights (18%)
- The most common light conditions associated with meaning 'stop (or prepare to stop)' were blue lights (34%), blue and red lights (22%), and red lights (21%)
- The most common response rate of not knowing what they might mean was green lights (37%), and amber and red lights (27%)
- The light conditions with the lowest response rate of not knowing what they might mean were blue lights (1%) and amber lights (1%)

The responses for actions that participants thought they should take are relatively aligned to 'understanding'. However, one key difference is for the amber light condition, where a small proportion of respondents (N=78) stated that they thought amber lights meant 'danger', while a larger proportion of respondents expressed that they would look for danger (N=151). Similar for amber and red lights in conjunction, a small proportion of respondents stated that they think this colour combination means 'danger' (N=80), while there were more responses stating that they would look for danger (N=126). This highlights a discrepancy in what respondents thought certain colours mean and what action they think they should take, indicating that responses regarding perceptions and beliefs do not always align with their intended behaviours.

A further consideration is that, as part of the post-trial questionnaires, participants were asked about what colour lighting and flash patterns they had seen during the trials:

- Track trials
    - Only 15 of the 31 (48%) daytime participants, and 20 of the 32 (65%) night-time participants were able to correctly identify that both red and amber lamps were used during the trial
    - 65% of daytime and 38% of night-time participants correctly identified that there was a change in the colours displayed on the recovery vehicle
    - 42% of daytime and 32% of night-time participants correctly identified that there was a change in flash patterns between scenarios
- Simulator trials
    - 46 of the 72 (64%) participants were able to correctly identify that both red and amber lamps were used during the trial. Note that simulator trial participants passed each colour variation three times, which might have resulted in improved recall
    - If only one colour was correctly stated, it was more likely to be amber (30.5%) than red (5.5%). This may be due to a general awareness that recovery vehicles would usually be displaying amber lighting
    - Three of the 72 (5%) participants stated that they saw white lighting (which was not displayed during the trial)
    - 38% of daytime participants correctly identified that there was a change in the colours displayed on the recovery vehicle, compared with just 16% of the night-time participants

Participants had not been briefed ahead of the trials on the purpose of the research, or that that they would be asked about the lighting and flash patterns. However, the low number of correct responses casts some doubt on their subsequent answers regarding their views on the lighting colours they had seen. It also suggests that, whilst driving, there was no conscious decision-making based on the colour of the lighting that they were seeing. This is supported by the findings from the track and simulator trials, that there were no statistically significant differences between driver behaviour in response to the variations of lighting colour.

13.3 Findings related to other improvements to safety

This project allowed the opportunity to undertake a wide range of research relating to vehicle and pedestrian conspicuity and safety. The main purpose of this project related to red flashing lamps, with the major finding that driver behaviour is not altered by either red, or red and amber lamps when compared with amber only.

It is very likely that any single collision will have several causal factors underlying it. It would, without detailed examination of each recovery industry vehicle collision, along with a thorough understanding of near misses, be speculation to determine all root causes.

Similarly, it is unlikely that any single intervention would address all relevant causal factors. However, it is essential that approaching drivers have their attention drawn to the recovery vehicle, then that they understand the appropriate way that they should react.

The holistic approach taken during delivery of this project has identified the main elements that could contribute to the basis for a strategy that the breakdown and recovery industry could implement to improve the safety of its technicians and other road users by improving the understanding that drivers have when approaching an incident location.

These research outcomes include lighting that can be used within current regulation and a range of potential interventions and innovations which could affect how drivers identify recovery vehicles and, potentially, reduce the likelihood of collisions and so improve safety for technicians, the industry's customers, and other road users.

Stakeholder engagement undertaken in this project, and its predecessor (Gaitner, et al. 2020), identified key industry concerns. These included differentiation of high-risk situations (see Section 5) and over-use of lighting. For over-use, stakeholders commented:

> *"There is clearly an overuse by the industry of our existing amber lights"*
>
> *"…the amber flashing light has been overused and has become devalued"*

Stakeholder comments noted that incorrect use of interventions such as red flashing lamps could be counter-productive:

> *"Negative is if they are not used correctly, over used or used irresponsibly, they will confuse the public and undermine their purpose*

Differentiation from other users or warning beacons was identified as a major concern:

> *"I don't think there are any issues at the moment, but you need to be able to distinguish between a recovery vehicle and a slow-moving dust car (*sic*)"*

This was examined in the **online participant survey**, where respondents overwhelmingly identified a clear division between emergency vehicles using blue lighting and amber being used by all other types listed as 'service vehicles' (including for roadworks and wide loads vehicles).

However, the online survey also included representations of beacons with the range of flash rates (1–4 Hz) permitted by GB road vehicle lighting regulations. The **Expert Review event** included 1 Hz, 2 Hz and 4 Hz flash rates. Online participants were asked, for each flash rate, whether they thought it would be an emergency or 'service' vehicle. There was a clear distinction that the slower 1 Hz rate was likely to be a service vehicle. Experts were asked which flash rates were more 'attention grabbing'. In daytime, experts rated the 4 Hz flash rate, with all of the beacon bar illuminated, as 'very' attention grabbing, compared with 1 Hz (all illuminated) as mostly 'somewhat' or 'not very' attention grabbing. This is supported by Turner et al (2014), who reviewed emergency vehicle warning lighting. They found that flash rates of 1 Hz receive a lower urgency rating than flash rates of 4 Hz and suggested development of an ‘urgent’ flash pattern. These findings provide the basis for development of lighting patterns to provide necessary differentiation of the warning and information given to approaching drivers of where the recovery vehicle is, i.e., whether it is in either a higher- or lower-risk location. Furthermore, as 4 Hz is permitted by UK regulations, development and implementation would not be hindered by any requirement to amend regulations or give additional authorisations.

During consultation, stakeholders acknowledged that public information and education may not provide full awareness for the public:

> *“…you can only educate them so far”*

Findings from the post-trials questionnaires and online surveys showed that drivers may be confused as to the meaning of amber and red flashing lamps displayed together. However, as research findings have identified that ‘urgency’ and ‘attention’ can be influenced by flash rate, this provides a basis for implementation of flash rates that are already understood and would not need to be accompanied by extensive – and, potentially, only partially-effective – advertising and awareness campaigns.

The **literature review** found research which suggested that, rather than on-off flash patterns, high-low intensity may improve drivers’ ability to identify pedestrians around stopped vehicles. Although high-low intensity beacons are not permitted by current regulations, fitment of additional permitted rear-facing red position lamps located adjacent to amber beacons might achieve a similar appearance.

On lighting intensity, some literature suggested upper limits, with adjustments made according to ambient lighting and weather conditions.

The technology and innovation search found equipment that could be incorporated, potentially improving conspicuity, including electroluminescent panels and projection systems. These are permitted by regulations. Some other equipment that was identified is not permitted by regulations. Also, options for provision of electronic information to approaching drivers was identified. However, the current project did not carry out assessment of any additional conspicuity equipment or innovation (whether vehicle-mounted, or electronic or other information to drivers) to determine whether it might result in any benefit or disbenefit.

13.4 Potential disbenefits

Both track and simulator trials found no statistically significantly different driving behaviours from participants reacting to the three lighting colour variants. Therefore, no evidence was found for potential safety benefits of red flashing lamps, in terms of their impact on driver behaviours.

When the amber only or red only variations were displayed, these alternated between sides on the roof-mounted light bar. However, when the amber plus red variation was displayed, both sides were displayed together (see Figure 7 for this, showing the differences between the track trial van lighting and simulator van lighting).

Although there are differences in actual light output between nominally identical amber and red colours, it is reasonable to approximate that the red plus amber variant is producing twice the brightness of the red only and amber only variants. Potentially, if the red plus amber variant was displayed without a reduction in overall light output (e.g. by reducing the number of modules that are active within the light bar), this could result in greater glare for approaching drivers; this point highlights the importance of how any change in lighting permissions were to be implemented, in terms of impact.

Also, disability glare from warning lighting may reduce the ability of drivers to identify pedestrians in the area around the recovery vehicle, although at night this can be improved if those people are wearing clothing incorporating sufficient retroreflective material.

Papers included in the literature reviewed (Section 4, Appendix C) suggested that the main factor (or at least the most investigated) affecting identification of pedestrians around conspicuous vehicles would appear to be the intensity of the flashing. The papers reviewed suggested that there is a need to determine a balance between intensities that are high enough to allow drivers to spot the vehicles, but not so high as to cause glare and impair identification of pedestrians. Also, some weather conditions may cause reduced visibility and light scattering (e.g., fog), and wet road surfaces can result in reflections that may result in glare problems for approaching drivers.

The Expert Review (Section 9, Appendix H), although not a full psychophysical test design, gathered data on subjective views on the lighting patterns displayed and suggested that faster flash rate patterns are attention grabbing, but also potentially too bright and may also be rated as distracting. Should any changes be made to permissions around red flashing lamps use, these topics should be considered in implementation.

As noted elsewhere, although the road recovery industry has drawn comparisons with the National Highways Traffic Officers' use of rear-facing red flashing lamps, some industry representatives have stated that they wish to display red flashing lamps whilst, for example, their vehicles are stationary on the hard shoulder. This would be contrary to the current Traffic Officer work instructions (see Appendix J).

Although the trials conducted within this project identified no statistically significant change in driver behaviour between the three lighting colour variations, participants responding to the post-trial and online surveys did report different understanding of meaning, and action likely to be required, for the three variations. Potentially, a substantial increase in display of rear-facing red flashing lamps in relatively lower risk locations (i.e. not in a live lane) could adversely affect drivers' association of 'red = danger', so losing the association with 'high risk'.

A further potential disbenefit from authorisation permitting much more widespread use of rear-facing red flashing lamps is the potential for other amber warning lamp users to suffer a reduction in their safety. This might occur if the 'red=danger' association develops, in particular, to cause road users approaching a vehicle displaying only amber warning lighting to assume that it is located alongside the main carriageway rather than within a live lane. Other amber warning lamp users whose work activities require them to stop in live lanes include road works traffic management vehicles (stopping to install or remove temporary traffic management equipment) and roads maintenance vehicles (such as drain and gully emptying and litter collection, or short-duration work such as pothole repairs). Thus, any change to permissions for any industry should consider, in designing implementation, potential impacts on others.

13.5 Creating an industry-wide safety strategy

Taken together, these findings demonstrate that there are several actions the industry could take, all permitted within current regulations, with the potential to improve safety for their technicians and other road users. These could be developed as a co-operative action by the industry, creating and implementing an industry-wide vehicle safety improvement strategy. This would identify:

- A common industry definition of 'high-risk location'
- A common 'urgent' flash rate (based on the permitted 4 Hz and research findings) for use in high-risk locations only
- A common, slower, lighting flash pattern (likely based on 1 Hz and research findings) to be used consistently in all other locations

Development of systems capable of controlling and displaying appropriate flash patterns and lighting intensity, complying with UK regulations, and aligning with research findings, is likely to entail working with lighting system designers and suppliers.

With these lighting patterns confirmed, the industry should then ensure that all technicians are aware of the purpose of these flash rates and understand the safety benefits from maintaining a clear differentiation in use – and the risks from not maintaining differentiation.

Implementation may need to be accompanied by changes to conditions of membership of industry groups and providing updates to guidance, potentially with monitoring and reporting of lighting use.

Potentially, when arriving at an incident, technicians should:

- Undertake a site-specific dynamic risk assessment to identify whether it is a high-risk location
- Display 'urgent' flash pattern lighting ONLY when in high-risk locations
- Not display warning lighting unless required. This should include when towing, unless they present a risk that other road users need to be aware of

Two other actions with potential long-term benefits are:

- Review additional conspicuity equipment and recommend to the industry those which are proven beneficial
- Record, investigate and report, on an open, common, database, all collisions involving industry vehicles and personnel. Use this information to inform improvements to working practices and development of targeted safety advice and equipment

A common theme, from numerous submissions, was that current amber beacons are heavily over-used. This not solely by the road recovery industry. An additional task for the industry could be to forge relationships with other authorised amber beacon users to encourage responsible and appropriate use of beacons, potentially improving safety for all users and the public.

13.6 Potential limitations in the research methods used

A wide range of research methods were used during delivery of this project. It is important to recognise that all research methods have limitations, then understand how those limitations were overcome during research design or evaluated as part of subsequent analysis.

Expectation: ideally, trials participants would have no awareness of the purposes of the trials or the scenarios being used. For both the participant track and simulator trials, care was taken during recruitment, with information provided, and with trials briefings, to avoid giving participants any indication of the industry to which the research related or the relevance of changes in lighting. However, as track trials participants saw three lighting colour alternatives and simulator participants saw the three alternatives within three different road environments, there could potentially have been increasing awareness during trials delivery. However, results of post-trials questionnaires (and comments made to researchers in trials cars) showed that many participants did not recognise the different lighting colours displayed.

Repeated exposure to similar scenarios may lead to learning effects. To overcome this possibility, trials were designed with counterbalancing for the orders in which lighting colours were displayed and, in the simulator, the order in which participants drove the three road environments.

For the Expert Review event, all attending knew the purpose of the project, were briefed on what they would see and the questions that they would be asked. Therefore, they were asked to try and view the lighting as if they were a member of the public. Subsequently, some attendees stated that they felt this request to be confusing and not a good use of their expertise. As well as knowing what they would be viewing, attendees had the luxury of time in which to consider what they were seeing and then to decide what they are going to do; approaching drivers would not have that time.

In lane obstruction: there were instances where participants would be required to make a lane change to avoid the parked van. These were during the track trial (‘rural’ environment) and the ‘urban’ and ‘high speed dual carriageway’ simulator environments. In these situations, it may be more obvious to participants that a lane change will be required.

Track method, participant ‘indicating’: during the participant track trials, those taking part indicated to the researcher the point at which they would demerge from the obstructed lane. Ideally, the participant would have been driving their own vehicle but, for insurance reasons, this was not possible. There is the possibility that participants’ stated intention to demerge might not align with their actual driving behaviour. However, through clear instruction, previous studies have demonstrated that stated behaviours has good links to real-world behaviours.

Limited sample size for track trial: This issue was highlighted in section 7.7.3, and the potential for this to have impacted the results for the ‘night’ participants. With the objective of informing the required sample sizes for any future trial, an additional power analysis was conducted, based on the results from this trial. Assuming the data collected for a future trial has similar characteristics to the data collected from this trial, (that is, that future participants have similar behaviour to the participants of this trial), we can make the following recommendations:

- For the daytime group, a future trial would require a sample size of 960 participants.
- For the night group, a future trial would require a sample size of 44 participants.

Simulator validity: using a simulator may be perceived as ‘not realistic’. However, using a simulator (see Section 8 for details of TRL’s DigiCar system) allows trials to be designed to be repeatable, eliminating – as far as possible – the ‘random’ events that could occur on-road. This means that results for the lighting conditions demonstrate differences due to the variables of interest that we would expect to see in the real world. Simulators have been shown to possess what is known as ‘relative’ validity – if people behave in different ways due to a change in the driving context (in this case the lamps and road types) in the simulator then we would expect them to in the real world, even if not necessarily to the same degree.

‘Double’ light: during the participant track and simulator trials, three lighting variations were displayed (see section 6.3). For the amber only and red only conditions, the lighting displayed alternated between being displayed on the left and right sides, with the lamps on the other side off. The amber + red condition, however, had both sides displayed together, e.g. red left and amber right or amber left and red right, with those pairs alternating (see Figure 7). This flash pattern was designed to replicate that used on National Highways’ Traffic Officer vehicles. This led to a concern that having additional lighting displayed might affect participants’ responses, but this was not identified in either the track or simulator data analysis. This is an interesting finding, suggesting that ‘more’ lighting on a vehicle does not necessarily result in approaching drivers reacting sooner.

Literature review: while a systematic approach was adopted to cover a wide range of available literature, the search was not exhaustive and there may be additional specifications that could influence the impact of the recommendations presented. It should also be noted that all of the studies reviewed were conducted under controlled conditions – either through simulated driving scenes or closed track trials – and do not cover the full breadth of factors that could impact driver behaviour and pedestrian visibility in a real-world setting. Where visually cluttered environments were used, they were either simulated, or limited in the ‘clutter’ involved. This limits the direct application of the findings, and the recommendations must, hence, be adapted to the need of the environment in which they are implemented.

Another consideration with regards to the features of the lamps involves the limited ranges of intensity and patterns investigated. Most of the flash patterns studied were set for a 50% duty cycle. There is more research required into the different flash patterns at varying duty cycles (e.g., strobing). Similarly, the paper’s recommendations for maintaining a minimum intensity at 10% of the peak (although it should be noted that this is not permitted by current GB regulations) may need amending with further research into impacts of lower intensities, which the current evidence pool lacks.

Horizon scanning – innovations not advertised: during the search for potential alternative methods for reducing the number of collisions with recovery vehicles, a search was undertaken for new and evolving technologies. There is a likelihood that, due to commercial sensitivities and for the protection of intellectual property, such innovations might not be found. Therefore, we requested information on innovations from within the recovery industry and contacted innovators and developers directly. All those who provided information were offered that, if their innovation were to be included, minimum details would be given to protect the innovation.

14 Conclusion and observation/recommendations

This project included extensive research, using a wide range of methods, to answer the DfT's requirements. Activities were delivered within three Work Packages (WPs):

- WP1: Develop guidance on vehicle warning lamps
- WP2: Proliferation of warning lamps
- WP3: Off-road trials of red flashing lamps on recovery vehicles

The guidance document delivered by Work Package 1 was informed by extensive consultation with road recovery industry experts and other stakeholders. The WP also included research to identify which equipment can be fitted to industry vehicles under current authorisations and GB vehicle lighting regulations and 'horizon scanning', to identify potential innovations and technologies which might improve safety for the industry. The guidance document also provides information that can be used by industry trainers and can inform technicians on their personal conspicuity.

Work Package 2 attempted to quantify the likely increase in the use of rear-facing red flashing lamps if authorisation were to be granted for their use by the road recovery industry. It was not possible to give a proportionate increase over current use as no data was provided by current authorised users. The data provided on incident attendance was from two smaller organisations, so it may not represent the types of breakdowns attended. Calculations were also informed by an anonymous survey of industry technicians on the likelihood that they would follow guidance provided. From the data available, supplemented by publicly-available figures on total incident numbers, two estimates were calculated:

- Between 1.2 million and 2.75 million additional instances each year where, should authorisation be given, recovery industry vehicles might display red flashing lamps in live lanes on high-speed roads
- Between 1.5 million and 2.75 million additional instances each year where, should authorisation be given, recovery industry vehicles might display red flashing lamps while stationary on hard shoulders

Work Package 3 (Off-Road Trials), required that the project should conduct off-road trials to generate the evidence to inform a decision on the use of rear-facing flashing red lamps by roadside recovery operators. Also, the testing should measure the road safety benefits and disbenefits of extending the use of red flashing lamps to recovery operators.

This evidence was gathered in two main types of research. These were participant trials (track and simulator) and participant questionnaires.

The track trials, undertaken in daytime and darkness, in a rural environment, recorded naïve participants' stated time to demerge, i.e. leave the obstructed lane to pass the recovery vehicle. The results showed no statistically significant impact on this behaviour in response to the variations of lighting colour.

- From the track trials data, there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of **time to demerge** in either daytime or night-time.

Simulator trials were undertaken in three environments: urban, high-speed dual carriageway and motorway with hard shoulder, in daytime and darkness. Data were recorded to identify change of speed in response to the recovery vehicle (all three environments) and distance from the recovery vehicle for demerge (urban and high-speed dual carriageway environments) or lateral movement (motorway environment, with the recovery vehicle on the hard shoulder).

- From the simulator trials data, in all three environments (urban, high-speed dual carriageway, motorway with hard shoulder), there is no evidence to support the hypothesis that colour of flashing lamps has an effect on drivers' responses in terms of **change in speed, lateral movement or distance of lane demerge**.

From the trials behavioural data therefore, we found no evidence to support any change to regulations on safety grounds, when safety is measured in terms of the behaviour of road users approaching stationary recovery vehicles. Additionally, results from post-trial questionnaires and the online survey do not show a clear understanding of red lighting by naïve participants and show potential confusion from amber and red together, although the colour red was associated with a slightly higher (but not consistent) likelihood of being perceived as meaning 'danger' and 'prepare to stop'.

From this combination of trials and survey data, we make the observation:

Observation:

There is no evidence in the current research trials that red flashing, or red plus amber flashing, lamps result in any discernible change to the response of drivers approaching a vehicle displaying them, when compared with amber lamps. Surveys suggest that they do seem to lead to a slight increase in perceiving the meaning of 'danger' or 'prepare to stop', compared with amber. Any decision to change regulations to allow the use of red flashing lamps by road recovery industry vehicles should be supported by extensive engagement with the industry to ensure that recovery operators are not led to expect direct safety benefits from this change alone.

This project has highlighted that:

- Red flashing lamps, or red plus amber flashing lamps, do not appear likely to change the behaviour of drivers approaching roadside incidents
- There are potential improvements to driver understanding of vehicle warning lighting and for identification of pedestrians around recovery vehicles that might be obtained from adaptations to lighting intensity and changes to flash rates, or installation of additional conspicuity equipment. Further review of these areas was beyond the scope of this project
- Current GB lighting regulations were written before the development of programmable LED lighting systems, which can provide the opportunity for a range of

flash patterns and lighting intensities. However, those lighting regulations may prohibit development of optimum warning lighting

- Technology solutions, such as provision of updates to online mapping services, may provide additional safety benefits

These findings lead to our first recommendation:

Recommendation 1:

The breakdown and recovery industry should work together to develop an improvement strategy incorporating various actions to improve safety. This should include how any permitted technologies, colours and flash patterns should be used.

Any changes in regulations that resulted in different warning lighting, or conspicuity technologies, being seen on the roads might result in confusion for drivers. The public appear to have a variable understanding of what different lighting colours and flash patterns mean even now, and therefore our second recommendation is:

Recommendation 2:

Any changes should be supported by public education on the meanings of different conspicuity technologies. This could include related elements within the Hazard Perception Test and Theory Test for new drivers, and changes to the Highway Code.

This project has identified several aspects where, should authorisation be granted for the road recovery industry to display rear-facing red flashing lamps, their more widespread use might potentially have adverse effects on other road users and other industries authorised to use amber warning lighting only. Some of these potential disbenefits could arise from increased glare (if the total amount of light output increases by adding red to existing amber), which could reduce drivers' ability to identify pedestrians in the area around the recovery vehicle.

Also, driver confusion could occur. Should red flashing lamps be routinely displayed on vehicles on the hard shoulder, this could reduce drivers' expectation of red light having the meaning that a live lane is obstructed.

Finally, during the Expert Seminar, the final element from the extensive range of work carried out during the project, an industry representative raised the following concern:

> *"[There should be consultation] with the Health and Safety Executive (HSE) as a key stakeholder on this matter as I believe there a disconnect in relation to this approach and the HSEs (and therefore Department for Work and Pensions) legislation and updated driving and riding safely for work."*

Several attendees agreed that this aspect of the industry's work should be discussed thoroughly.

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Appendix A Experts online survey and interview findings

A.1 Method

A.1.1 Background

As part of the holistic activities of this research study, experts in the road recovery and other industries were consulted to understand their opinions on the current and future guidance on warning lamps. An online survey (hosted on Smart Survey) was used to gauge their attitudes towards the current guidance for the use of warning lamps in the recovery industry and their perceptions on the use of amber and red flashing lamps within the recovery industry. The survey also included questions surrounding numbers of recovery incidents attended and what permissions they have regarding the colour of lamps displayed on their vehicles.

Additional to the online survey, interviews were conducted via teleconferencing to provide further detail into experts' viewpoints on the use of warning lamps in the recovery industry. Interviews allowed the experts to elaborate on their survey responses and to discuss them with the research team.

Responses to both the survey and interview findings were each aggregated. There was no intention, for either, to distinguish between those from the recovery industry and from other experts.

A.2 Recruitment

A.2.1 Online survey

The survey was disseminated, through an online link, to TRL's existing contacts, including recovery industry companies, industry representative and training organisations, and authorised red flashing lamp users. The survey was sent to 21 experts, with 15 respondents completing the survey in total.

A.2.2 Interviews

The online survey allowed respondents to express their interest in taking part in a 30-minute interview related to their responses. Of the 15 survey respondents, 13 experts stated their interest in taking part in an interview and 10 participated. Two TRL researchers were present during the interviews, one facilitating the discussion and one taking notes. The interviews were conducted via Microsoft Teams, and (if the interviewee gave their consent) the interviews were recorded and transcribed to supplement researchers' notes for analysis.

A.3 Analysis

A.3.1 Online survey

Basic quantitative analysis was conducted on the responses to the online survey (due to the small sample size). This analysis included descriptive statistics, pie charts and bar charts as shown in section A.4.

Qualitative data from the online survey was analysed using thematic analysis, to understand the key themes of responses.

A.3.2 Interviews

Thematic analysis was conducted on the responses to each of the questions in the interviews, using researchers' notes and the interview transcriptions. This allowed the extraction of key themes in relation to each of the topic areas shown in section A.4.A.1.1

A.4 Findings

The following topics were pre-established based on the survey questions and topic guides of the interviews:

- Views surrounding existing guidance on warning lamps
- The use of warning lamps in certain situations
- Conspicuity measures for the recovery industry
- What the future guidance should look like
- Educating members of the public

Themes within these topics were explored and outlined in the sections below.

A.4.1 Existing guidance on the use of warning lamps

In the survey, participants were asked about their attitudes towards the current guidance on the use of warning lamps within the recovery industry. The question was a Likert scale, ranging from 1 (very negative) to 5 (very positive). The findings (shown in Figure 26) show that the most common answer is 'neutral' (N=5). The next most common answers are 'positive' (N=4) and 'very positive' (N=3).

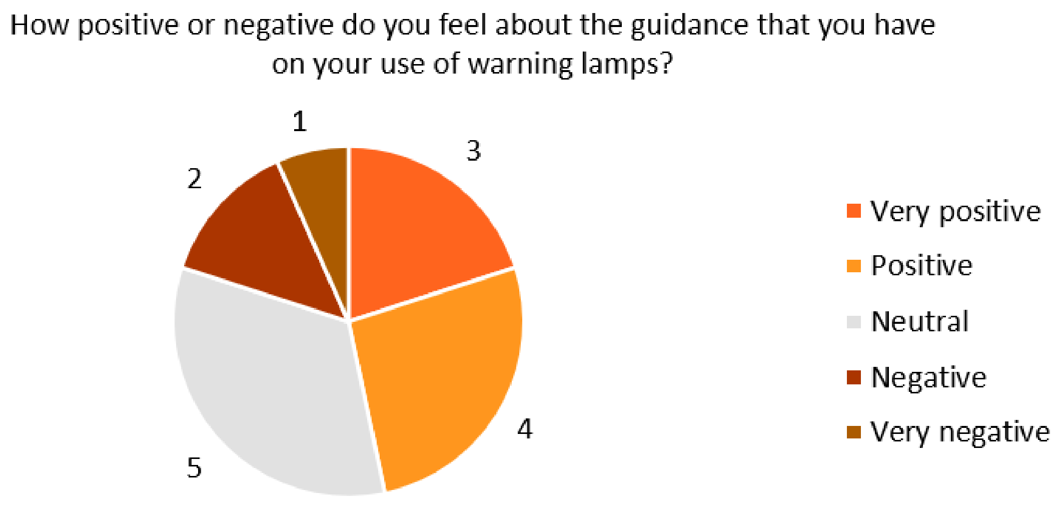

Figure 26: Pie chart showing how positive or negative experts feel about the current guidance they have on the use of warning lamps

One third of the sample did not have a strong opinion on the current guidance on warning lamps, but just over half felt positive about it. This suggests there is a neutral to positive perception of the current guidance overall (being mindful of the small sample size).

However, respondents were then asked whether current guidance could be improved, with the findings represented in Figure **27**. Most of the responses were 'yes' (N=12).

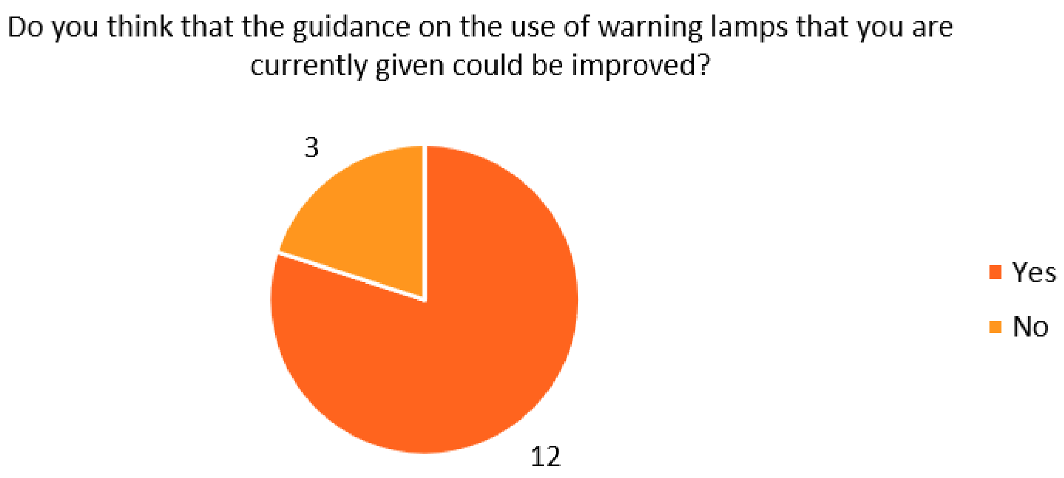

Figure 27: Pie chart showing whether experts think the current guidance on the use of warning lamps could be improved

Free text survey responses were analysed to understand experts' responses. The quotes below provide recommendations for the improvement of current guidance, including the need for better guidance and preventing the overuse of amber lamps.

A need for better guidance	Preventing the overuse of amber lamps
• *"Better guidance on flash patterns, width/standards, and use of amber beacons"* • *"Many users put them on when not required, maybe some form of training when to use or not to use them"* • *"The guidance given for current warning lamps I believe is sufficient, however stronger enforcement of misuse and public awareness would benefit"*	• *"There is clearly an overuse by the industry of our existing amber lights"* • *"Greater emphasis needs to be put on not overusing and using warning lights in the right circumstances"* • *"Amber lights can indicate anything from a milk float to a refuge worker, tipper, or fork truck. This results in the public ignoring the message the light should portray. This is a direct reflection on the lack of guidance available"*

During the interviews, experts had the opportunity to elaborate on their survey responses. The elaboration supported the theme of the overuse of amber lamps diluting both the effectiveness of warning the public about roadside recoveries, and the safety of personnel within the recovery industry. This finding was supported by key interviews quotes such as *"the amber flashing light has been overused and has become devalued"* and *"the current regulations are diluting the safety of the personnel within the recovery industry"*. With regards to how the public perceive amber lamps, a respondent indicated that *"people ignore amber light as there are too many around and used incorrectly"*. This finding is important to consider throughout the research, particularly when understanding how people react in response to different coloured flashing lamps.

Key Finding 1: The use and perceived meaning of amber lamps is currently unclear as they are currently used too frequently and for different purposes.

A.4.2 The use of warning lamps in different recovery situations

This topic area refers to the experts' viewpoints on the use of amber and red flashing lamps in certain recovery scenarios, both separately and in combination with each other. Figure **28** displays the findings from the survey.

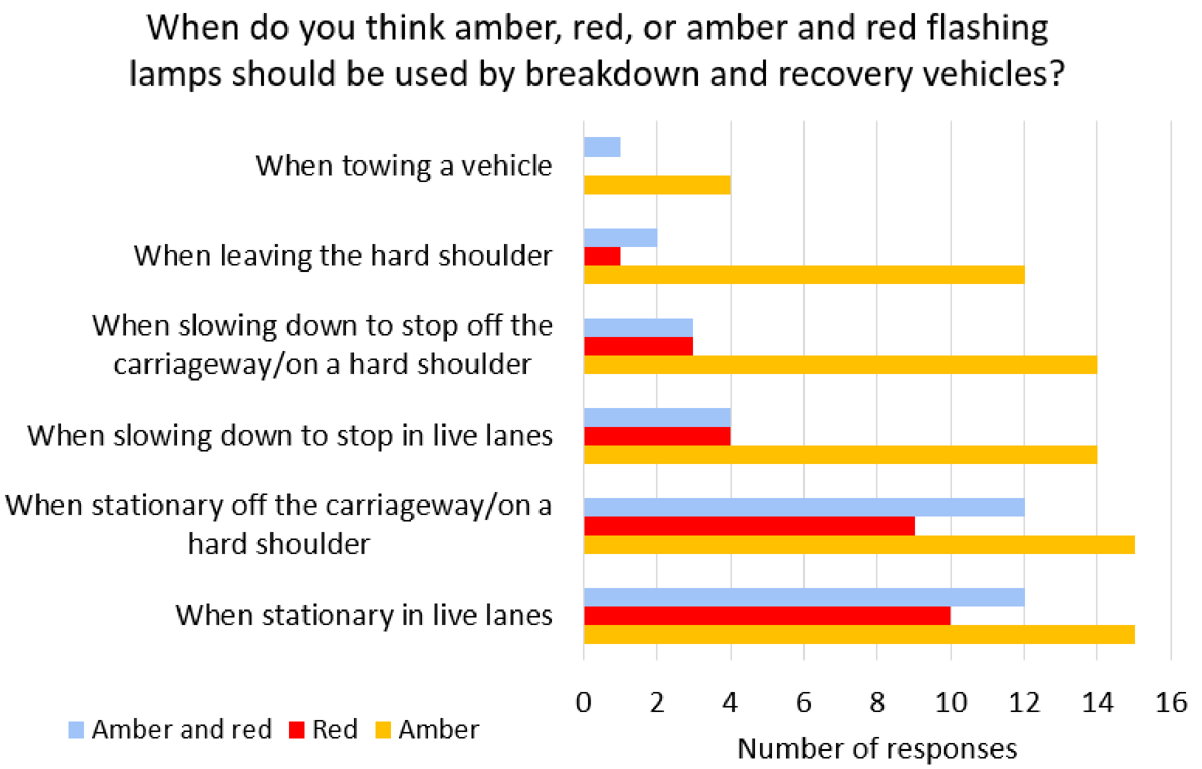

Figure 28: Bar chart showing when and in which recovery scenarios experts think certain light colours/combinations should be used

A.4.2.1 Amber lamps

Survey responses revealed that all respondents felt that amber lamps should be used when stationary in live lanes and when stationary off the carriageway. Of the 15 respondents, 14 thought that amber lamps should also be used when slowing down to stop in live lanes and when slowing down to stop off the carriageway. Of the 15 experts, 12 thought that amber lamps should also be used when leaving the hard shoulder. Four participants thought amber lamps should also be used when towing a vehicle.

During the interviews, respondents elaborated on exactly when and why amber lamps should be used. Experts believed that amber lamps should be used when:

- Approaching the scene to make the traffic behind aware that something is occurring, and the recovery vehicle will soon be stopping roadside
- Stationary at the scene so road users can slow down and give sufficient space to the operators to complete the job
- Leaving the scene, then turning off once the recovery vehicle is driving with the flow of traffic

Key Finding 2: Experts believed that amber lamps show other road users that they need to be aware that something is happening and to proceed with caution.

A.4.2.2 Red flashing lamps

When responding to the survey, 10 of the 15 respondents indicated that red flashing lamps should be used when stationary in live lanes. Nine of the participants indicated red flashing lamps should also be used when stationary off the carriageway, and four respondents thought red flashing lamps should be used when slowing down to stop in live lanes. Only three respondents thought red flashing lamps should be used when slowing down to stop off the carriageway and one respondent thought red flashing lamps should be used when leaving the hard shoulder. No participants thought red flashing lamps should be used when towing a vehicle.

When addressed further during the interviews, most of the experts suggested that red flashing lamps would be more effective at drawing attention to the breakdown or recovery scene: *"red flashing lamps indicate that there is something a little bit more special going on"*, and *"red indicates danger so it is the most logical colour to display".* However, it was recognised throughout the interviews that it is vital that red flashing lamps should not be overused and the impact of them diluted.

Figure **29** shows to what extent respondents agree that 'displaying only rear-facing red flashing lamps on breakdown and recovery vehicles could improve safety for all road users, compared with amber lamps. The most common response was "strongly agree" (N=6) followed by "agree" (N=4). This suggests that two thirds of the sample perceive that red flashing lamps would provide greater safety benefit to all road users than amber lamps.

Key Finding 3: Experts believe that red flashing lamps indicate more danger than amber

Key Finding 4: Respondents state the believe that they think red flashing lamps provide a greater safety benefit to all road users than amber.

However, this finding (like any finding from the small sample of experts interviewed) should be taken with caution, due to the small sample size and due to the attitudinal survey being conducted before other research tasks (such as the behavioural trials) on this project.

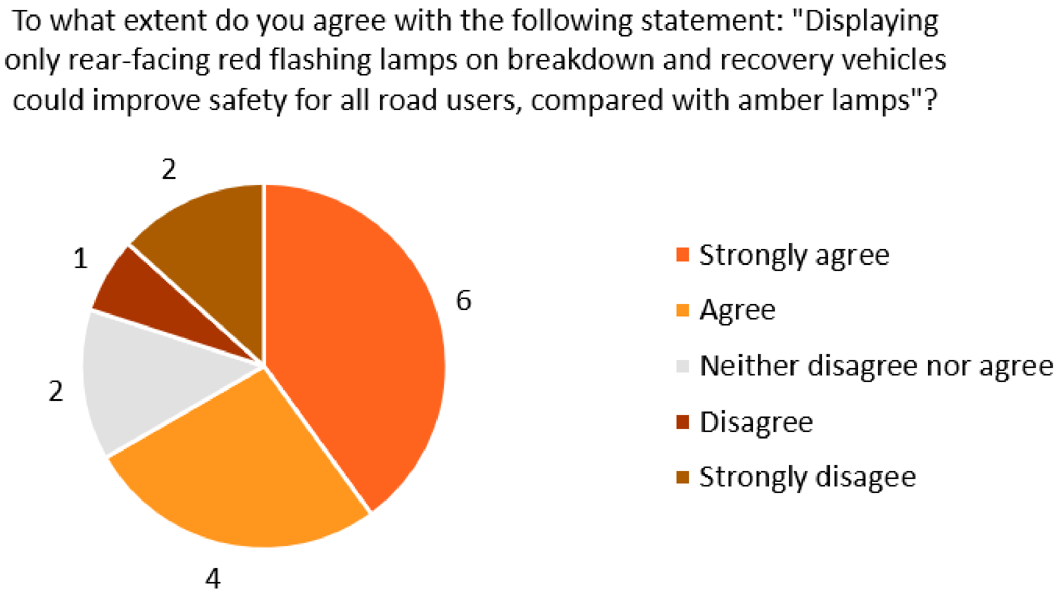

Figure 29: Pie chart showing views on the perceived impact of red flashing lamps on safety for all road users when compared with amber lamps

A.4.2.3 Amber and red flashing lamps in combination

Survey responses indicated that 12 participants thought that amber lamps and red flashing lamps should be used in combination when recovery vehicles are stationary in live lanes and when stationary off the carriageway. Four participants reported that amber and red flashing lamps in combination should be used when recovery vehicles are slowing down to stop in live lanes. Three participants reported red and amber lamps in combination should be used when recovery vehicles are slowing down to stop off the carriageway. Two participants reported that the combination should be used when leaving the hard shoulder, and one participant reported when towing a vehicle.

During the interviews, multiple experts stated that the combination of both amber and red flashing lamps might be beneficial for different parts of the recovery process; for example, using amber lamps when approaching a recovery scene, red flashing lamps when stationary to enhance conspicuity, then amber and red flashing lamps together when moving away from the scene and re-joining the flow of traffic. Quotes supporting this finding are: *“the combination of the two hits the eyes and the public act totally different”* and *“the familiarity of the amber lamps will help draw initial attention to the scene”*.

Respondents were asked to what extent they agree that displaying both amber and red flashing lamps could improve safety for all road users (Figure **30**). The most common response was ‘strongly agree’ (N=7), the next most common being ‘agree’ (N=5). The 12 respondents that either agreed or strongly agreed that displaying both amber and red flashing lamps could improve safety for all road users, were the same 12 respondents who indicated that amber and red flashing lamps should be used in combination when recovery vehicles are stationary in live lanes and when stationary off the carriageway.

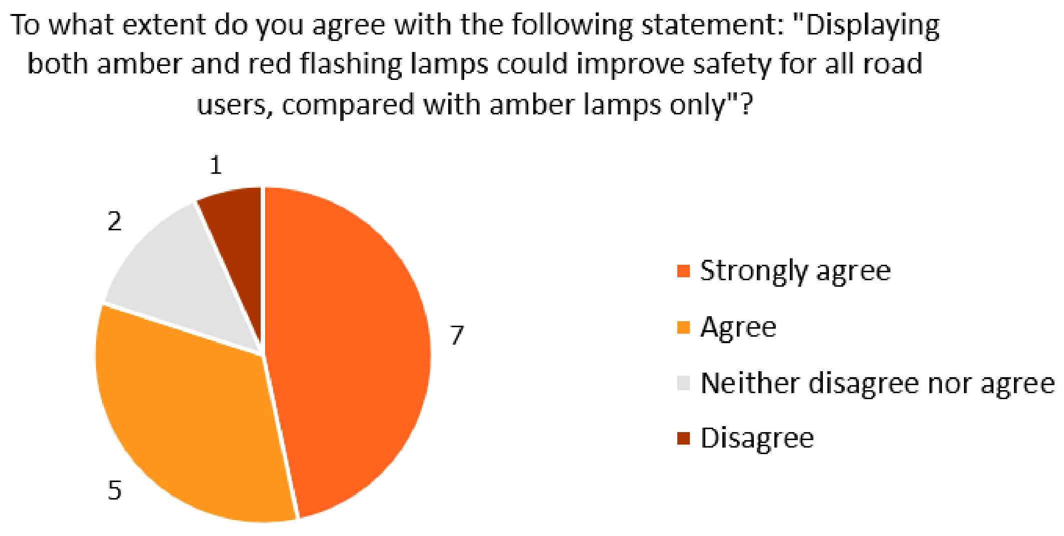

Figure 30: Pie chart showing views on the perceived impact of red and amber flashing lamps in combination on safety for all road users when compared with amber lamps

This suggests that two thirds of the sample (although it is a small sample) agreed that the combination of red and amber flashing lamps improves the safety for all road users compared with the current standard of amber lamps only. The expert opinion that red flashing lamps, or amber and red flashing lamps in combination, would improve safety for all road users shows evidence for the need to test the actual safety of the proposed lighting. It is important that actual safety is compared with the perceived safety, using rigorous behavioural data.

Key Finding 5: Respondents state the belief that they think red and amber lamps in combination provide a greater safety benefit to all road users than amber.

A.4.3 Flashing sequences

Additionally to the use of amber and red flashing lamps together, interviewees indicated that static lights do not give any advantage to making recovery vehicles conspicuous, as they do not catch the public's eye. Instead, interviewees highlighted that flashing lamps are more impactful at presenting a hazard to other road users when the recovery vehicle is stationary. Supporting quotes of this finding are that static lamps *"don't have too much impact at all because they don't catch your eye"* and *"random flashes draw more attention"*.

This suggests that static lights should not be used during the behavioural testing in this research study, and that the focus should be on the colour of flashing warning lamps.

A.4.4 Conspicuity measures for the recovery industry

Another topic examined in both the survey and interviews was the conspicuity measures that recovery workers use to be as conspicuous as possible to other road users. Figure **31** indicates what conspicuity aids are used on recovery vehicles according to the survey responses. Other additional conspicuity aids identified in the interviews include reflective materials, high glow tape, orange and pink high-visibility jackets, LED flashing lights, ‘air bars’, progressive lighting, arrow boards, elevated signs, and cones on A-roads. Survey responses relating to satisfaction levels of current conspicuity measures were mixed (Figure **32**). The most common answer was ‘neither satisfied nor dissatisfied’ (N=5), with the next most common answers being ‘dissatisfied’ (N=3) and ‘satisfied’ (N=4).

During the interview, many of the experts indicated that recovery vehicles are as conspicuous as possible in alignment with regulations and policies, and that the issue lies with the meaning behind the warning lamps that are becoming lost due to the proliferation of amber lamps by a variety of industries. Supporting quotes for this finding are *“I don’t think there are any issues at the moment, but you need to be able to distinguish between a recovery vehicle and a slow-moving dust car”* and that the current conspicuity measures are *“too limited and too optional”*.

The findings highlight that the experts’ attitudes towards the current conspicuity measures for recovery workers are mixed and inconclusive. It could perhaps indicate that the current conspicuity measures are not significant or powerful enough to be relied on as the key distinguisher between roadside recovery workers and other industries who use amber lamps. The findings also suggest that the conspicuity measures are too optional, implying that measures should be made mandatory rather than suggested.

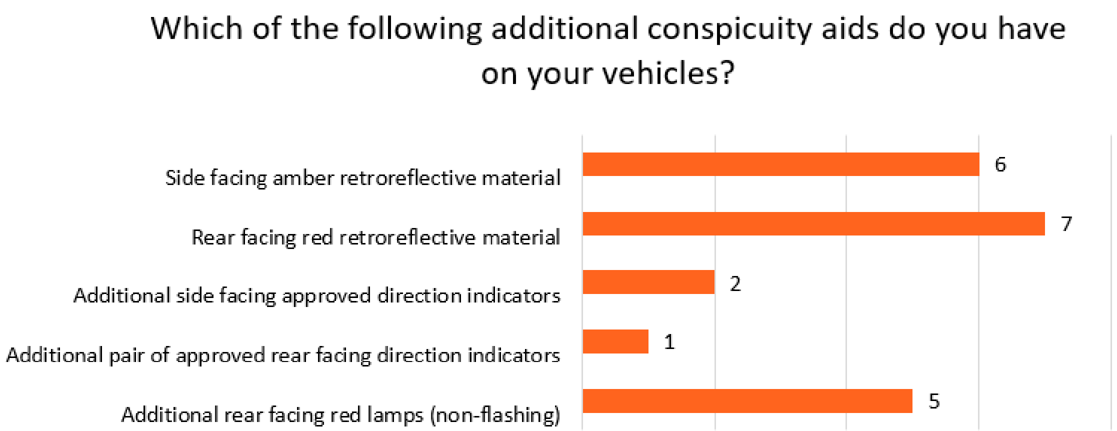

Figure 31: Bar chart representing what additional conspicuity aids are used on recovery vehicles

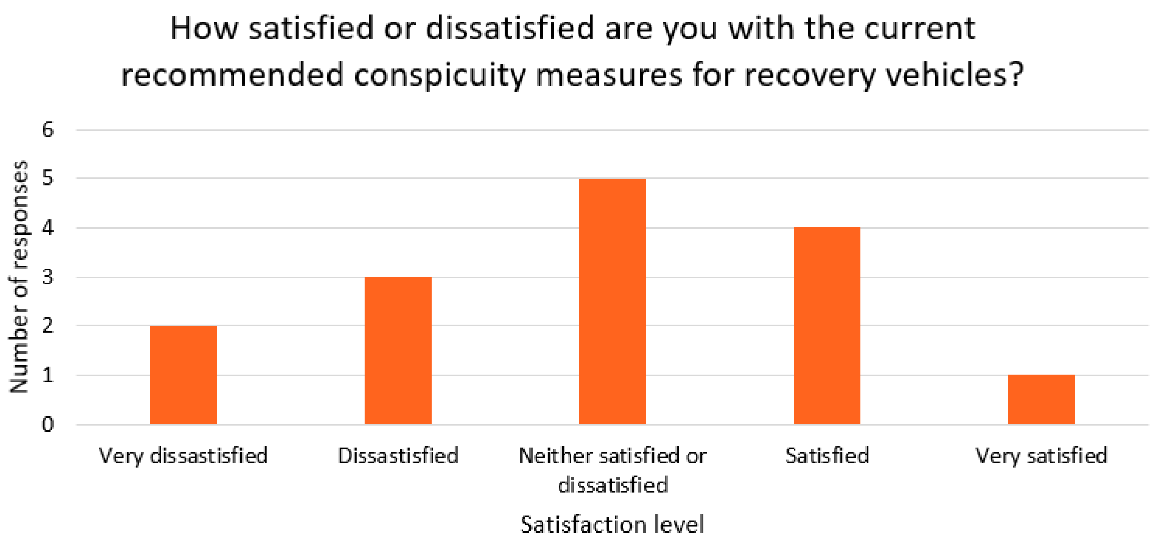

Figure 32: Bar graph displaying satisfaction levels of the current recommended conspicuity measures for recovery vehicles

A.4.5 Future guidance

This section explores what the experts think the future guidance should look like if red flashing lamps are permitted for use by the recovery industry. The overriding finding during the interviews was that the guidance should be mandatory rather than advisory and is regulated and monitored properly. One participant expressed that the future guidance needs to be regulated as *"people will start respecting what reds are for, otherwise it will disappear into the void again"*. Supporting quotes for this finding are *"there should be guidance and rules laid down that those operators have to comply with"* and *"it's important that the industry is regulated"*. Multiple experts expressed that this is to make it clear who is authorised to use red flashing lamps, so the public know what to expect and how to interpret the colour of the lights. The experts also emphasised that not everyone should be permitted to use red flashing lamps.

Another perspective that the experts expressed was that training and accreditation should be used to authorise personnel / organisations to use red flashing lamps on their vehicles. This is to ensure that recovery operators and organisations receive training on when they should use particular-coloured lighting and are examined on this to ensure they are used appropriately.

Key Finding 6: Experts strongly believe that the use of red flashing lamps and the associated guidance will need to be regulated

Key Finding 7: Training on the use of red flashing lamps will need to be implemented for those in the recovery industry

A.4.6 Educating members of the public

This topic explores education for members of the public about the dangers of recovery workers at roadside and what the different colours and flashing sequences mean. It was highlighted by multiple experts that you can only educate the public so far about this topic. This may be due to the challenges of reaching the target population and that some members of the public are simply not concerned about the dangers and risks associated with driving past someone working at the roadside. Quotes supporting this finding are *"you can only educate them so far"* and that education *"needs to be directly enforceable"*.

During the interviews, experts identified methods by which the public could be educated about the dangers associated with working roadside and what the different colours and flashing sequences mean. These included being part of the Highway Code and implementing a campaign like 'Slow Down Move Over', advertising through television, radio, magazines and newspapers, bulletins, in press releases and, lastly, by being part of the driving test.

Key Finding 8: Public awareness campaigns should be considered to make the public aware of the meaning and use of red flashing lamps.

A.4.7 Road recovery data and permission to use red flashing lamps

In the survey, experts were asked if their organisation was permitted to use rear-facing red flashing lamps on their vehicles. Figure 33 displays the results, which indicate that of the 14 respondents, the majority (N=9) are not permitted to use red flashing lamps on their recovery vehicles.

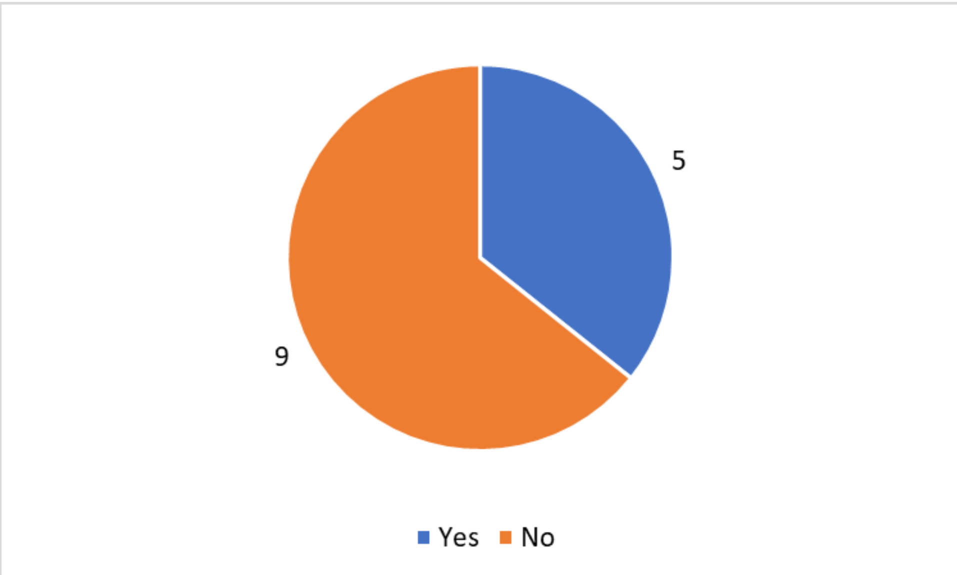

Figure 33: Organisations permitted to display red flashing lamps

In your organisation's fleet, how many vehicles are authorised to display red flashing lamps?

- Traffic Management contractor – 30
- Emergency service 1 – 180
- Emergency service 2 – 350
- Anonymous responses – 10

If your organisation is a permitted user, how many incidents do your vehicles attend each year? In how many of those incidents did vehicles display red flashing lamps?

- Anonymous response – 100 annually, 75 with red flashing lamps

If your organisation is not already a permitted user, how many vehicles does your organisation have which operate in high-risk locations and potentially could display these lamps, should further authorisation be granted?

- Anonymous response – 12
- Organisation 1 – 5,000
- Organisation 2 – 1,800
- Organisation 3 – 15
- Organisation 4 – 1,200

If your organisation is not a permitted user, how many incidents do your vehicles attend annually?

- Anonymous response – 7,188
- Organisation 2 – 1,800,000
- Organisation 3 – 25,000
- Organisation 4 – 33,650

Live lanes, high-speed roads (50 mph and above)

- Organisation 3 – 5,000
- Organisation 4 – 3,700

Hard shoulder, high-speed roads (50 mph and above)

- Organisation 3 – 5,000
- Organisation 4 – 4,475

Off-road e.g., in car parks

- Organisation 3 – 2,500
- Organisation 4 – 11,500

Rural roads

- Organisation 3 – 5,000
- Organisation 4 – 3,700

Urban roads (30mph or 40mph speed limits)

- Organisation 3 – 5,000
- Organisation 4 – 4,775

Residential roads

- Organisation 3 – 2,500
- Organisation 4 – 5,500

Additional responses

- Organisation 5: From data on our system, we cannot break down what you are asking in our area we have no hard shoulders. To break down what you are asking would be roughly 40% high speed dual carriage way roads over 50mph, 30% on single-track high-speed roads and 30% in other inc. residential / urban and car parks.
- Would need further time to be able to get detail of road attendance split. High proportions are on high-speed roads including dual carriageways and motorways (Organisation 2)

A.5 Discussion

Experts within the recovery industry held strong viewpoints surrounding the overuse of amber lamps displayed on vehicles by several organisations, which dilutes the effectiveness of signalling a hazard for recovery operators working on the roadside. The findings from the interviews with experts in the recovery industry highlighted an overriding notion that the use of amber flashing lights is not recognisable enough as a warning symbol for other road users. The key finding from this topic was that the experts believed that the authorisation to display red flashing lamps would be beneficial for the safety of the recovery industry workforce.

During the interviews, there was a discussion of what colour lights and flashing sequences should be used in a range of recovery scenarios. The key finding was that most experts believed that amber flashing lights should be used while approaching the scene, then for red flashing lights to be used in combination while stationary at roadside, then just amber lights when pulling away from the scene and joining the flow of traffic. Experts felt that red light symbolises danger and catches other road users' attention much more effectively than amber lights, and that other road users are more likely to slow down and move away from the scene. Furthermore, the flashing sequences of the lights were also discussed. The experts felt that flashing lights presented more of a hazardous situation and catches other road users' eyes than static lights, which could be confused with brake lights or other road signals.

With regards to the conspicuity measures for the recovery industry, it was highlighted that recovery workers are as conspicuous as they can legally be according to the regulations. Conspicuity aids identified during the interviews were reflective materials, high glow tape, orange and pink high-visibility jackets, LED flashing lights, 'air bars', progressive lighting, arrow boards, elevated signs, and cones on A-roads. Discussions with the experts led to an understanding that the issue does not lie with the conspicuity regulations, rather how the measures are perceived and what effect they have on other road users to be wary or knowledgeable of people working at the roadside. It was highlighted that the current conspicuity measures are too optional, indicating that the measures should be mandatory rather than recommended for use.

During the interview, experts had an opportunity to express what they thought the future guidance of warning lamps should look like if red flashing lamps were authorised for the recovery industry's use. From the discussions, it was recognised multiple times that the guidance should be properly regulated, and organisations should be accredited to be permitted to use red flashing lamps only after relevant training has taken place. The purpose of this is to reduce the proliferation of the use of red flashing lamps and ensure they are not overused like amber lamps have been. It is also so red flashing lamps do not lose their impact and significance in warning other road users that there is a roadside recovery taking place and to take caution.

With regards to how best to educate members of the public about the dangers of roadside recoveries and what the different colours signify, most experts believed that you simply cannot educate all the public. This finding is based on the idea that clusters of the general population currently have limited understanding about the dangers associated with working within the recovery industry, and do not want to understand it in the future. With reference to how best attempt to make the public aware, there were multiple suggestions. This included making guidance part of the Highway Code or a section of the driving test and developing an awareness campaign using media channels such as television, radio, magazine, and newspaper advertising to reach a wide range of the population.

A.6 Conclusion and key findings

The following key findings were drawn from the expert consultation, with considerations for other work packages in this research project, as well as recommendations on proceeding with future guidance on the use of warning lamps on recovery vehicles.

- The use and perceived meaning of amber lamps is currently unclear as they are currently used too frequently and for different purposes
- Experts believed that amber lamps show other road users that they need to be aware that something is happening and to proceed with caution
- Experts believe that red flashing lamps indicate more danger than amber lamps
- Respondents state the belief that they think red flashing lamps provide a greater safety benefit to all road users than amber
- Respondents state the belief that they think red and amber lamps in combination provide a greater safety benefit to all road users than amber
- Experts strongly believe that the use of red flashing lamps and the associated guidance will need to be regulated
- Training on the use of red flashing lamps will need to be implemented for those in the recovery industry
- Public awareness campaigns should be considered to make the public aware of the meaning and use of red flashing lamps

From the consultation with experts within the recovery industry, it can be concluded that if authorisation of red flashing lamps on recovery vehicles were to be granted, there would be support from experts. In their opinion, there would be a positive impact of red flashing lamps on the safety of roadside recovery technicians. Despite the overall positive support for red flashing lamps, the survey and interview results highlighted that if red flashing lamps were permitted for use, they must be heavily regulated. The guidance must be mandatory rather than advisory, training should be provided for recovery workers to establish what colour lamps to display in certain situations and to provide accreditation to display the red warning lamps. It was thought that this will help road users to be able to differentiate between recovery vehicles and other vehicles using amber warning lamps, making the roads safer for all users.

Appendix B Potential proliferation of lighting

As part of data gathering to determine potential proliferation of warning lighting should rear-facing flashing red lamps be authorised for use by the breakdown and recovery industry, a survey of technicians was carried out.

The purpose of the survey (hosted on Smart Survey) was to understand whether technicians within the recovery industry would use red flashing lamps if their recovery vehicles were fitted with them, and in what situations they would use them. The survey also assessed how likely the participants would be to follow any guidance on the use of red flashing lamps if permitted. The survey was anonymous. To encourage participation, all those who took part were offered the opportunity to enter a draw for a £25 Amazon e-voucher. Although it was technically possible to align a participant's survey responses with the email address submitted for the draw, this was not done.

B.1 Recruitment

The invitation to complete the online survey was sent to the existing experts identified by TRL to distribute to technicians in their company. We received responses from 94 technicians from 21 organisations.

B.2 Analysis

The data from the online survey was transferred to Microsoft Excel for preparation and analysis. Basic quantitative analysis was conducted to produce descriptive statistics, pie charts and bar charts as shown in section B.3.

B.3 Findings

B.3.1 The primary function of vehicles

Technicians were asked what the primary function of their vehicles were, so we could gauge how many respondents were active in roadside assistance or recovery. According to the survey results, out of the 94 responses, the most common primary function of the vehicle that respondents drive is for roadside assistance (N=48). The next most common functions of vehicles were recovery (N=21) and roadside assistance, occasional recovery (N=17). The other functions identified were tyre fitting (N=2), police recovery (N=2) and other (N=4). These results can be seen in Figure 34.

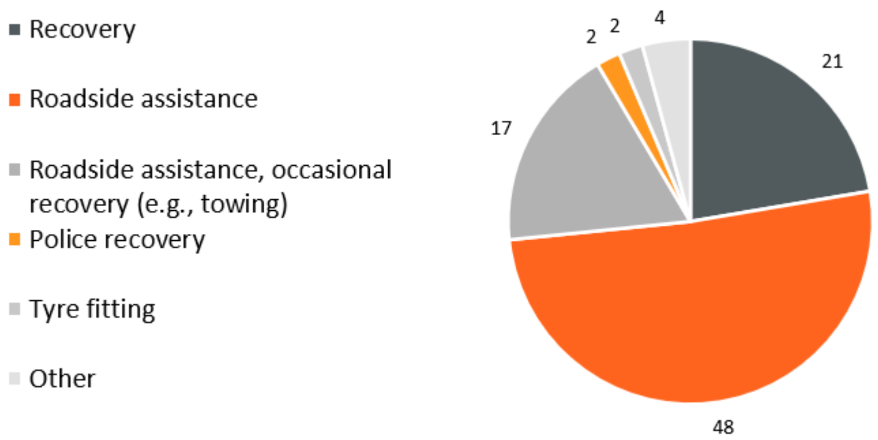

Figure 34: Primary function of participants' vehicles

B.3.2 The use of red flashing lamps in certain situations

Technicians were asked how often they would use red flashing lamps in recovery situations, if their vehicle was fitted with them (Figure 35).). Of the 94 respondents, 57 stated that they would use red flashing lamps in "some working situations". Thirty-six respondents reported that they would use red flashing lamps in 'every working situation'. Only one participant said that they would never use red flashing lamps if their recovery vehicle were fitted with them, instead only display amber flashing lamps. This respondent did not explain their reason for this answer in the free text box within the survey.

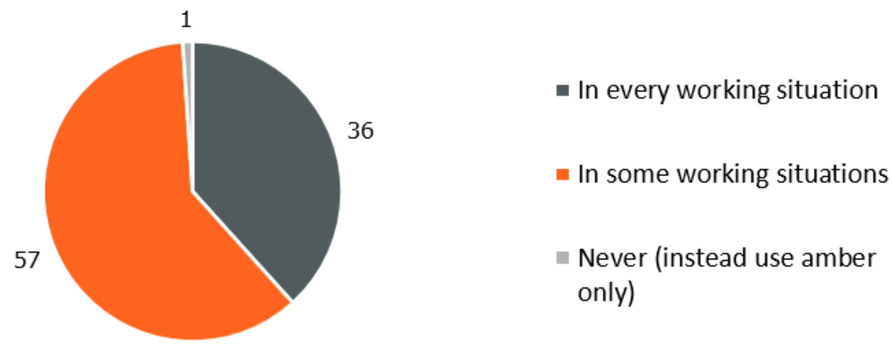

Figure 35: Situations where respondents would use red flashing lamps

Below are qualitative responses explaining technicians' views on when red flashing lamps should be used, and at which point in the recovery process.

Red flashing lamps in some working situations	Red flashing lamps in every working situation
• *“I do not believe they [red lamps] should be used as an alternative for amber lights but should be to further support in certain high-risk situations"* • *"There should be clear guidelines on how they should be used with perhaps technology being incorporated to only use when stationary”* • *“I would only use the red flashing lights after doing my dynamic risk assessment and only if I feel it is very necessary considering of the traffic flow and speed”* • *“If the red flashing lights are always used, they will end up being like the amber flashing lights and some people may not pay too much attention"*	• *“Red is more visible and easier to be seen”* • *“To protect myself against oncoming vehicles while alerting drivers that there is a hazard ahead”* • *“I would use them as much as possible to increase the visibility of my service vehicles and overall increase safety within the environment I was working in”* • *“If the red light gets me noticed better than the current legislation, I'd use them in line with our company policy of use”* • *“People take notice of reds more than ambers”*

Key Finding 1: Most technicians believe that red flashing lamps should be used in some working situations, rather than all working situations, after conducting a risk assessment of dangers and risks of the recovery situation.

B.3.3 The use of red flashing lamps in certain locations

Technicians were asked in which locations they would use red flashing lamps on their recovery vehicles. According to the left pie chart in Figure 36, 11 of the 94 respondents would use red flashing lamps in urban areas. Urban areas include housing estates and being parked on the road. According to the pie chart displayed on the right in Figure 36, only one of the 94 respondents reported that they would use red flashing lamps in urban areas when parked off the road.

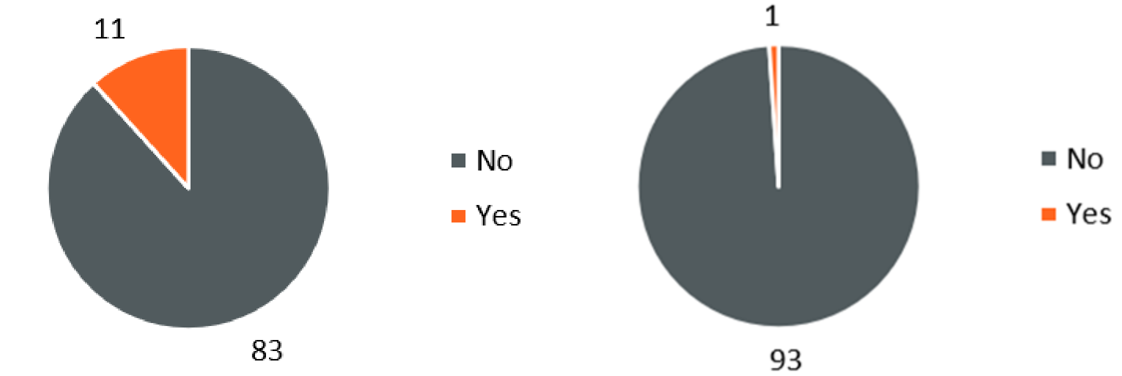

Figure 36: Pie charts indicating whether technicians think that red flashing lamps should be displayed in urban areas, parked on the road (left), or parked off the road (right)

Technicians were asked if they would use red flashing lamps on high-speed roads (50 mph and above). The pie chart on the left of Figure 37 indicates that 55 of the 94 respondents would use red flashing lamps on high-speed roads with no hard shoulder, when parked on the road. The pie chart displayed on the right of Figure 37 shows that 40 of the 94 respondents would use red flashing lamps on high-speed roads with no hard shoulder when parked off the road.

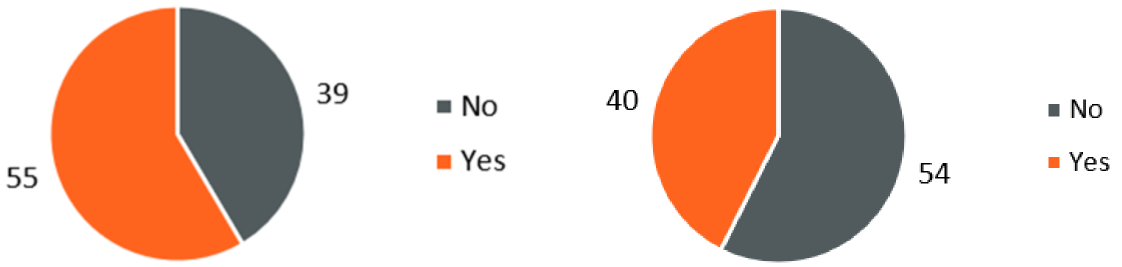

Figure 37: Pie charts indicating whether technicians think red flashing lamps should be displayed on high-speed roads, with no hard shoulder, parked on the road (left) or parked off the road (right)

Figure 38 shows that 53 of the 94 respondents would use red flashing lamps on high-speed roads on the hard shoulder. Lastly, Figure 39 indicates that only two of the 94 respondents would use red flashing lamps while moving at normal traffic speeds (while towing or carrying a broken-down vehicle).

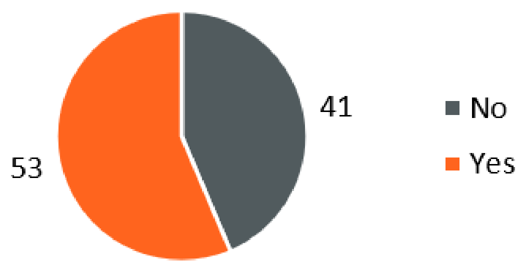

Figure 38: Pie chart indicating whether technicians think red flashing lamps should be displayed on high-speed roads, parked on the hard shoulder

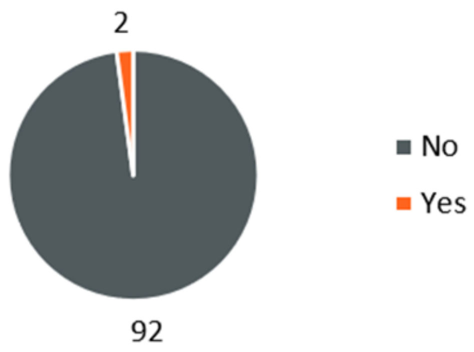

Figure 39: Pie chart indicating whether technicians think red flashing lamps should be displayed while moving at normal traffic speeds

These findings indicate that most technicians would use red flashing lamps when the risk level is high, such as when parked on the road. This suggests that the views on use of red flashing lamps is situational depending on the risk associated with the location.

Key Finding 2: Most technicians believe that red flashing lamps should not be used in urban areas including housing estates.

Key Finding 3: Most technicians reported that they think that red flashing lamps should be used on high-speed roads.

B.3.4 Guidance

This section looks at how likely technicians were to follow the guidance published by their employers or industry best practice guides, if they were to state that red flashing lamps should only be used in certain circumstances (such as 'only use when stopped in live lanes on high-speed roads'). This question was asked using a Likert scale from 1 to 5, 1 being very likely to follow the guidance and 5 being very unlikely to follow the guidance. Figure 40 indicates that 74 respondents said that would be 'very likely to follow guidance'.

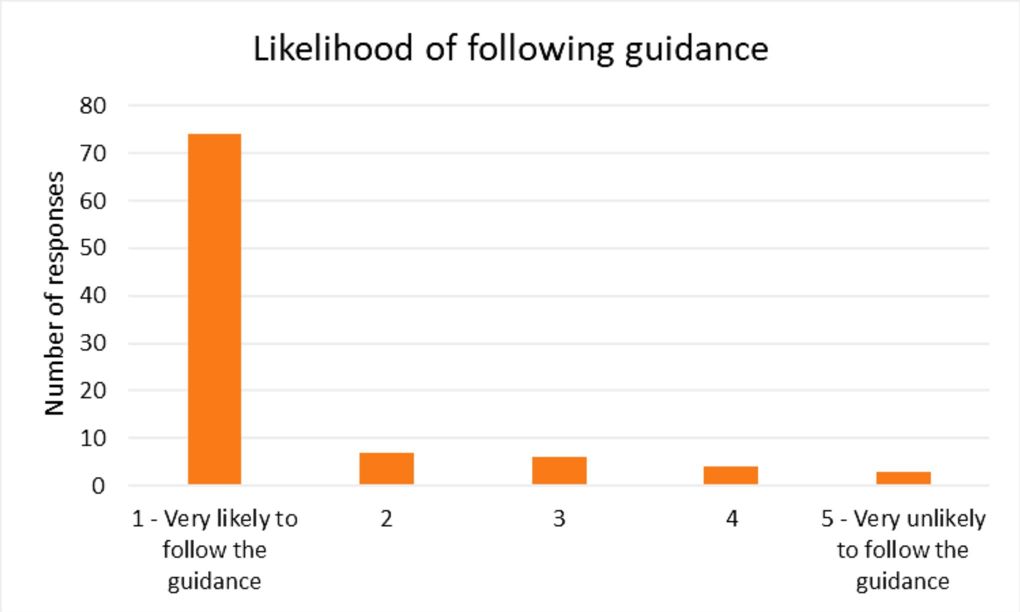

Figure 40: Bar graph indicating how likely respondents are to follow the guidance on the use of red flashing lamps, if permitted

Key Finding 4: Most technicians reported that they would be very likely to follow the guidance stating that red flashing lamps should only be used in certain circumstances.

B.4 Conclusion and key findings

The survey aimed to understand technicians' perceptions, if red flashing lamps were permitted for use in the recovery industry. This included the situations and locations they would and would not use them in, and how likely they would be to follow the guidance on the use of them. The key findings of the survey are outlined in the diagram below.

Key Finding 1

Most technicians believe that red flashing lamps should be used in some working situations, after conducting a risk assessment of dangers and risks of the recovery situation.

Key Finding 2

Most technicians believe that red flashing lamps should not be used in urban areas including housing estates.

Key Finding 3

Most technicians reported that they think that red flashing lamps should be used on high-speed roads.

Key Finding 4

Most technicians reported that they would be very likely to follow the guidance stating that red flashing lamps should only be used in certain circumstances.

From the findings, it can be concluded that a majority of the 94 technicians who completed the survey believed that if red flashing lamps were permitted for use, they should not be used in all recovery situations. This is because they are wary of the red flashing lamps being overused and a dilution of their meaning (as it was suggested has happened to amber lamps). This finding suggests that technicians believe that the colour(s) displayed by recovery vehicles should be based on a risk assessment, measuring the safety aspects of certain situations, to improve safety of recovery workers. Survey results also revealed that most technicians stated they would be very likely to follow the guidance on red warning lamps if authorised for use.

Appendix C Literature review

A desktop review was undertaken to identify any existing research evidence relating to drivers' ability to identify pedestrians when approaching vehicles displaying beacons. The review identified research relating to two particular aspects of using additional lamps:

- The visibility and conspicuity of both recovery vehicles and recovery operators; and
- Whether, if red and amber lamps are displayed alternately, there would be a sufficient duration when beacons are 'off' to allow approaching drivers to identify any pedestrians who are adjacent to the recovery vehicle.

This review did not replicate the literature review undertaken in the previous project, which related to lighting colour, not to pedestrian safety.

C.1 Method

A review of available literature was undertaken across a range of sources including TRID, ScienceDirect and Google Scholar, to allow for both academic and industry inputs. A set of relevant search terms were applied within these research databases, with 44 articles being identified and considered for review. Each article was systematically scored using a set of inclusion criteria (relevance, quality, and timeliness). Table 11 elaborates on the scoring criteria. Only articles with a total score above 7 and a minimum score of 2 across each dimension were considered for further review. Seven articles (four academic articles and three industry reports) were shortlisted and reviewed in full.

Table 11: Scoring criteria for the review

	Score		
	1	**2**	**3**
Relevance	Not relevant to the objectives of the project	Some indirect relevance to the objectives of the review	Directly relevant to the objectives of the review
Quality	Non-scientific evidence (e.g., online source, newspaper, or magazine article)	Scientific evidence which conducts an assessment, but does not control for potential confounding variables	Scientific evidence which conducts a robust assessment (e.g. RCT) while controlling for confounding variables
Timeliness	Evidence published over 15 years ago	Evidence published between 10 and 15 years ago	Evidence published within the last 10 years

C.2 Factors influencing pedestrian visibility

Over the seven reviewed articles, the impacts of various features of pedestrians and their environments were studied. Table 12 lists these features.

Table 12: Influencing factors identified within the review

Environmental features	Time of day	Day | Night
	Weather conditions	Fog | Dry
	Presence of other lights	Visual clutter | No visual clutter | Additional illumination for workers | Vehicle headlights | Fluorescent and reflective markings
Pedestrian features	Location	In front of the parked vehicle | Adjacent to the road | 5° off the side of the road | To the left/right of the road| To the left/right of the vehicle| Near/away from the lamps
	Reflective markings	No retroreflective markings | Low retroreflective markings | High retroreflective markings
Lamp features	Colour	Red | Blue | Yellow
	Flash intensity (cd)	Off | 25 | 80 | 150 | 170 | 190 | 400 | 700 | 850 | 2270 | 3100 | 4000 | 15500
	Flash frequency (Hz)	1 | 2 | 4
	Flash pattern	Off | All LEDs continuously on | All LEDs turning on and off in unison | Half of the LEDs alternately turning on and off | All LEDs on at full intensity and 10% of intensity alternately | Shielded to produce a beam angle of 10° in the direction of the observer | Shielded by a black baffle 1 m in front of the beacon

C.2.1 Flannagan and Devonshire (2007)

Flannagan and Devonshire (2007) conducted closed track trials to investigate the impacts of warning lamp colours, patterns and intensities on pedestrian visibility and driver behaviour in a night-time emergency scene. All three features of the lamps were found to have a significant impact on when the participants spotted the pedestrian. Blue lights were found to allow participants to spot the pedestrians earlier than red lights – a finding that has been corroborated by previous studies (Wells, 2004). Similarly, visibility of participants was found to be better when lamp intensities were low (causing less glare) as well as when the lamps were off for at least brief periods of time during their duty cycles. In all of these scenarios, however, visibility of pedestrians was best when they had some type of retroreflective markings on them.

C.2.2 Rea and Bullough (2016a)

Rea and Bullough (2016a) conducted a laboratory experiment looking to define specifications for yellow flashing warning beacons by studying the impact of various environmental factors, flash intensities and beacon locations on the drivers' ability to detect the beacons and surrounding low contrast objects (here, a Landolt C ring). The impact of these factors on the driver's judgements of gap closure between their own vehicle and a parked vehicle was also measured. Visibility of low contrast objects around the beacons was worst when the object was placed 5° off the observer's line of sight and was being viewed at night-time under high intensity lighting. Based on this study, they recommended limiting flash intensities for yellow lights between 750 cd and 2000 cd, with a minimum flashing intensity of at least 10% of its peak. They also found that having two beacons instead of one improved a driver's judgements of gap closure.

C.2.3 Rea and Bullough (2016b)

Rea and Bullough (2016b) used a simulated driving scene to investigate the impacts of warning beacon intensity distribution across various fog densities. Their findings align with those of previous studies (Flannagan & Devonshire, 2007; Rea & Bullough, 2016a), with low intensity beacons (150 cd) allowing for better visibility of the simulated pedestrians. They also suggest that visibility is best when the light is distributed as a beam instead of an omnidirectional beacon as it reduces the scattering of light.

C.2.4 Bullough and Rea (2016c)

Bullough and Rea (2016c) conducted a review of literature alongside engineer questionnaires and technical analyses to understand the practices and technologies used in work zones to provide illumination, while minimising glare. Based on their investigation, they recommended minimum peak intensities of 600 cd during daytime, which then need to be limited to 200 cd at night. They also suggest that a high-low flash pattern, as opposed to an on-off pattern might be better for worker visibility.

C.2.5 Kersavage et al. (2018)

Kersavage et al. (2018) conducted closed track trials looking at the impact that flash frequency and the use of reflective safety clothing had on drivers' ability to identify workers in a work zone during night-time. In line with Flannagan and Devonshire (2007), workers wearing high-visibility retroreflective clothing were spotted much earlier than those without any. Workers were also found to be spotted earliest for intensities of 25 cd, though these detection times were not much different than those for intensities of 150 cd. Peak intensity flashing (750 cd) was found to impact worker visibility only in cases where the workers were not wearing reflective safety clothing.

C.2.6 Bullough, Skinner and Rea (2019)

Bullough, Skinner and Rea (2019) conducted a laboratory experiment investigating the impact of lamp colour, flash intensity and the presence of low-level vehicle illumination on the drivers' ability to detect a police officer figure near emergency vehicles, as well as their experiences of discomfort glare. They found that visibility was best when there were no flashing lights present. While visibility with flashing lights was best without any additional illumination, white LEDs used for illumination did not negatively affect visibility, in the absence of flashing lights. As with the other studies, lower intensities (400 cd) also contribute to better visibility. Similar results were also found in the case of discomfort glare. Red lights were also found to lead to lesser discomfort glare, though colour did not affect the visibility of pedestrians.

C.2.7 Emergency Responder Safety Institute (2021)

Bullough, Parr, Sblendorio and Hiebner conducted closed track trials to identify the impact of the intensity, flash rate, modulation and colour of flashing lights as well as the impact of additional retroreflective chevron markings in a night-time setting. The impact of these factors on driver's perceptions of visibility of the vehicle and surrounding emergency responders as well as their experiences of glare were studied. Participants drove around the track and demonstrated the visibility of a firefighter silhouette by pressing the vehicle's horn. After the drive they rated the visibility and glare of the lights. While participants found the higher intensity lights to cause noticeably more glare than lower intensity lights, their visibility was only marginally higher. Similarly, blue and white lights were found to cause more glare than red or yellow lights. In the case of the visibility of emergency responders around the vehicle, visibility was higher without additional retroreflective chevron markings on the vehicle than with, for both high as well as low intensity flashing lights. The difference, however, was not statistically significant and may require further research.

C.3 Recommendations

Based on the papers that have been reviewed here, the main factor (or at least the most investigated) when understanding the impacts of flashing lamps on the identification of pedestrians adjacent to vehicles with the lamps, would appear to be the intensity of the flashing. There is a need to determine a balance between intensities that are high enough to allow drivers to spot the vehicles, but not so high as to cause glare and impair pedestrian visibility.

1. Peak intensity – A few factors that may assist in determining optimal peak intensities include:
    a. Time of day – Peak intensities need to be lower at night-time. Bullough and Rea (2016c) suggest peak intensities of 600 cd during the day and 200 cd during night-time.

   b. Weather – Peak intensities need to be lower in cases where the weather may cause reduced visibility (e.g. fog) and scattering of light. Bullough and Rea (2016b) recommend peak intensities around 150 cd in such conditions.
   c. Pedestrian features – Where possible, workers and other personnel should be encouraged to use high visibility retroreflective safety clothing. Peak intensities may need to be lower in areas where pedestrians are less likely to have such safety clothing on (e.g. near cities) to reduce glare and enhance visibility (Flannagan & Devonshire, 2007 and Kersavage *et al*., 2018)
2. Minimum intensity – Rea and Bullough (2016a) suggest that minimum flash intensities need to be at least 10% of the associated peak intensities.

While the frequency of the flashing did not make a substantial difference in pedestrian visibility, some recommendations can be made for the pattern of the flashing:

1. To allow drivers to effectively spot the vehicles as well as the pedestrians around it, a high-low flash pattern is recommended (Bullough & Rea, 2016c).
2. Where a high-low flashing pattern is adopted, the flashing should maintain its intensity to at least 10% of the lamp's peak intensity at all times (Bullough & Rea, 2016c).
3. Where a lamp array is used in an on-off flashing pattern, a 'full on' - 'full off' flashing sequence (where all lamps are on and off in unison) is better suited to pedestrian visibility than a 'half on' - 'half off' sequence (where groups of lamps alternate between being on and off) (Flannagan & Devonshire, 2007).

C.3.1 Limitations

While a systematic approach was adopted to cover a wide range of available literature, the search was not exhaustive and there may be additional specifications that could influence the impact of the recommendations presented. It should also be noted that all of the studies reviewed were conducted under controlled conditions – either through simulated driving scenes or closed track trials – and do not cover the full breadth of factors that could impact driver behaviour and pedestrian visibility in a real-world setting. Where cluttered environments were used, they were either simulated, or limited in the 'clutter' involved. This limits the direct application of the findings, and the recommendations must, hence, be adapted to the need of the environment in which they are implemented.

Another consideration with regards to the features of the lamps involves the limited ranges of intensity and patterns investigated. Most of the flash patterns studied were set for a 50% duty cycle. There is more research required into the different flash patterns at varying duty cycles (e.g., strobing). Similarly, the recommendations for maintaining a minimum intensity at 10% of the peak (although this is probably not permitted by current GB vehicle lighting regulations) may need amending with further research into impacts of lower intensities, which the current evidence pool lacks.

Appendix D Horizon Scanning

To complement the other tasks within this body of work, an exploration of alternative conspicuity enhancements was undertaken. This involved a web search and engagement with relevant contacts within the industry to identify technologies that are currently available that could improve the conspicuity of recovery vehicles and surrounding pedestrians. In addition, future technologies, either in development or theoretically possible, were explored. Where appropriate, these technologies were assessed on whether they are compliant with existing regulations.

D.1 Currently available

These conspicuity enhancements are available and may be used, or are under consideration, by some providers.

For any lamps or lighting installed on a vehicle, it is illegal to cause undue dazzle or discomfort to other road users.

D.1.1 Electroluminescent panels

Electroluminescent lighting could be installed as separate panels, or behind the red rear-facing vehicle retroreflective panels, supplementing the retroreflection, to provide a constant glow which potentially increases the conspicuity of the vehicle in low light conditions. The constant glow is claimed to create less glare than a flashing beacon. These panels are likely to be considered as optional position lamps.

D.1.2 Projected light

Light projection systems could delineate safety zones from live lanes. These systems can be mounted on recovery vehicles and may improve road user awareness of the presence of such vehicles and their operators.

If the technology does not cause undue dazzle or cause discomfort to road users, and is in appropriate colours, then projected light systems will comply with regulations.

D.1.3 Lightbars

Roof-mounted lightbars are a versatile conspicuity technology as they can be configured to display a range of different colours and flashing patterns.

With its ability to be freely customised, the lightbar could be set up to function as a range of lighting and colours. Depending on the configuration of the equipment:

- If the signal is front-facing then it may be either amber (flashing as part of a beacon) or white (non-flashing, as work area lighting)
- If side-facing, this is limited to amber (non-flashing unless as part of a beacon) as a side marker
- If the non-flashing lamp is rear-facing, then it may only be red in colour, as a position lamp

- Can operate as additional indicators (amber) or brake lamps (red)

D.1.4 Wirelessly connected trailer bar

A trailer bar has been developed which is intended to provide conspicuity enhancement for a vehicle being recovered or attended to, with benefits suggested for two situations in particular:

- When the casualty vehicle is unable to use its own lighting
- When the size of the casualty vehicle obstructs the warning lighting on the breakdown or recovery vehicle

Wireless connectivity (rather than cabling) to the breakdown / recovery vehicle means that vehicle can be repositioned around the casualty vehicle without disconnecting the trailer bar.

However, in its current form, the trailer bar displays amber rear-facing flashing warning lamps, which are not currently permitted by regulations.

D.1.5 Inflatable side warning lighting

Inflatable membrane LED strips have been designed to fit on the side of a vehicle. When activated, the device is inflated, and the LED strip flashes. This is intended to create a safety zone alongside a stationary vehicle for technicians working alongside a vehicle in a live lane. The illumination of the device could give approaching road users additional warning and so give the stationary vehicle greater clearance while passing.

Lamps and reflectors are excluded from the dimensions of a vehicle. As such, devices such as this, which extend from the side of a vehicle, are not prohibited by either the RVLR or the RV (Construction and Use) Regulations. Providing that the inflation of the devices when activated is not considered as “swivelling, deflecting, or otherwise”, then the devices could also be allowed while the vehicle is in motion under R12. However, if they are to be considered as ‘side marker lamps’, then the restriction applies that they must be turned on/off with the vehicle’s position lamps and rear registration lamp, etc., and must be the appropriate colour and not flashing.

Creating a safety zone alongside the vehicle means that passing traffic would, by being further away from the stationary vehicle, be closer to traffic in adjacent lanes, or oncoming traffic.

If the stationary vehicle was on a hard shoulder, in or in a layby, there is a risk that the devices could protrude into the adjacent live lane and so affect passing traffic.

D.1.6 Digital alert systems

Some currently available online mapping and directions systems allow users to provide updates to give other users awareness of localised incidents such as collisions and breakdowns that might affect traffic flow. Similarly, a system already in use for notifications of roadworks, could provide similar mapping updates by breakdown and recovery operators when arriving on-scene.

D.1.7 Enhanced radar detection

Technology which has been introduced for fitment onto roadworks Impact Protection Vehicles may also be suitable for adding to objects such as temporary signage or cones. The reflectors are intended to improve the likelihood of detection by vehicle manufacturers' radar sensors and operate an approaching vehicle's Automatic Emergency Braking System (AEBS).

D.2 Proposed / prototype innovations

These innovations have been developed and proposed by individuals or companies working in the breakdown and recovery industry.

D.2.1 Red 'X' signs

Smart motorways utilise red 'X' signs over lanes to give warning to road users about upcoming closures. A variant of these red 'X' signs has been developed for use by recovery vehicles. The sign alternates between a flashing red 'X' to indicate a lane closure, and a flashing arrow to direct traffic around the recovery vehicle appropriately. Three variations of this sign have been developed; one which can be fitted to the rear of a vehicle so it can be visible at all times, a smaller version designed for the top of a pilot vehicle, and a rechargeable, free-standing version for positioning on a road.

Currently, there are limited authorisations for the display of signs and signals on vehicles. Examination would be required to understand whether this system complies with existing regulations. Also, the system would need to be of the correct size, colour, and type as prescribed by Section 64 of the Road Traffic Act 1984.

Further assessment would be needed to determine road users' understanding of the displayed warnings, and how effective it is in improving safety outcomes compared to other measures.

D.2.2 Auxiliary strobe & stop lamp

The intention of this device is to give road users greater warning of braking when a recovery vehicle arrives on location. When braking initiates, the auxiliary strobe and stop lamp produces a sequence of five amber flashes before a solid red light is displayed. It is suggested that this light sequence has a greater ability to draw attention and awareness to the vehicle's actions, while not overwhelming other road users with long periods of flashing. This device could be utilised when a recovery vehicle arrives on location to alert road users that the vehicle is stopping and to supplement other conspicuity aids.

Additional stop lamps are permitted by RVLR; however, these must be red in colour. The amber flashing sequence, as described, on the application of the brake is prohibited as it conflicts with RVLR and UNECE Regulation No 48 (Installation of lighting and light-signalling devices)

D.2.3 Recovery vehicle emergency light safety shutdown instrument

This device is intended to support the use of red flashing lamps, should their use be authorised for breakdown and recovery vehicles. Were red flashing lamps to be used by stationary vehicles, the device's purpose is to turn off these warning lamps when the vehicle starts to move. This would ensure that red flashing lamps are not used when a vehicle is in motion, which could create confusion for other road users.

One key requirement of this device is that it must be designed to mitigate any risk of it being falsely triggered by any vehicle vibration or movement. Scenarios where the device might unintentionally turn off the warning lights must be avoided as these could present a risk to recovery operators and road users.

D.3 Future possibilities

The technologies identified in this section are either at the development stage or are in use elsewhere. They are included here as they demonstrate that driver awareness may not solely be gained from vehicle-mounted conspicuity equipment.

D.3.1 Streetlight technology

Technology incorporated into streetlighting, also known as intelligent streetlighting or adaptive lighting, is a public light fixture that utilises camera and sensor technology to allow for real-time monitoring functionalities. These devices are claimed to detect the movement of road users and pedestrians to produce dynamic lighting in their presence. Though they are more expensive than traditional streetlighting, they are claimed to have reduced running costs and longer lamp life.

Real-time monitoring technology such as that used in this streetlighting could be applied to recovery vehicle warning lamps. For instance, appropriate lamps could be triggered by pedestrians or workers in the vicinity of the vehicle to create greater visibility and awareness of their presence, while being inactive at all other times. This system could be effective at improving both pedestrian and recovery vehicle conspicuity. However, such a system has yet to be applied in the context of recovery vehicles and would require significant investigation on its effectiveness and the best approach to its application.

D.3.2 Connected technology

Vehicle-to-infrastructure (V2I) connected technology can be utilised to further improve road user awareness of any operations occurring on the road. Camera and sensor systems are already being utilised within some roadworks which provide site operators with clear alerts of any changes to the traffic management or safety zone, such as a knocked over sign or an incursion. These alerts can include the sounding of an alarm, a warning light, and information being presented on monitoring software.

Extending from this, approaching road users can be alerted in real-time of upcoming roadworks or recovery operations through in-vehicle systems (e.g. navigation systems or mobile devices). Such systems have already been developed and shown to be effective at encouraging road users to take appropriate action. V2I warning systems could complement vehicle conspicuity aids by providing road users with greater advanced warning of any road operations.

D.3.3 Colour changing road marker studs

Technology is available to install remotely controlled colour changing road marker studs into the carriageway. Their remote control would allow advance warning to be given to approaching drivers, although that would potentially require a driver awareness campaign to gain full benefits. Also, the changing colour would conflict with the current colours used on carriageways.

Appendix E Post-trial questionnaires

Following the track and simulator trials, participants were asked to complete a Post-Trial Questionnaire (PTQ) to understand their perceptions of the scenarios presented during the trial. This included perceptions towards how the lights affected where they thought the vehicle was located, whether it was moving, as well as how attention-grabbing they perceived the lights to be.

The PTQ from the track trial was paper based, whereas the simulator trial PTQ was administered on a tablet computer. Both methods of administration required the participants to enter their own responses.

E.1 Public track trial

The track trials with participants from the general public took place in two lighting conditions, daytime (N=31) and night-time (N=32). Basic quantitative analysis was conducted on participants' responses to the survey. this included descriptive statistics, pie charts, and bar charts as shown in the section below.

Participants were asked the following question: "While you were being driven around the track you passed a vehicle with flashing lights, can you remember what colour lights it was showing?". Figure 41 below shows the responses.

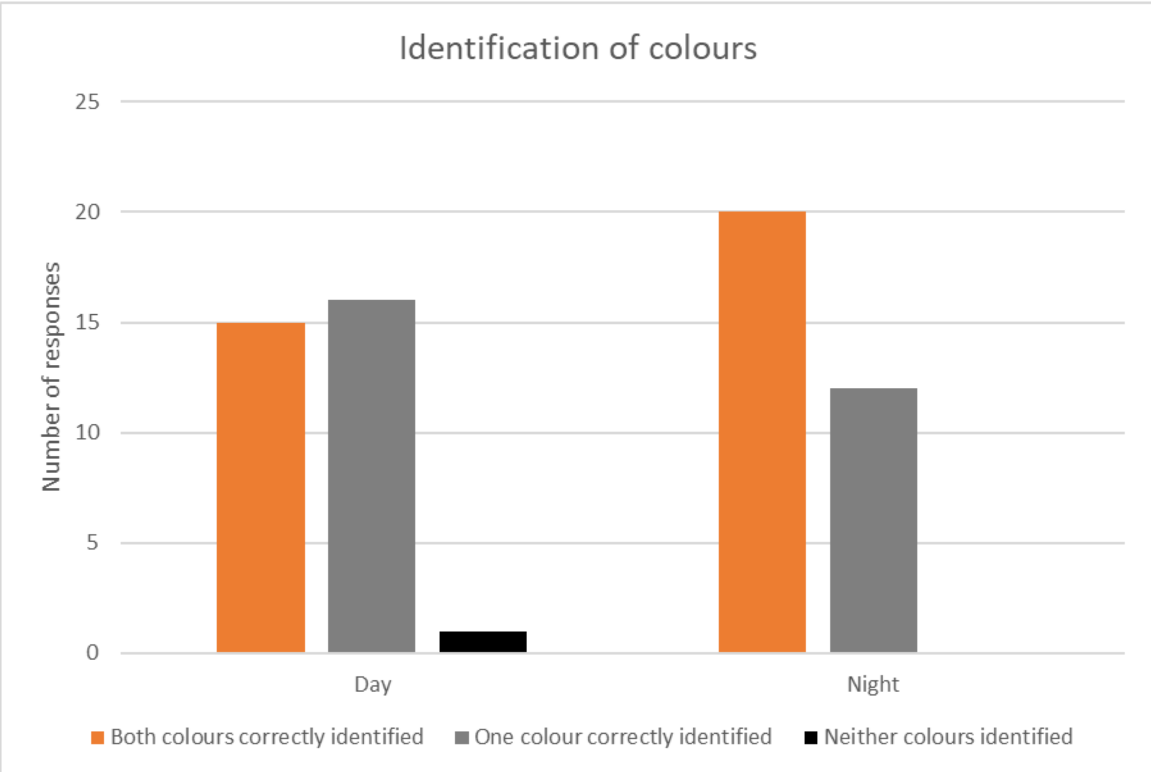

Figure 41: Column chart showing how many participants correctly identified the colours of lights that they were shown in the track trial, comparing day and night conditions

It was important to understand whether the correct colours were identified by participants before analysing their self-reported perceptions of red and amber lamps. Figure 41 shows 15 of the 31 'day' participants, and 20 of the 32 'night' participants were able to correctly identify that both red and amber lamps were used during the trial. This question was more successfully answered by those that completed the trial in the night condition, compared with the day, suggesting that driving during the day made it more difficult to identify the colours.

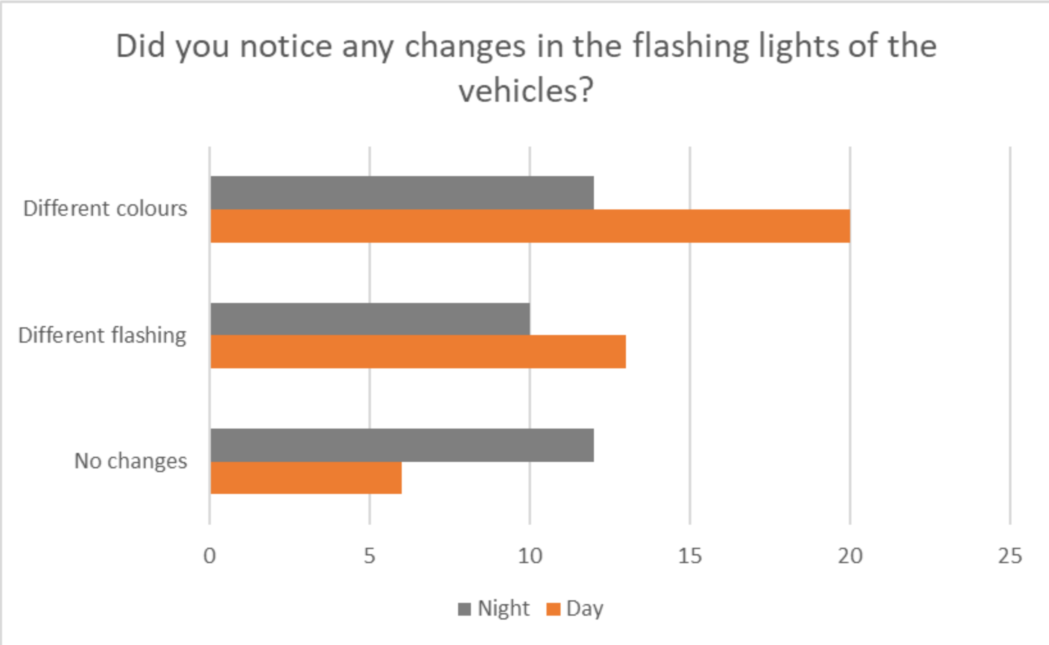

Figure 42: Column chart showing perceived differences in the lights that were displayed

When asked if they noticed a change in colours or flash patterns, participants' responses were inconsistent between day and night conditions. The results are displayed in Figure 42. The day condition participants were more likely to correctly identify that there was a change in the colours displayed on a recovery vehicle (65% of subsample), compared with the night condition participants (38% of subsample). This finding suggests that those driving during the day condition found it easier to distinguish a change in colour.

When asked whether they noticed a change in flash patterns, the day condition participants were more likely to correctly identify that there was a change in flash patterns between scenarios (42% of subsample), compared to the night condition participants (32% of subsample). This finding suggests that those driving during the day condition found it easier to distinguish a change in flash pattern displayed by the recovery vehicle.

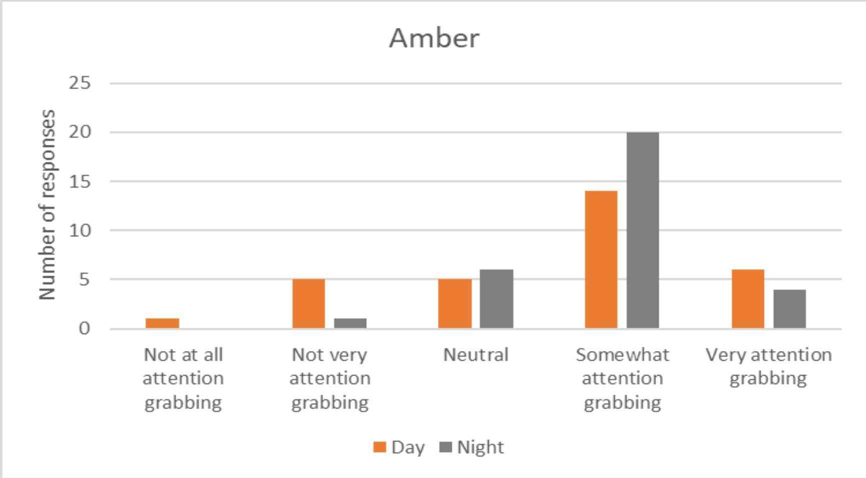

Figure 43: Column chart showing the extent to which participants thought that amber lights affected their attention

Participants were asked the following question: “when you were not actively looking for the flashing lights, how did the lighting affect your attention?”. The results are displayed in Figure 43, Figure 44 and Figure 45.

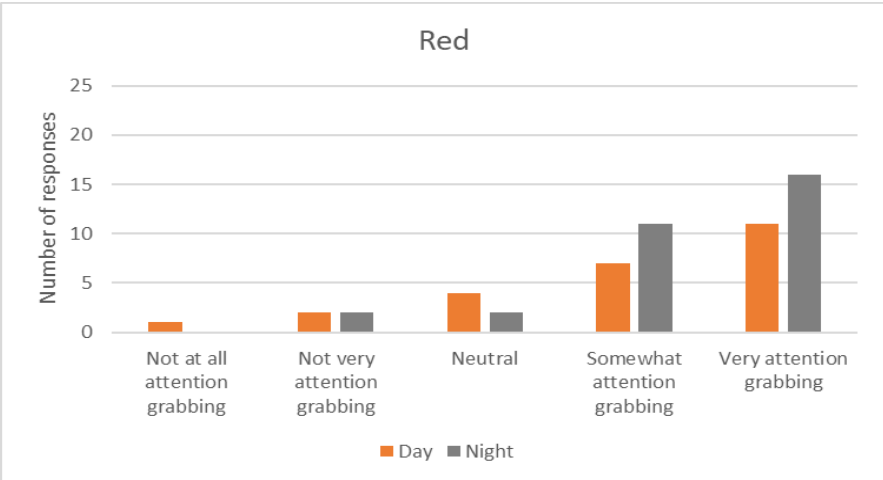

Figure 44: Column chart showing the extent to which participants thought that red lights affected their attention

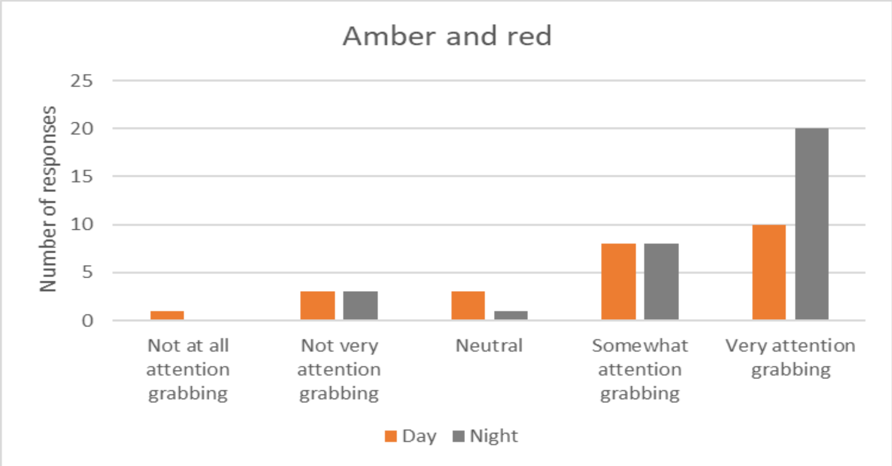

Figure 45: Column chart showing the extent to which participants thought that amber and red lights affected their attention

The findings indicate that the most prevalent answer was that all colour light displays were somewhat or very attention grabbing. Specifically, red lights and amber and red lights displayed together were more effective at grabbing the participants' attention than amber lights, and in the night condition. However, as noted earlier, just 35% of day condition subsample participants and 51% of night condition of subsample had correctly identified that there was a change in the colours displayed on the recovery vehicle. Participants were asked the following question: "When the flashing lights were in use, how did the vehicle look?". The results from this question are displayed in Figure 46, Figure 47 and Figure 48 below.

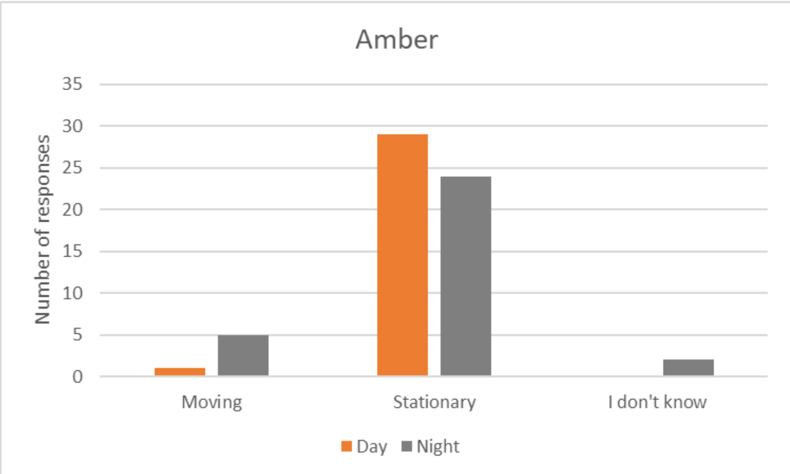

Figure 46: Column chart displaying how participants thought the vehicle looked when displaying amber lights

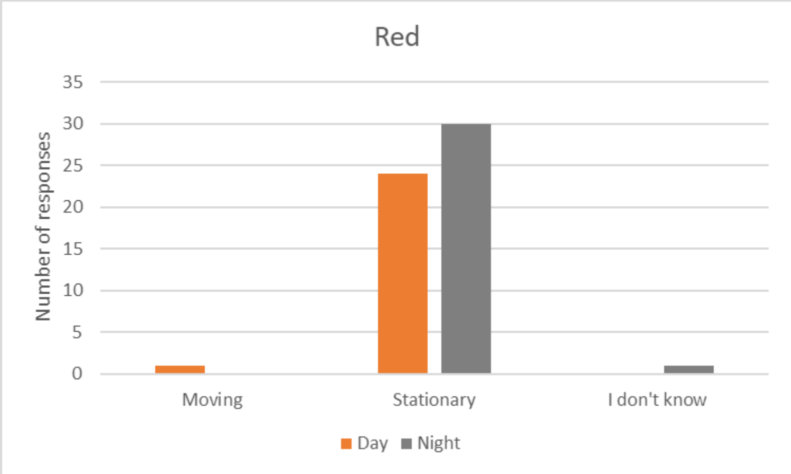

Figure 47: Column chart displaying how participants thought the vehicle looked when displaying red lights

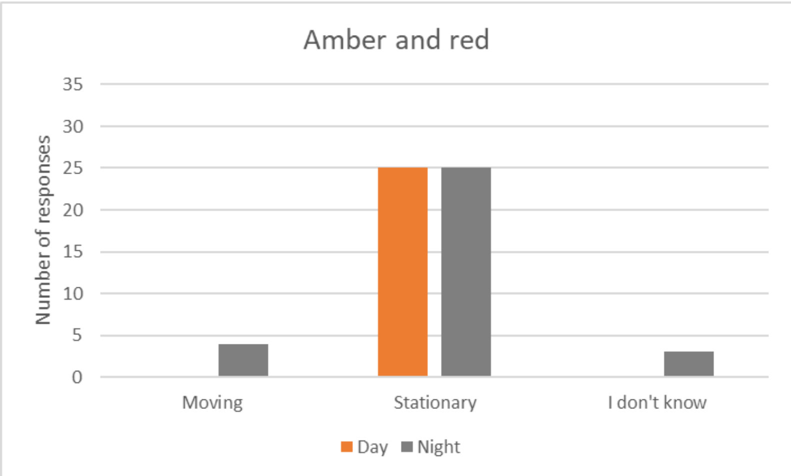

Figure 48: Column chart displaying how participants thought the vehicle looked when displaying amber and red lights together

The findings suggest that the majority of participants perceived the vehicles to be stationary in both day and night conditions, with little discrepancy between the colour lights displayed on the recovery vehicles. More detail on the size of the majority is reported in Table 13.

This suggests that the colour of the lights in both day and night conditions does not impact what other road users think about whether the vehicle looks like it is moving or not.

Table 13: Number of participants that reported they perceived the vehicle to be stationary when displaying light combinations

Colour combination	Number of participants reporting 'stationary'	
	Day (*N*= 31)	Night (*N*= 32)
Amber	29	24
Red	24	30
Amber and red	25	25

Participants were asked the following question: "When the flashing lights were in use, what did you think it meant for the location of the vehicle?". The responses from this question are displayed in Figure 49, Figure 50 and Figure 51 below.

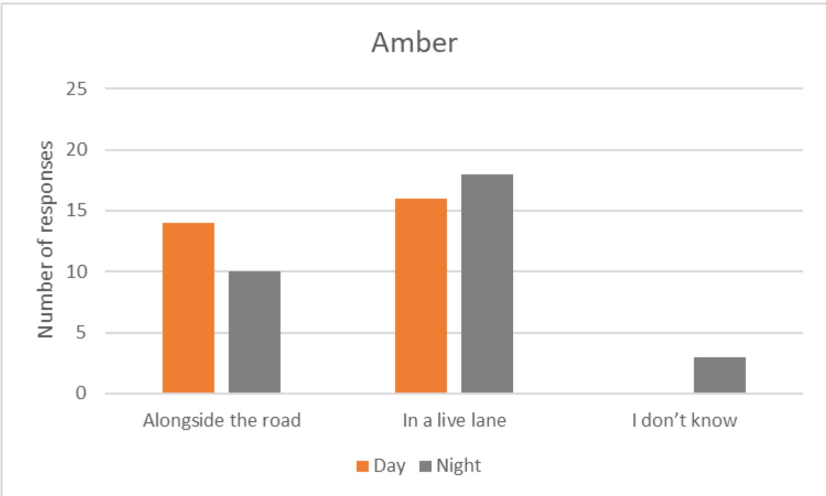

Figure 49: Column chart showing where participants thought the vehicle would be located when displaying amber lights

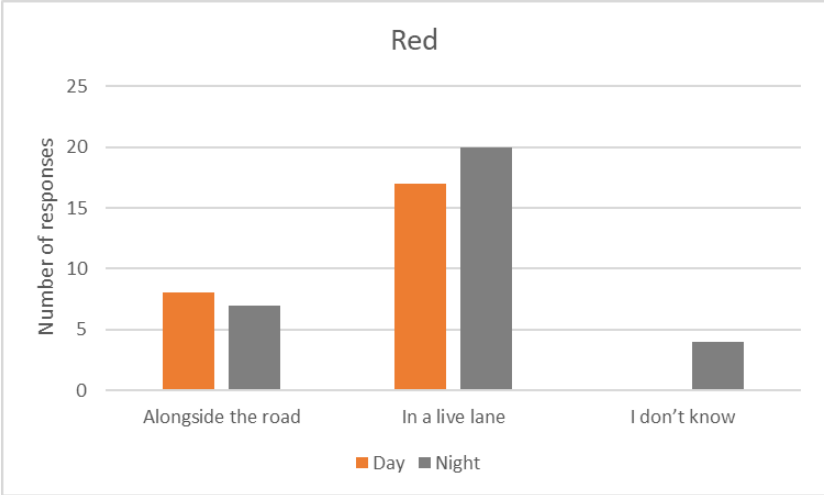

Figure 50: Column chart showing where participants thought the vehicle would be located when displaying red lights

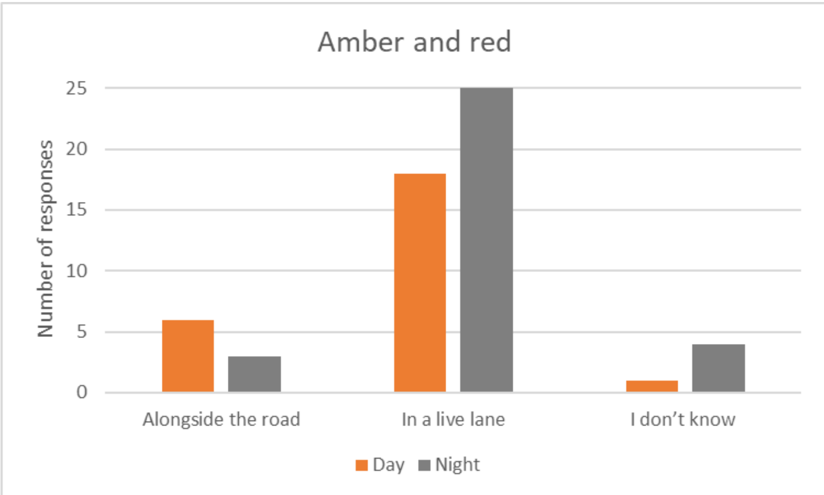

Figure 51: Column chart showing where participants thought the vehicle would be located when displaying amber and red lights together

The findings show that the most common answer across all lighting conditions was that participants expected the vehicles to be located in a live lane. However, when the vehicle is displaying amber lights, more participants thought this vehicle would be located alongside the road, in comparison with a vehicle displaying red lights, or amber and red lights together. This finding suggests that although the most prevalent answer for all light colour conditions was to be located in a live lane, there was a slight perceived difference in meaning; that red, or red and amber lights indicate that the vehicle is more likely to be in a live lane than when displaying only amber lights.

Participants were asked the following question: “To what extent do you agree with the following statement: ‘The flashing lamps would prevent me from seeing around the vehicle (e.g., pedestrians)’?”.

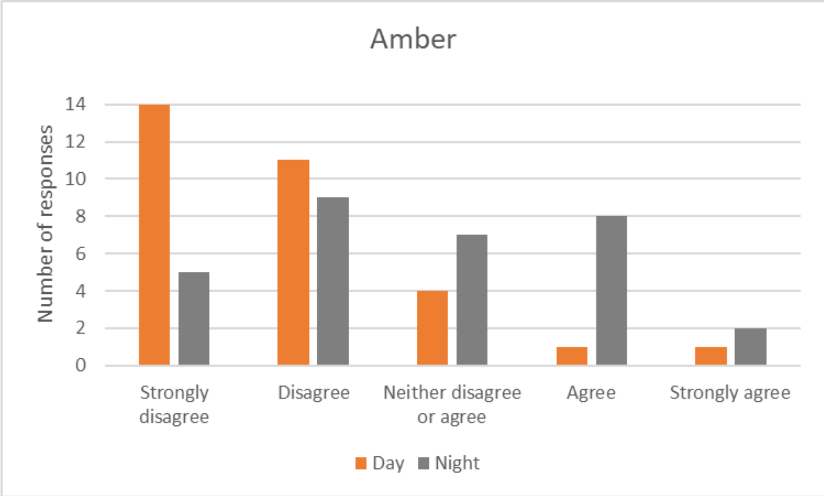

Figure 52: Column chart displaying the extent to which participants agree that when amber lights are being displayed, it would prevent them from seeing around the vehicle in day and night conditions

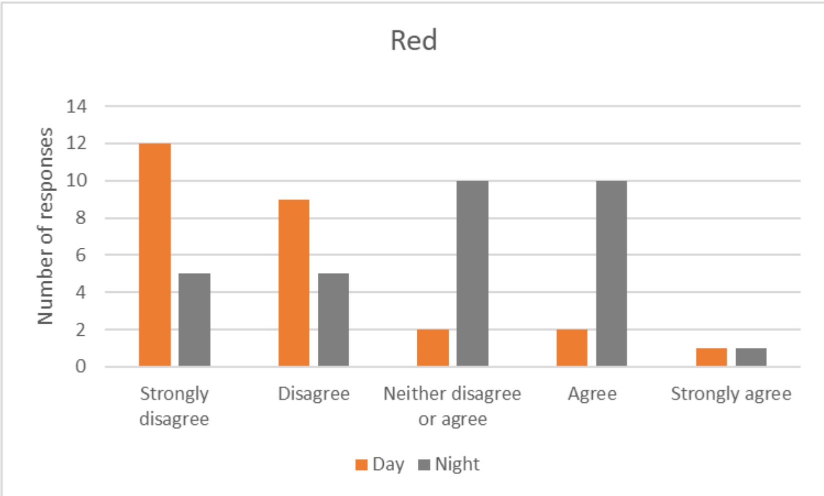

Figure 53: Column chart displaying the extent to which participants agree that when red lights are being displayed, it would prevent them from seeing around the vehicle in day and night conditions

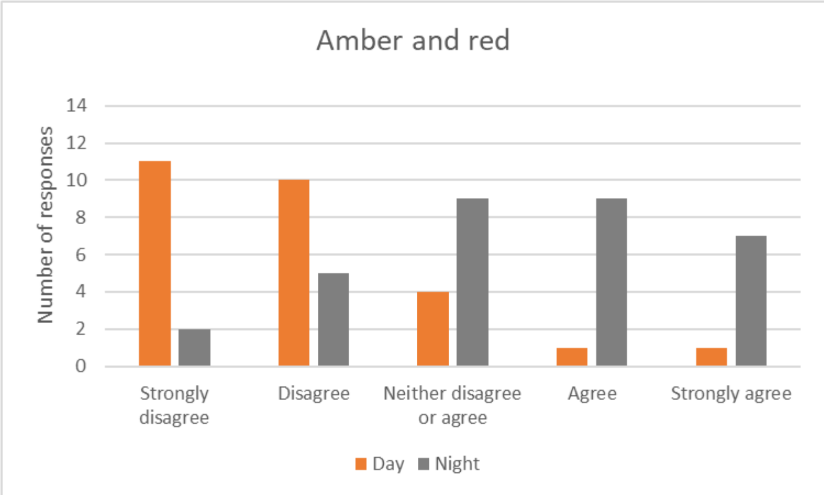

Figure 54: Column chart displaying the extent to which participants agree that when amber and red lights are being displayed together, it would prevent them from seeing around the vehicle in day and night conditions

The results from this question elicited similar responses across all the lighting colour conditions. The findings indicate that for all lighting colour conditions, most participants reported that the lights would prevent them from seeing around the vehicle in the night condition, suggesting that extra caution should be taken when road users see a vehicle displaying all colour lights during night-time and poor light conditions. This also has implications for technicians working around vehicles and other pedestrians, who may or may not be associated with the casualty vehicle.

The last section of the post-trial questionnaire asked the participants what they thought the different colours displayed on a recovery vehicle meant. These findings are compared with a study conducted in 2009 which asked the same question. It is worth noting here that the 2009 survey had an additional choice option of 'beware', which was not included in the current project's survey response choice. These results are shown in Figure 55.

With reference to recovery vehicles displaying amber flashing lights, the results from the current project and the study conducted in 2009 were relatively similar. The most common response (over 50%) in both projects was 'caution', followed by 'slow down'. The least frequent response was 'I don't know' which indicates that amber lights were, and still are, well understood by other road users.

For the red flashing light condition, the most common answer in the current project was 'danger' (33%), compared with the 2009 study which had a response rate of approximately 25%. The most prevalent response of what participants thought red flashing lights meant in the 2009 study was 'stop or prepare to stop' (approximately 40%), compared to the current study which indicated a response rate of 27%. This proposes that 'danger' and 'stop or prepare to stop' are the two most common perceptions of red flashing lamps.

When displaying amber and red flashing lights together, the most prevalent answer in the current project was that participants thought it meant 'caution needed' (36%), which was also one of the most prevalent responses in the 2009 study (approximately 25%). The next most common responses in the current study were ‘slow down’ (26%) and ‘danger’ (24%), while the next most frequent responses in the 2009 study were ‘stop or prepare to stop’ (approximately 25%), ‘danger’, and ‘slow down’ (both approximately 15%).

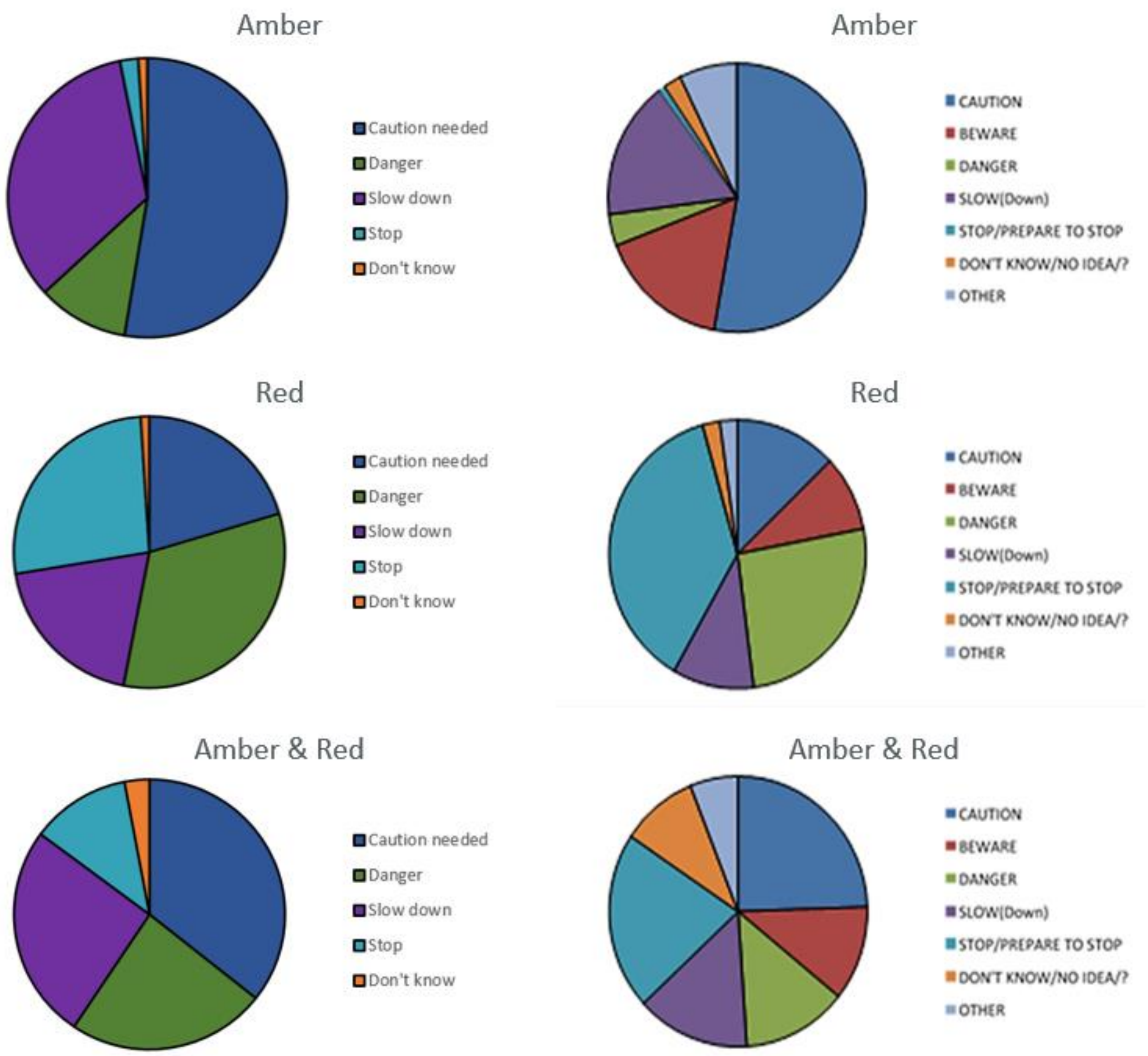

Figure 55: Pie charts displaying responses to what participants thought the different colours displayed on recovery vehicles meant. The current project results are shown on the left, and the results from the (unpublished) 2009 project are shown on the right

E.1.1 Conclusion and key findings

The aim of the post-trial questionnaire was to understand which colour and flash patterns were noticed by road users and what they perceived different colours to mean. The key findings of the trial PTQ are outlined in the diagram below, along with the relevant caveats related to the findings.

Key Finding 1

Only 55% of participants were able to correctly identify both colours of lights that were displayed during the track trial

Key Finding 2

Approximately 50% of participants reported that the red and amber and red flashing lamps in combination were 'very attention grabbing', compared with amber lights alone where less than 25% of participants said they were 'very attention grabbing'

Key Finding 3

Almost all (over 96%) of participants reported that the vehicles appeared static in day conditions and all light colour conditions, however 16% of participants reported that the vehicle looked like it was moving when displaying amber lights in night conditions

Key Finding 4

Participants perceived that a vehicle was more likely to be in a live lane when displaying red or amber and red lights, compared with amber lights

Key Finding 5

The majority of participants stated that amber lights mean 'caution', red lights mean 'stop' and 'danger', and amber and red lights in combination mean 'caution', 'danger' in both day and night conditions, and 'slow down' in day condition

With reference to Key Finding 1, there was no significant difference in correct identification of colours between the day and night conditions. Incorrect identification included only red, only amber, white, or blue (potential expectation for emergency colours). If participants recalled one colour, they were more likely to recall amber than red, suggesting it was slightly more attention grabbing.

With reference to Key Finding 5, caution should be taken when interpreting self-reported experience of lights. Careful attention should be paid to behavioural data to understand real effects of variations in lighting on driving behaviour.

E.2 Simulator trial

The simulator trials took place in two lighting conditions, day (N=36) and night (N=36). Basic quantitative analysis was conducted on the quantitative responses to the survey. this included descriptive statistics, pie charts, and bar charts as shown in the section below. Comparisons were made to previous research (2009 trial).

Qualitative data from the online survey was analysed using thematic analysis, to understand the key themes of responses and to provide context for some of the Likert scales in the survey.

E.2.1 Participants' experience of lights in the trial

This section focuses on the colours and flash patterns that participants noticed while driving.

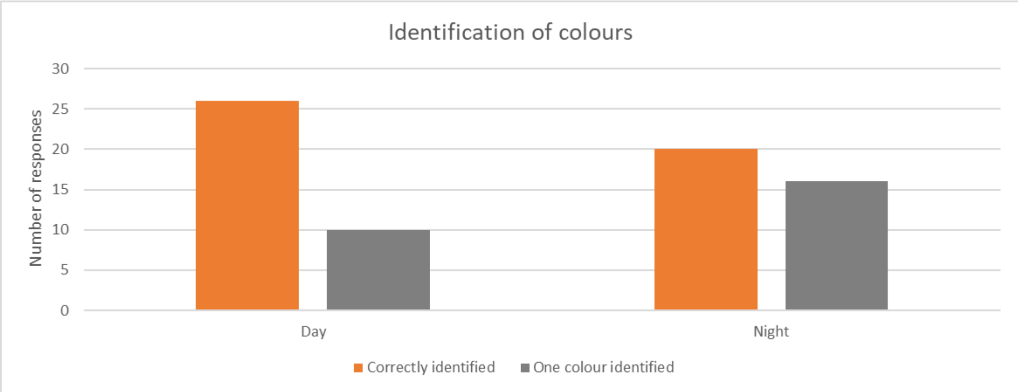

Figure 56: Column chart showing how many participants correctly identified the colours of lights that they were shown in the simulator trial, comparing day and night conditions

To understand the perception of red and amber lights, it was important to understand whether the different colours were identified. Figure 56 shows that the majority of participants (64%) were able to correctly identify that both red and amber lamps were used during the trial. This question was more successfully answered by those that completed the trial in the day condition, compared with the night, suggesting that driving at night made it more difficult to identify the colours. This is an interesting finding as the track trial PTQ results suggested it was easier to identify the colour of lights at night.

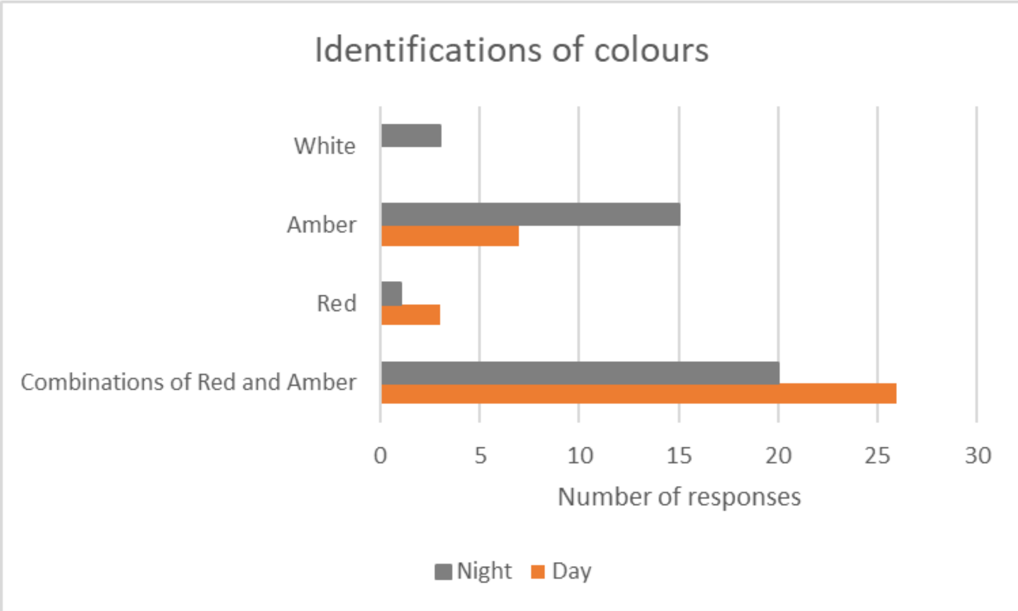

Figure 57: Bar chart showing the colour combinations that participants identified from the simulator trial, comparing responses from day and night conditions

To expand on this, Figure 57 shows which colours were identified if only one was correctly stated in the post-trial questionnaire. This shows that amber was more easily identifiable to participants than red. Additionally, three participants stated that they saw a white light in the trial (despite this not being one of the trial conditions).

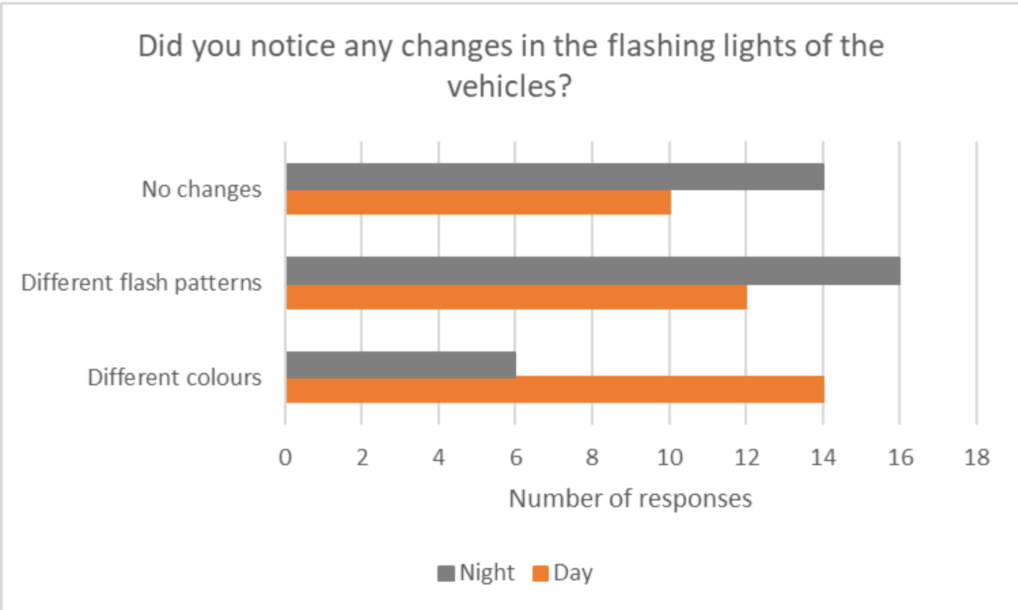

Figure 58: Bar chart showing whether participants noticed differences in the lights that were displayed, and what those differences were

This means that the perception of red lights in the following sections should be taken with caution, as some participants did not explicitly register seeing them and therefore their perceptions may not be based on a clear memory of the experience. The behavioural data from the simulator should be used to understand if there was an actual impact on behaviour.

When asked whether they noticed a change in colours displayed by the recovery vehicle, the day condition participants were more likely to correctly identify that there was a change in the colours that were displayed on the recovery vehicle (38% of subsample), compared with the night condition participants (16% of subsample). This suggests that those driving at night found it more difficult to distinguish a change in colour of the lights. With reference to the different flash patterns, the night condition participants were more likely to correctly identify that there was a change in flash pattern between scenarios (44% of subsample), compared with the day condition participants (33% of subsample).

It should be noted that the drivers in the track trial did not have the additional workload of controlling their vehicle, which may help to explain why the findings on memory for lighting was different in the two trials.

Participants were asked the following question: "When you were not actively looking for the flashing lights, how did the lighting affect your attention?". Figure 59, Figure 60 and Figure 61 show the results of that question.

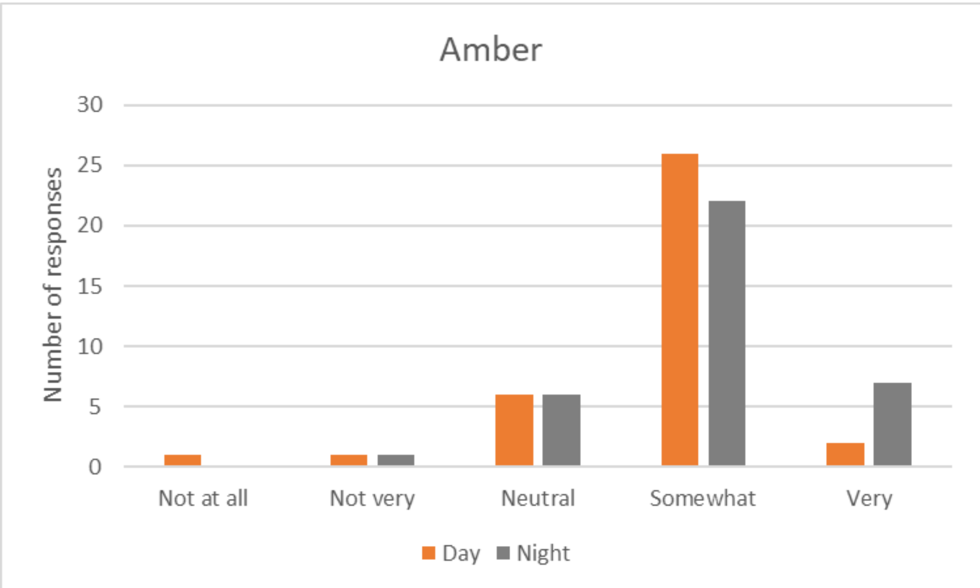

Figure 59: Column chart showing the extent to which participants thought that amber lights affected their attention

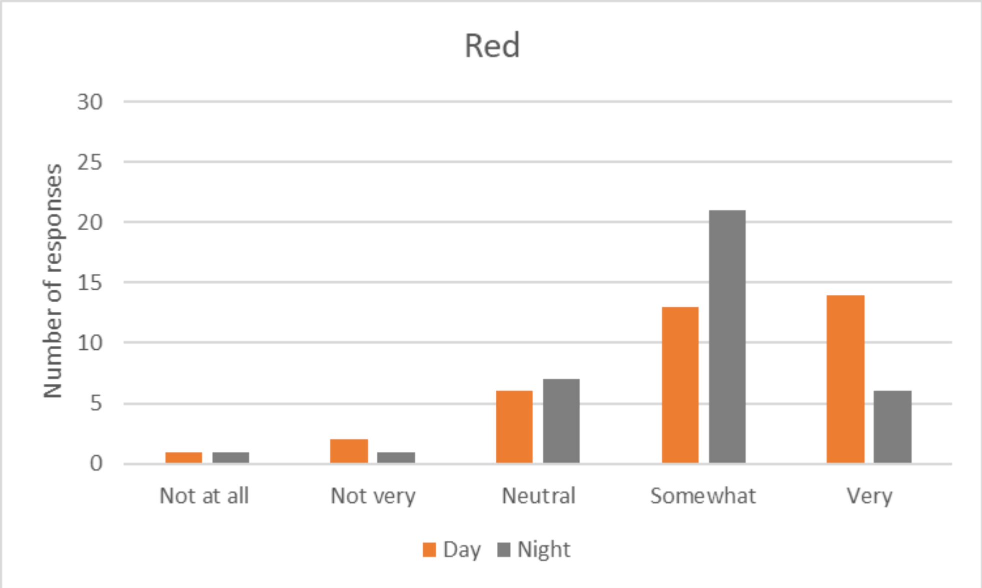

Figure 60: Column chart showing the extent to which participants thought that red lights affected their attention

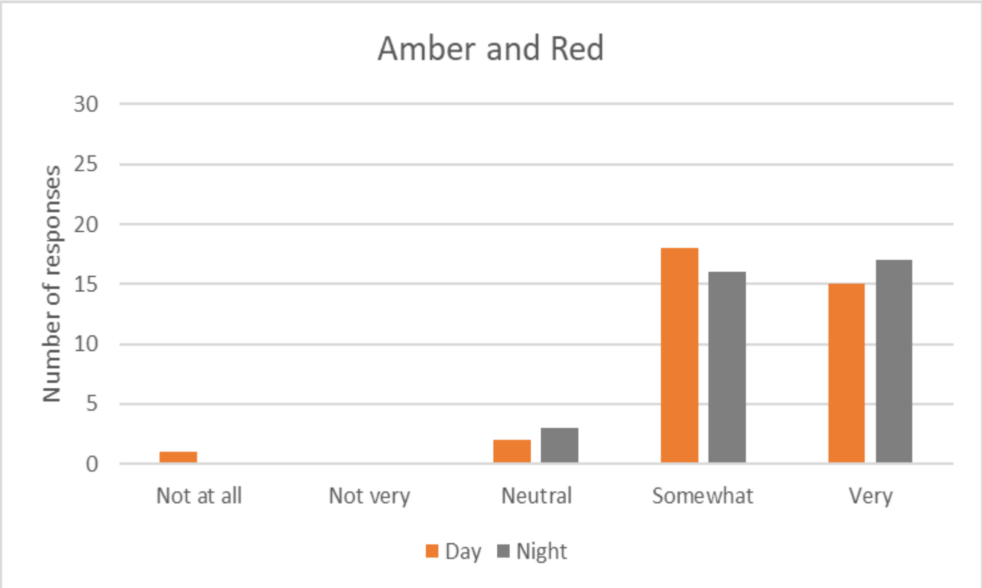

Figure 61: Column chart showing the extent to which participants thought that the combination of red and amber lights affected their attention

Similar to the track trial, the most prevalent answer for all light colours was that they were somewhat or very attention grabbing (Day condition – amber *N*=28, red *N*=27, amber and red *N*=33 out of 36 participants. Night condition – amber *N*=29, red *N*=27, amber and red *N*=33 out of 36 participants). However, the results in response to the combination of red and amber suggest that participants perceive them to be more attention grabbing, compared with when red and amber lights were displayed separately.

Participants were asked the following question: “When the flashing lights were in use, how did the vehicle look?”. Results can been seen in Figure 62, Figure 63 and Figure 64.

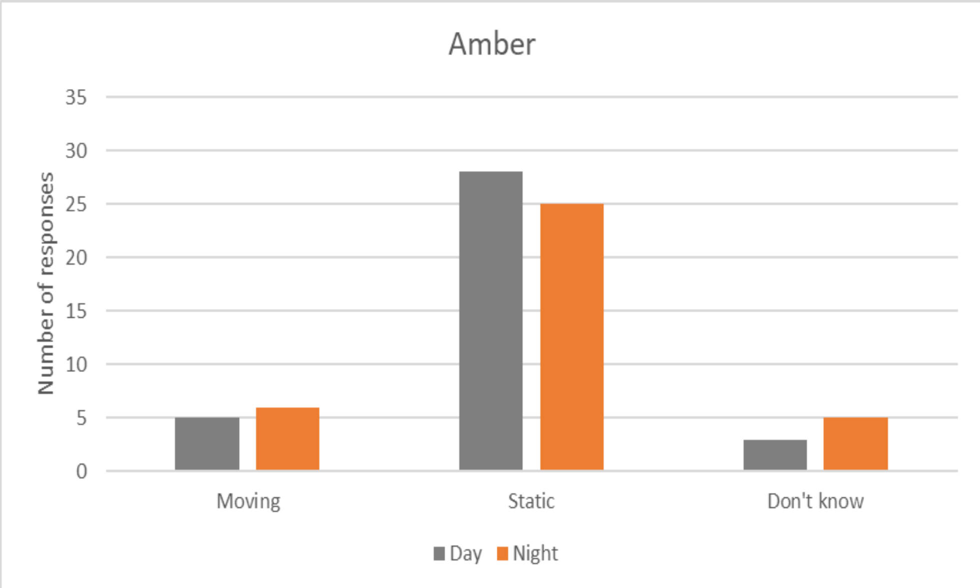

Figure 62: Column chart showing responses to how the participants thought the vehicle looked when displaying amber lights

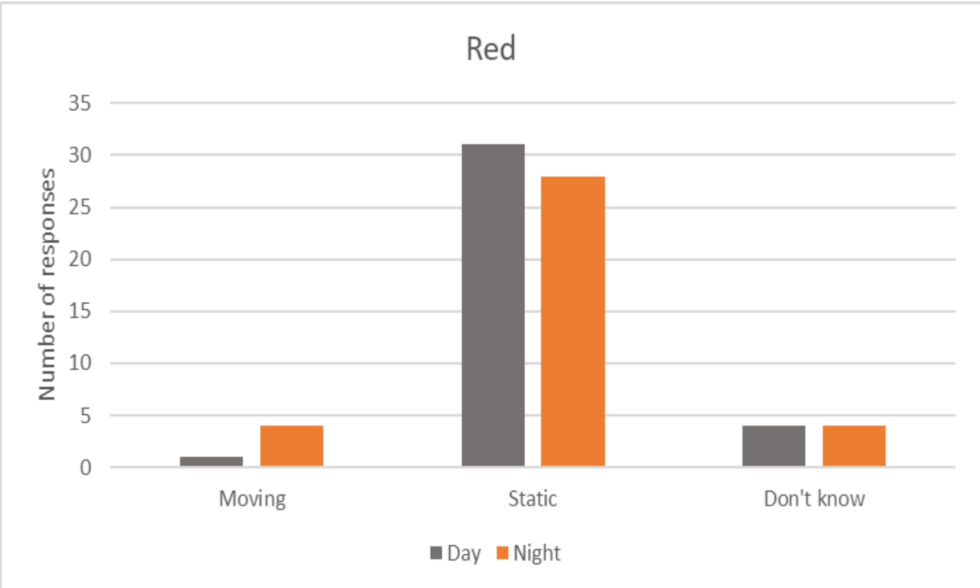

Figure 63: Column chart showing responses to how the participants thought the vehicle looked when displaying red lights

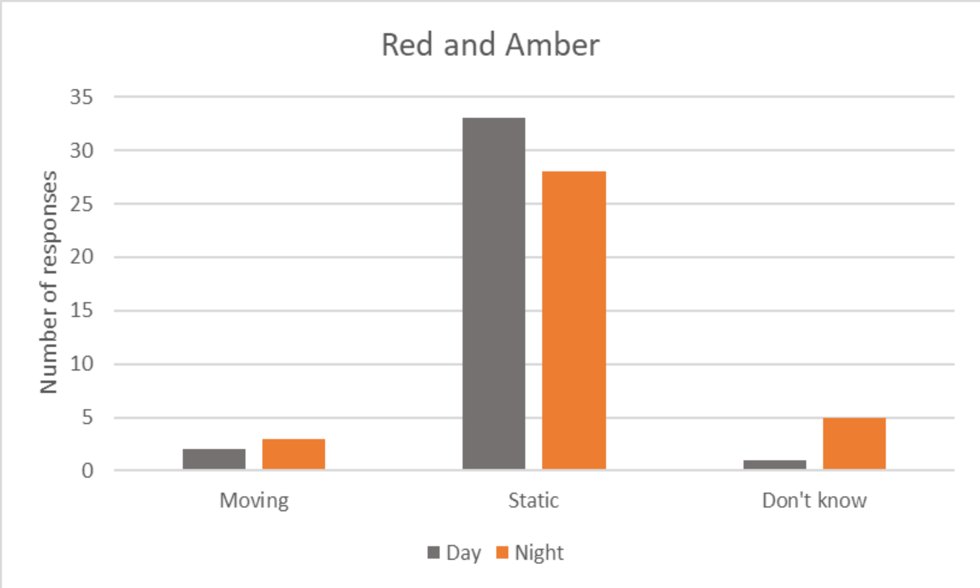

Figure 64: Column chart showing responses to how the participants thought the vehicle looked when displaying red and amber lights in combination

Confirming the results of the track trial questionnaires, responses suggest that the most prevalent answer was that the vehicles appeared "static" in both day and night conditions, when displaying amber lights, red lights, and amber and red lights in conjunction (Day condition – amber N=28, red N=31, amber and red N=33, out of 36 participants. Night condition – amber N=25, red N=28, amber and red N=28, out of 36 participants). This suggests that participants perceived the vehicles to look the same regardless of the colour lights displayed, and in both lighting conditions. However, slightly more respondents thought that amber could mean that the vehicle is moving, whereas in the track trial this was found for red flashing lamps.

Participants were asked the following question: "When the flashing lights were in use, what did you think it meant for the location of the vehicle?" Responses are shown in Figure 65, Figure 66 and Figure 67.

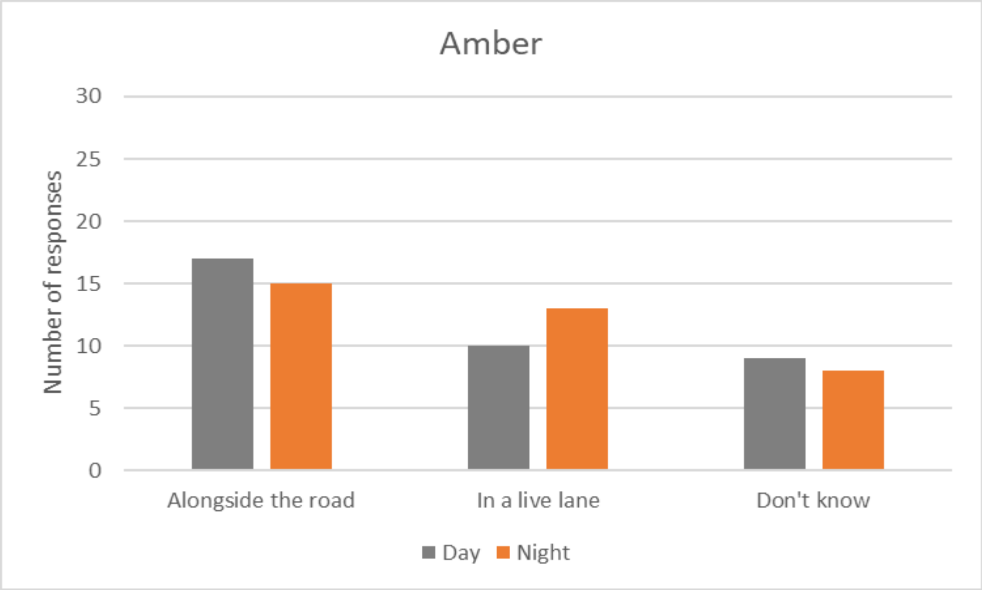

Figure 65: Column chart displaying where participants thought the vehicle was located when displaying amber flashing lights

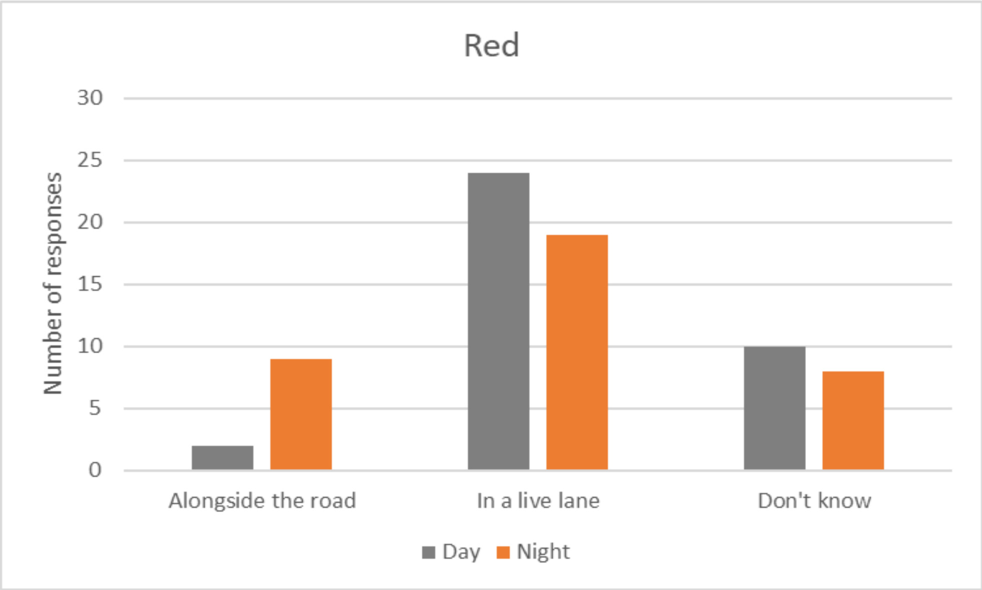

Figure 66: Column chart displaying where participants thought the vehicle was located when displaying red flashing lights

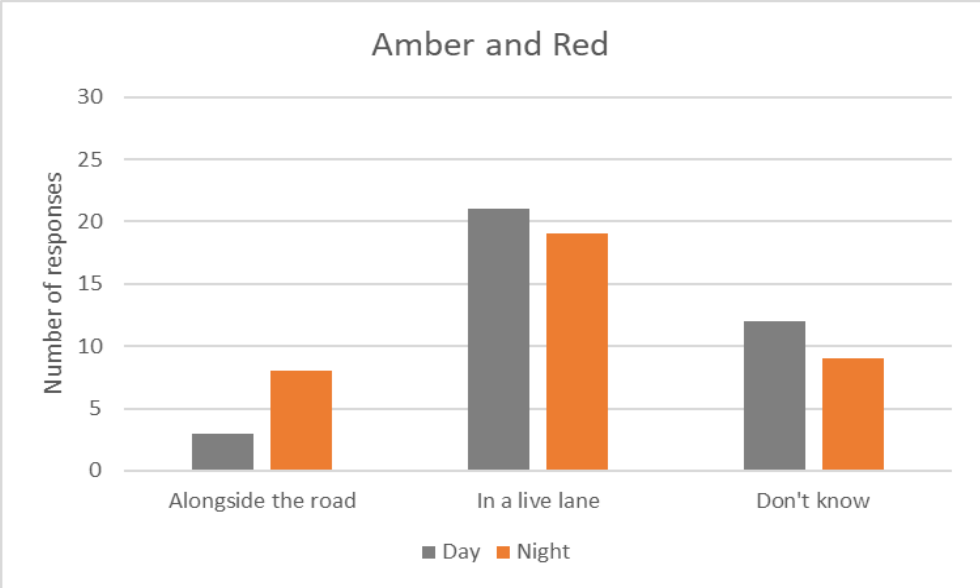

Figure 67: Column chart displaying where participants thought the vehicle was located when displaying amber and red flashing lights

The responses indicate that when a recovery vehicle was displaying amber lights, 32 of the 72 participants (45%) thought the vehicle was likely to be alongside the road (e.g., in a layby). When red flashing lights were being displayed, participants thought the vehicle was likely to be in a live lane in the carriageway. Lastly, when the recovery vehicle was displaying a combination of amber and red flashing lights, the majority of participants (56%) thought the vehicle was likely to be in a live lane in the carriageway.

The last section of the survey assessed what the participants thought the different colours displayed on a recovery vehicle meant. These findings are compared with a study conducted in 2009 which asked the same question. These results can be seen in Figure 68.

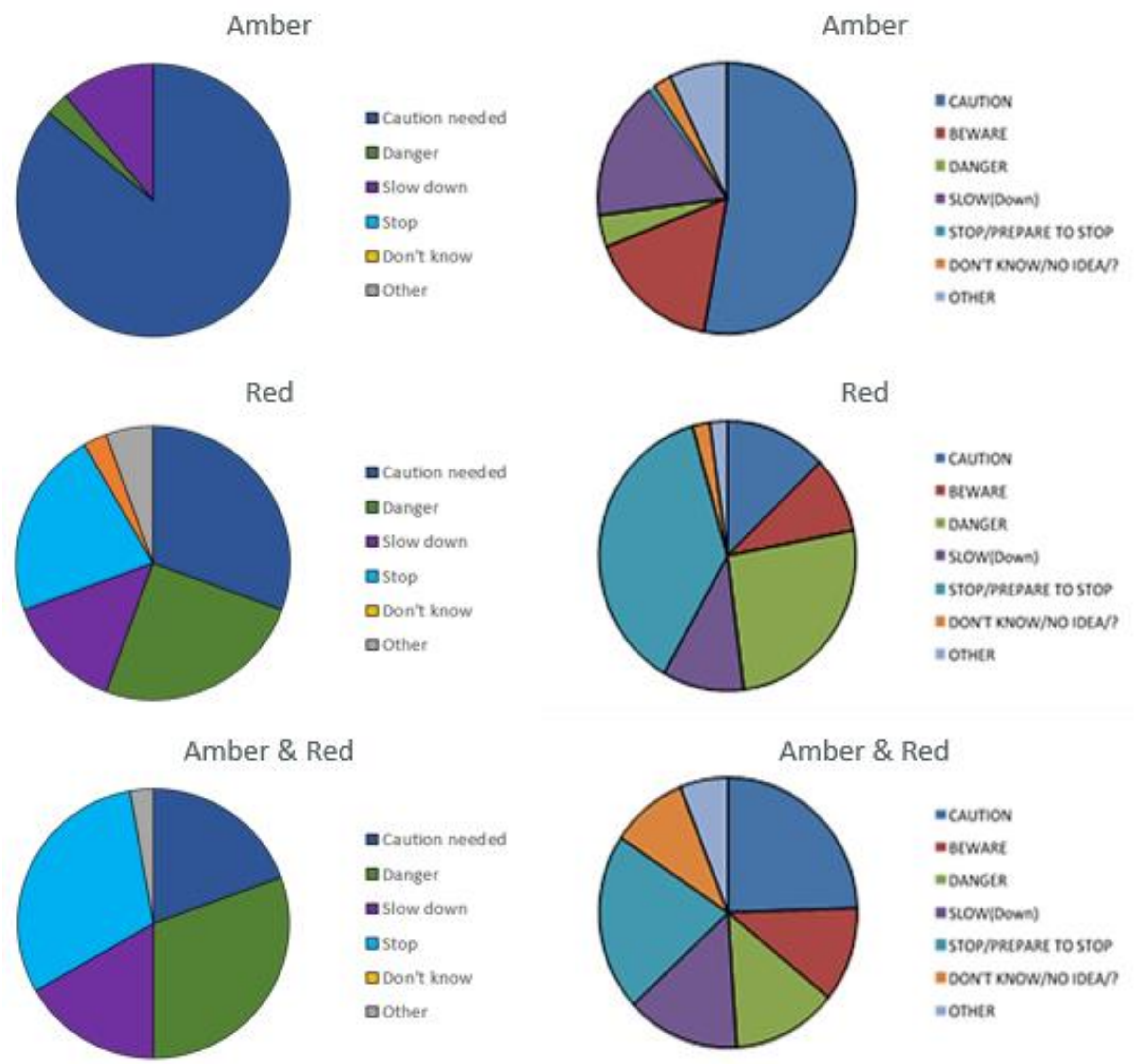

Figure 68: Pie charts displaying responses to what they thought the different colours displayed on recovery vehicles meant. The current project results are shown on the left, and the results from the (unpublished) 2009 project are shown on the right

When asked what amber lights mean, the results from the current project's survey indicated that 'caution needed' was the most common response (86%), and 'slow down' was reported by a handful of respondents (11%). The results from the 2009 survey show that the most common meaning was also 'caution' (approximately 50%). However, there were a number of other commonly reported meanings such as 'beware' (which wasn't an option in the current project's survey) and 'slow down'. This suggests that amber lights were understood less clearly in 2009 in comparison with today.

When asked what red lights mean, the most common responses from the current project were 'danger' and 'stop' (31% each), with 'caution' and 'slow down' being reported by less frequently (19% and 17% respectively). This is supported by the free text responses from a participant: ***"I thought red meant I had to stop completely"***. This suggests that the use of red flashing lights presents an extra warning of danger to road users, in comparison with amber flashing lights which presents caution. The results from the 2009 survey indicate that 'stop' was the most common meaning, followed by 'danger'. In 2009, a number of other meanings were reported such as 'slow down', 'caution', and 'beware'. This discrepancy between results propose that red lights are more understood today, emphasising on the notion that red lights indicate danger rather than warning or caution.

Respondents were asked what they perceived the combination of red and amber lights to mean, and there was a mixed response. The results from the current project's survey indicate the most common response was 'caution' (31%), followed by 'danger', and 'stop' (25% and 22% respectively). This suggests that there may be some confusion around what the combination of light colours mean, as amber lights are commonly used and seen at roadside, while the combination of red and amber is unfamiliar. Free text responses support confusion, one respondent said, ***"I wasn't clear what to do, should I stop or continue"***. The results from the 2009 survey suggest similar findings, as the most common response was 'caution', followed by 'stop', then 'beware', 'slow down', and 'danger'. These findings suggest that the combination of amber and red lights is still not fully understood as it is perceived to mean many things.

E.2.2 Conclusion and key findings

The aim of the post-trial questionnaire was to understand which colour and flash patterns were noticed and what road users perceived them to mean. The key findings of the simulator PTQ are outlined in the diagram below, along with the relevant caveats related to the findings.

Key Finding 1

Only 50% of participants were able to correctly identify both colours of lights that were displayed during the simulation trial

Key Finding 2

Participants perceived red and amber lights to be more attention grabbing when displayed in combination than when displayed separately

Key Finding 3

Participants perceived that the vehicles appeared static in both day and night conditions, and for all lighting conditions

Key Finding 4

Participants perceived that the vehicle was likely to be in a live lane when red lights were displayed either separately or in combination with amber lights

Key Finding 5

Participants stated that, if they were on-road and saw amber lights would mean caution, red lights would mean danger and stop and amber and red lights in combination would mean caution, danger, and stop

With reference to Key Finding 1, participants were more likely to recall amber than red if they only recalled one colour, and day participants were more successful at identifying which colour lights were displayed. This contrasts with the findings from the track trial, although as noted above this may be related to the slightly different workload in the track (being driven) and simulator (driving) trials. The difficulty identifying and recalling colours of lamps correctly means that caution should be taken when interpreting participants' self-reported experience. Additionally, careful attention should be paid to behavioural data to understand real effects of variations in lighting on driving behaviour.

Appendix F Participant online survey (perceptions of lighting)

F.1 Method

In total, 394 respondents from TRL's participant register completed an online questionnaire to understand their perceptions of certain colour lights and flashing patterns displayed on vehicles. Respondents were incentivised to take part in the questionnaire with a chance to win a £25 Amazon gift voucher. Exclusion criteria to take part in the questionnaire were if respondents had colour vision issues or if flashing images might cause them difficulties.

F.2 Findings

F.2.1 Perceptions and associations of different colour lamps displayed on vehicles

For this section of the survey, respondents were presented with a sequence of static blocks of colour images, as displayed below in Figure 69, and were asked a series of questions about them.

Figure 69: Static blocks of colour images

Respondents were asked the following question after each colour image was presented: "If you see these flashing lights on a vehicle, what type of vehicle do you expect to see?", along with the following response options: 'emergency service', 'National Highways Traffic Officers', 'breakdown/recovery', 'roadworks/construction', 'wide load', or 'I don't know'. the results can be seen in Figure 70. Respondents could choose more than one response option for this question; therefore, percentages are used to interpret the results.

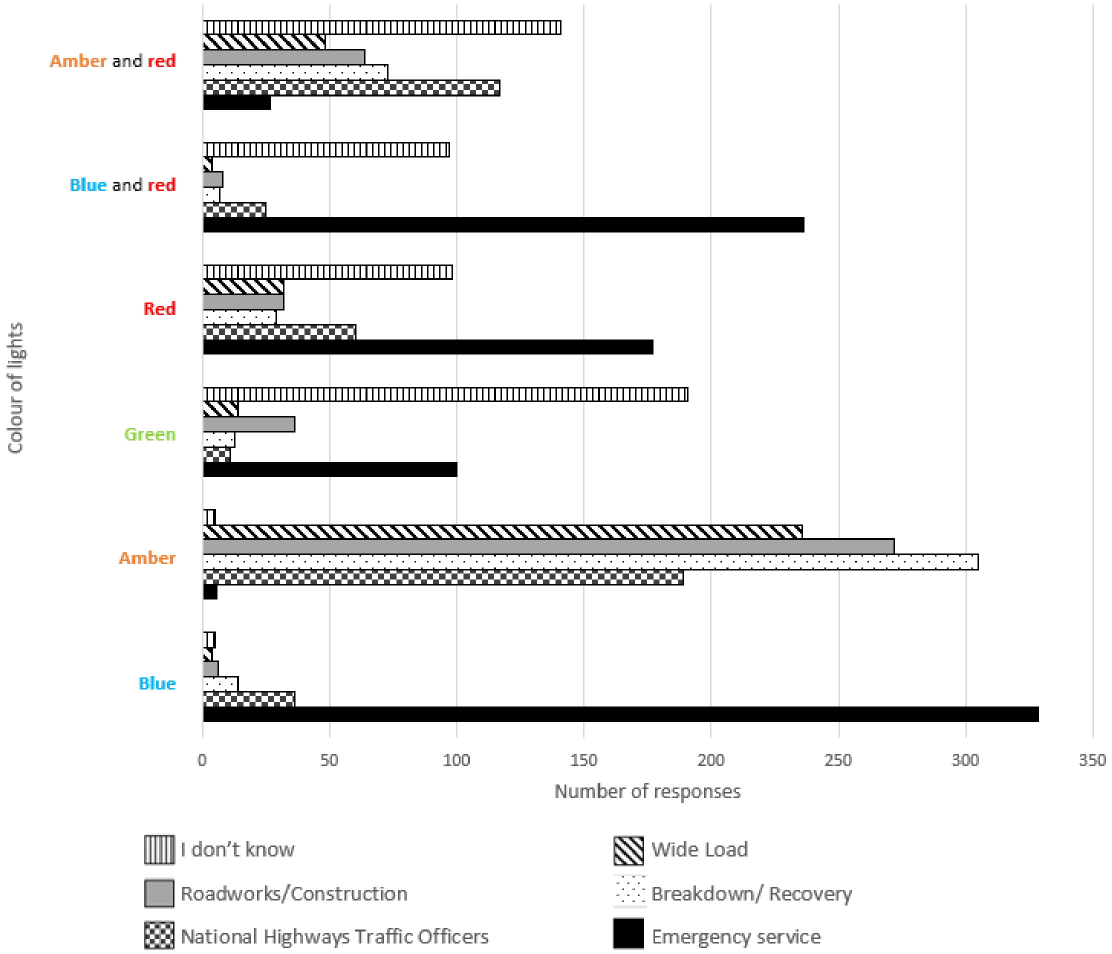

Figure 70: Clustered bar chart showing what type of vehicles respondents expected to see when they see a certain colour of lights displayed

Respondents' understanding of the meanings of lighting colours were mixed. The findings indicate that if amber and red flashing lights are displayed together, there was not a majority-driven response. 30% of the respondents reported that they would not know what vehicle to expect, 25% reported that they would expect to see a National Highways Traffic Officer vehicle, or breakdown/recovery vehicle (18%).

If blue and red flashing lights were displayed together, most respondents reported that they expect to see an emergency service vehicle (63%).

Responses indicate that if red flashing lights were to be displayed on their own, there wasn't a majority-driven response. 41% of the responses indicate that respondents expect to see an emergency service vehicle, followed by the respondents not knowing what vehicle to expect if red flashing lights were displayed (23%).

If green flashing lights were to be displayed on a vehicle, the majority of responses suggest that the respondents would not know what vehicle they would expect to see (52%), followed by an emergency service vehicle (27%). This suggests that green lights are not as well understood as other light colours.

Responses suggest that if amber flashing lights were displayed on a vehicle, there was not a majority-driven response. The most agreed upon vehicle type reported was a breakdown/recovery vehicle (30%), followed by roadworks/construction vehicle (27%) and a wide loads vehicle (23%). The least commonly reported response for this scenario was 'I don't know' (0.5%), suggesting that amber lights are relatively well understood by the public as being the colour of everything except emergency vehicles.

If blue flashing lights were displayed on a vehicle, the majority of responses suggest that respondents expect to see an emergency services vehicle (84%). The least commonly reported responses for this question were 'wide load' (1%) and 'I don't know' (1%), which similar to, amber lights, suggests that blue flashing lights are generally well understood by the public and they know what vehicle to expect to see.

As part of this research, we wanted to understand whether lights affect people's expectation of where recovery vehicles are and whether they are moving. Respondents were asked the following question: "If you see these flashing lights on a vehicle, do you expect it to be parked or moving, and where do you expect it to be?". The options for the latter question were 'alongside the road (e.g., in a layby)', 'in a live lane/in the carriageway', or 'I don't know'. The findings from this question are presented in Figure 71 below.

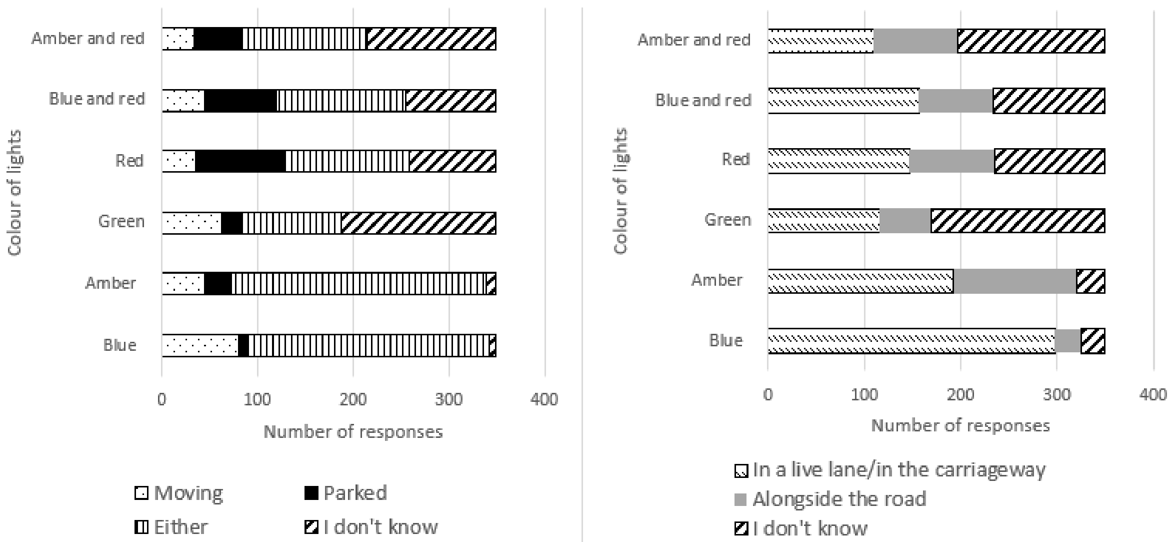

Figure 71: Stacked charts showing responses to whether respondents expect the vehicle to be parked or moving (left) and where the respondents expect the vehicle to be located when displaying certain colour lights (right)

If respondents saw amber and red flashing lights on a vehicle, the findings suggest most respondents would not know if the vehicle was parked or moving (*N*=135). A similar number of respondents reported that they expect the vehicle to be either parked or moving (*N*=130), and fewer expect it would be parked (*N*=50) or moving (*N*=34). The most frequently reported response to the expected location of the vehicle was 'I don't know' (*N*=153), followed by in a live lane (*N*=110), then alongside the road (*N*=86).

If respondents saw blue and red flashing lights on a vehicle, the responses indicate that they would expect the vehicle to be either moving or parked (*N*=136). The next most frequently reported response was that they would not know (*N*=94), followed by parked (*N*=74), then moving (*N*=45). The majority of respondents expect the vehicle to be in a live lane (*N*=156), followed by not knowing (*N*=116), then alongside the road (*N*=77).

Similar to the first two light colour conditions, if red flashing lights were displayed on vehicles, there were mixed responses to whether respondents expect the vehicle to be moving or not. The most common answer for this condition was either parked or moving (*N*=132), followed by parked (*N*=92), not knowing (*N*=90), then moving (*N*=35). The most frequently reported response to where respondents expect the vehicle to be was in a live lane (*N*=147), followed by not knowing (*N*=113), then alongside the road (*N*=89).

If green flashing lights were to be displayed on a vehicle, the most common response was that the respondents would not know whether it would be moving or not (*N*=161). This was the highest response for not knowing across all light colour conditions. The next most common response was either (*N*=106), followed by moving (*N*=63), then parked (*N*=19). Most respondents reported that they would not know the location of the vehicle (*N*=179). The next most common answer was in a live lane (*N*=116), followed by alongside the road (*N*=54).

If amber flashing lights are displayed on vehicles, the responses suggest that the most common expectation would be that the vehicle was either moving or parked (*N*=255), followed by moving (*N*=45), then parked (*N*=28). This lighting condition had a low response rate of the respondents not knowing if the vehicle would be moving or not (*N*=10). Most respondents said that they would expect the vehicle to be in a live lane (*N*=192), followed by alongside the road (*N*=129). A small portion of respondents said they would not know where to expect the vehicle to be (*N*=28).

Similar to amber flashing lights, if blue flashing lights are displayed on vehicles, the responses imply that the respondents know to expect to see the vehicle either moving or parked (*N*=255), followed by moving (*N*=81), parked (*N*=7), then not knowing (*N*=6). The blue light condition had the lowest response rate of respondents not knowing if the vehicle would be moving or not, implying that blue lights are commonly expected on the roads. The majority of respondents expect the vehicle to be in a live lane (*N*=297), followed by alongside the road (*N*=28). Similarly, to amber flashing lights, a small portion of respondents said they would not know where the vehicle would be (*N*=24).

The next sub-section looks at respondents' perceptions of meanings of different colour lights. Respondents were asked questions regarding what they thought the colour of lights on a vehicle mean, and what action they think they should take depending on the colour of lights. The findings from these questions are compared and presented below.

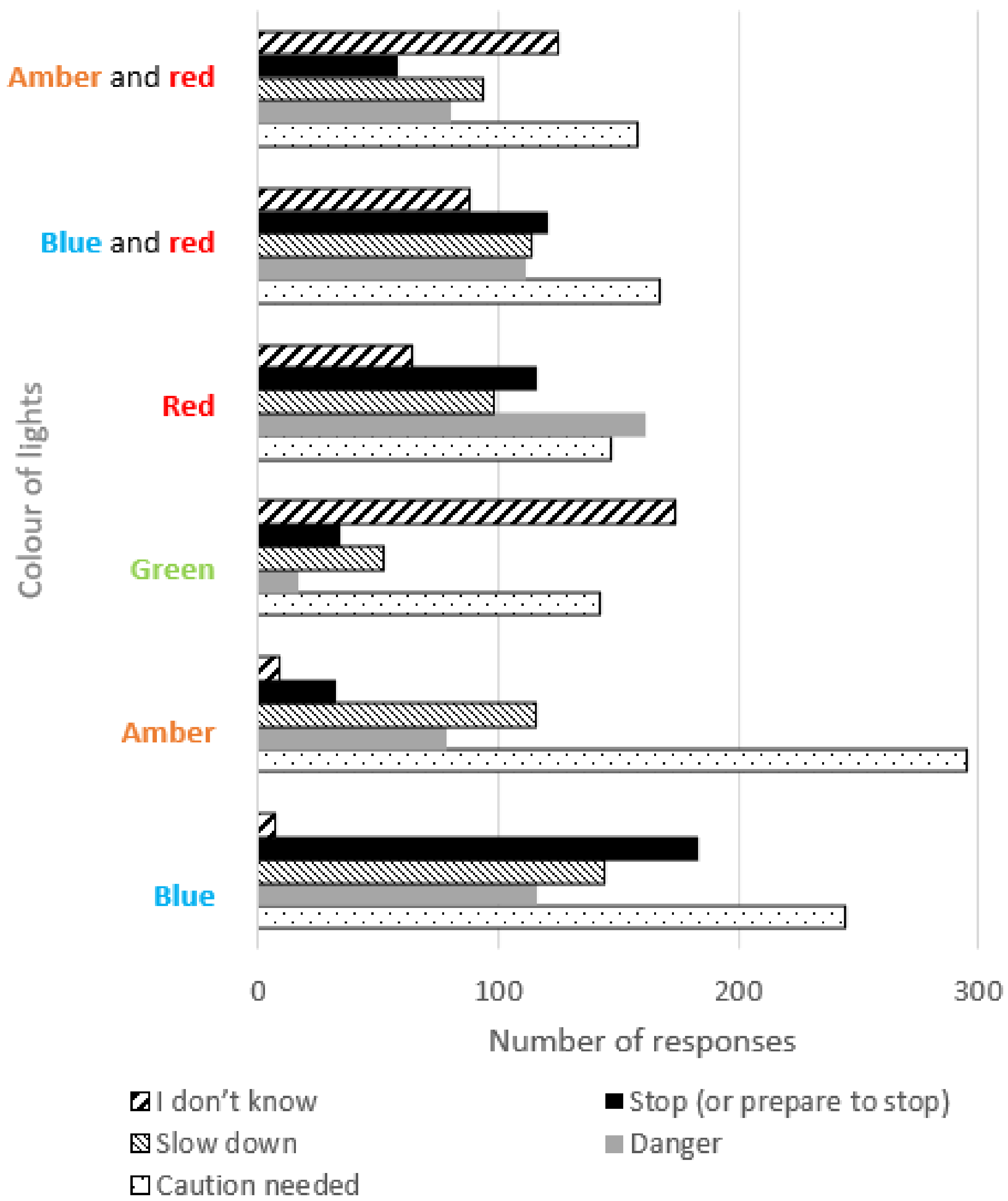

Figure 72: Clustered bar chart displaying what respondents thought certain colour lights displayed on vehicles meant

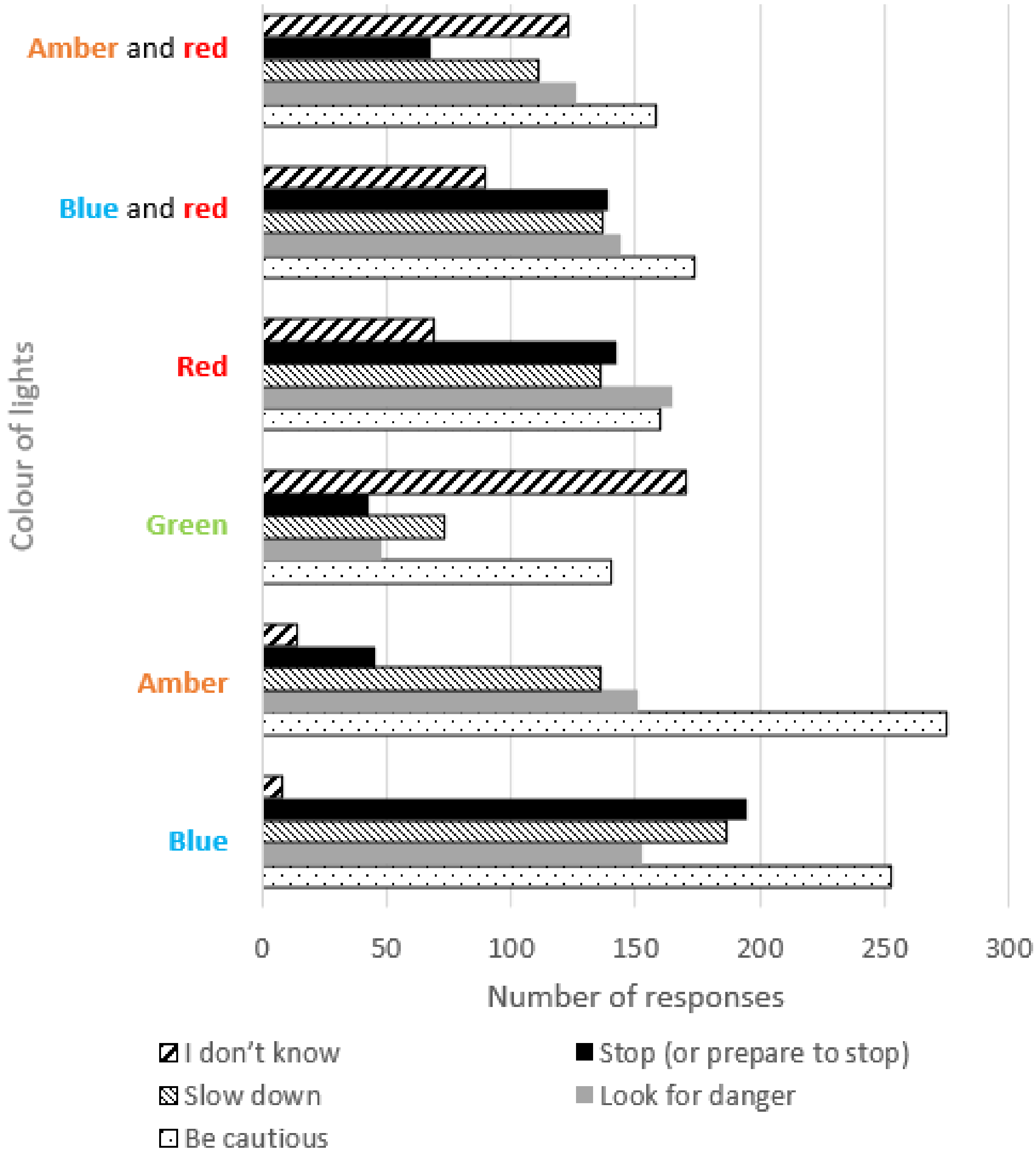

Figure 73: Clustered bar chart displaying what action respondents they think they should take

According to the findings on what respondents thought the different coloured lights mean (Figure 72), the most common light conditions associated with meaning 'caution needed' were amber lights (*N*=295) and blue lights (*N*=245). With reference to the meaning 'danger', the light conditions most associated were red lights (*N*=161), blue lights (*N*=116), and red and blue lights in conjunction (*N*=112). The meaning of 'slow down' was most associated with blue lights (*N*=144), followed by amber lights (*N*=116) and blue and red lights (N=114). The most common light conditions associated with meaning 'stop (or prepare to stop)' were blue lights (*N*=183), blue and red lights (*N*=121), and red lights (*N*=116). The light conditions with the most common response rate of not knowing what they might mean was green lights (*N*=174), and amber and red lights (*N*=125). This suggests that if amber and red lights were to be permitted for use by recovery vehicles, the public would need to be educated about what they mean and how they should act. The light conditions with the lowest response rate of not knowing were blue lights (*N*=7) and amber lights (*N*=9). This implies that these lights, when displayed on vehicles, are most understood by the public.

With regards to the actions respondents think they should take (Figure 73); the responses are relatively aligned. One key difference is for the amber light condition, whereby a small proportion of respondents (*N*=78) stated that they thought amber lights meant 'danger, while a larger proportion of respondents expressed that they would look for danger (*N*=151). Similar for amber and red lights in conjunction, a small proportion of respondents stated that they think this colour combination means 'danger' (*N*=80), while there were more responses stating that they would look for danger (*N*=126). This highlights a discrepancy in what respondents thought certain colours mean and what action they think they should take, indicating that responses regarding perceptions and beliefs do not always align with their intended behaviours.

F.2.2 Flash patterns

Figure 74 is a static image of the start of the videos (shown at 25 frames per second), with lights '1' and '2' representing a pattern often seen on emergency and service vehicles (numbers were not shown as part of the animated lighting patterns).

Figure 74: Image representing a light bar as displayed on emergency and service vehicles

The flash pattern conditions and speeds are explained in Table 14. 1 Hz represents a slower flash pattern, 4 Hz represents a faster flash pattern. UK vehicle lighting regulations permit warning beacons to flash at a rate between 1 and 4 Hz.

Table 14: Flash pattern conditions and speeds

Pattern number	Flash pattern and speed
Flash 1	1 Hz, 1 and 2 simultaneously
Flash 2	1 Hz, 1 and 2 alternatively
Flash 3	2 Hz, 1 and 2 simultaneously
Flash 4	2 Hz, 1 and 2 alternatively
Flash 5	3 Hz, 1 and 2 simultaneously
Flash 6	3 Hz, 1 and 2 alternatively
Flash 7	4 Hz, 1 and 2 simultaneously
Flash 8	4 Hz, 1 and 2 alternatively

F.2.2.1 Flash patterns – user type

The survey assessed respondents' perceptions and associations of beacon flash patterns and the findings are shown in this section. Respondents were shown a series of eight three-second videos, with varying flashing patterns as identified in Table 14. The animated videos were white, respondents were instructed not to consider the colour.

Respondents were asked two questions following each video. The first question explored whether respondents thought the flashing lights displayed in the video was more likely to be an emergency vehicle or a service (i.e. roadworks, breakdown or recovery) vehicle, see Figure 75. The second question explored whether the respondents would expect the vehicle displaying the lighting pattern shown in the video to be parked or moving. The results from these questions are displayed in Figure 76.

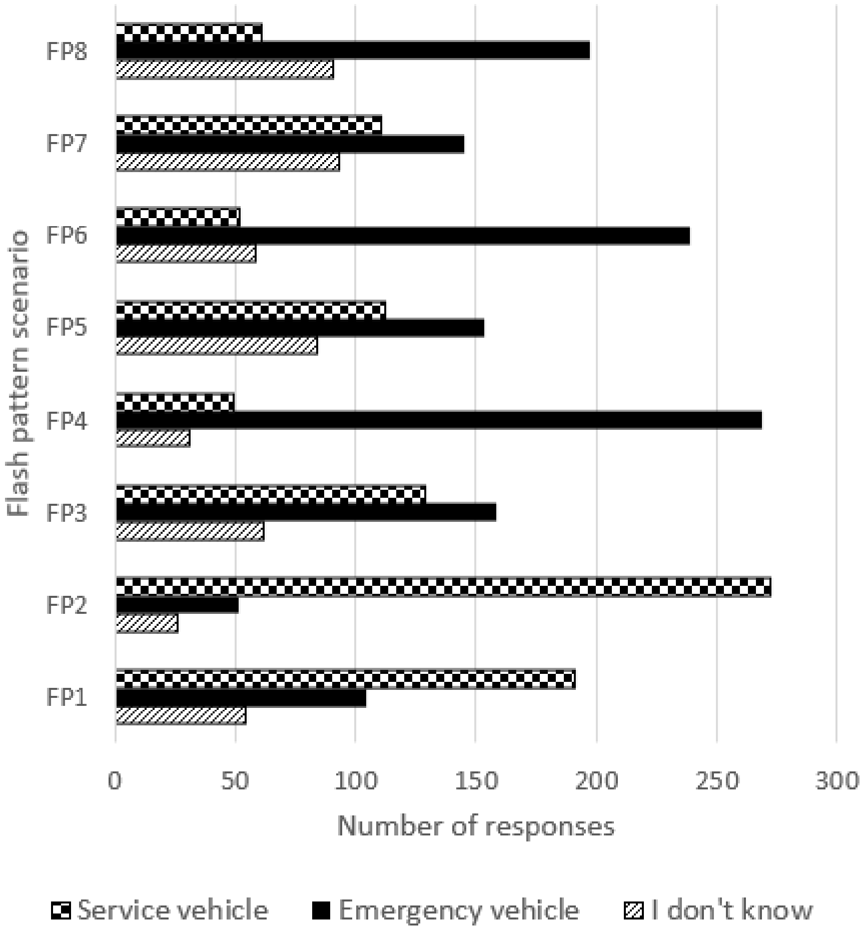

Figure 75: Clustered bar chart displaying where respondents thought the vehicle would be

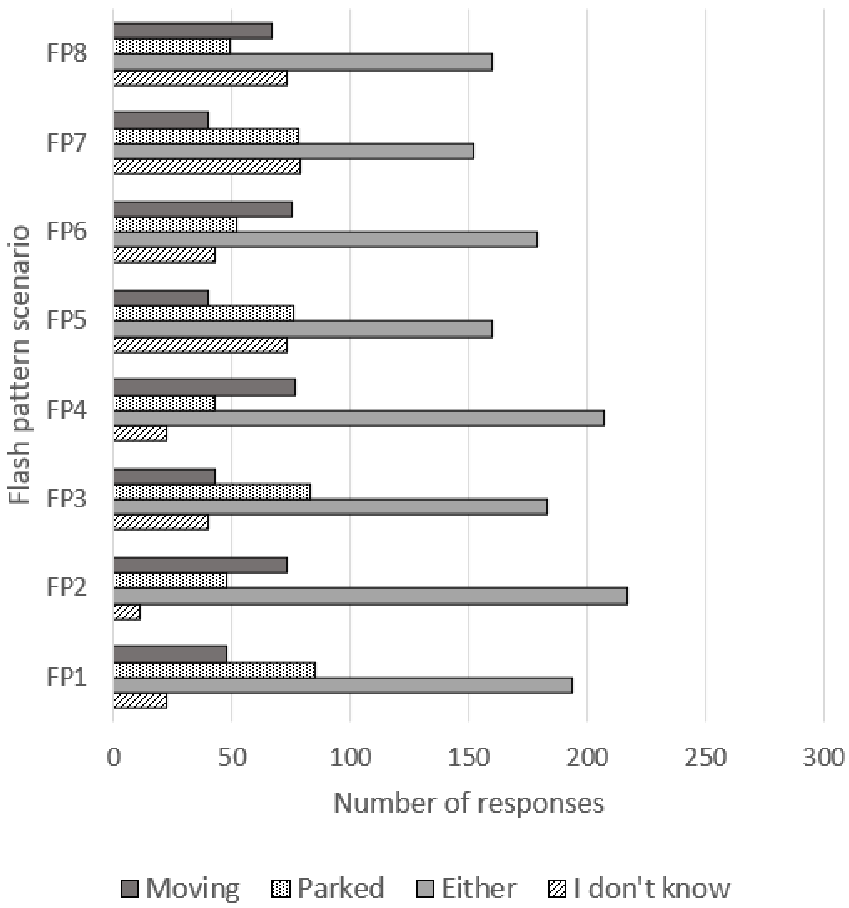

Figure 76: Clustered bar chart displaying whether respondents expect the vehicle to be parked or moving

For all of the flash pattern conditions, the majority of respondents stated that they expect the vehicles to be either moving or parked. For flash pattern 1, responses indicated that the majority of respondents expect the vehicle to be a service vehicle (*N*=191), compared to an emergency vehicle (*N*=104). Approximately a fifth of respondents (*N*=54) reported that they did not know what type of vehicle to expect if they saw a vehicle displaying flash pattern 1. Flash pattern 2 elicited most respondents to expect the vehicle to be a service vehicle (*N*=272), and to be either moving or parked (*N*=217). Flash pattern 3 saw the majority of respondents stating that they expect the vehicle to be an emergency vehicle (*N*=158), followed closely by a service vehicle (*N*=158). Flash pattern 4 elicited a large proportion of respondents reporting that the expect the vehicle to be an emergency vehicle (*N*=269). For flash pattern 5, the most common response to what vehicle the respondents expect was an emergency vehicle (*N*=153). Flash pattern 6 saw a similar response, with the majority of respondents expressing that they expect the vehicle to be an emergency vehicle (*N*=239). For flash pattern 7, most respondents stated that they expected the vehicle to be an emergency vehicle (*N*=145), although closely followed by expecting a service vehicle (*N*=111). This flash pattern saw the most responses of ‘I don’t know’ (*N*=93). Lastly, flash pattern 8 saw the majority of respondents reporting that they expect the vehicle to be an emergency vehicle (*N*=197).

In conclusion, 6 out of the 8 flash patterns (numbers 3-8) saw respondents reporting they were more likely to expect to see an emergency vehicle. The flash patterns that elicited the most respondents to expect to see an emergency vehicle were conditions in which the flash patterns were quicker (2-4 Hz), and lights 1 and 2 were displayed alternatively, opposed to simultaneously. This suggests that flashing lights displayed alternatively (see Figure 1 and Table 14) are more commonly associated with road users expecting to see an emergency vehicle, in comparison with flashing lights displayed at the same time.

F.2.2.2 Flash patterns – 'off' period

This section shows the findings of the presentation of 8 nine-second videos to understand perceptions and impacts of the use of all 'off' periods, which may improve approaching drivers' ability to identify pedestrians in close proximity of vehicles. The nine-second videos were the same videos as displayed to the respondents in Section F.2.2, repeated three times. Respondents were asked three questions following each video; the first two questions were the same as the section before (what vehicle they expected it to be, see Figure 77, and whether they expected the vehicle to be parked or moving, see Figure 78), with an additional question asking them what action they would take, with the following choices of 'be cautious', 'look for danger', 'slow down', 'stop (or prepare to stop)', or 'I don't know' (see Figure 79).

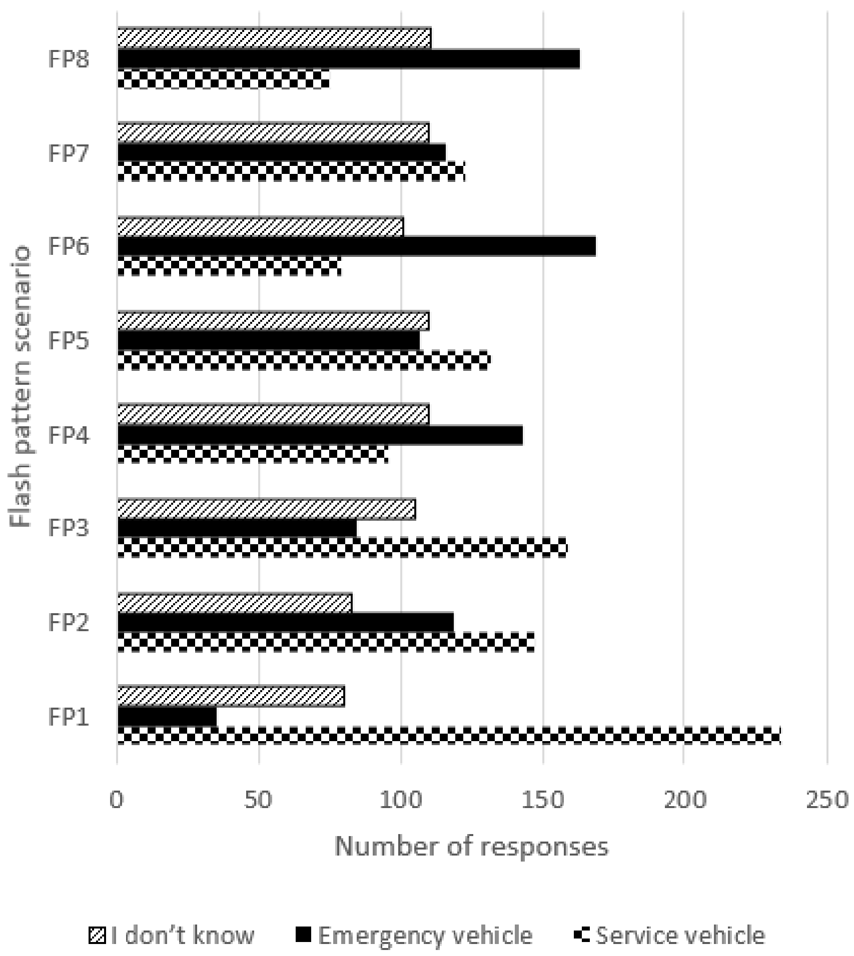

Figure 77: Clustered bar chart displaying where respondents thought the vehicle would be

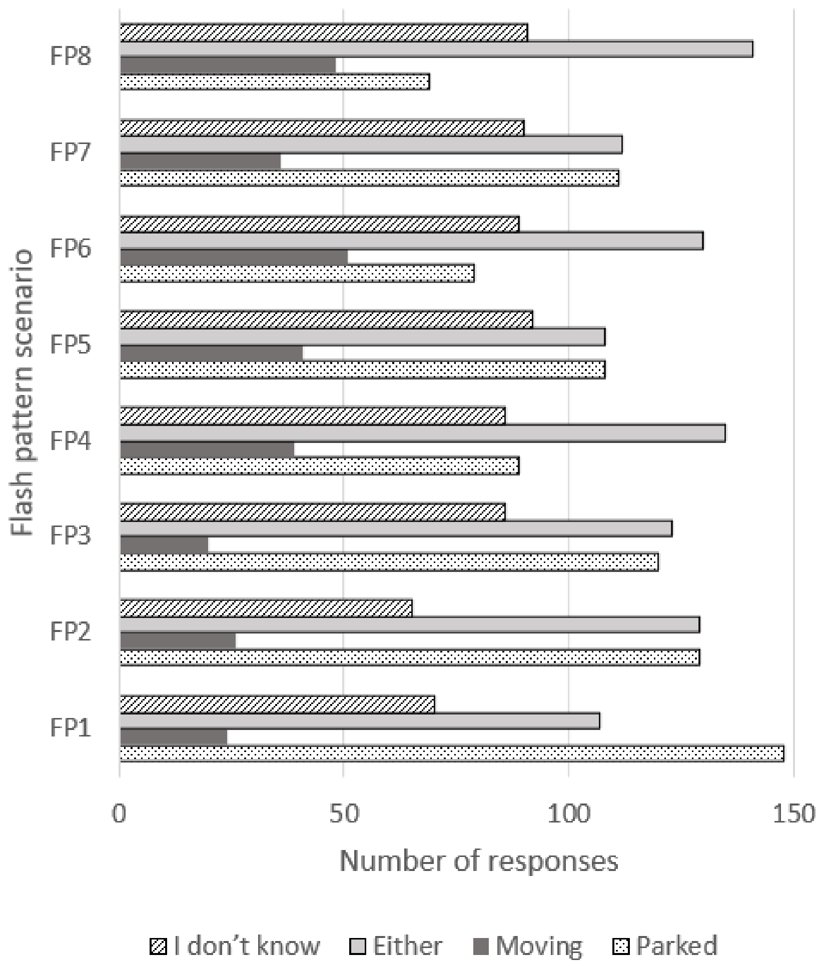

Figure 78: Clustered bar chart displaying whether respondents expect the vehicle to be parked or moving

With regards to flash pattern 1, responses indicated that respondents were most likely to expect to see a service vehicle (*N*=234), and for this vehicle to be parked (*N*=148). For flash pattern 2, the most common response was that respondents expect to also see a service vehicle (*N*=147), followed closely by an emergency vehicle (*N*=119), and for this vehicle to either be parked (*N*=129) or either parked or moving (*N*=129). Flash pattern 3 saw most respondents expecting to see a service vehicle (*N*=159), and for this vehicle to be either parked or moving (*N*=123), closely followed by parked (*N*=120). With regards to flash pattern 4, the most common answer for what vehicle respondents expected to see was an emergency vehicle (*N*=143), and for this vehicle to be either parked or moving (*N*=135). For flash pattern 5, more respondents expect to see a service vehicle (*N*=132) compared to an emergency vehicle (*N*=107), and for this vehicle to be either parked (N=108) or either parked or moving (*N*=108). Flash pattern 6 saw the majority of respondents reporting that they would expect to see an emergency vehicle (*N*=169) and for this vehicle to be either parked or moving (*N*=130). With regards to flash pattern 7, responses were relatively similar between options. The most respondents expected to see a service vehicle (*N*=123), followed by an emergency vehicle (*N*=116), then not knowing (*N*=110). A similar number of respondents stated that they would expect the vehicle to be parked (*N*=111), or either parked or moving (*N*=112). Lastly, flash pattern 8 saw most respondents stating that they would expect the vehicle to be an emergency vehicle (*N*=163), and to be either moving or parked (*N*=141).

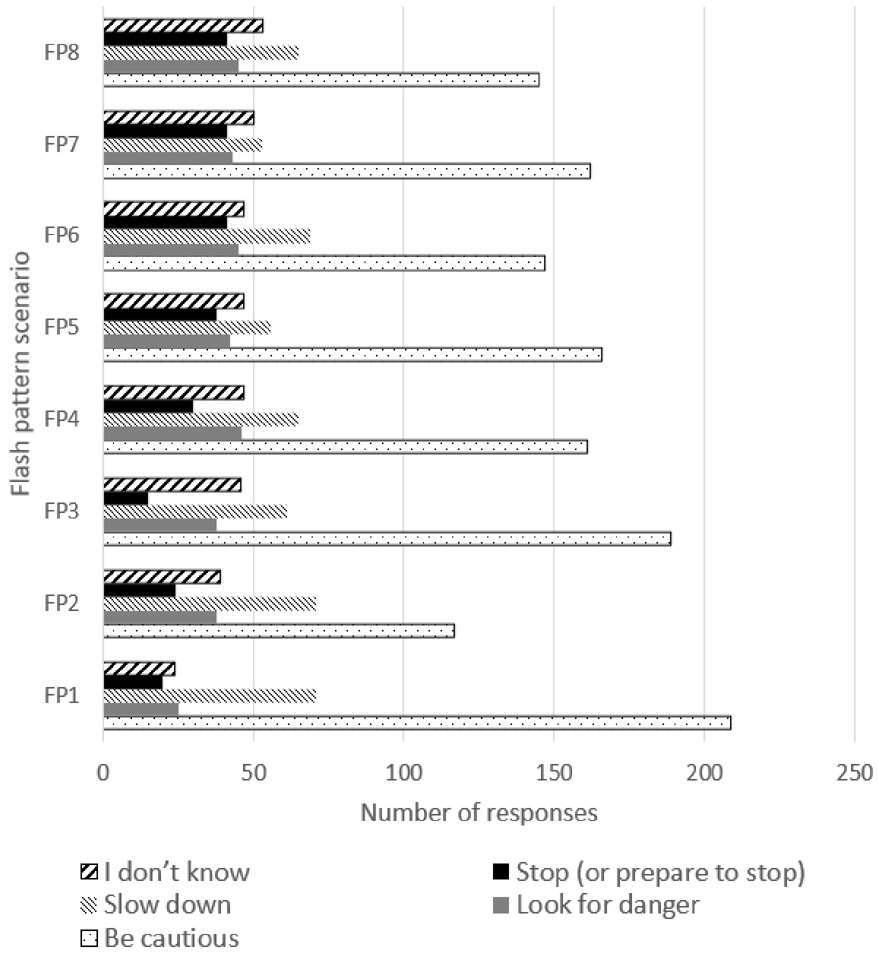

Figure 79: Clustered bar chart representing participant responses to what action they would take depending on the flash pattern displayed on a vehicle

The response from **Figure** 79 indicates that the majority of respondents stated that they would be cautious if they saw a vehicle displaying all flash pattern conditions. The next most common action across all flash pattern conditions was that the respondents would slow down. The findings suggest that the quicker the lights are flashing, the more likely respondents are to stop (or prepare to stop), for example more respondents reported this action for flash pattern 8 (N=41) compared to flash pattern 1 (N=20).

In the next sub-section of the survey, respondents were shown a short video of a red cross with alternate left and right flashing red lamps, a representation of the 'Red X' as displayed above lanes on motorways (see Figure 80).

Figure 80: Still image of a red cross with red flashing lamps in the right top and bottom corner, representing the flashing signal as displayed above lanes on motorways

Respondents were asked the following questions: “If you see this signal, what do you think it means?” and “if you see this signal, what action do you think you should take?”. The results from these questions are displayed in Figure **81** and Figure 82 below.

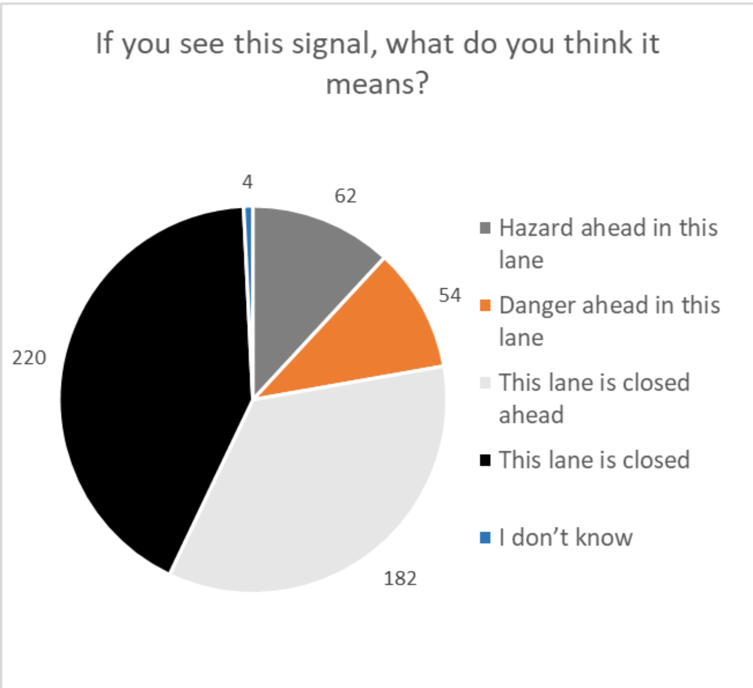

Figure 81: Pie chart showing responses to what respondents think the signal means

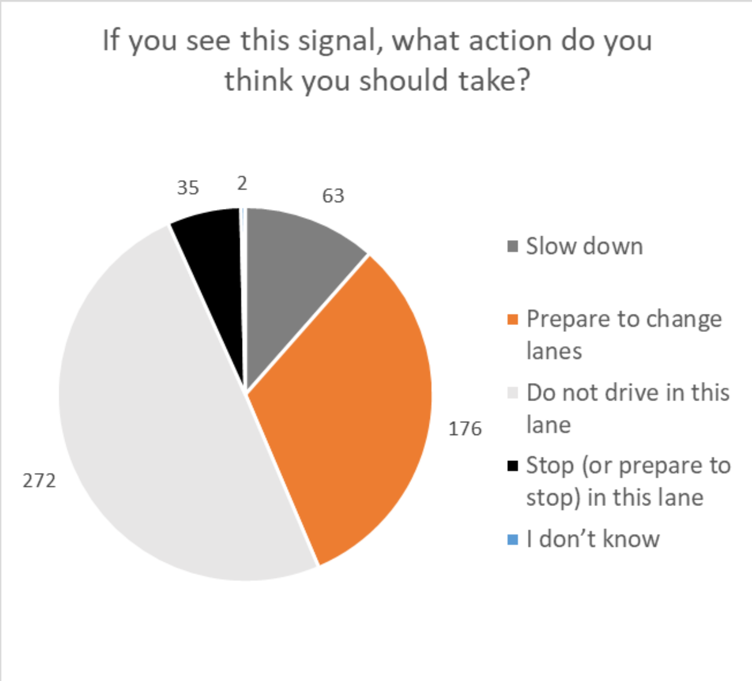

Figure 82: Pie chart showing responses to what action respondents think they should take

Figure **81** suggests that the most reported meaning for the red cross was 'this lane is closed' (*N*=220), followed by 'this lane is closed ahead' (*N*=182). The least common response was 'I don't know' (*N*=4) which suggests that this symbol is well understood by road users. Figure 82 states that the most reported action respondents think they should take if they see the red cross was 'do not drive in this lane' (*N*=272), followed by 'prepare to change lanes' (*N*=176).

Highway code Rule 258 states:

> *Red flashing light signals and a red 'X' on a sign identify a closed lane in which people, stopped vehicles or other hazards are present. You MUST NOT drive in a closed lane.*

Highway Code (DfT)

Lastly, respondents were asked the following question: "If you see flashing lights on a stopped vehicle, do you expect to see people nearby?". The result from this question is shown below.

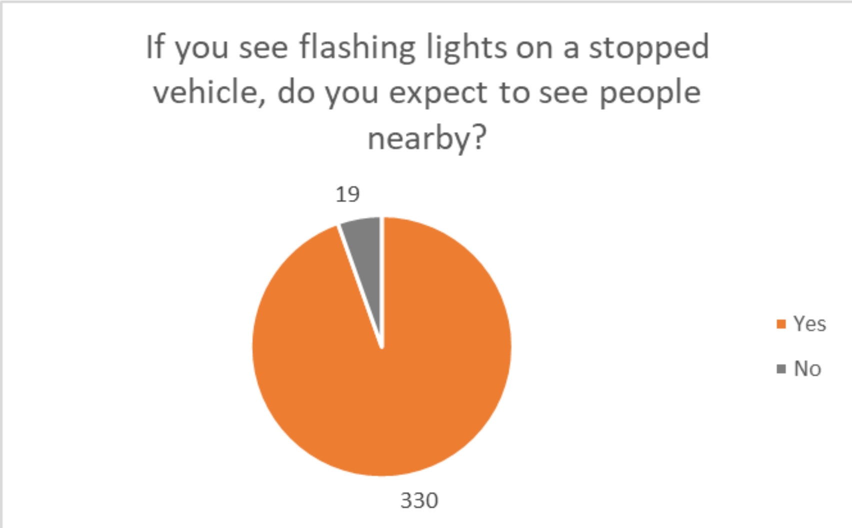

Figure 83: Pie chart showing responses to whether respondents expect to see people nearby a stopped vehicle

The findings from this question indicate that a strong majority of respondents (*N*=330) stated that they would expect to see people nearby if they see flashing lights on a stopped vehicle. This suggests that independently of what colour and flashing pattern the lights displayed on a vehicle were, the public are aware that there will be dangers such as people near the vehicle at the scene.

F.3 Conclusion and key findings

This online survey assessing the public's perception of light colours and flash patterns displayed on vehicles aimed to understand how other road users interpret different colour and flash conditions. The key findings from the survey are outlined in the diagram below.

Key Finding 1

Red lights are most associated with emergency vehicles, amber lights are most associated with breakdown/ recovery vehicles, and red and amber lights together are not well known enough by respondents to make a judgement.

Key Finding 2

Respondents expect vehicles displaying amber lights to be either parked or moving and to be in a live lane (*N*=266). There was not a conclusive finding regarding whether respondents expect vehicles displaying red lights to be parked or moving.

Key Finding 3

Amber lights are most associated with meaning 'caution needed' (*N*=295), red lights are most associated with meaning 'danger' (*N*=161), and amber and red lights together are most associated with meaning 'caution needed' (*N*=158).

Key Finding 4

Quicker flash patterns are more associated with respondents expecting to see an emergency vehicle rather than a service vehicle, and respondents are more likely to stop or prepare to stop.

Key Finding 5

When shown a video of a red cross with alternative flashing lights in the corners, the majority of respondents think this means that the lane is closed (*N*=220), and they would not drive in the lane (*N*=272).

Appendix G Expert review lighting patterns

The following lighting patterns were shown at the Expert Viewing event:

Pattern (fpm = flashes per minute)	Condition and distances
P1 – 75 fpm amber flash	Daylight (200m, 300m); Darkness (200m, 300m)
P2 – 75 fpm amber alternating side flash	Daylight (200m, 300m); Darkness (200m, 300m)
P3 – 120 fpm amber flash	Daylight (200m, 300m); Darkness (200m, 300m)
P4 – 120 fpm amber alternating side flash	Daylight (200m, 300m); Darkness (200m, 300m)
P5 – 240 fpm amber flash	Daylight (200m, 300m); Darkness (200m, 300m)
P6 – 240 fpm amber alternating side flash	Daylight (200m, 300m); Darkness (200m, 300m)
P7 – 75 fpm red flash	Daylight (200m); Darkness (200m, 300m)
P8 – 75 fpm red alternating side flash	Daylight (200m); Darkness (200m, 300m)
P9 – 120 fpm red flash	Daylight (200m); Darkness (200m, 300m)
P10 – 120 fpm red alternating side flash	Daylight (200m); Darkness (200m, 300m)
P11 – 240 fpm red flash	Daylight (200m); Darkness (200m, 300m)
P12 – 240 fpm red alternating side flash	Daylight (200m); Darkness (200m, 300m)
P13 – amber alternating varied speed	Daylight (300m); Darkness (200m, 300m)
P14 – alternating red/amber double varied speed	Daylight (300m); Darkness (200m, 300m)
P15 – double flash reds – fast	Daylight (300m); Darkness (200m, 300m)
P16 – In-out amber with flashing reds	Daylight (300m); Darkness (200m, 300m)

Appendix H Expert review results

The detailed findings from the expert event are presented in this appendix. Note that all findings are provided as indicative only, since the small sample size is not sufficient to support statistical tests of significance.

H.1 Attention grabbing

How attention grabbing the light patterns were perceived to be measured on a scale 'not at all attention grabbing to 'very attention grabbing'.

H.1.1 Patterns P1-P6 – day and night

The following section presents the comparisons of lighting patterns P1-P6. The flashes per minute of these patterns varied and all flashes were either amber alternating or amber flash.

It can be seen that the patterns presented at 120 fpm alternating, 240 fpm flashing and 240 fpm alternating were perceived as attracting more attention across both day and night scenarios, at 300 metres (see Figure 84 and Figure 85).

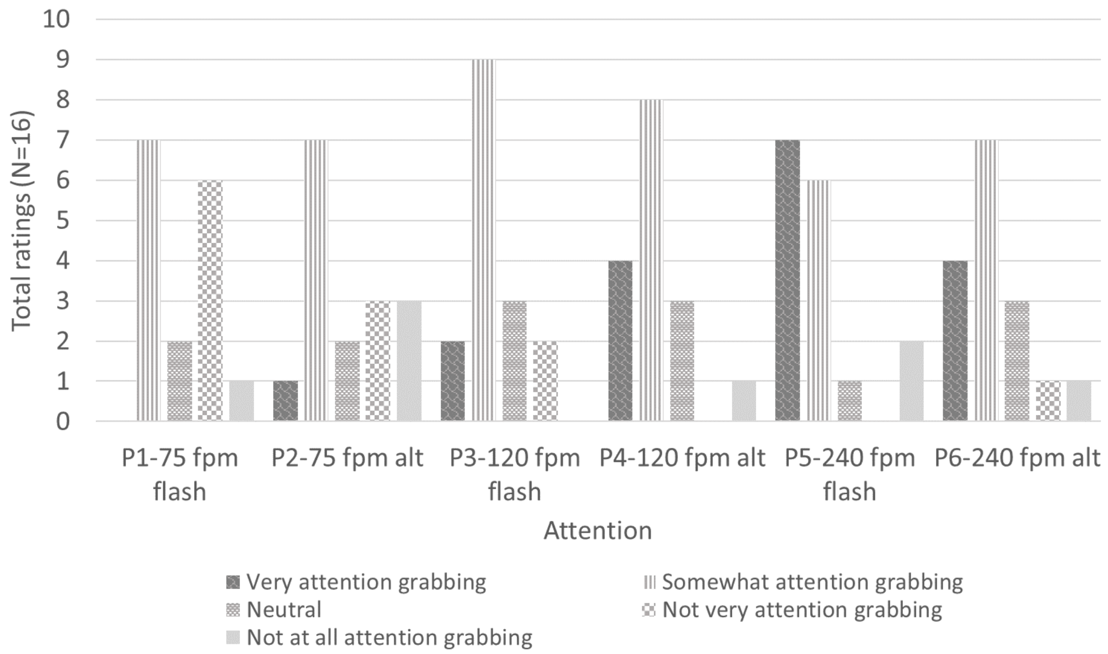

Figure 84: Graph to show the perceived attention grab of the vehicle at 300 metres in the day

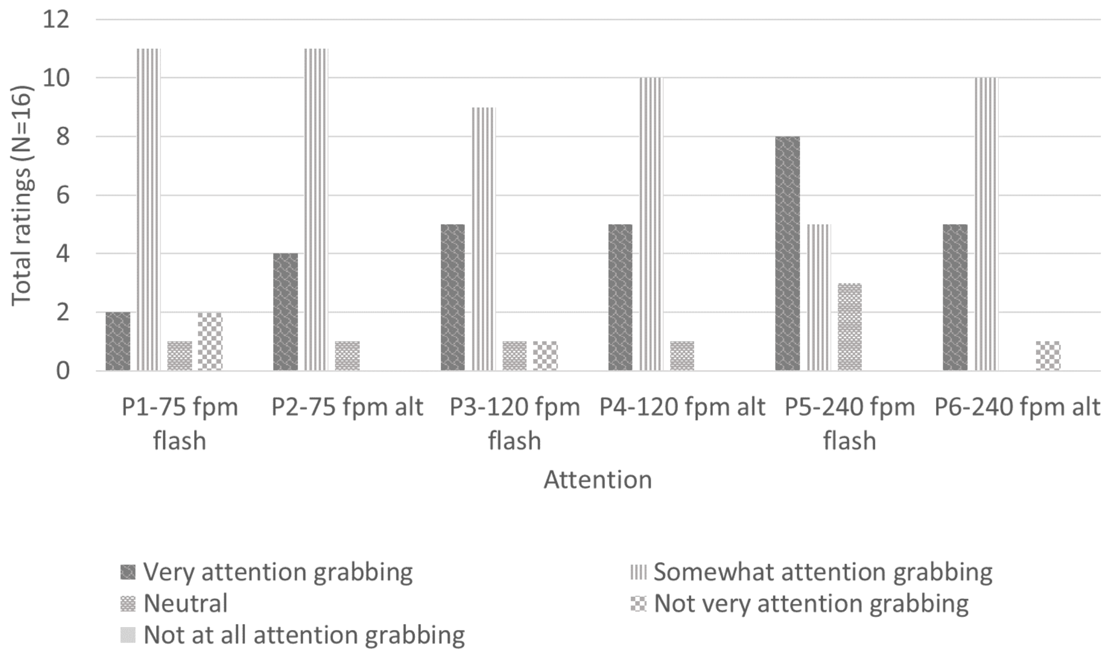

Figure 85: Graph to show the perceived attention grab of the vehicle at 300 metres at night

As Figure 86 and Figure 87 show, the patterns presented at 120 fpm alternating, 240 fpm flashing and 240 fpm alternating were perceived to be more attention grabbing in the night at 200 metres, compared to the day at 200 metres. When examining the day 200 metres data exclusively, no lighting pattern appears to be particularly attention grabbing.

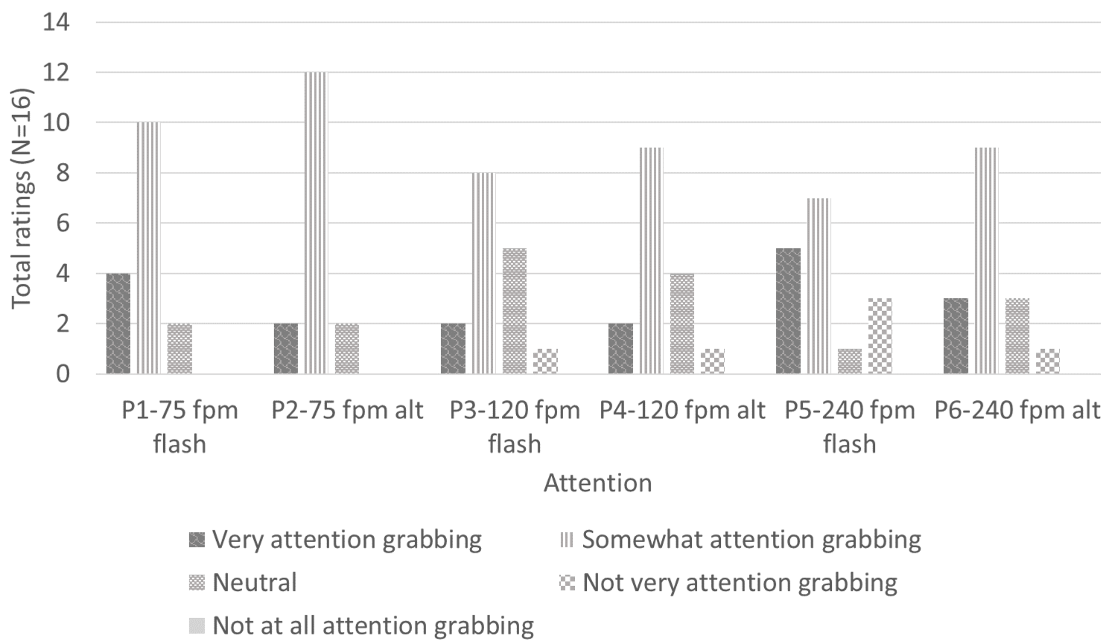

Figure 86: Graph to show the perceived attention grab of the vehicle at 200 metres in the day

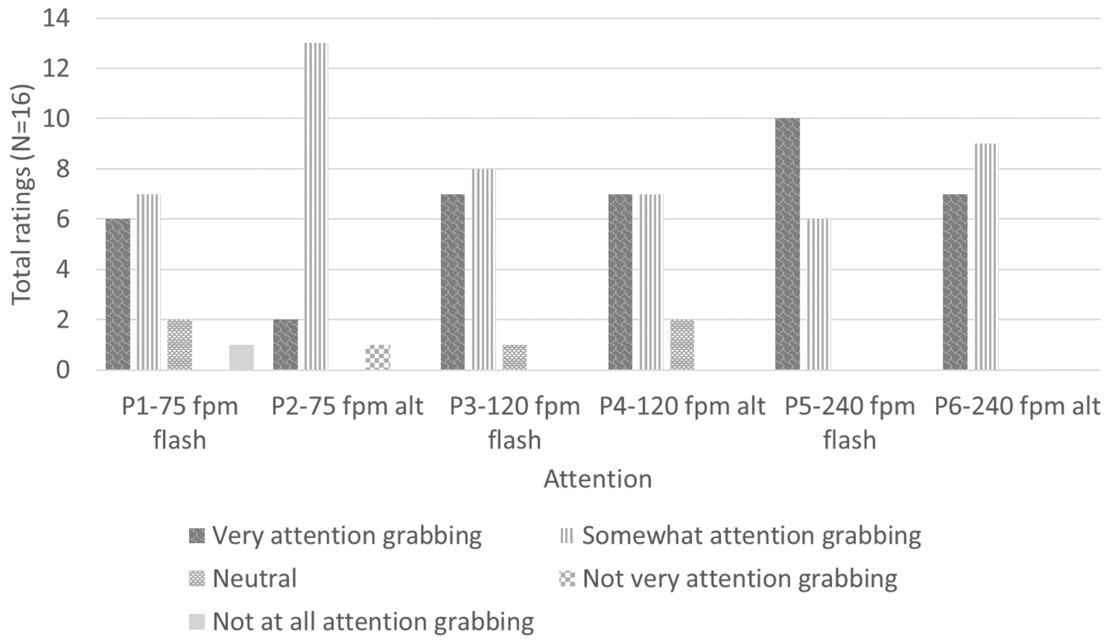

Figure 87: Graph to show the perceived attention grab of the vehicle at 200 metres in the night

H.1.2 Patterns P1-P6 – distance

When comparing the attention ratings at 200 metres and 300 metres in the day and night, no significant differences were found between lighting patterns P1-P6.

H.1.3 Patterns P7-P12 – day and night

The following section presents the comparisons of lighting patterns P7-P12. The flashes per minute of these patterns varied and all flashes were red.

When comparing the total ratings of lighting patterns P7-P12 at 300 metres in the day and night, as Figure 88 and Figure 89 show, the majority of lighting patterns were perceived as attracting more attention at night than in the day.

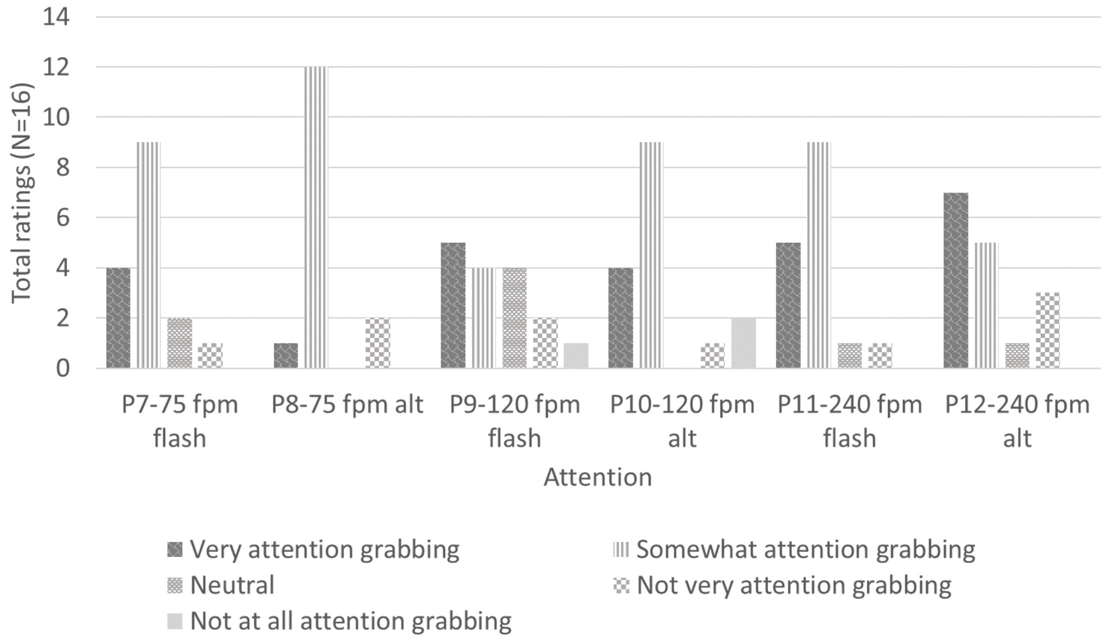

Figure 88: Graph to show the perceived attention grab of the vehicle at 300 metres in the day

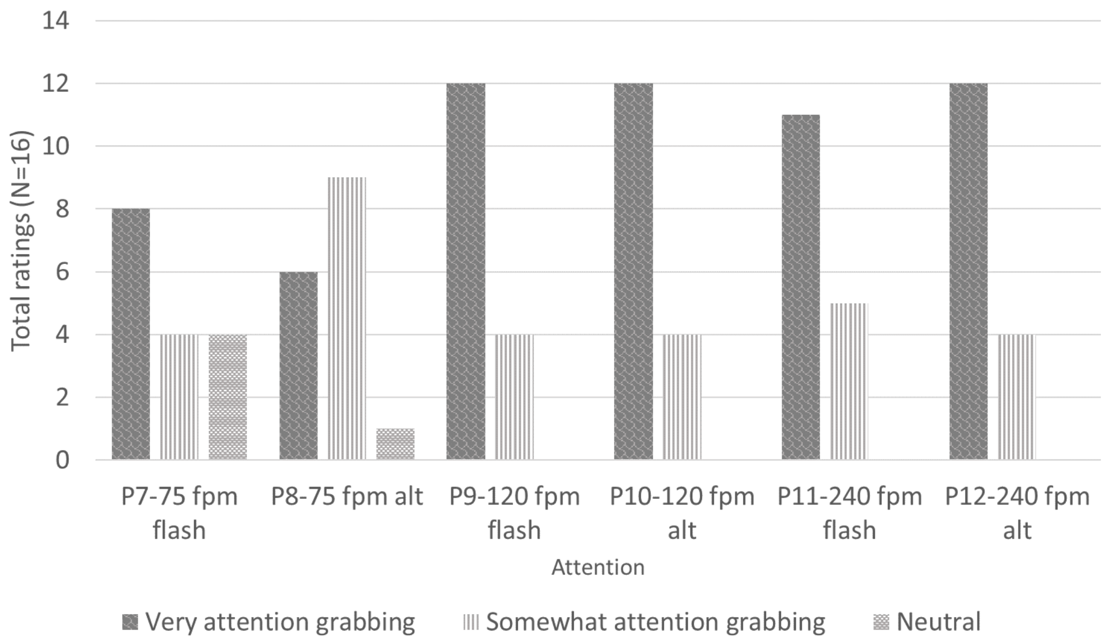

Figure 89: Graph to show the perceived attention grab of the vehicle at 300 metres at night

When comparing the total ratings of lighting patterns P7-P12 at 200 metres in the day and night, all patterns appeared to attract more attention at night, compared to in the day. This effect was noticable in the patterns presented at 75 fpm flashing, 120 fpm alternating, 240 fpm alternating and 240 fpm flashing (see Figure 90 and Figure 91).

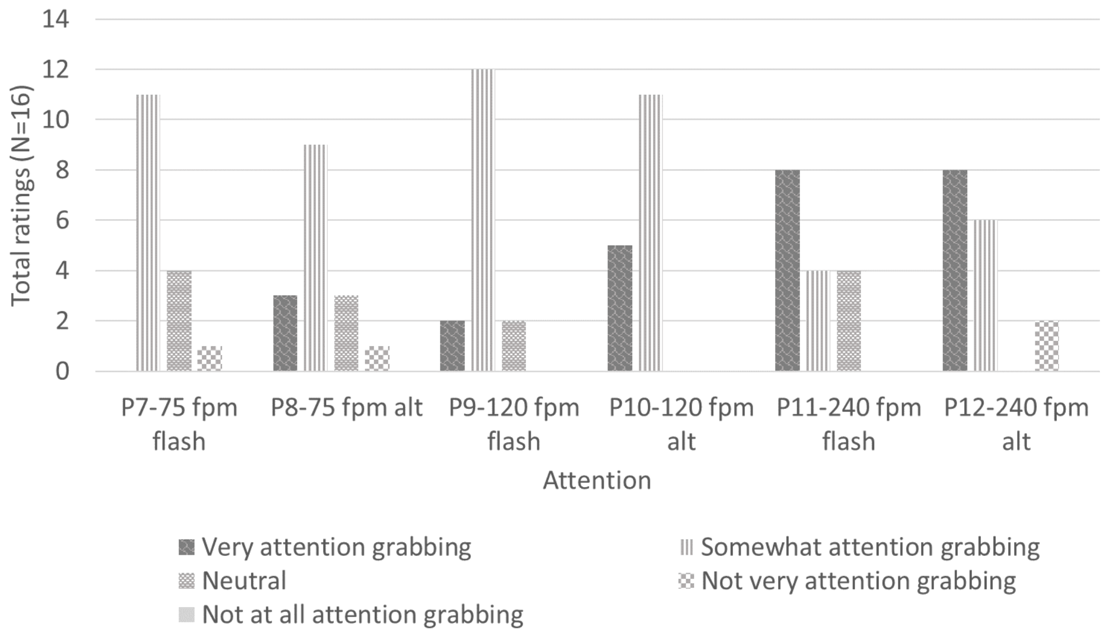

Figure 90: Graph to show the perceived attention grab of the vehicle at 200 metres in the day

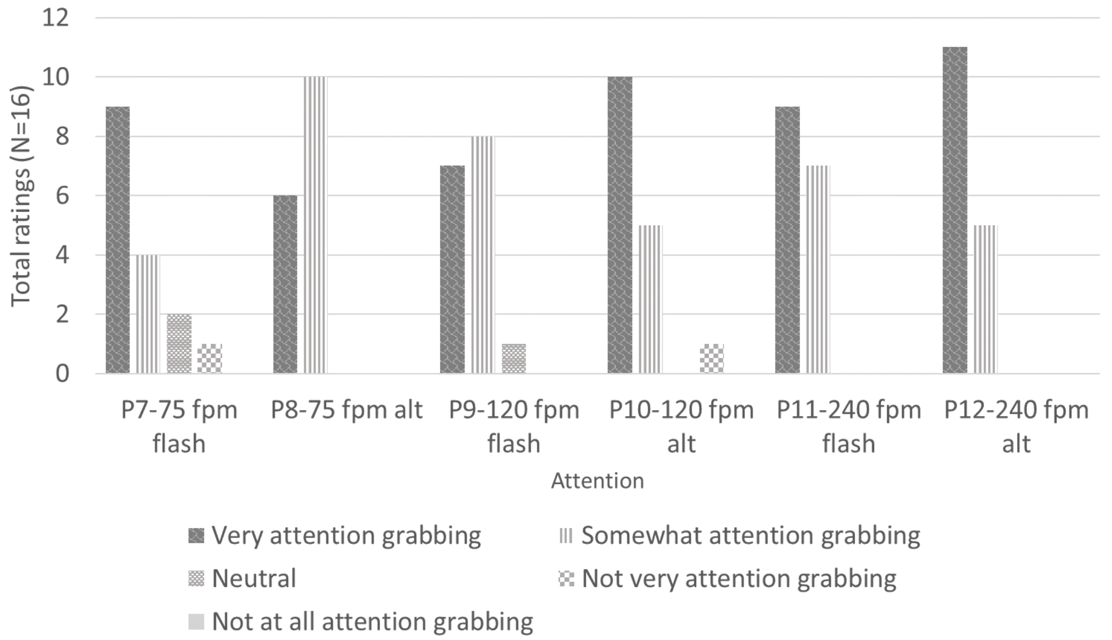

Figure 91: Graph to show the perceived attention grab of the vehicle at 200 metres at night

H.1.4 Patterns P7-P12 – distance

When comparing the total ratings of lighting patterns P7-P12 at 200 metres and 300 metres in the day, the patterns presented at 120 fpm alternating, 240 fpm flash and 240 fpm alternating appeared to attract more attention at 200 metres versus 300 metres. These findings are shown in Figure 92 and Figure 93.

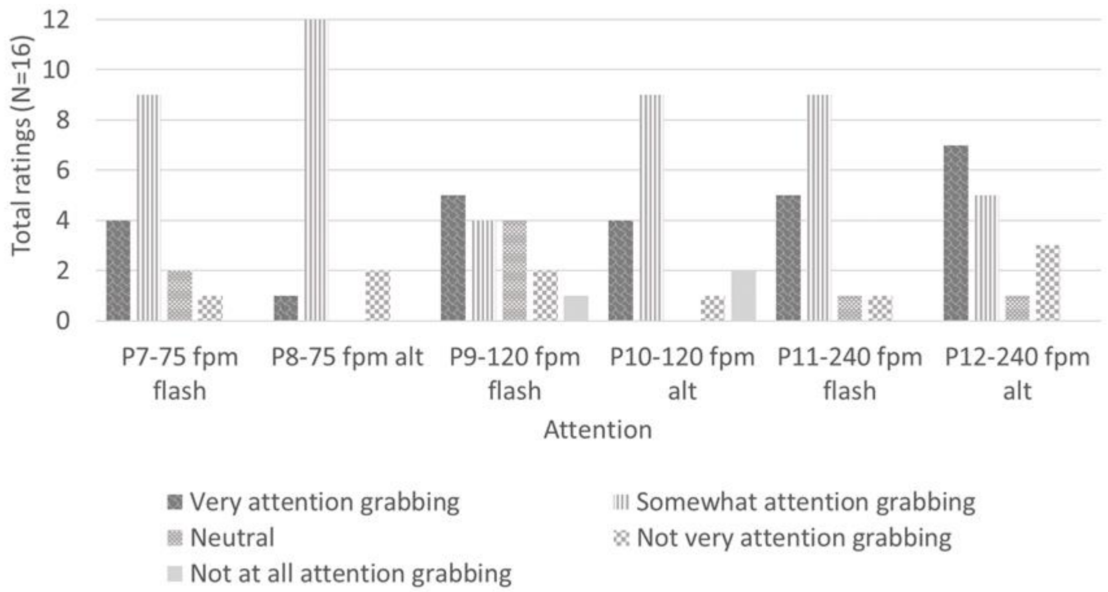

Figure 92: Graph to show the perceived attention grab of the vehicle at 300 metres in the Day

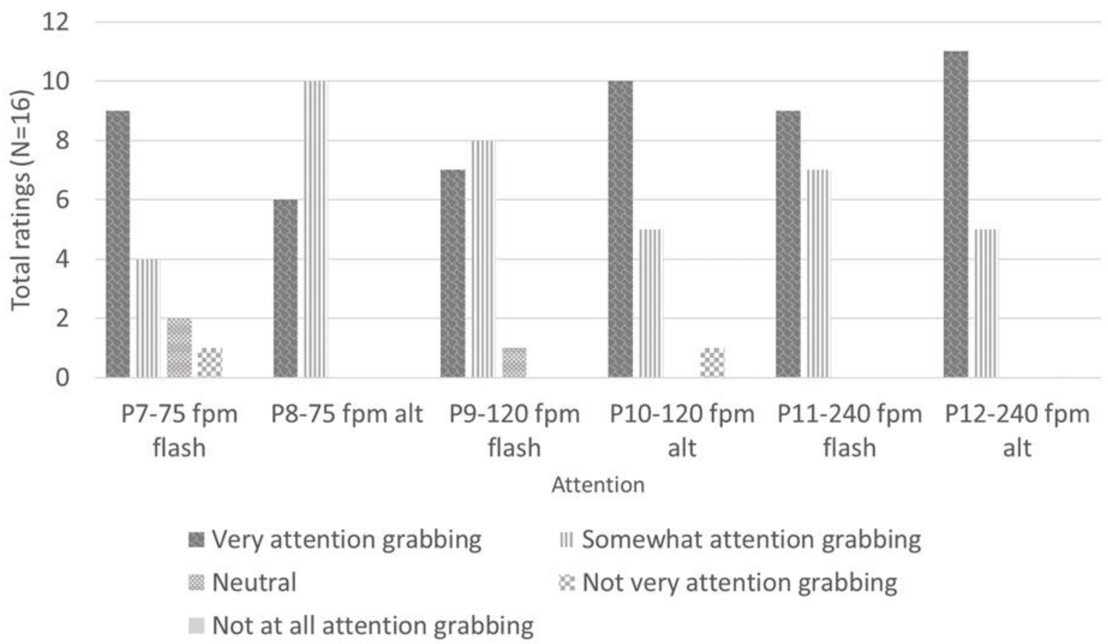

Figure 93: Graph to show the perceived attention grab of the vehicle at 200 metres at night

When comparing total ratings of lighting patterns P7-P12 at 200 metres and 300 metres in the night, no obvious differences in attention grab were observed across the lighting patterns across either of the distances (see Figure 94 and Figure 95).

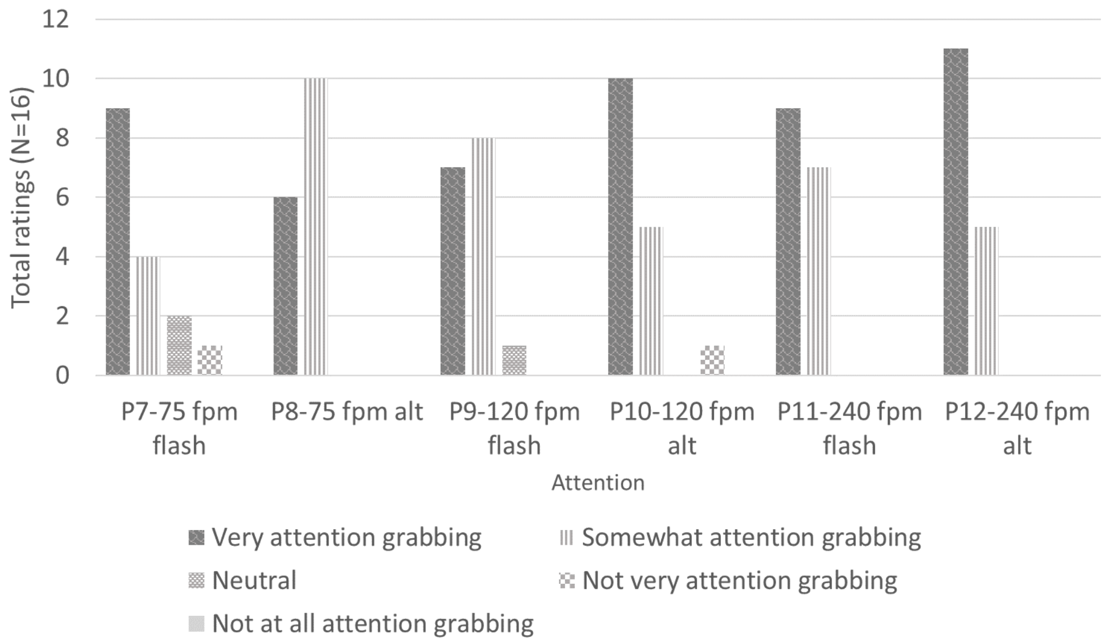

Figure 94: Graph to show the perceived attention grab of the vehicle at 200 metres at night

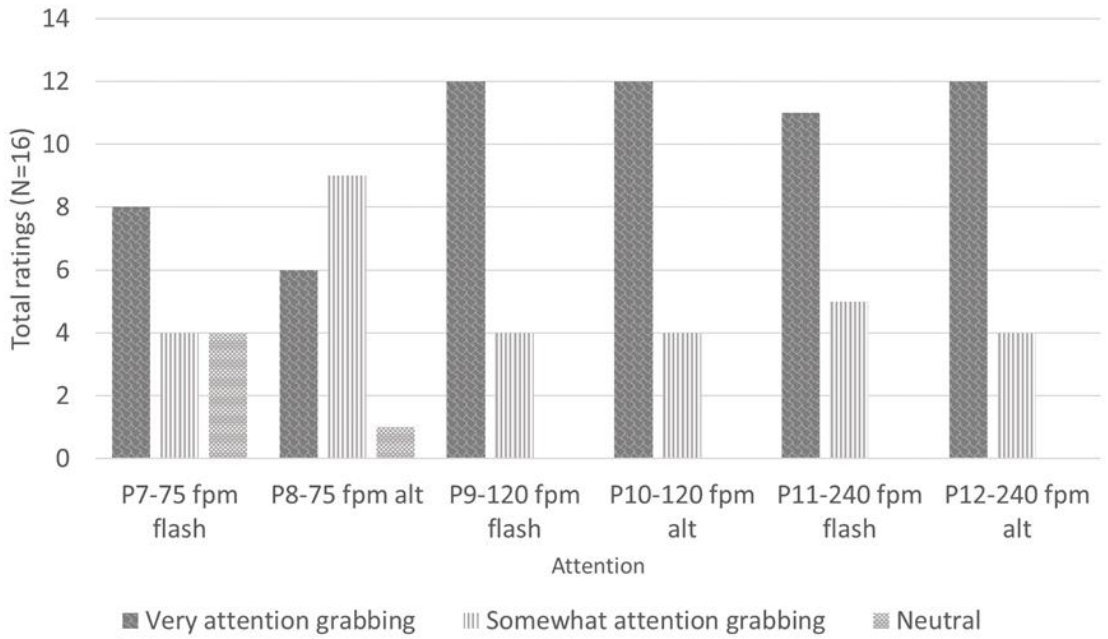

Figure 95: Graph to show the perceived attention grab of the vehicle at 300 metres at night

H.1.5 Patterns P13-P16 – day and night

The following section presents the comparisons of lighting patterns P13–P16, comprised as follows.

- Pattern P13–amber alternating varied speed
- Pattern P14–alternating red/amber double varied speed
- Pattern P15–double flash reds – fast
- Pattern P16–In-out amber with flashing reds

Due to complications with the data obtained, only two comparisons were made.

- Day 300 versus night 300 (to compare day vs night)
- Night 200 versus night 300 (to compare distance)

When comparing the lighting patterns at 300 metres in the day to at night, the lighting patterns appeared to be more attention grabbing at 300 metres in the night, compared to the day (see Figure 96 and Figure 97). No clear differences were observed when comparing the lighting patterns at 200 metres and 300 metres at night (see Figure 97 and Figure 98).

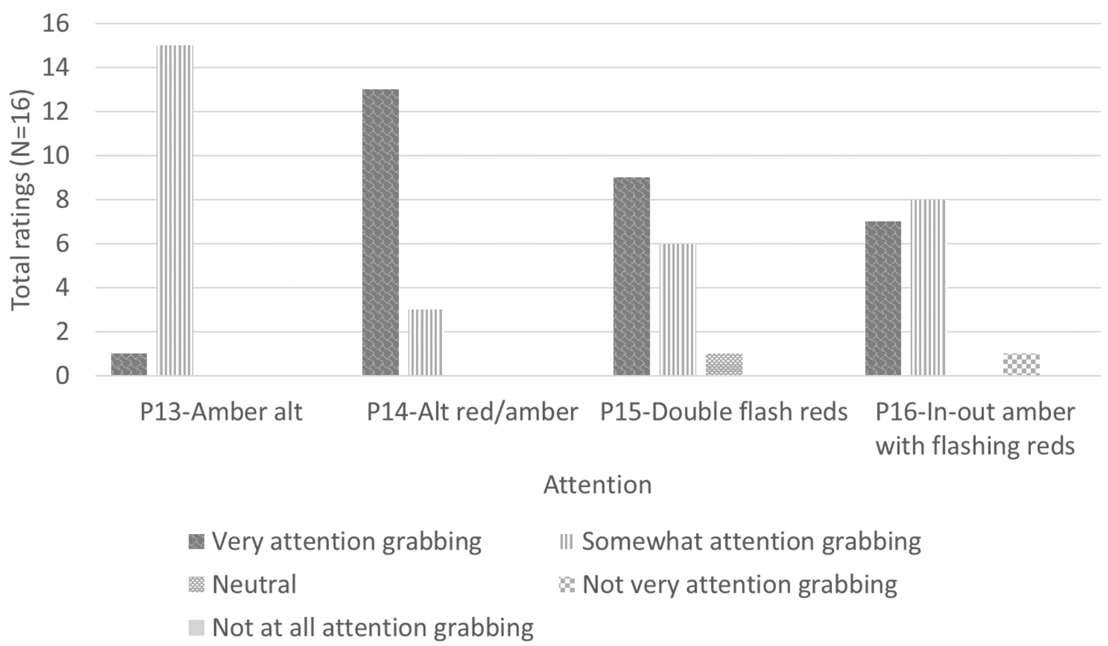

Figure 96: Graph to show the perceived attention grab of the vehicle at 300 metres in the day

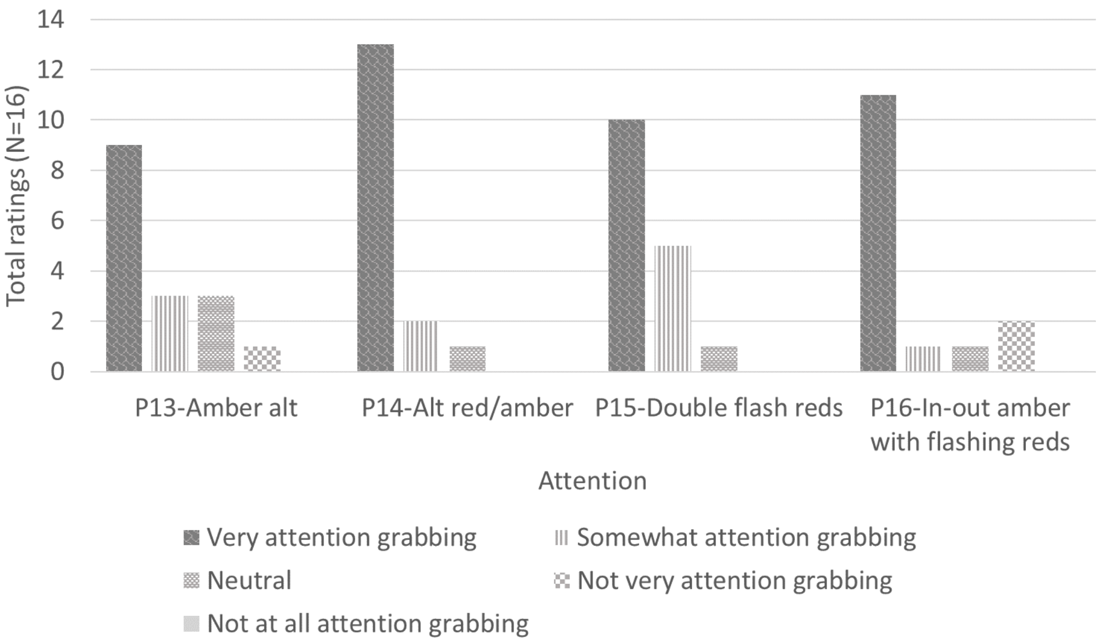

Figure 97: Graph to show the perceived attention grab of the vehicle at 300 metres at night

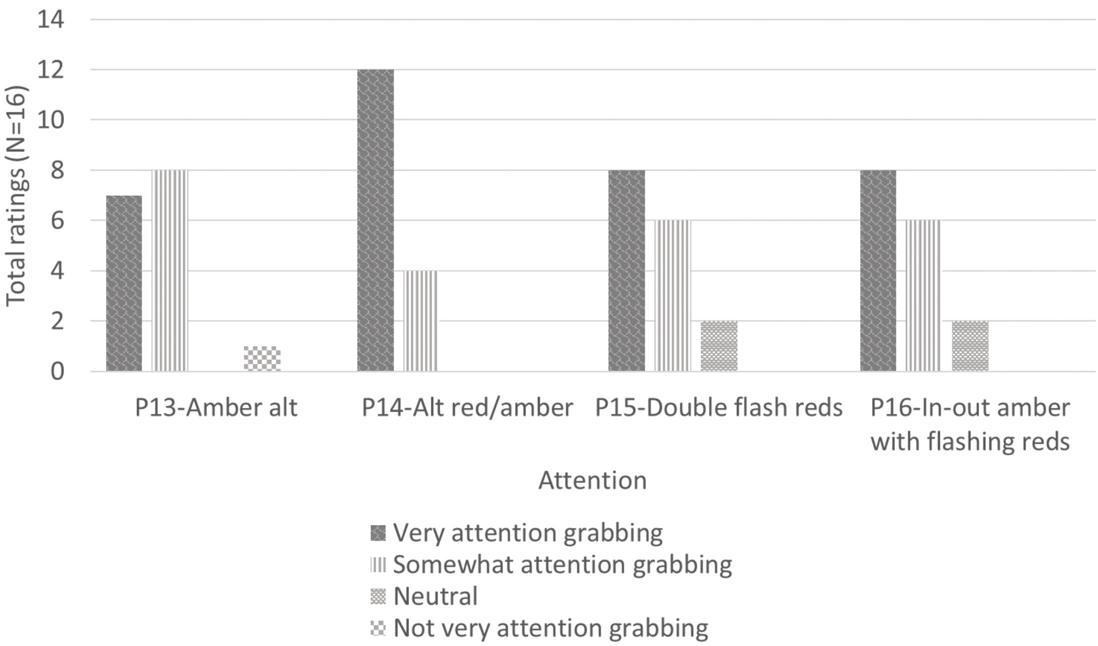

Figure 98: Graph to show the perceived attention grab of the vehicle at 200 metres at night

H.2 Appearance of vehicle

The appearance of the vehicle was measured on a scale from A-C; A being like it is moving, B like it is static and C I don't know.

H.2.1 Patterns P1-P6 – day and night

When comparing the appearance of the vehicle in the day versus night at 300 metres, across both scenarios, all the lighting patterns were perceived to make the vehicle look static. This is shown in Figure 99 and Figure 100.

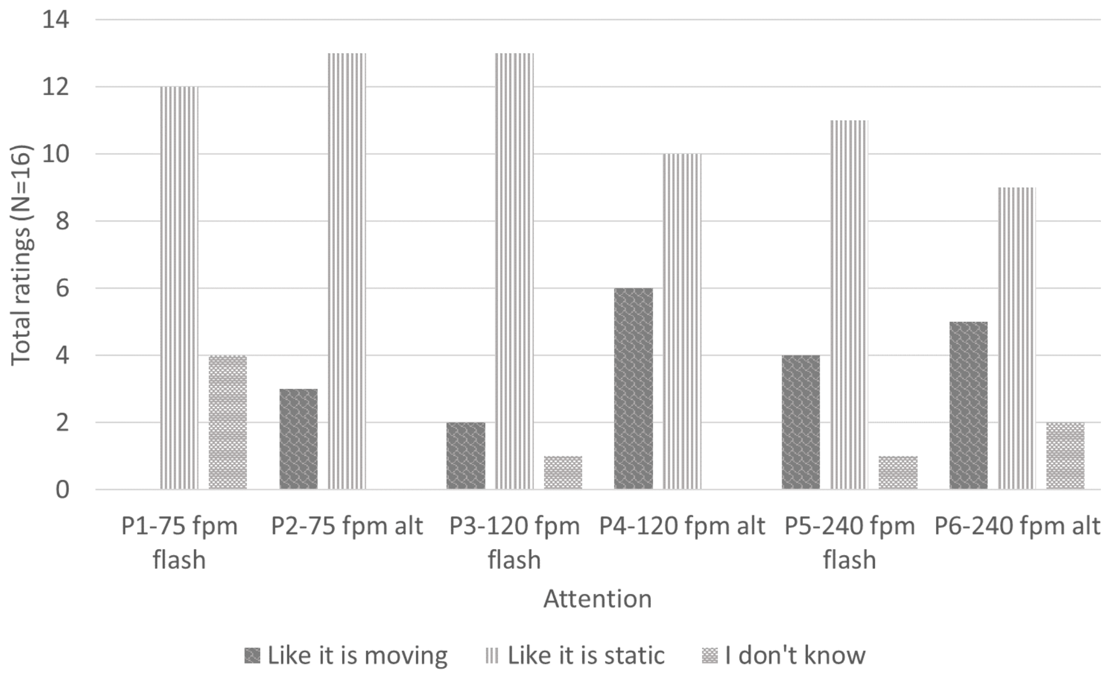

Figure 99: Graph to show the perception of the vehicle at 300 metres in the day

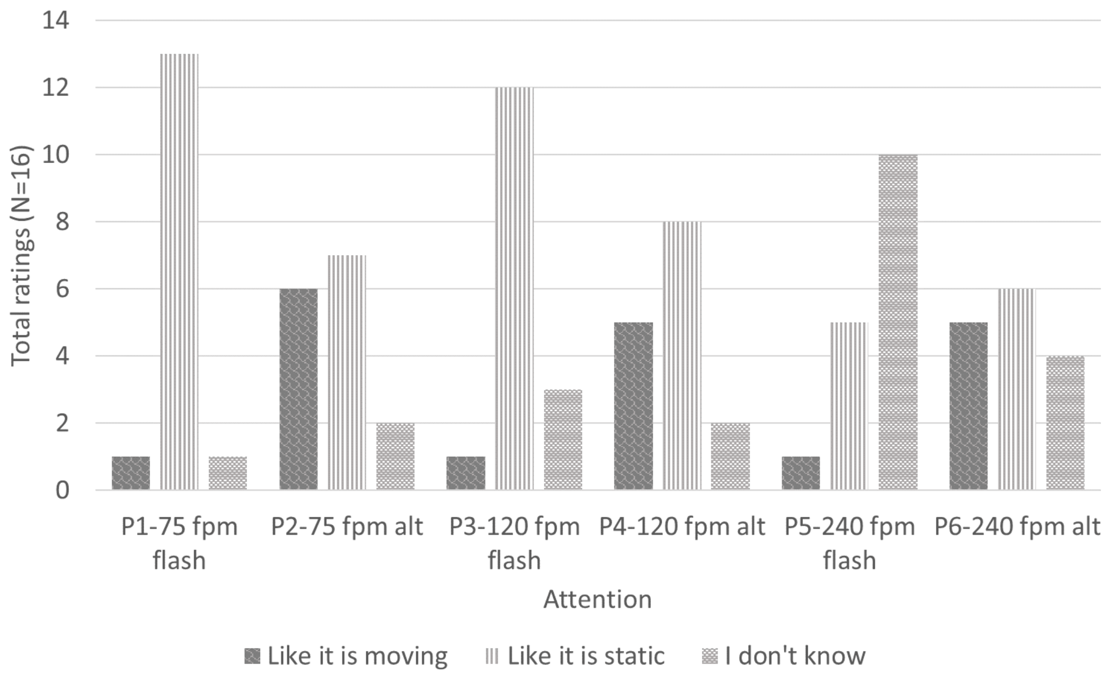

Figure 100: Graph to show the perception of the vehicle at 300 metres at night

When comparing the appearance of the vehicle in the day versus night at 200 metres, across both scenarios, all the lighting patterns were perceived to make the vehicle look static in the day but not at night (see Figure 101 and Figure 102). The exception to this was the 75 fpm flash pattern, which was rated highest as static at 200 metres at night.

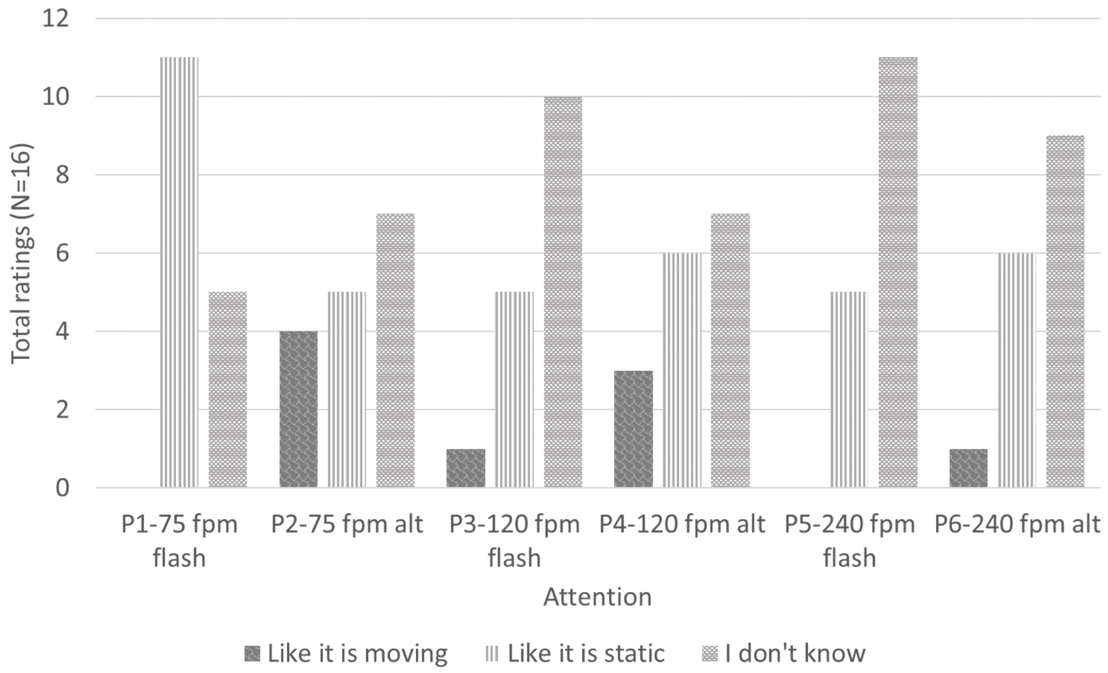

Figure 101: Graph to show the perception of the vehicle at 200 metres in the night

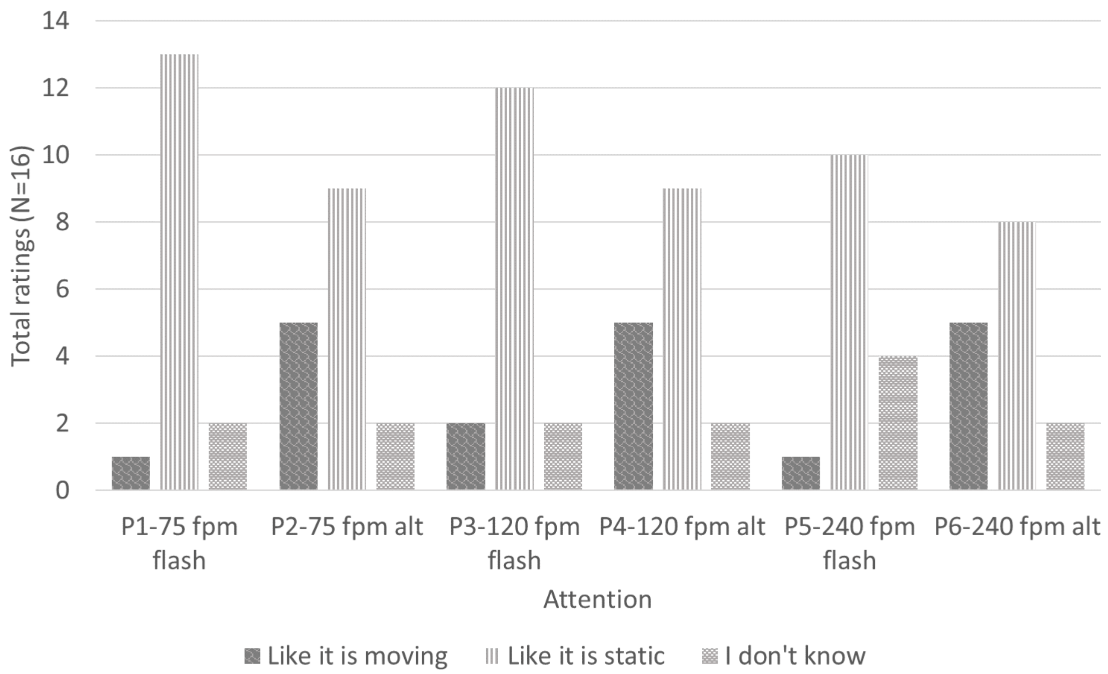

Figure 102: Graph to show the perception of the vehicle at 200 metres in the day

H.2.2 Patterns P1–P6 – distance

To examine the impact of distance from the lighting, distance (300 metres versus 200 metres in the day) was compared. As Figure 103 and Figure 104 show, no differences were observed between the perceptions of the vehicle at 300 metres versus 200 metres in the day.

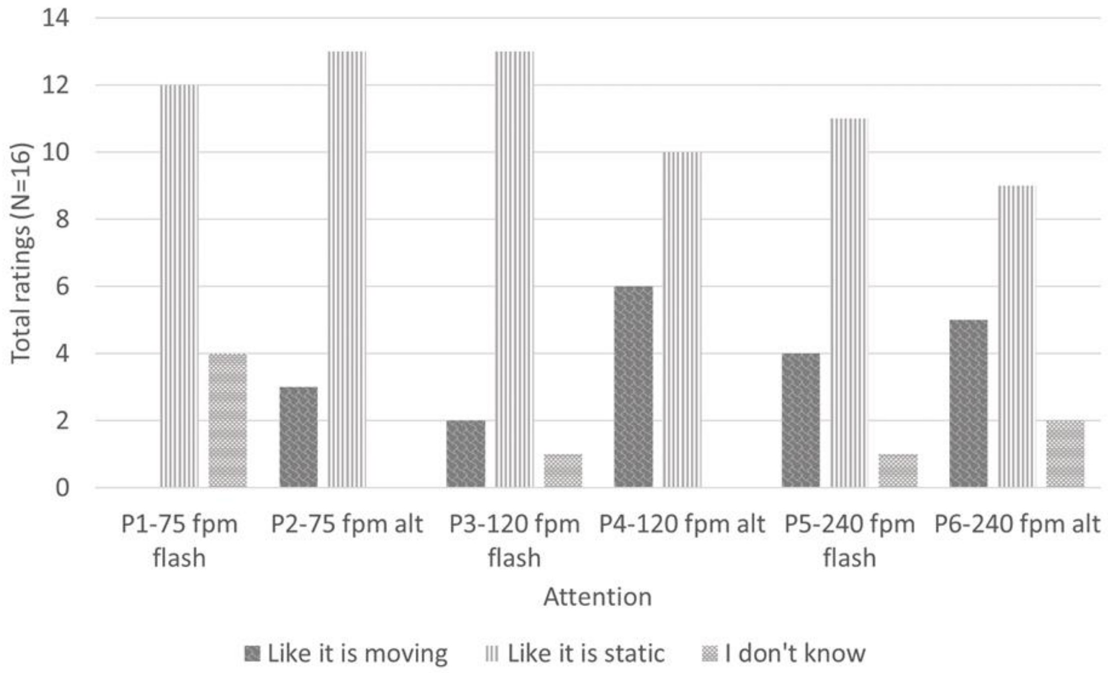

Figure 103: Graph to show the perception of the vehicle at 300 metres in the day

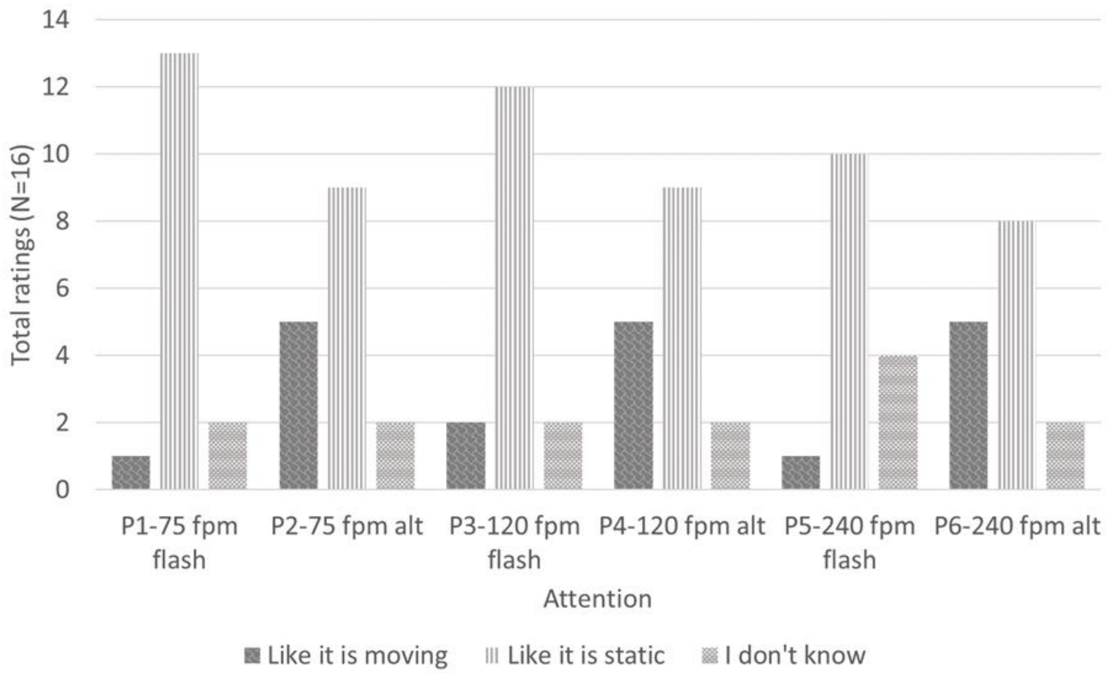

Figure 104: Graph to show the perception of the vehicle at 200 metres in the day

When comparing the perceptions of the vehicle at 200 metres versus 300 metres at night, as Figure 105 and Figure 106 show, attendees were more likely to rate the vehicle as appearing to be moving at 200 metres, compared to 300 metres.

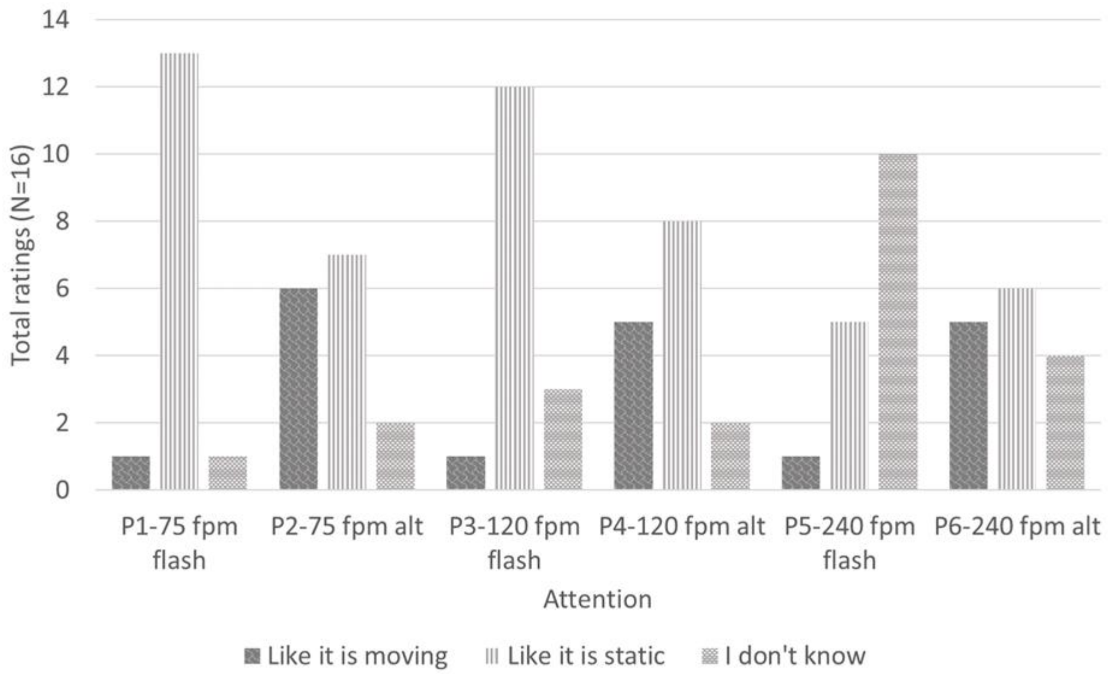

Figure 105: Graph to show the perception of the vehicle at 300 metres at night

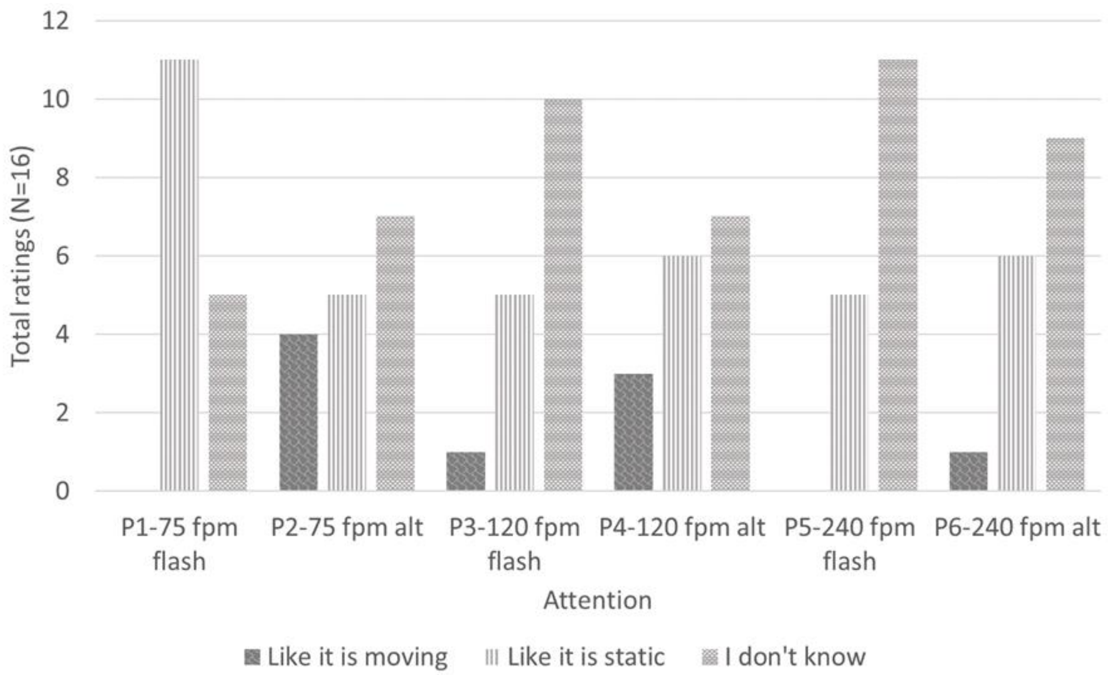

Figure 106: Graph to show the perception of the vehicle at 200 metres in the night

H.2.3 Patterns P7–P12 – day and night

The following section presents the comparisons of lighting patterns P7–P12. The flashes per minute of these patterns varied and all flashes were red.

As Figure 107 and Figure 108 show, a higher proportion of the attendees stated that the vehicle looked like it was moving from a distance of 300 metres in the day, compared to 300 metres at night.

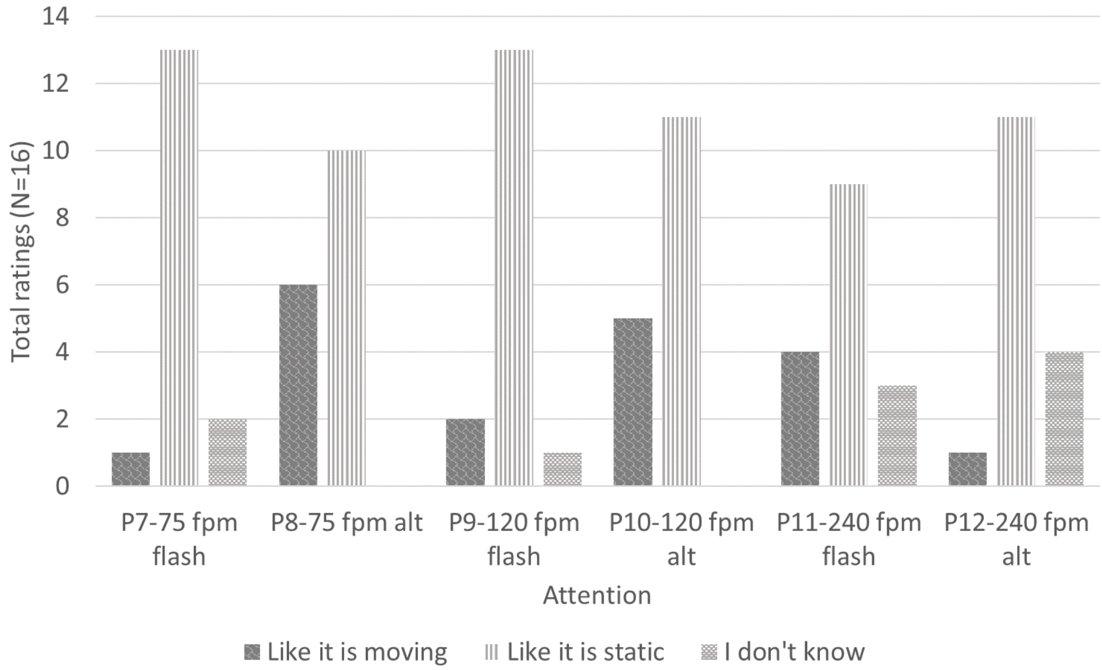

Figure 107: Graph to show the perception of the vehicle at 300 metres in the day

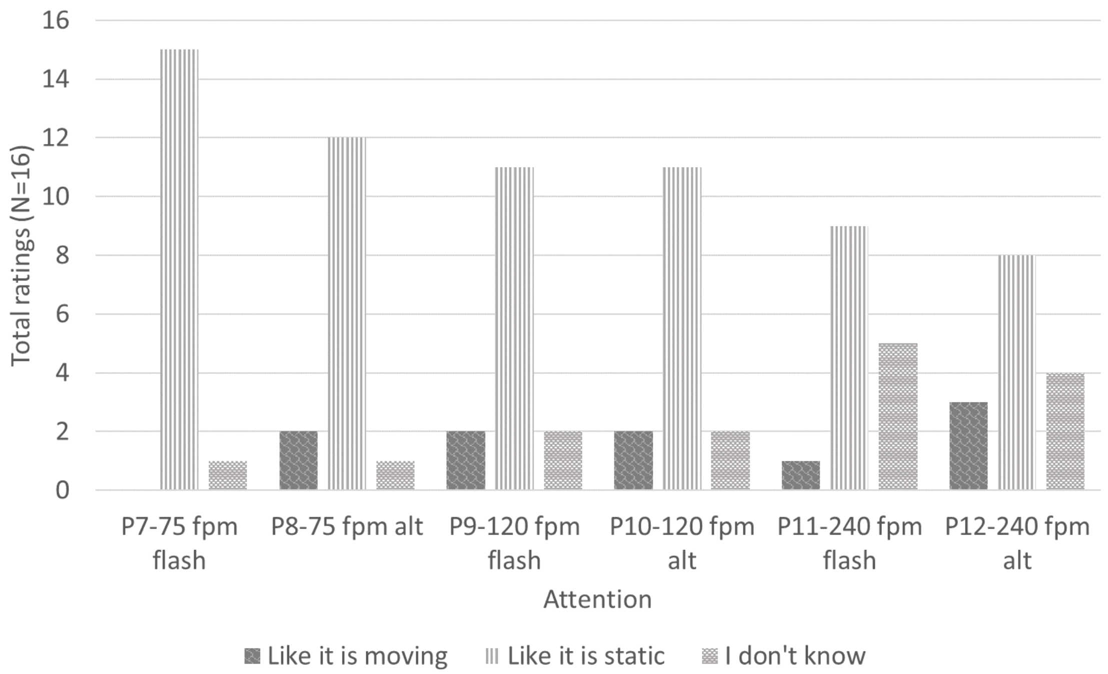

Figure 108: Graph to show the perception of the vehicle at 300 metres in the night

When comparing the appearance of the vehicle in the day versus night at 200 metres, there are no clear differences across both scenarios for how the vehicle appeared to attendees–see **Figure 109** and **Figure 110**

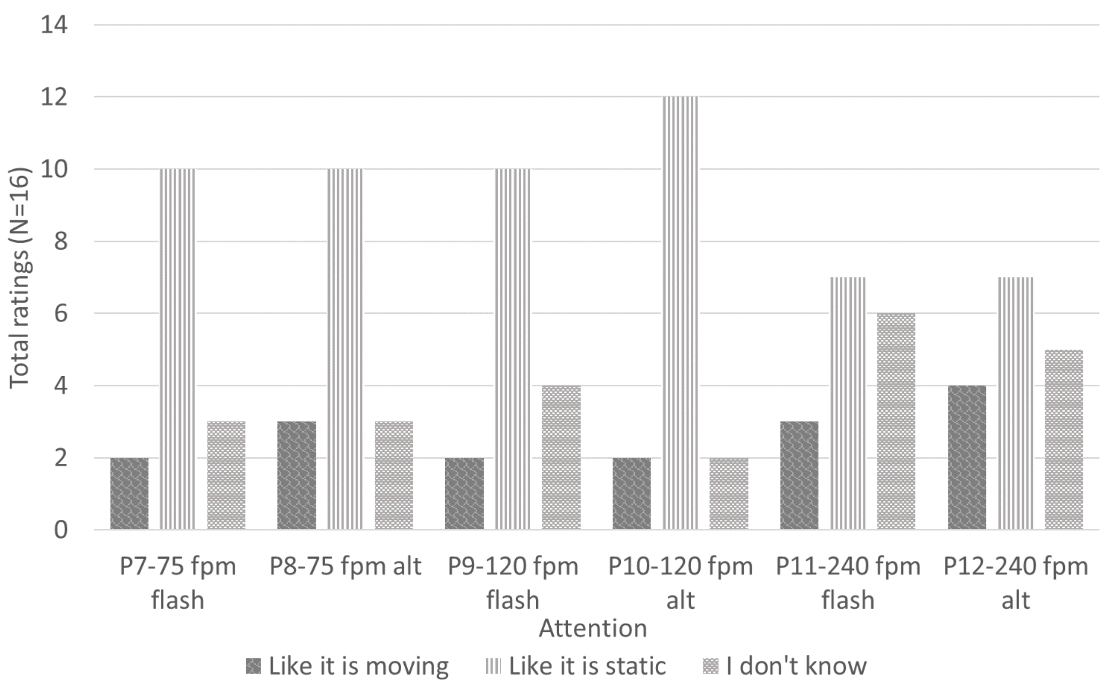

Figure 109: Graph to show the perception of the vehicle at 200 metres at night

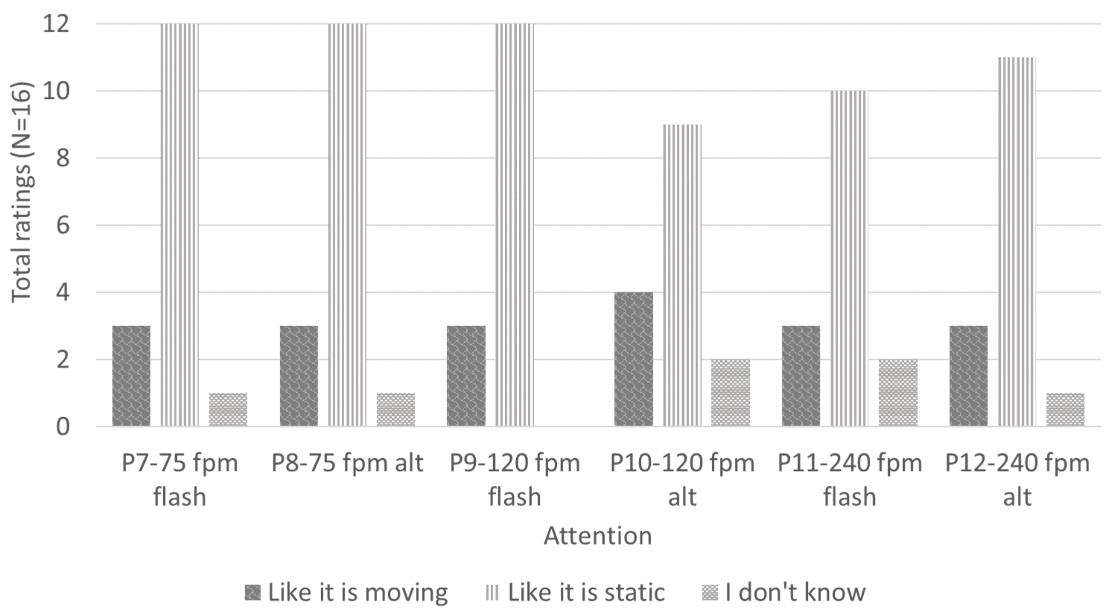

Figure 110: Graph to show the perception of the vehicle at 200 metres in the day

H.2.4 Patterns P7–P12 – distance

When comparing the appearance of the vehicle in the day at 200 metres and 300 metres, the 75 fpm flash and alternating patterns appeared to make the vehicle seem to be moving more at 300 metres compared to 200 metres (see Figure 111 and Figure 112).

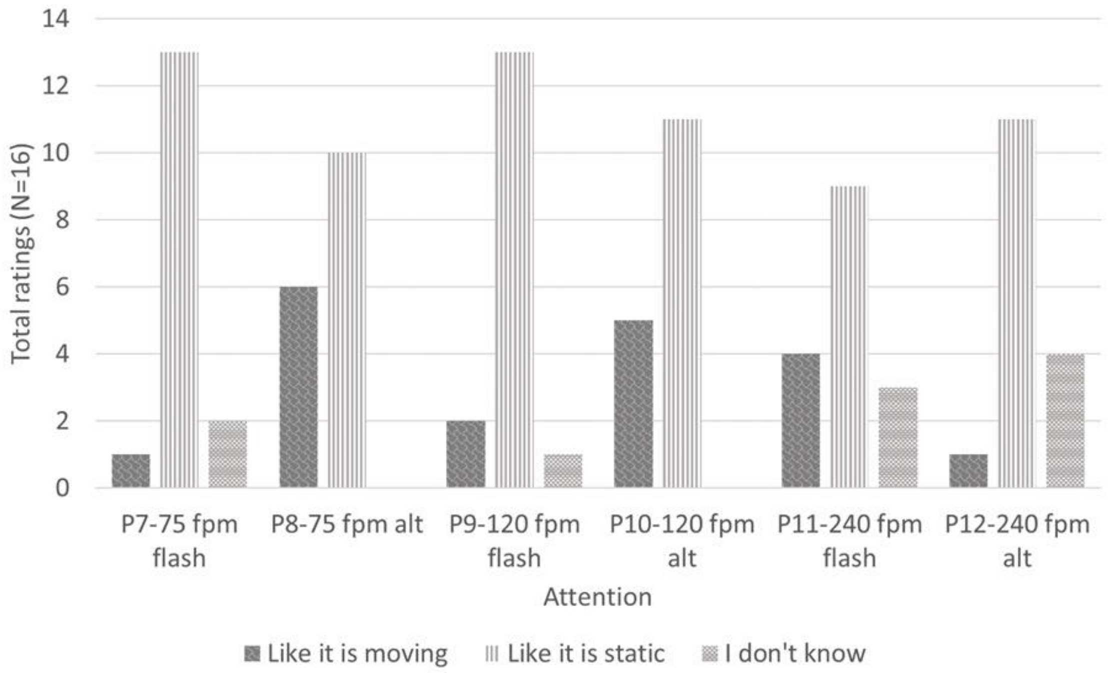

Figure 111: Graph to show the perception of the vehicle at 300 metres in the day

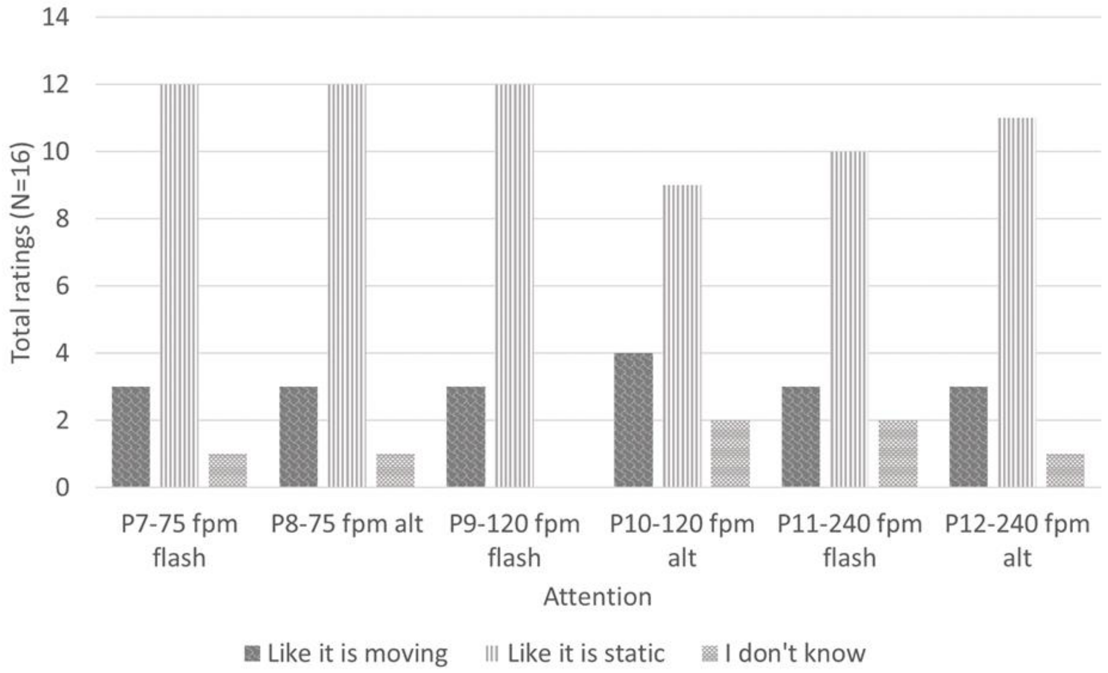

Figure 112: Graph to show the perception of the vehicle at 200 metres in the day

When comparing the appearance of the vehicle at night at 300 metres and 200 metres, across both scenarios, attendees appeared to perceive the vehicle to be static compared to moving. No differences were observed between the attendees rating of whether the vehicle appeared to be moving between the two distances (see Figure 113 and Figure 114).

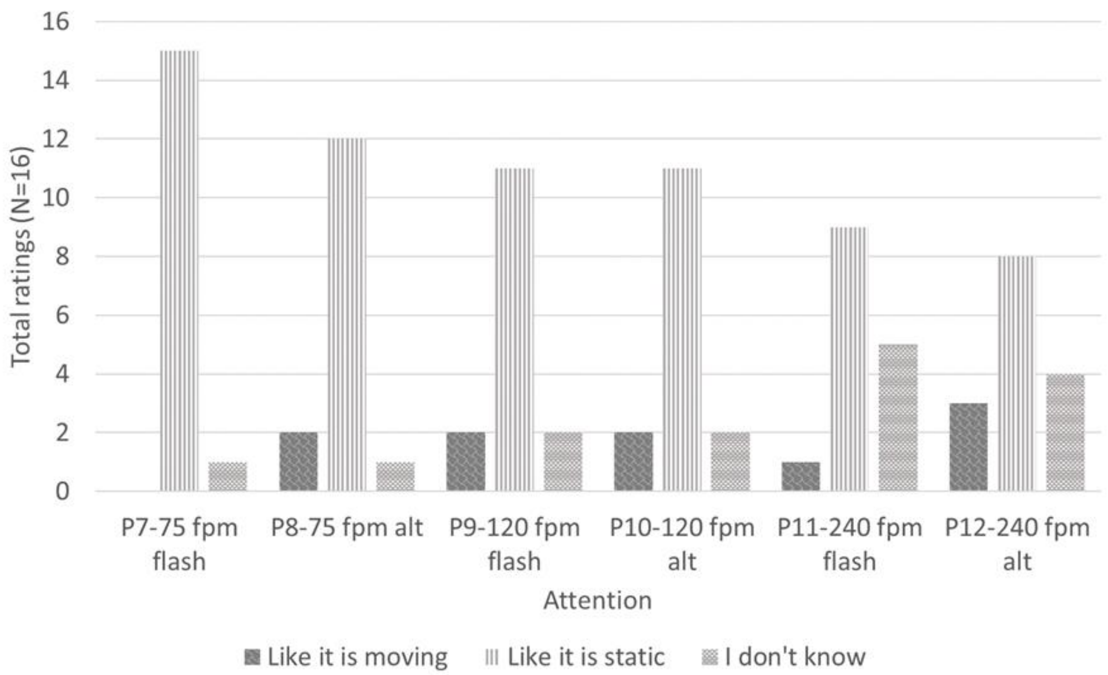

Figure 113: Graph to show the perception of the vehicle at 300 metres at night

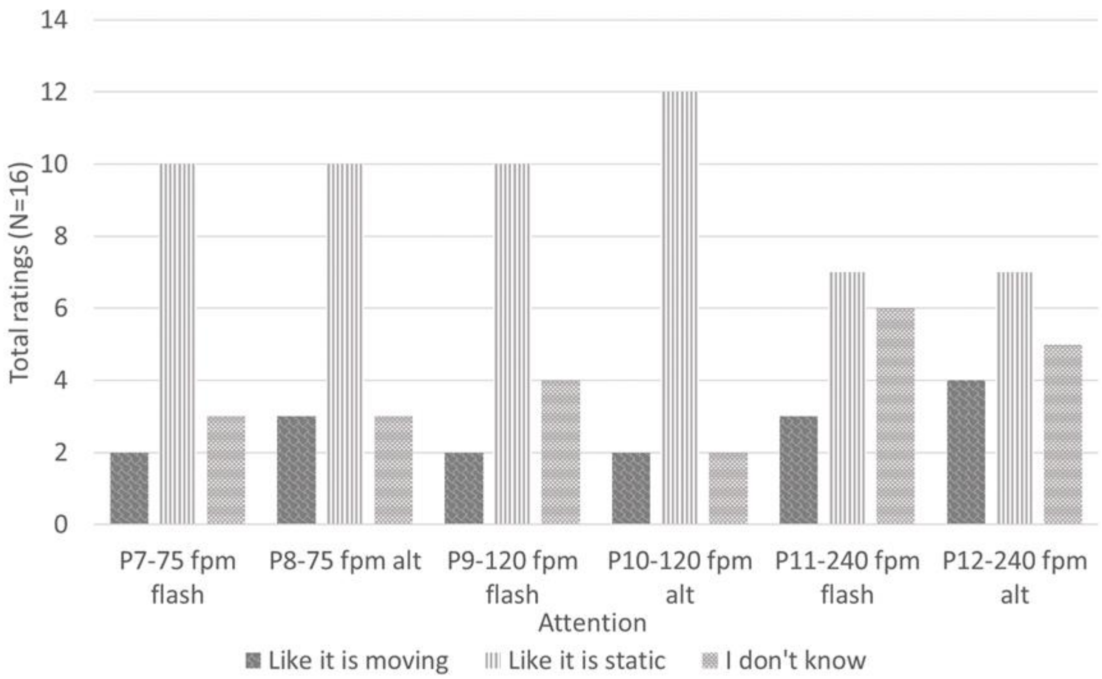

Figure 114: Graph to show the perception of the vehicle at 200 metres at night

H.2.5 Patterns P13–P16 – day and night

The following section presents the comparisons of lighting patterns P13-P16, comprised as follows.

- Pattern P13–amber alternating varied speed
- Pattern P14–alternating red/amber double varied speed
- Pattern P15–double flash reds – fast
- Pattern P16–In-out amber with flashing reds

Due to complications with the data obtained, only two comparisons were made.

- Day 300 versus night 300 (to compare day vs night)
- Night 200 versus night 300 (to compare distance)

When comparing the perceptions of the vehicle at 300 metres in the day versus night, as Figure 115 and Figure 116 show, the vehicle was rated as appearing to be static across both day and night. Interestingly, a high proportion of participants reported being unclear about how the vehicle looked when presented with the amber alternating flash pattern at night.

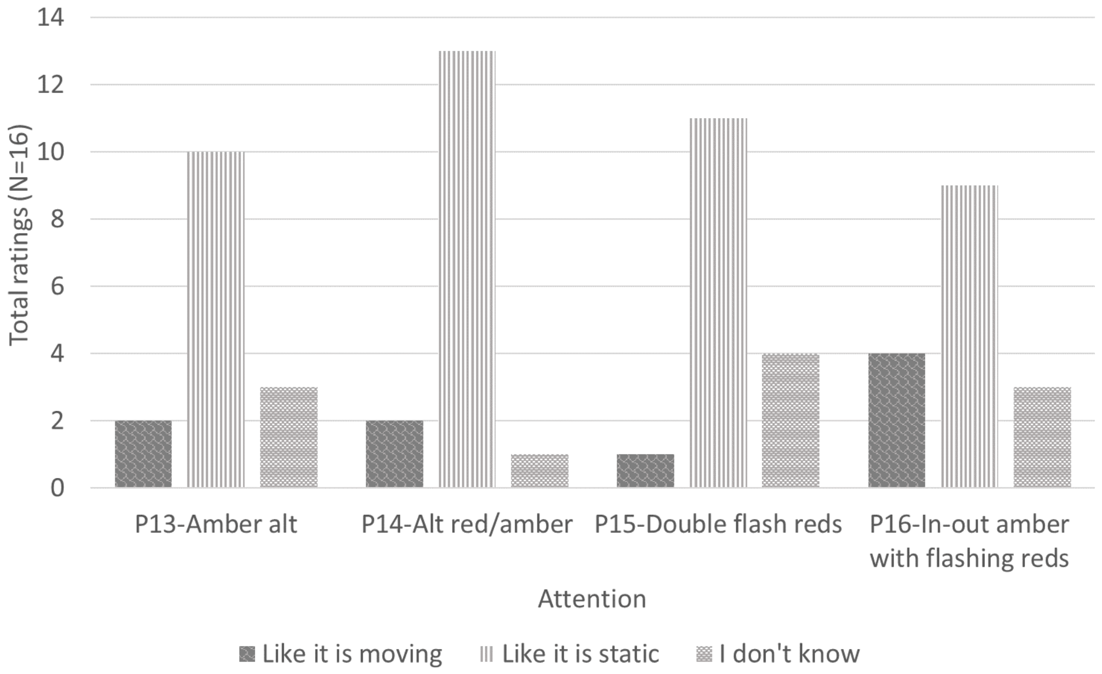

Figure 115: Graph to show the perception of the vehicle at 300 metres in the day

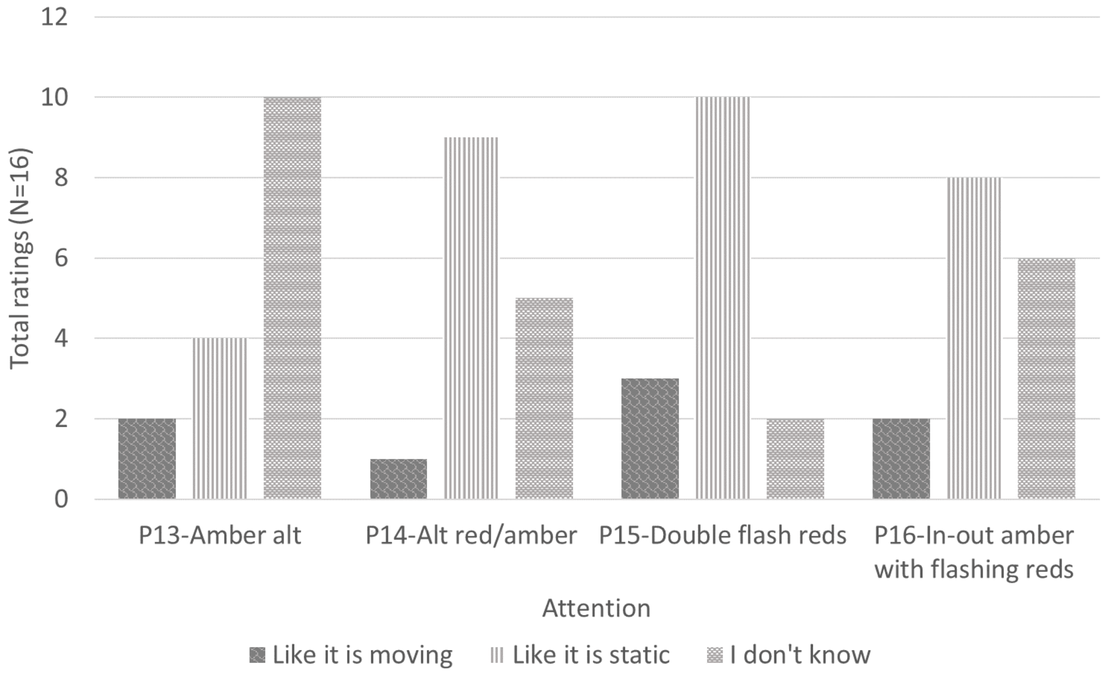

Figure 116: Graph to show the perception of the vehicle at 300 metres at night

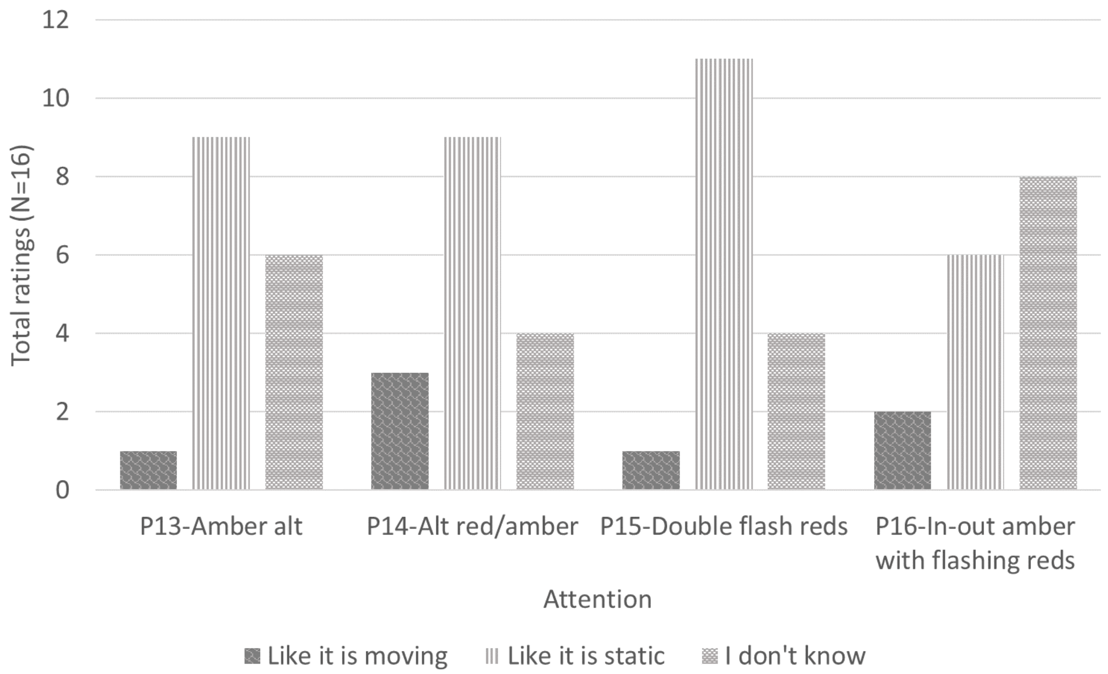

Figure 117: Graph to show the perception of the vehicle at 200 metres at night

When comparing the perceptions of the vehicle at 300 metres and 200 metres at night, as Figure 116 and Figure 117 show, the vehicle was rated as appearing to be static across distances. Interestingly, a lower proportion of participants reported being unclear about how the vehicle looked at 200 metres, compared to 300 metres.

H.3 Location of the vehicle

The perceived location of the vehicle was measured on a scale from A–C, with A being 'likely to be alongside the road' and C being 'I don't know'.

H.3.1 Patterns P1-P6 – day and night

The following section presents the comparisons of lighting patterns P1–P6. The flashes per minute of these patterns varied and all flashes were either amber alternating or amber flash.

As Figure 118 and Figure 119 show, no clear overall differences were observed between the 300 metres day data and the 300 metres night data, in terms of the perceived location of the vehicle.

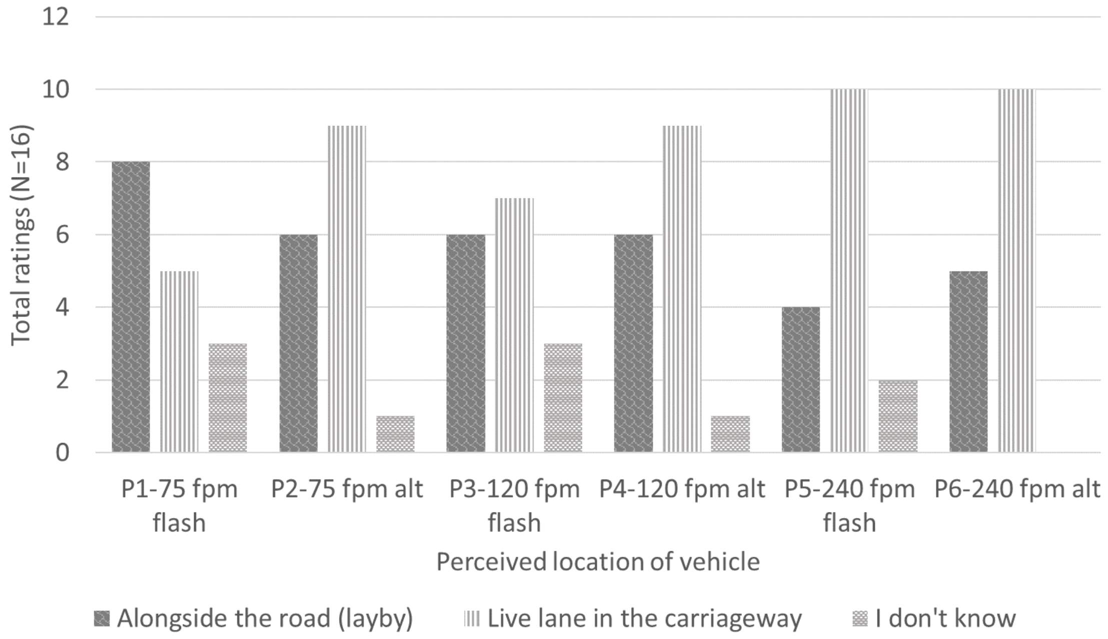

Figure 118: Graph to show the perceived location of the vehicle at 300 metres in the day

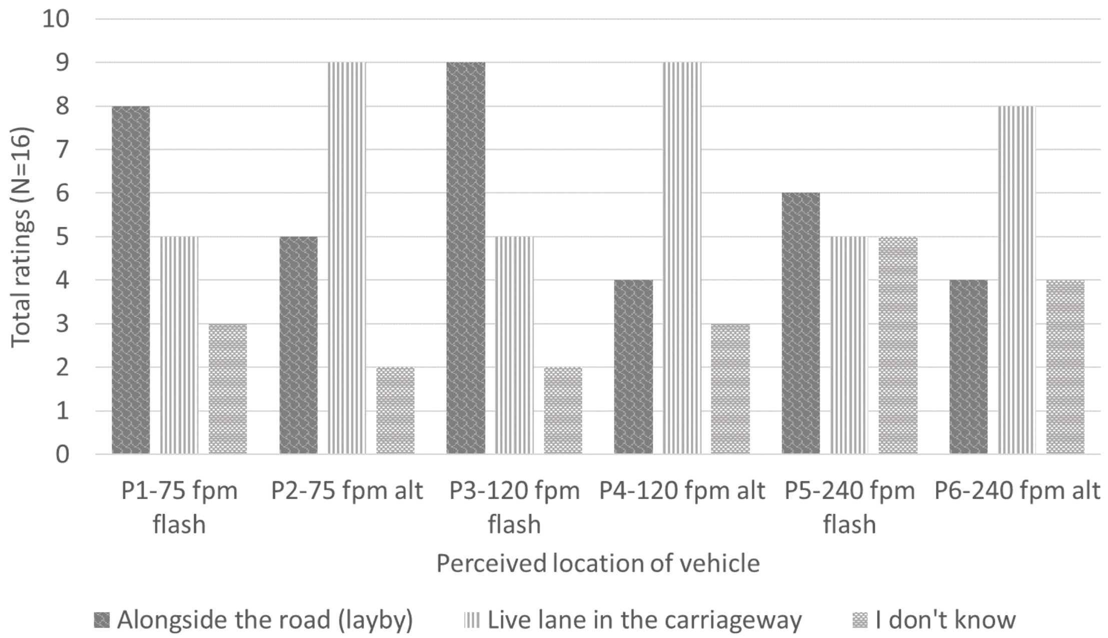

Figure 119: Graph to show the perceived location of the vehicle at 300 metres at night

As shown by Figure 120 and Figure 121, the ratings of the location of the vehicle at day and night were fairly similar across both day and night, at 200 metres. No other differences were noted.

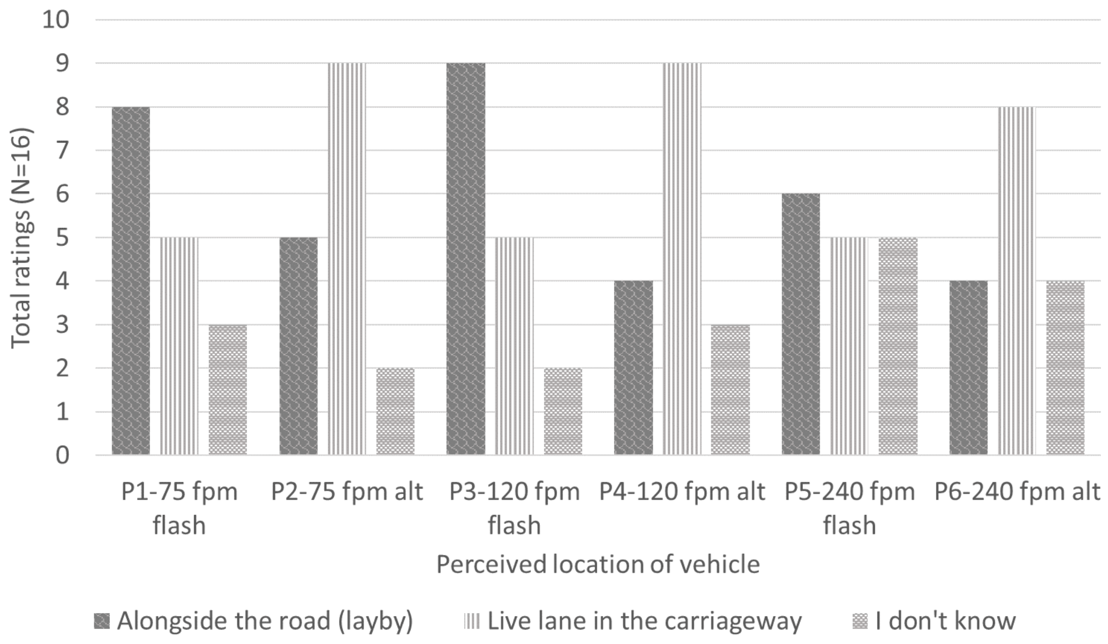

Figure 120: Graph to show the perceived location of the vehicle at 200 metres at night

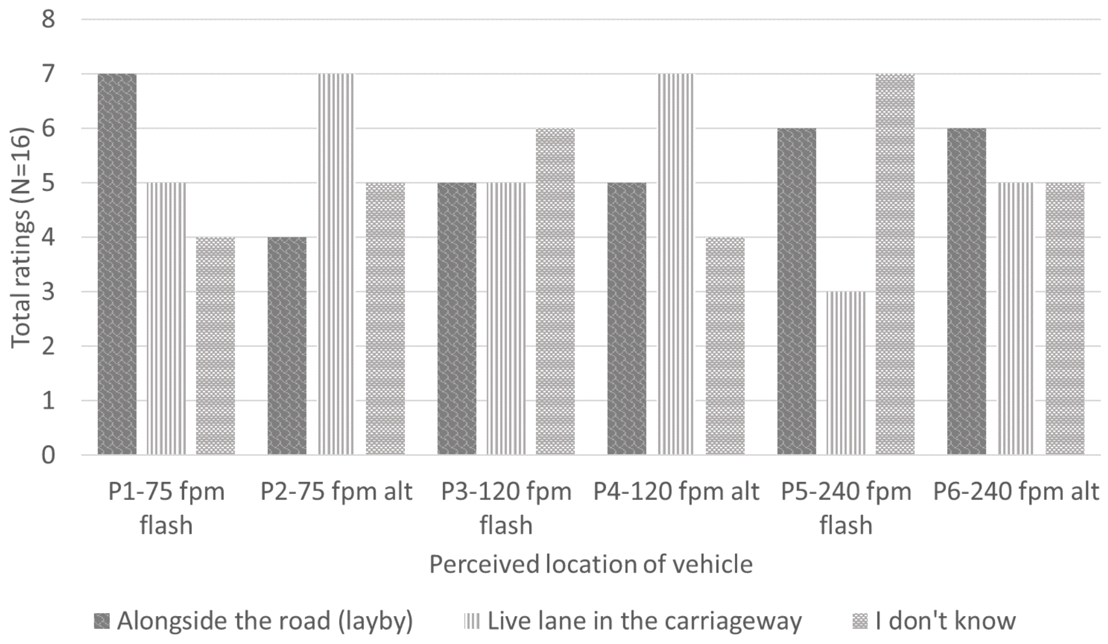

Figure 121: Graph to show the perceived location of the vehicle at 200 metres in the day

H.3.2 Patterns P1-P6 – distance

As Figure 121 and Figure 122 show, attendees perceived the location of the vehicle to be in the live lane more than alongside the road in the 300 metres day data, compared to the day 200 metres data. In the day 200 metres data, ratings were roughly evenly spread between alongside the road and in the live line of the carriageway.

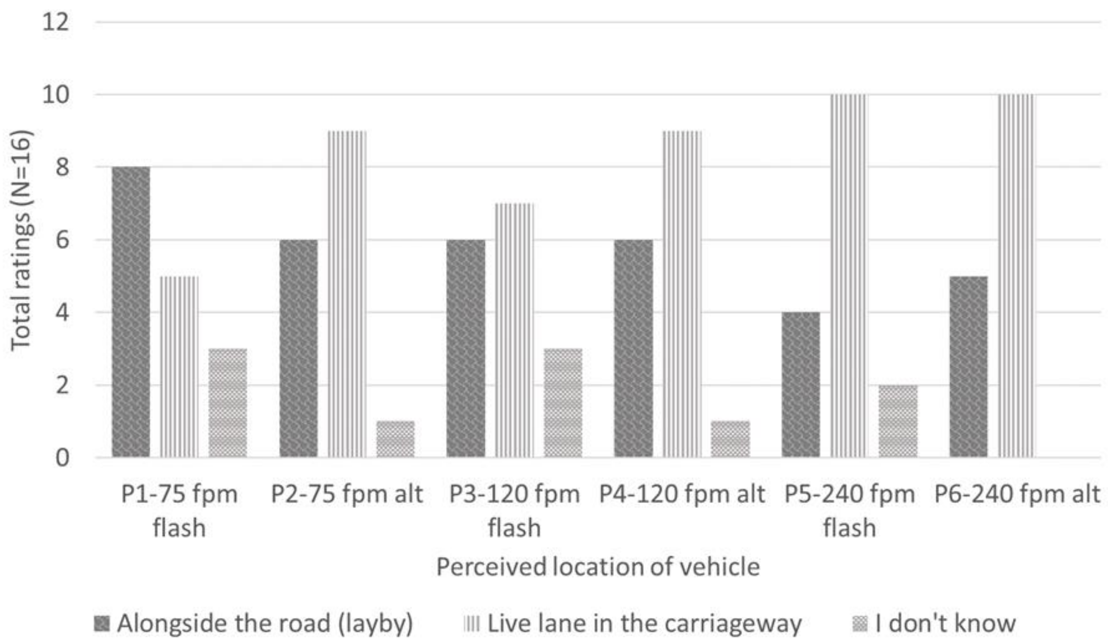

Figure 122: Graph to show the perceived location of the vehicle at 300 metres in the day

As Figure 123 and Figure 124 show, the 75 fpm flashing and 120 fpm flashing patterns were rated as representing the vehicle being alongside the road the most across the 200 metres and 300 metres night data. The 120 fpm flash was perceived to represent the vehicle alongside the road; this effect was noticed across the 300 and 200 metres night data.

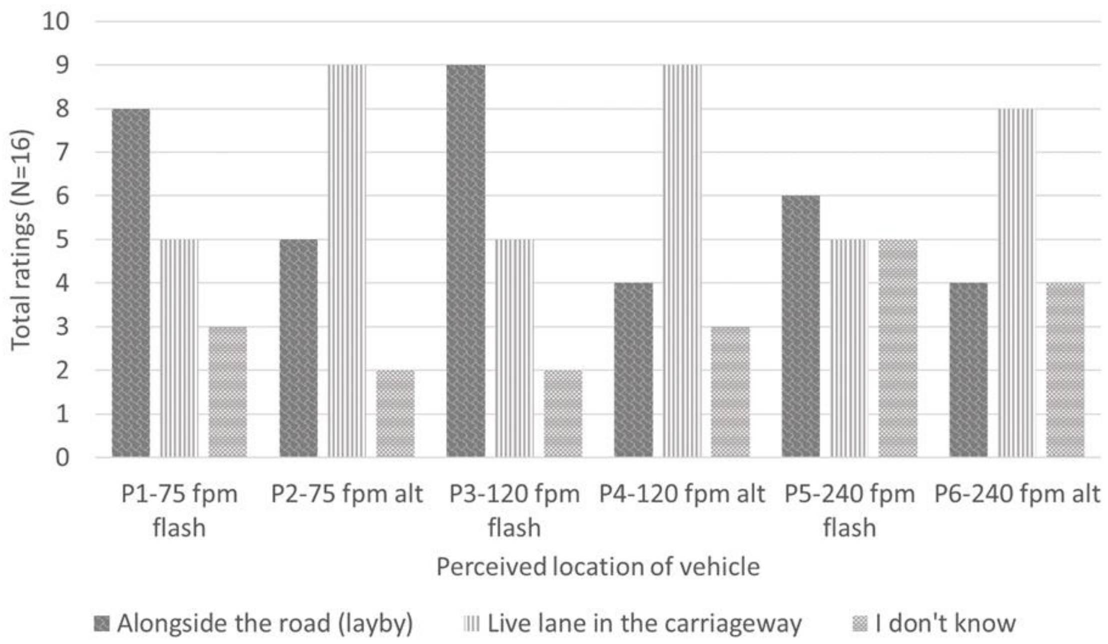

Figure 123: Graph to show the perceived location of the vehicle at 300 metres in the night

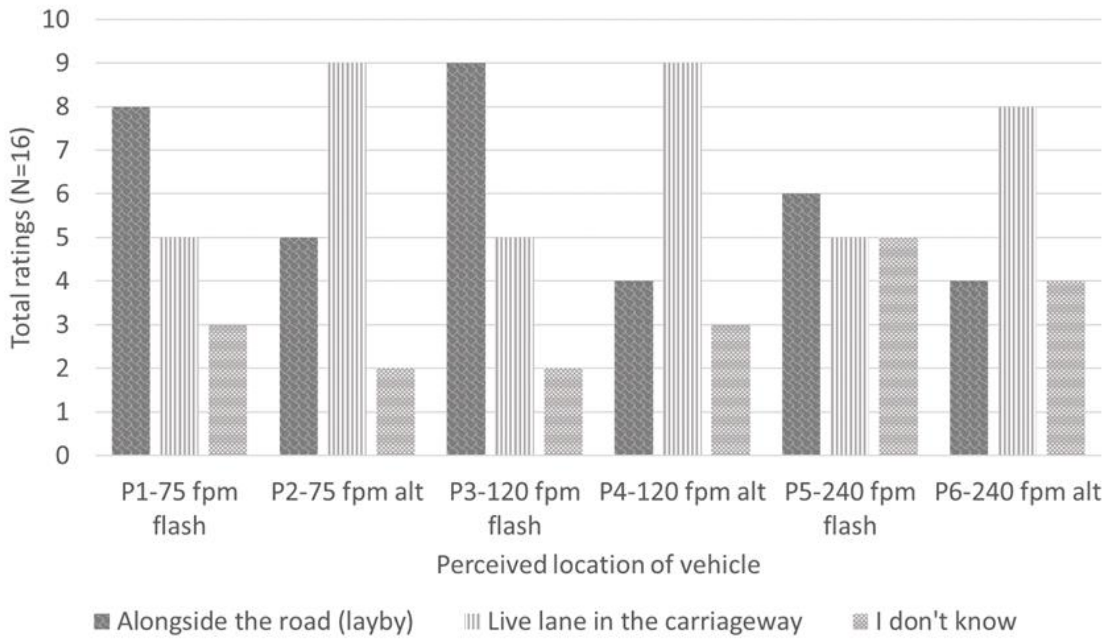

Figure 124: Graph to show the perceived location of the vehicle at 200 metres in the night

H.3.3 Patterns P7-P12 – day and night

The following section presents the comparisons of lighting patterns P7–P12. The flashes per minute (fpm) of these patterns varied and all flashes were red.

As Figure 125 and Figure 126 show, across both the 300 metres day and night data, the majority of the flash patterns were perceived to indicate that the vehicle was in a live lane. The exception was the 75 fpm pattern, which was perceived to represent the vehicle being alongside the road in the day 300 metres data, though the ratings for live lane were still higher.

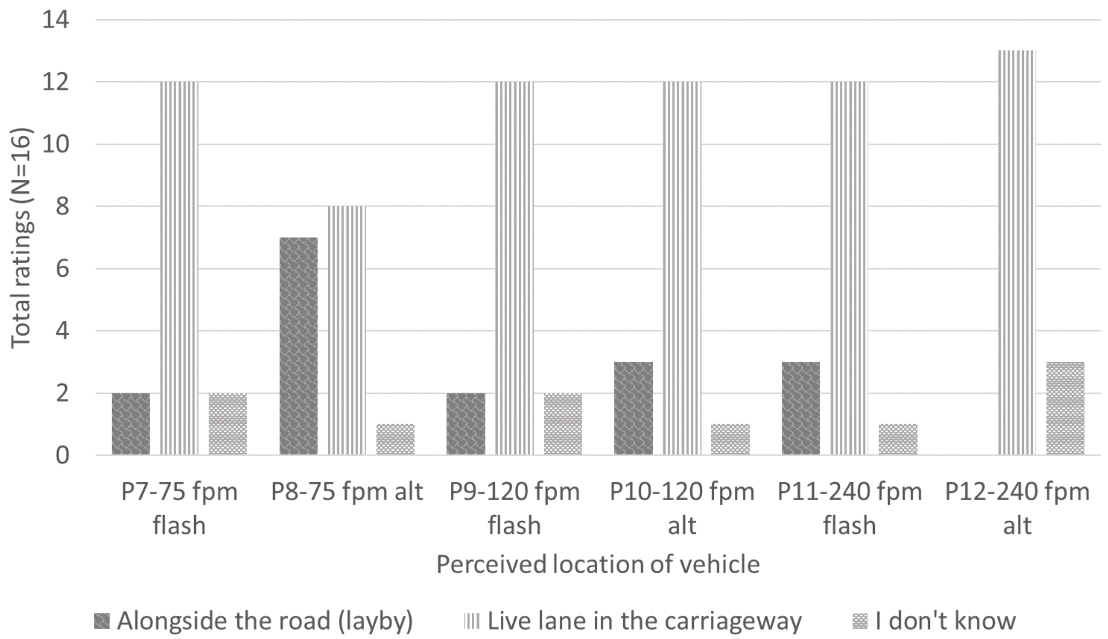

Figure 125: Graph to show the perceived location of the vehicle at 300 metres in the day

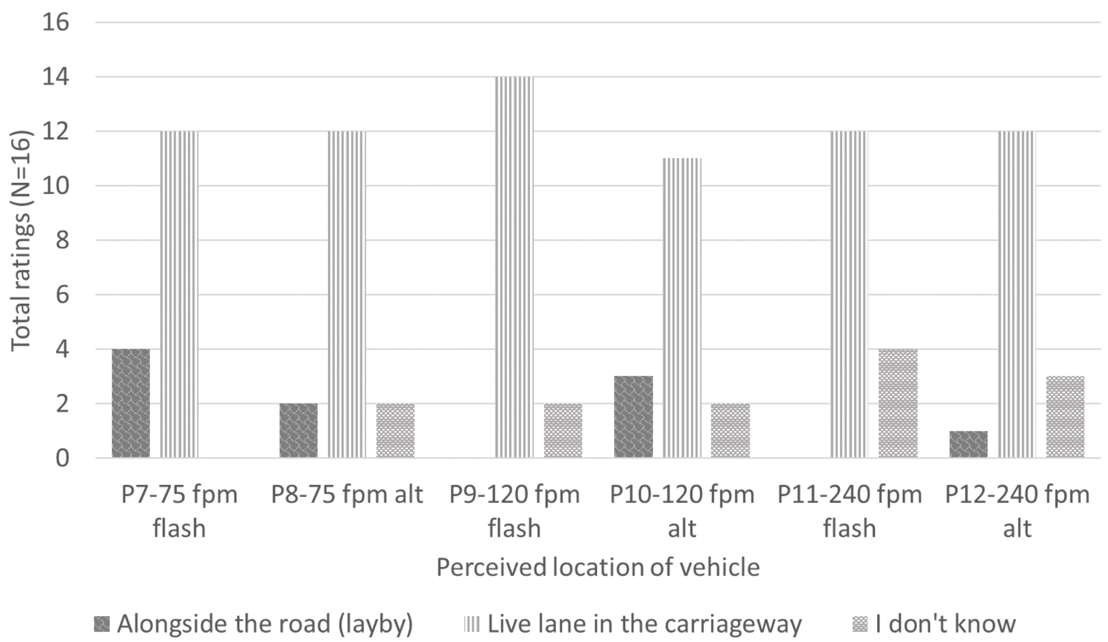

Figure 126: Graph to show the perceived location of the vehicle at 300 metres at night

As Figure 127 and Figure 128 show, no differences were observed between the 200 metres at night versus 200 metres in the day data, for the perceived location of the vehicle.

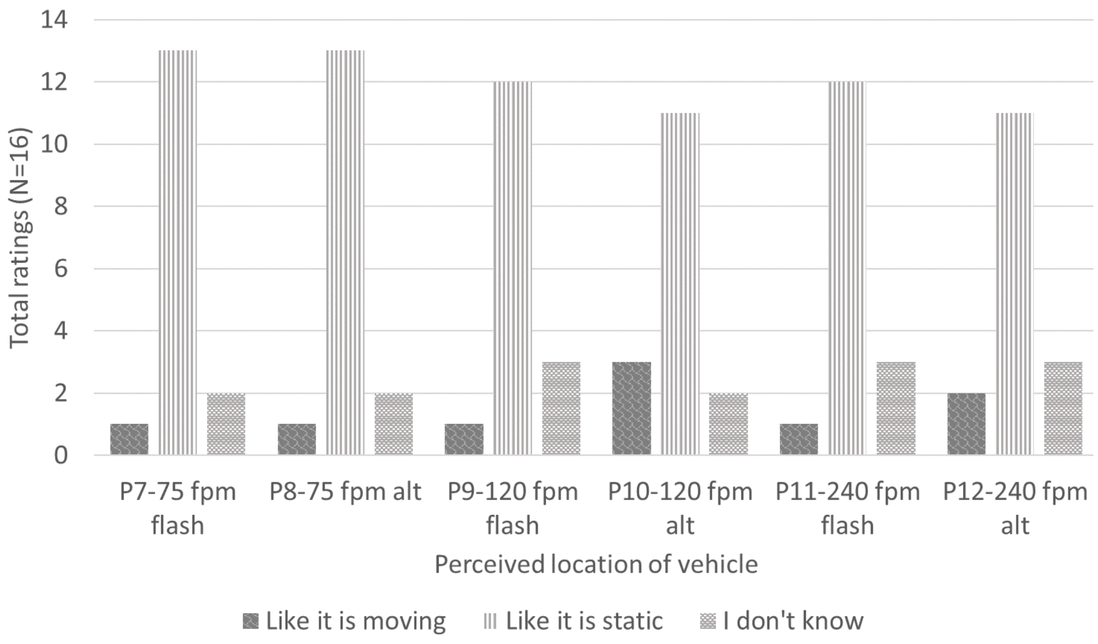

Figure 127: Graph to show the perceived location of the vehicle at 200 metres at night

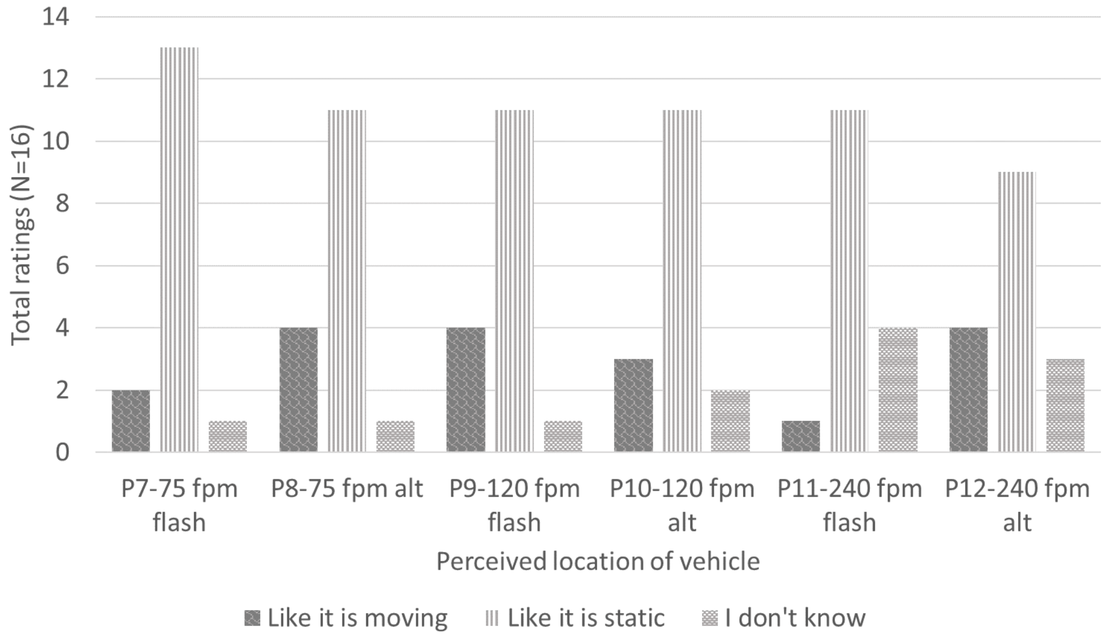

Figure 128: Graph to show the perceived location of the vehicle at 200 metres in the day

H.3.4 Pattern P7-P12 – distance

When comparing the perceived location of the vehicle at 300 metres and 200 metres in the day, no differences were observed across the lighting patterns between the two distances, for the perceived location of the vehicle. As Figure 129 and Figure 130 show, the attendees consistently rated the vehicle as appearing to be in the live lane., compared to alongside the road. This finding is mirrored across the night 300 and night 200 data (see Figure 131 and **Figure 132**). Interestingly, in the 300 metres data uniquely, attendees rated that the 75 fpm alternating pattern represented the vehicle as appearing alongside the road highest, compared to the other patterns.

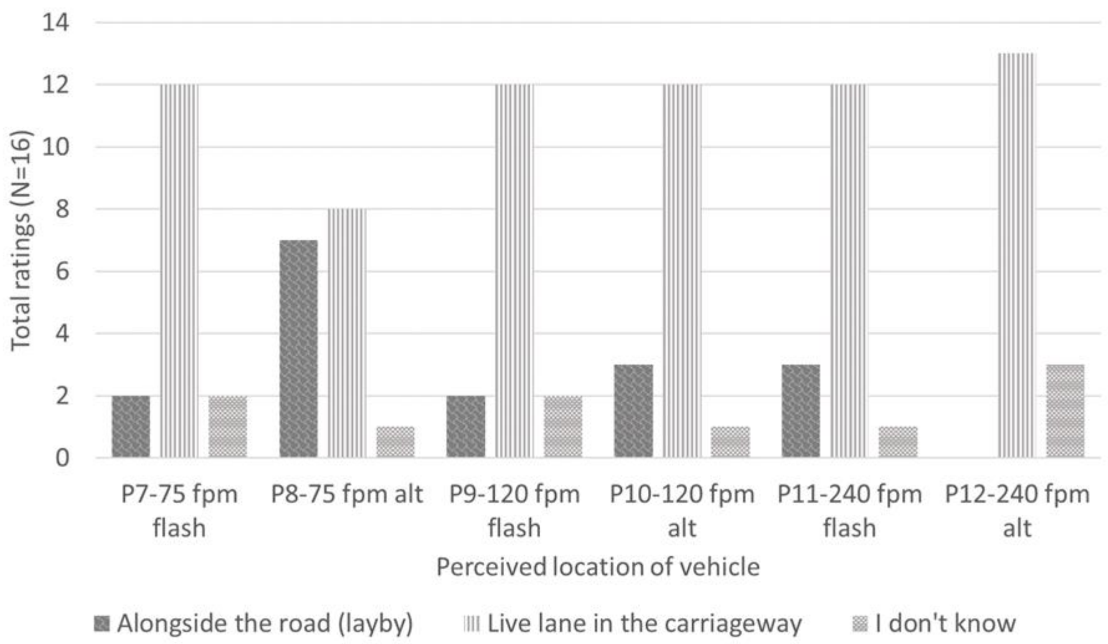

Figure 129: Graph to show the perceived location of the vehicle at 300 metres in the day

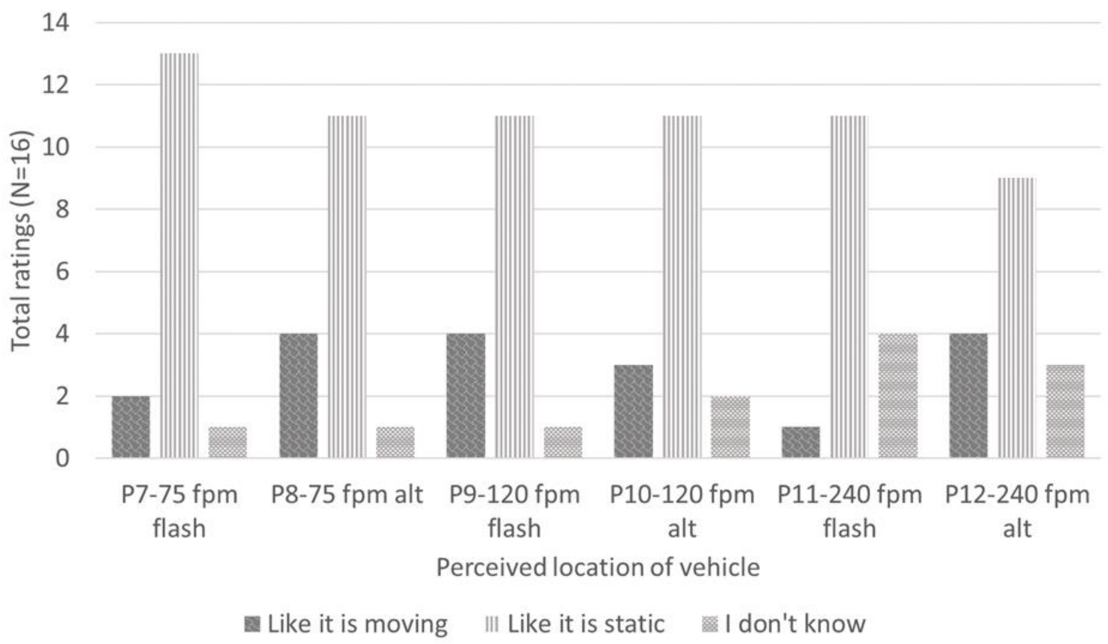

Figure 130: Graph to show the perceived location of the vehicle at 200 metres in the day

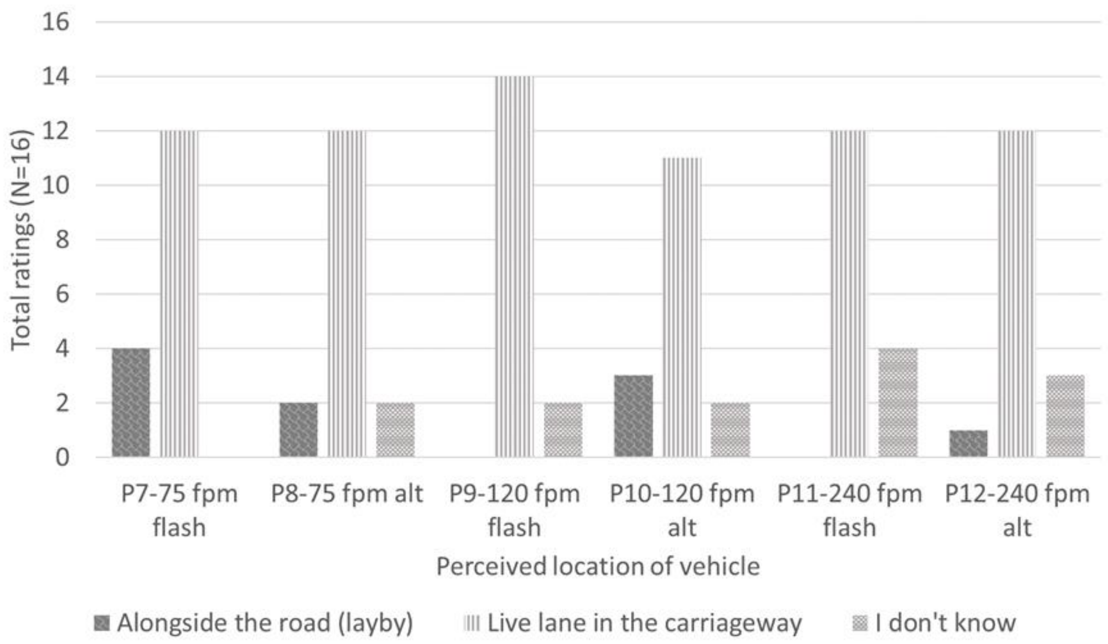

Figure 131: Graph to show the perceived location of the vehicle at 300 metres at night

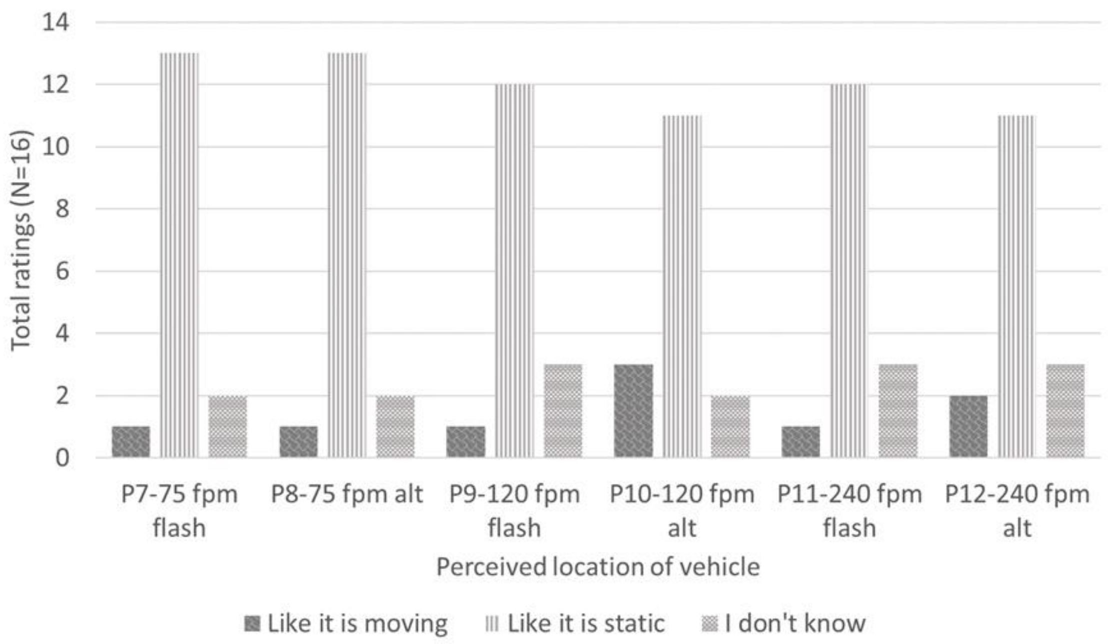

Figure 132: Graph to show the perceived location of the vehicle at 200 metres at night

H.3.5 Patterns P13-P16 – day and night

The following section presents the comparisons of lighting patterns P13 – P16, comprised as follows.

- Pattern P13–amber alternating varied speed

- Pattern P14–alternating red/amber double varied speed
- Pattern P15–double flash reds – fast
- Pattern P16–In-out amber with flashing reds

Due to complications with the data obtained, only two comparisons were made.

- Day 300 versus night 300 (to compare day vs night)
- Night 200 versus night 300 (to compare distance)

When comparing the perceived location of the vehicle at 300 metres and 200 metres in the day, no clear differences were observed between the two scenarios (see Figure 133 and Figure 134). No clear differences were observed when comparing between 300 metres and 200 metres at night.

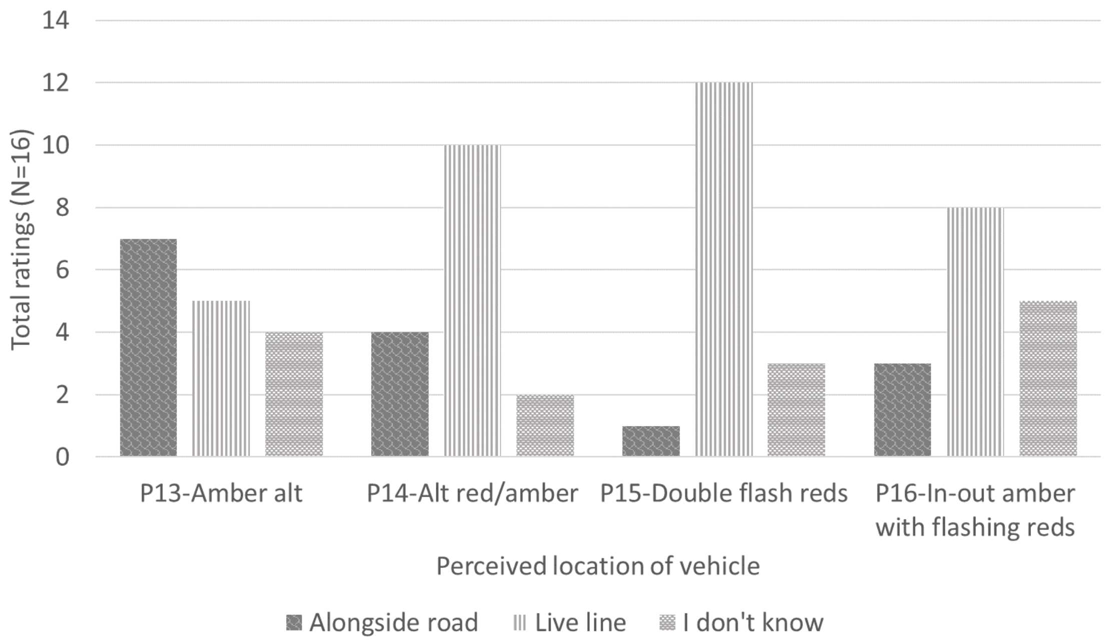

Figure 133: Graph to show the perceived location of the vehicle at 300 metres in the day

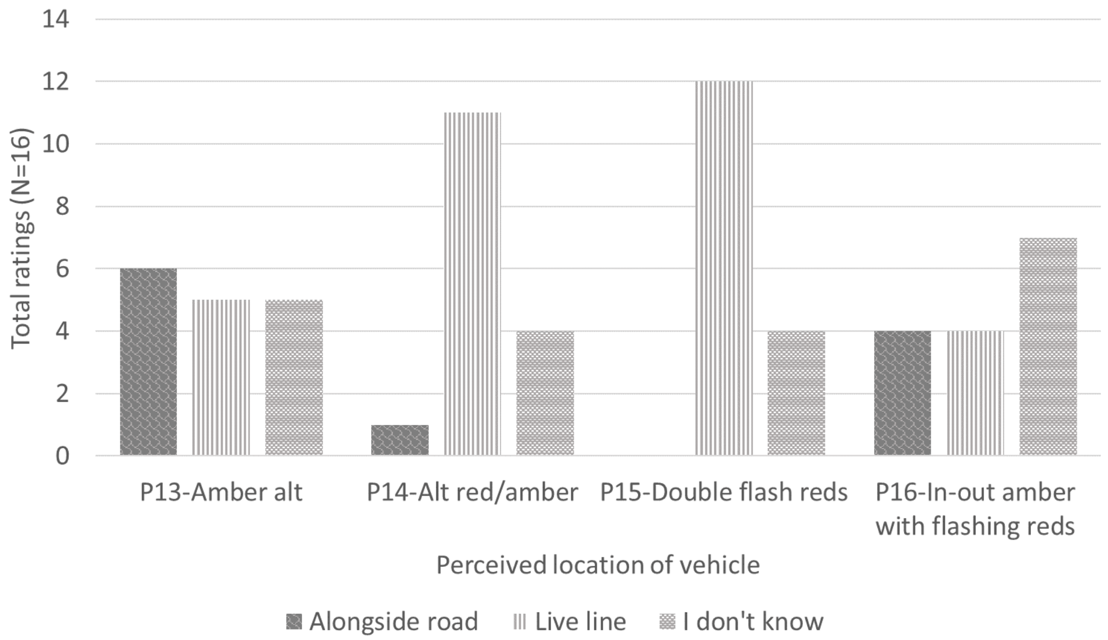

Figure 134: Graph to show the perceived location of the vehicle at 300 metres at night

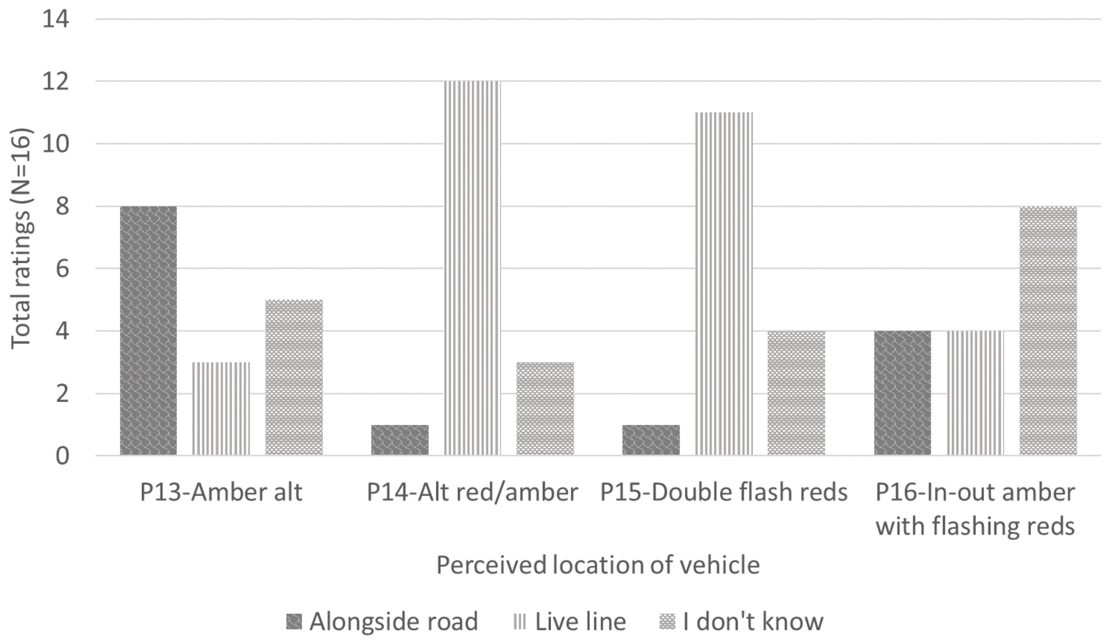

Figure 135: Graph to show the perceived location of the vehicle at 200 metres at night

H.4 Perceived brightness

How bright the lighting was perceived to be was measured on a scale from A–E, with A being strongly disagree and E being strongly agree.

H.4.1 Patterns P1-P6 - Day and Night

The following section presents the comparisons of lighting patterns P1–P6. The flashes per minute of these patterns varied and all flashes were either amber alternating or amber flash.

When comparing the perceived brightness of the lighting at a distance of 300 metres in the day vs night, attendees either disagreed or strongly disagreed that the lighting was too bright when presented with the 75 fpm and 120 fpm patterns in the day. Similar, yet smaller effects were noted in the 300 metres night data (see Figure 136 and Figure 137).

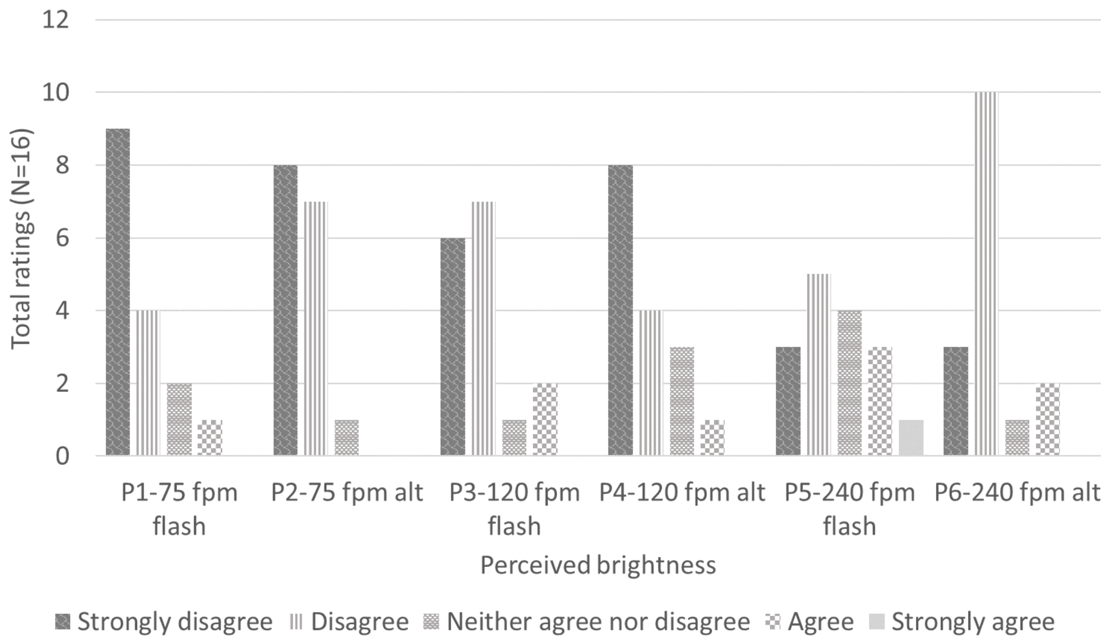

Figure 136: Graph to show the perceived brightness of the lighting 300 metres in the day

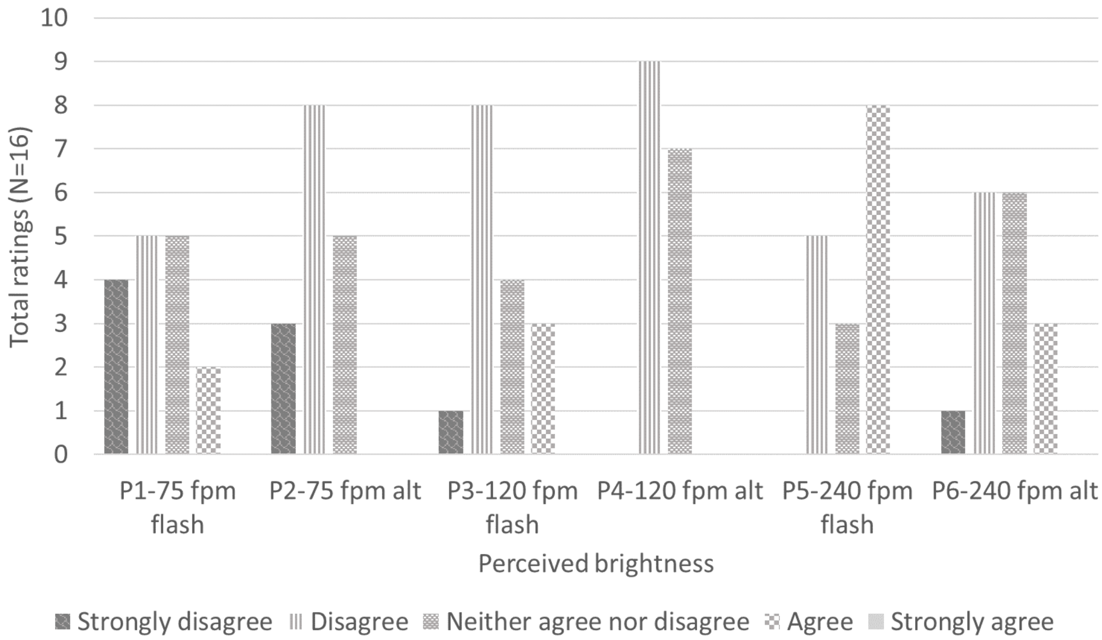

Figure 137: Graph to show the perceived brightness of the lighting at 300 metres at night

When comparing the perceived brightness of the lighting at 200 metres in the day vs night, disagreement was noted across the lighting patterns in the day, particularly the 120 fpm flashing pattern and the 240 fpm alternating pattern (see Figure 138). Strong disagreement was noted for the 75 fpm alternating pattern. The night data differed; no ratings of strongly disagree were noted (see Figure 139), except for the 240 fpm alternating pattern. Attendees also agreed that the 120 fpm flashing pattern and 240 fpm flashing pattern were too bright at night, from a distance of 200 metres. These findings suggest that the 120 fpm flashing pattern was perceived to be too bright at night, but not in the daylight.

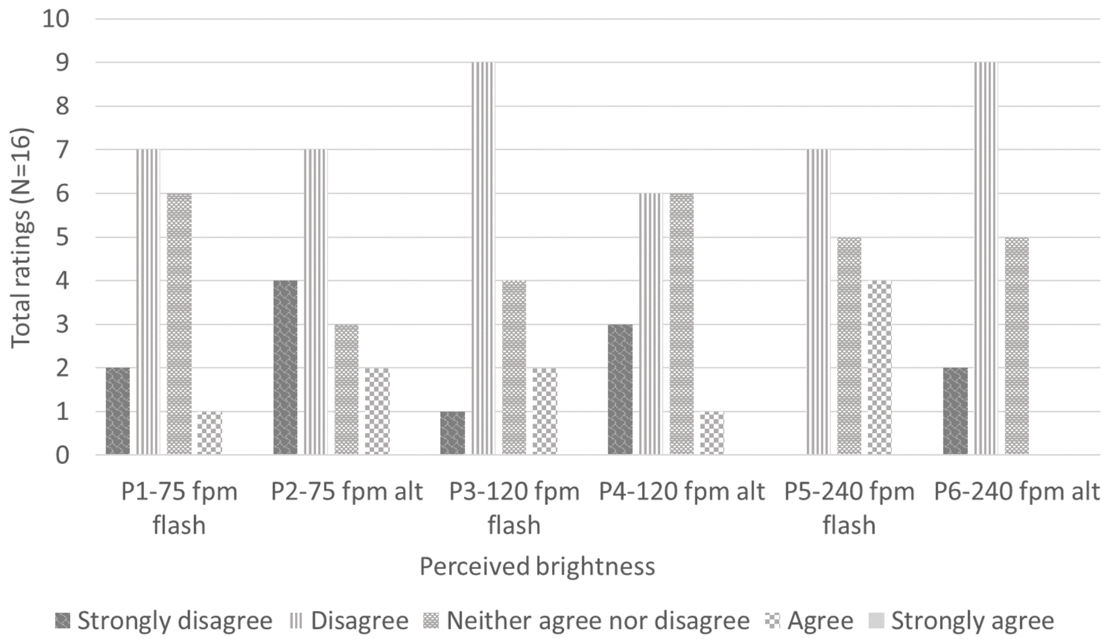

Figure 138: Graph to show the perceived brightness of the lighting 200 metres in the day

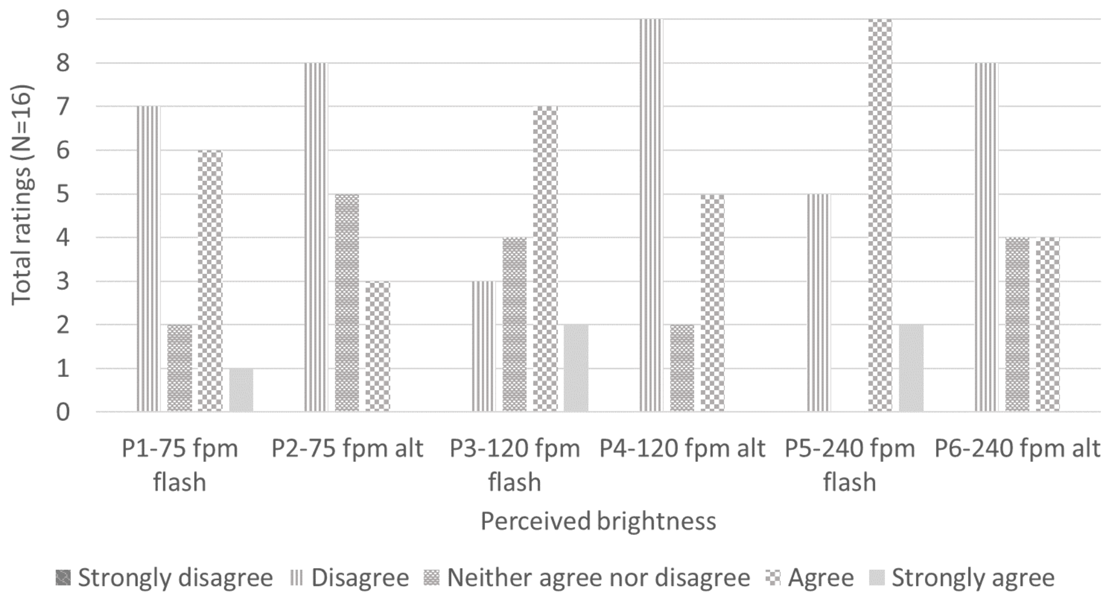

Figure 139: Graph to show the perceived brightness of the lighting 200 metres at night

H.4.2 Patterns P1–P6 – distance

When comparing the perceived brightness of the lighting at 200 metres and 300 metres in the day, disagreement that the lights were too bright was consistently noted across both scenarios. Attendees appeared to disagree that the 120 fpm flashing lighting pattern was too bright in the 200 metres data, compared to the 300 metres data (see Figure 140 and Figure 141).

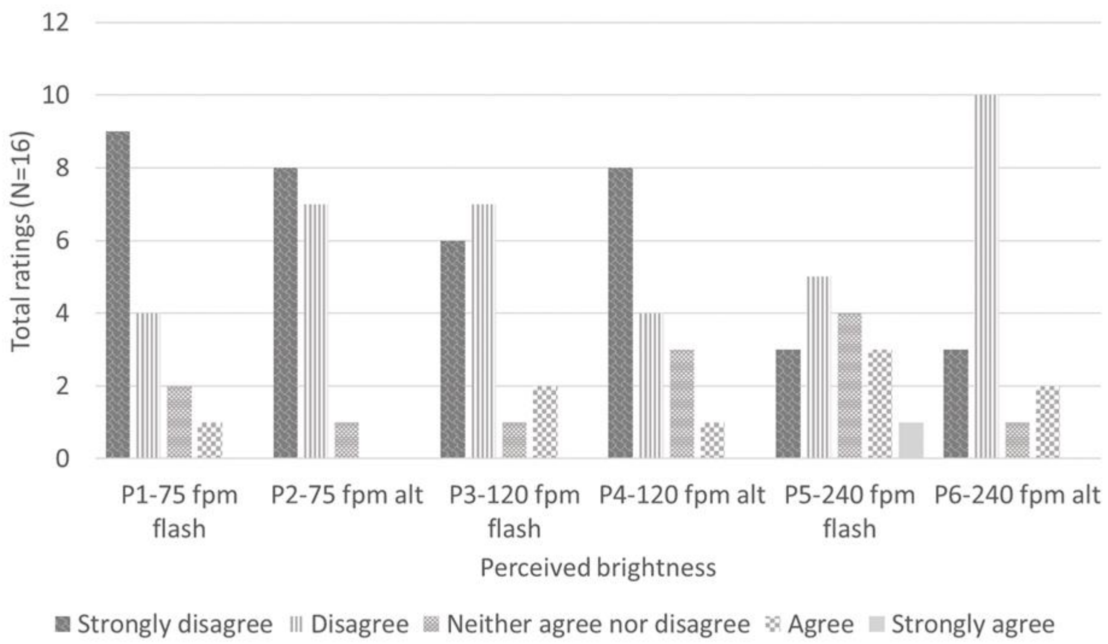

Figure 140: Graph to show the perceived brightness of the lighting 300 metres in the day

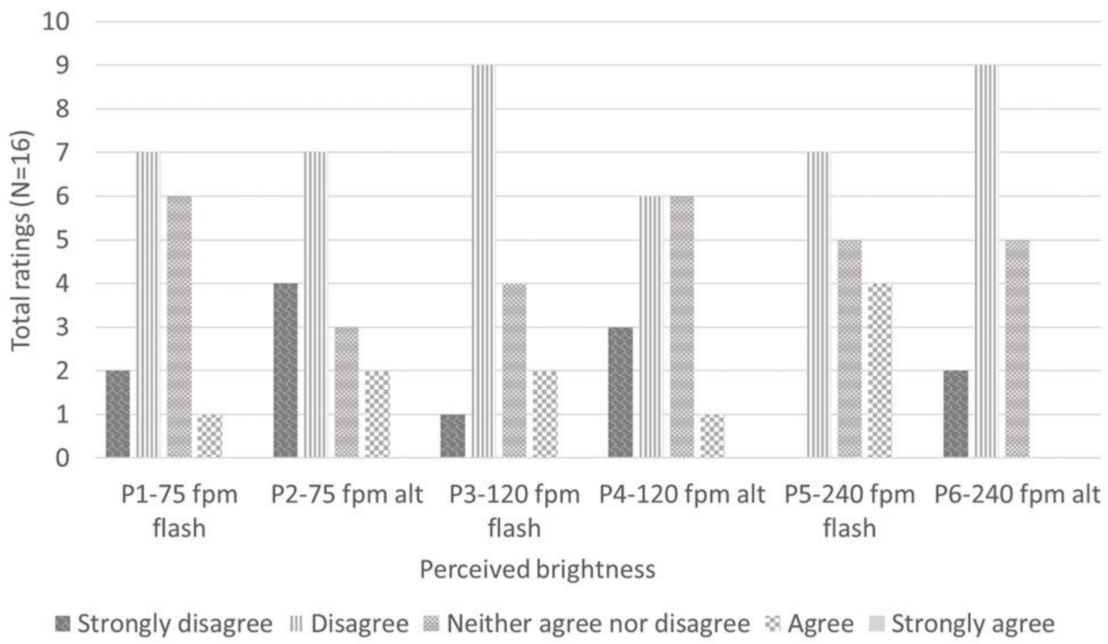

Figure 141: Graph to show the perceived brightness of the lighting 200 metres in the day

When comparing the perceived brightness of the lighting at 300 and 200 metres, as Figure 142 and Figure 143 show, more agreement was noted for the 200 metres data, compared to the 300 metres data. This suggests that the distance to the lighting patterns affects the perceived brightness.

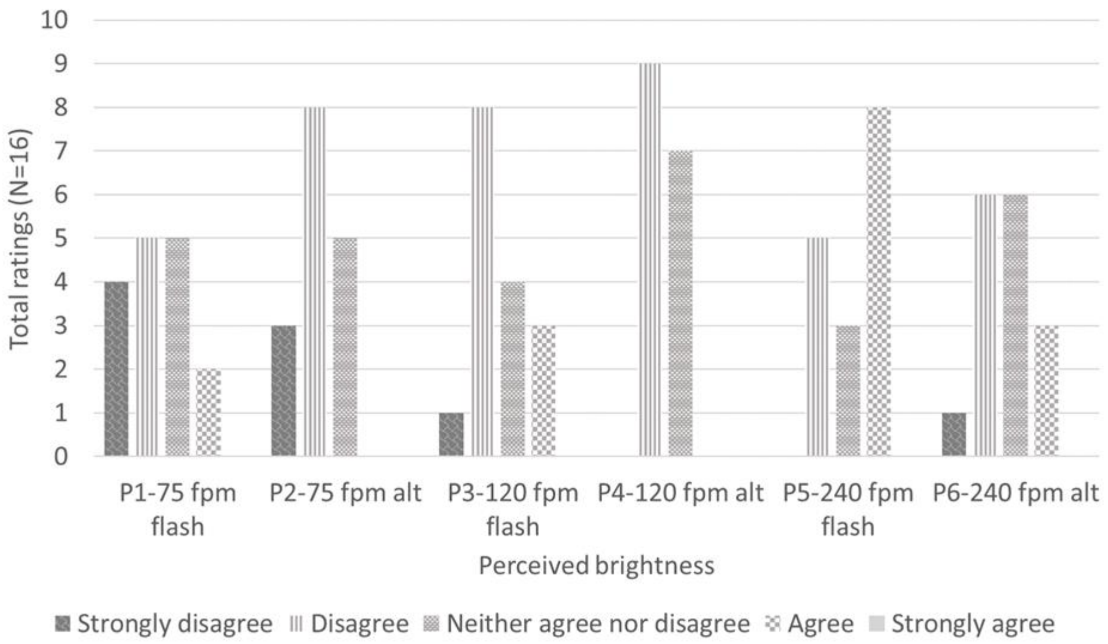

Figure 142: Graph to show the perceived brightness of the lighting at 300 metres at night

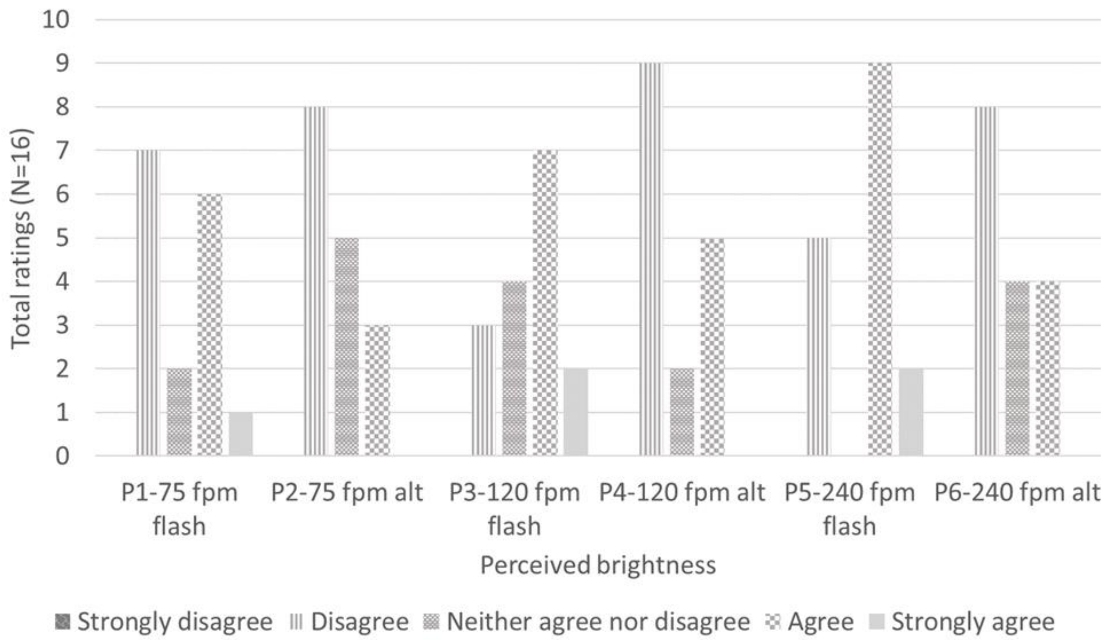

Figure 143: Graph to show the perceived brightness of the lighting at 200 metres at night

H.4.3 Patterns P7-P12 – day and night

As Figure 144 and Figure 145 show, more disagreement with the statement was noted across the lighting patterns in the 300 metres day data, compared to the 300 metres night data. This was particularly noticeable with both 75 fpm lighting patterns, in the 300 metres day data.

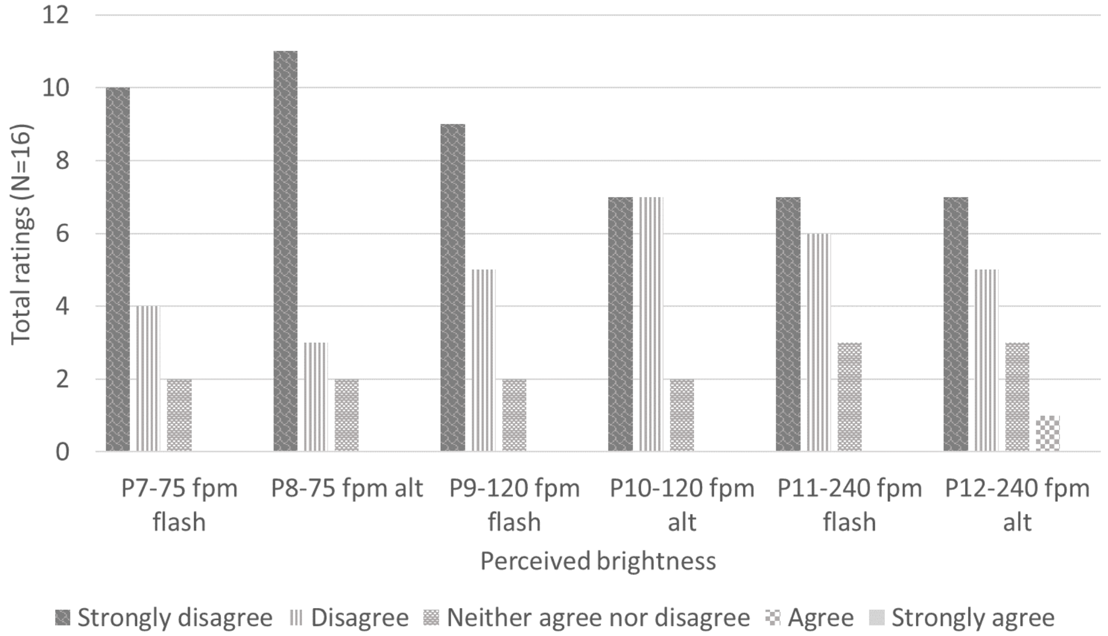

Figure 144: Graph to show the perceived brightness of the lighting at 300 metres in the day

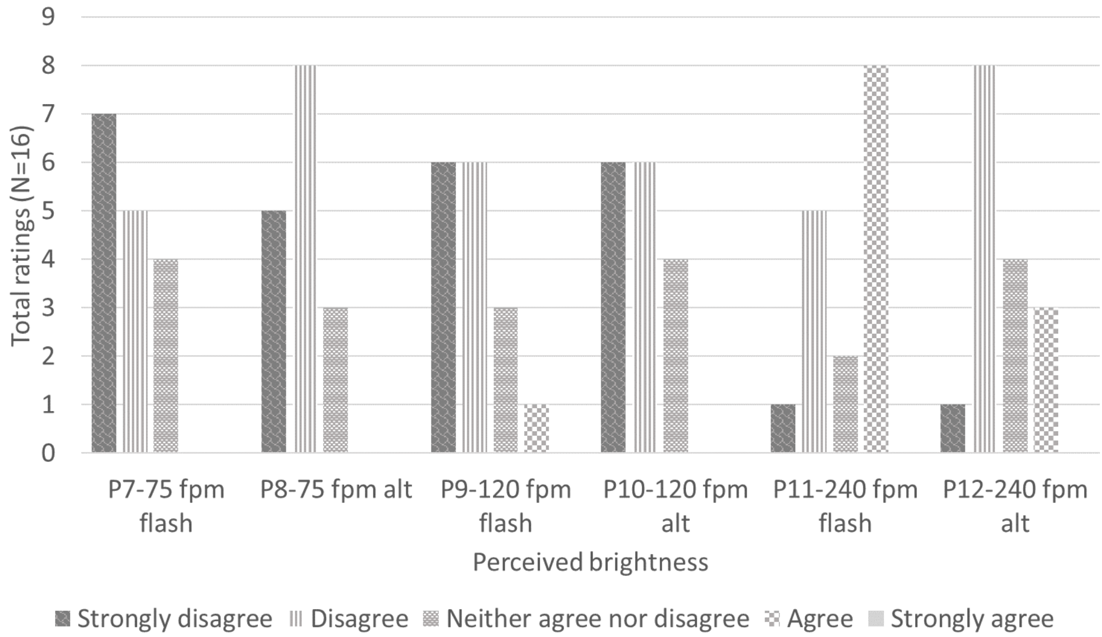

Figure 145: Graph to show the perceived brightness of the lighting at 300 metres at night

When comparing the perceived brightness of the lighting at 200 metres in the day versus night, as shown by Figure 146 and Figure 147, disagreement, and particularly strong disagreement, was noted more at night, compared to the day. This suggests that the lighting patterns were perceived to be sufficiently bright in the day, compared to night.

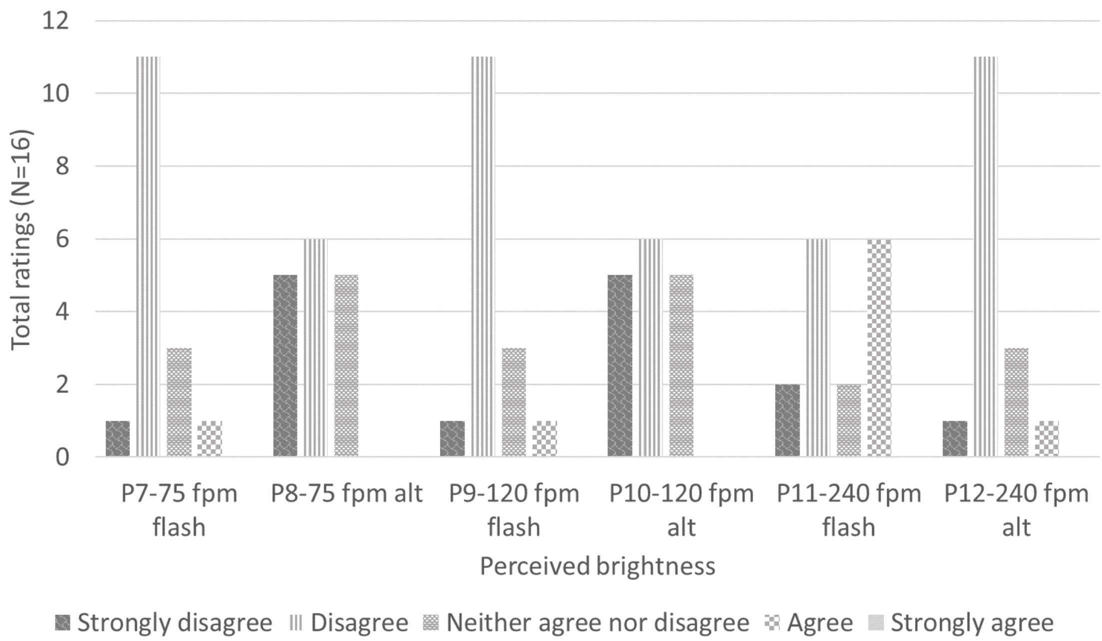

Figure 146: Graph to show the perceived brightness of the lighting at 200 metres at night

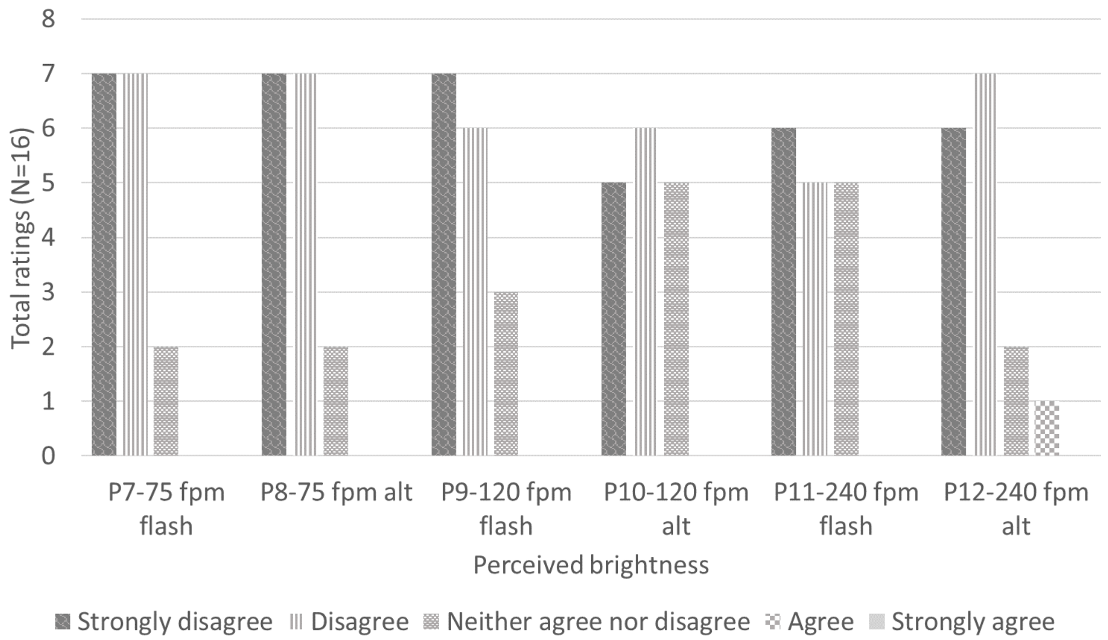

Figure 147: Graph to show the perceived brightness of the lighting at 200 metres in the day

H.4.4 Patterns P7-P12 – distance

As Figure 148 and Figure 149 show, across both the 200 and 300 metres captured in the day, strong disagreement with the statement was noted. This suggests that the lighting patterns were judged to be of sufficient brightness in conditions of daylight.

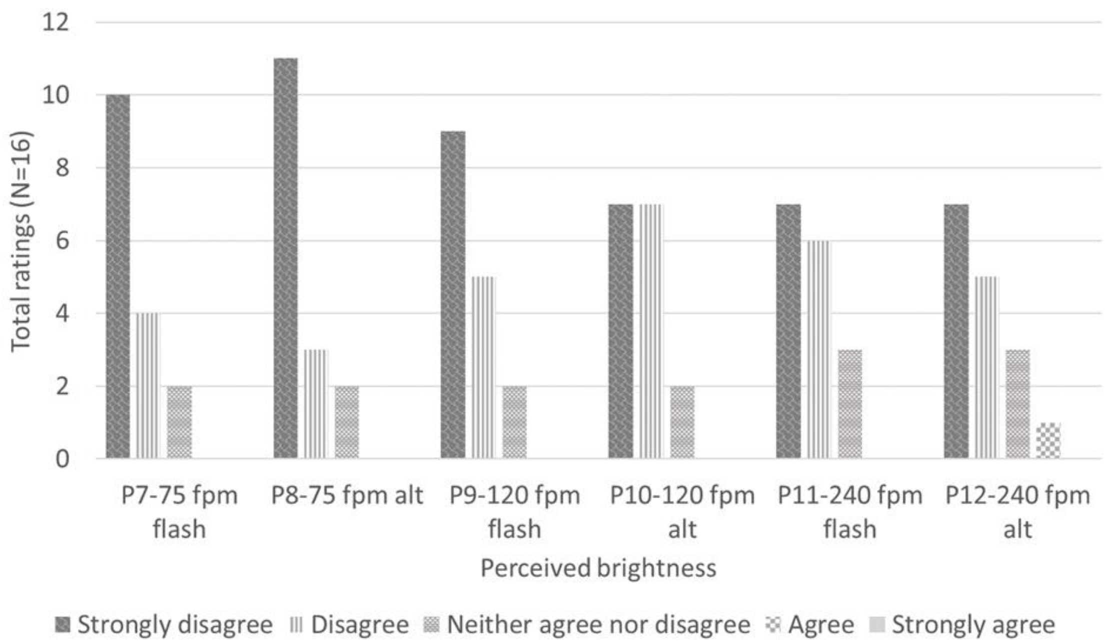

Figure 148: Graph to show the perceived brightness of the lighting at 300 metres in the day

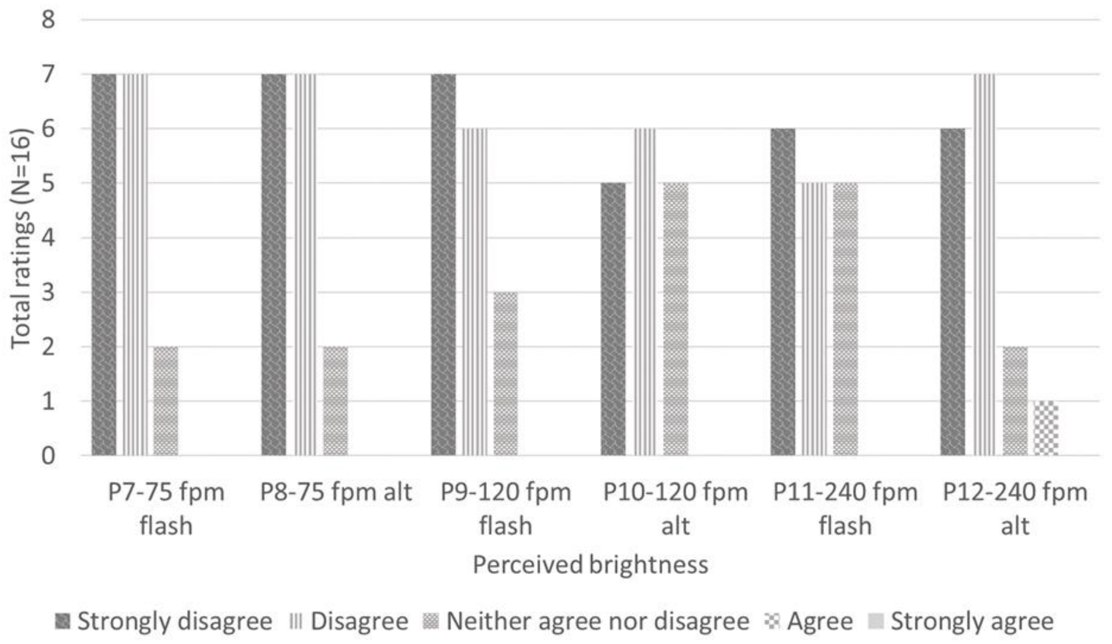

Figure 149: Graph to show the perceived brightness of the lighting at 200 metres in the day

When comparing the perceived brightness of the lighting patterns at 300 and 200 metres at night, as Figure 150 and Figure 151 show, the ratings of strongly disagree were greater at a distance of 300 metres, compared to 200 metres. This suggests that the attendees perceived the brightness of the patterns to be more comfortable, at this distance.

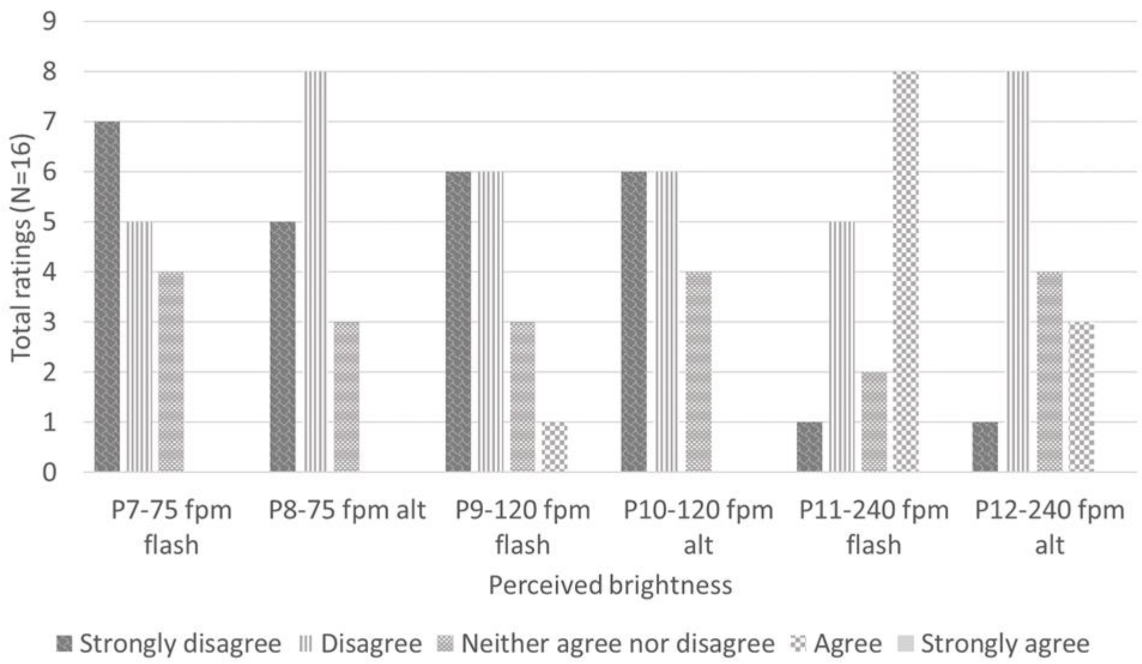

Figure 150: Graph to show the perceived brightness of the lighting at 300 metres at night

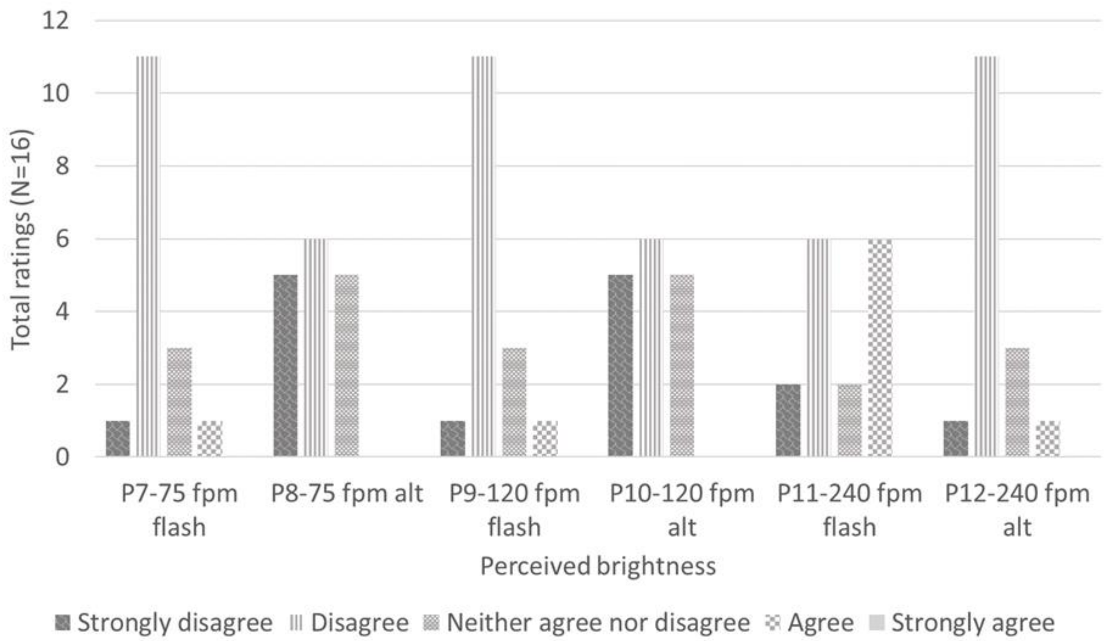

Figure 151: Graph to show the perceived brightness of the lighting at 200 metres at night

H.4.5 Patterns P13–P16 – day and night

The following section presents the comparisons of lighting patterns P13–P16, comprised as follows.

- Pattern P13 – amber alternating varied speed
- Pattern P14 – alternating red/amber double varied speed
- Pattern P15 – double flash reds – fast
- Pattern P16 – In-out amber with flashing reds

When comparing the perceived brightness of the lighting patterns at 300 metres in the day with 300 metres at night, as Figure 152 and Figure 153 show, more attendees strongly disagreed with the statement in the day, compared to at night. This finding was mirrored in the 200 metres day and night data (see Figure 154 and Figure 155). In the night data, agreement was noted when the attendees were presented with in-out amber with flashing reds pattern.

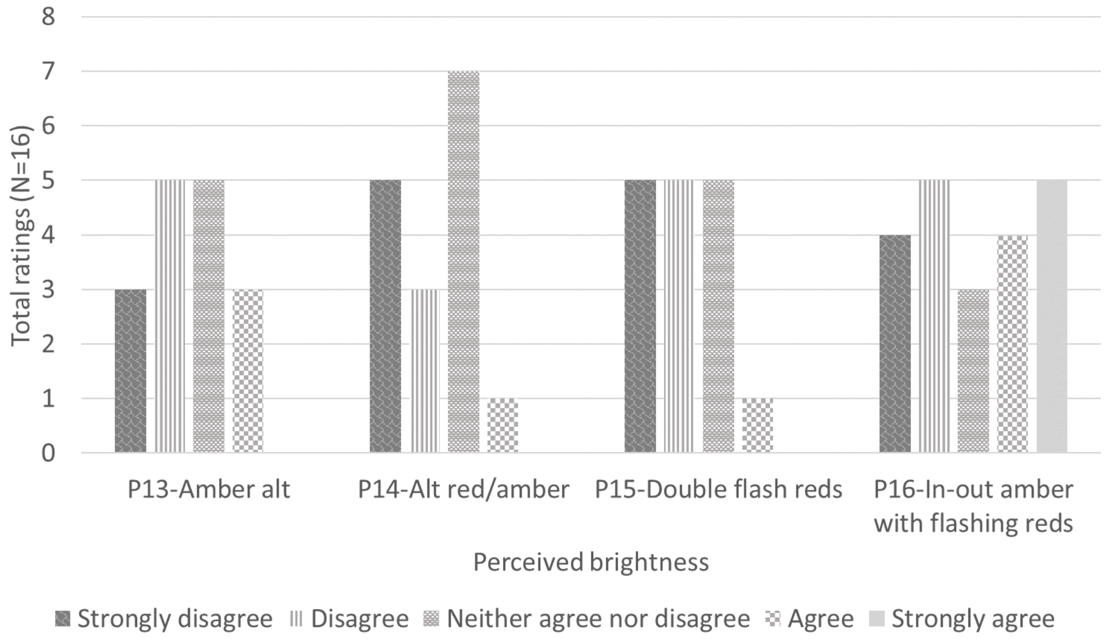

Figure 152: Graph to show the perceived brightness of the lighting at 300 metres in the day

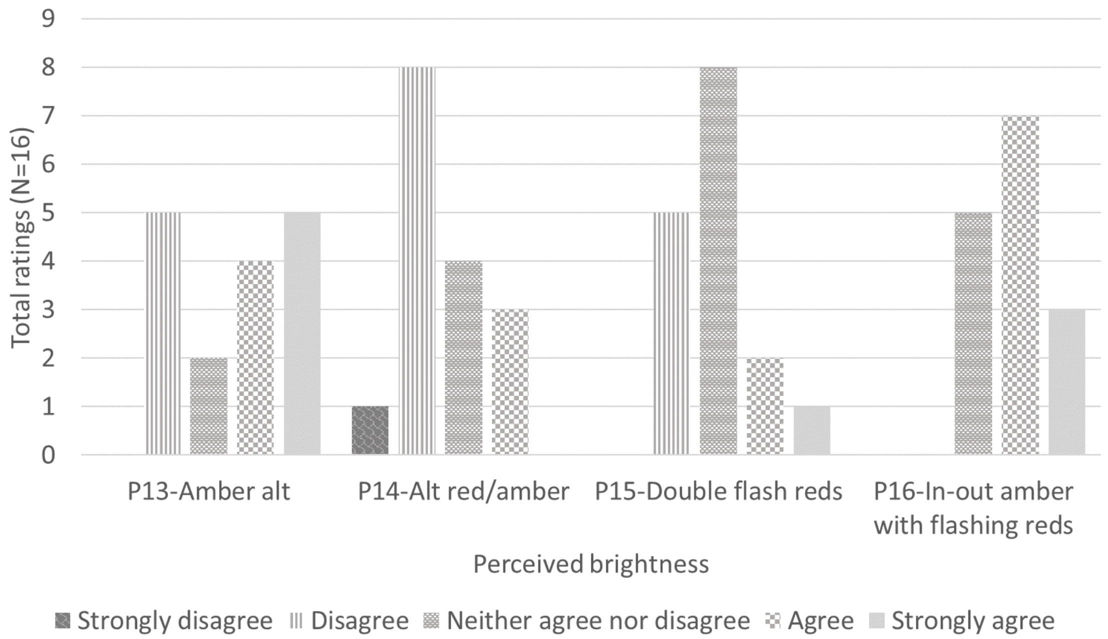

Figure 153: Graph to show the perceived brightness of the lighting at 300 metres at night

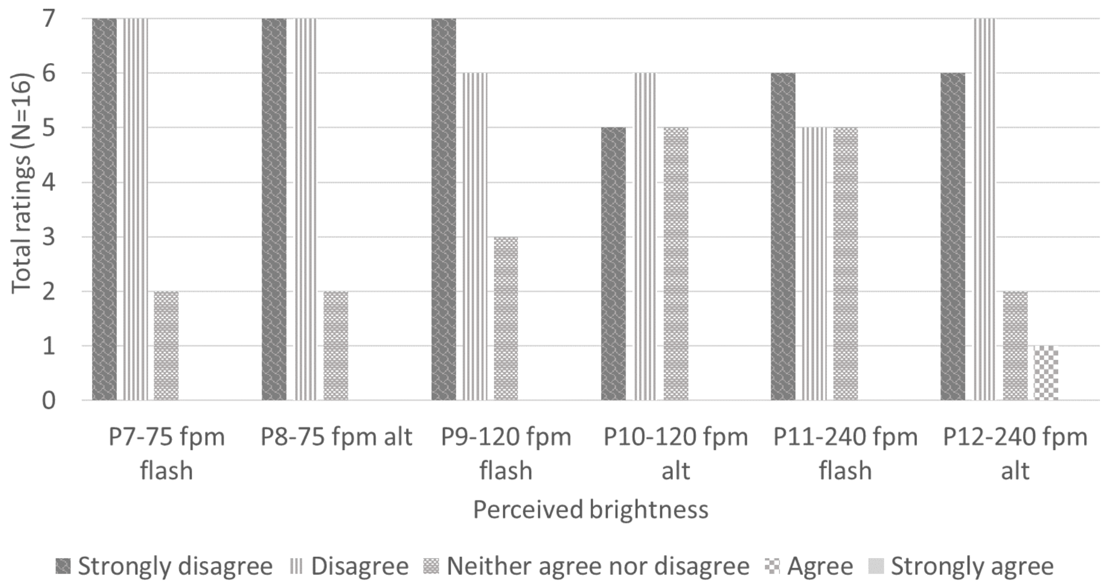

Figure 154: Graph to show the perceived brightness of the lighting at 200 metres in the day

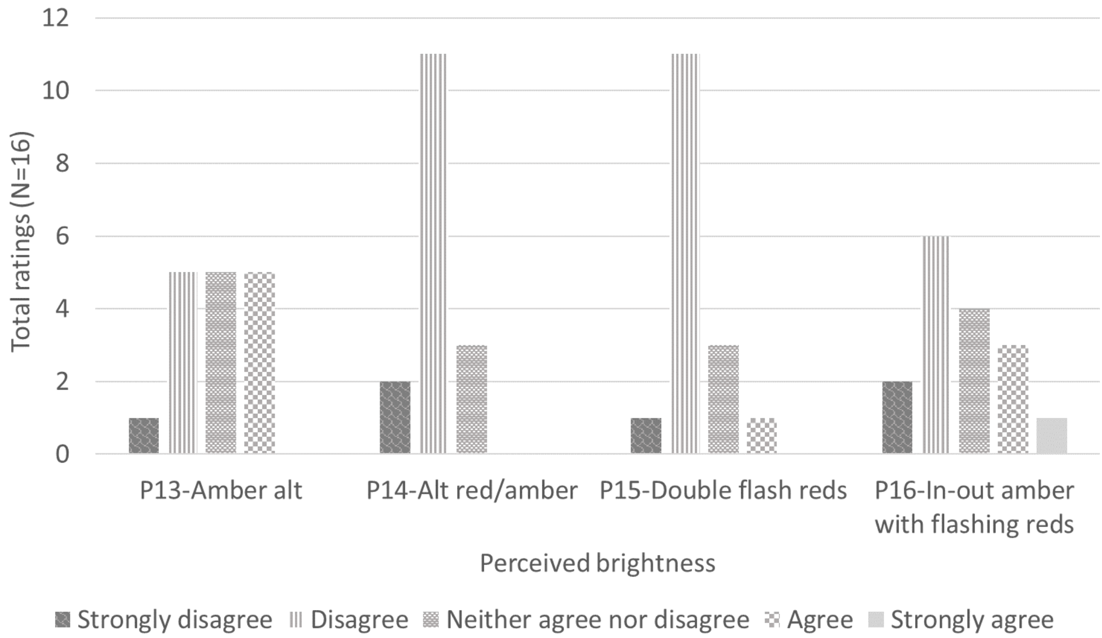

Figure 155: Graph to show the perceived brightness of the lighting at 200 metres at night

H.4.6 Patterns P13–P16 – distance

When comparing the perceived brightness of the lighting patterns at 200 and 300 metres in the day, as Figure 157 and Figure 156 show, more disagreement was noted in the 200 metres data, compared to the 300 metres data. This may suggest that the attendees were more comfortable with the brightness of the lighting patterns at 200 metres, compared to 300 metres.

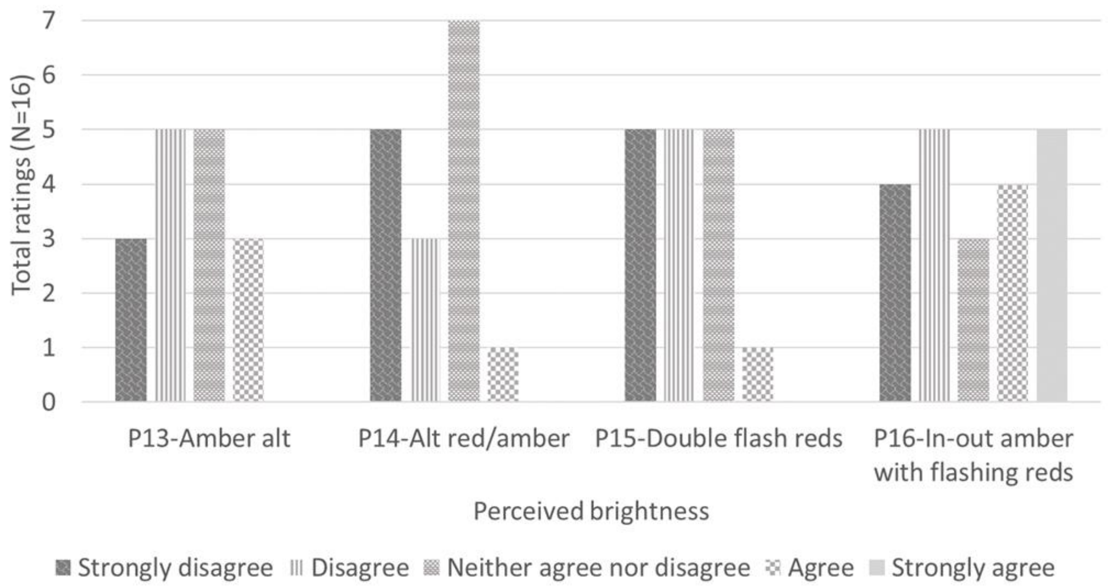

Figure 156: Graph to show the perceived brightness of the lighting at 300 metres in the day

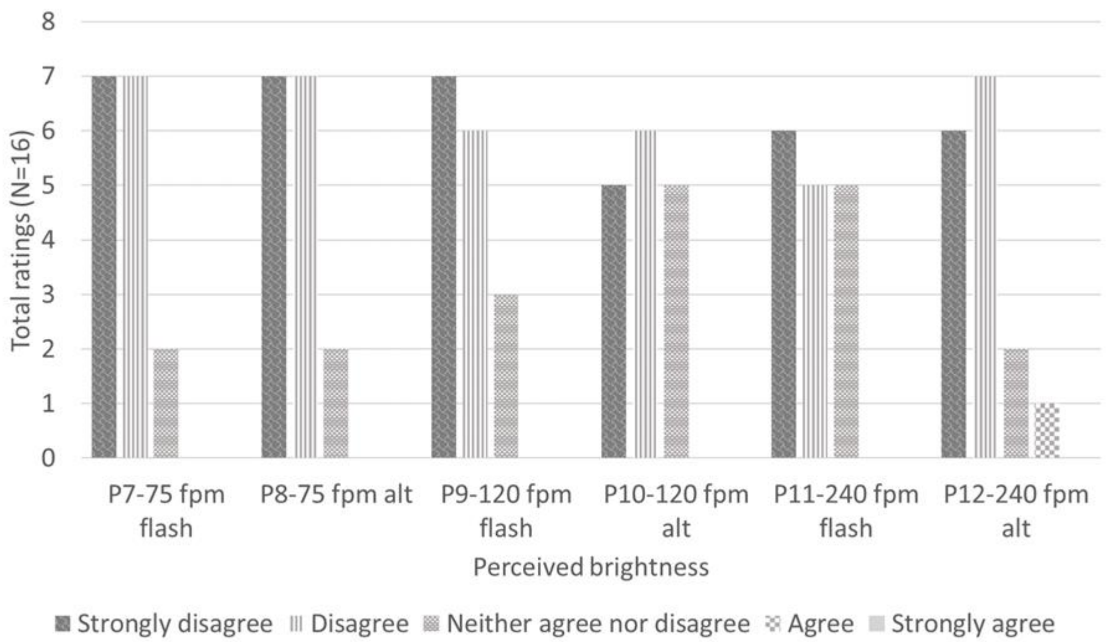

Figure 157: Graph to show the perceived brightness of the lighting at 200 metres in the day

When comparing the perceived brightness of the lighting patterns at a distance of 200 metres vs 300 metres at night, it can be seen that disagreement was expressed towards the alternating red/amber pattern across both scenarios (see Figure 158 and Figure 159).

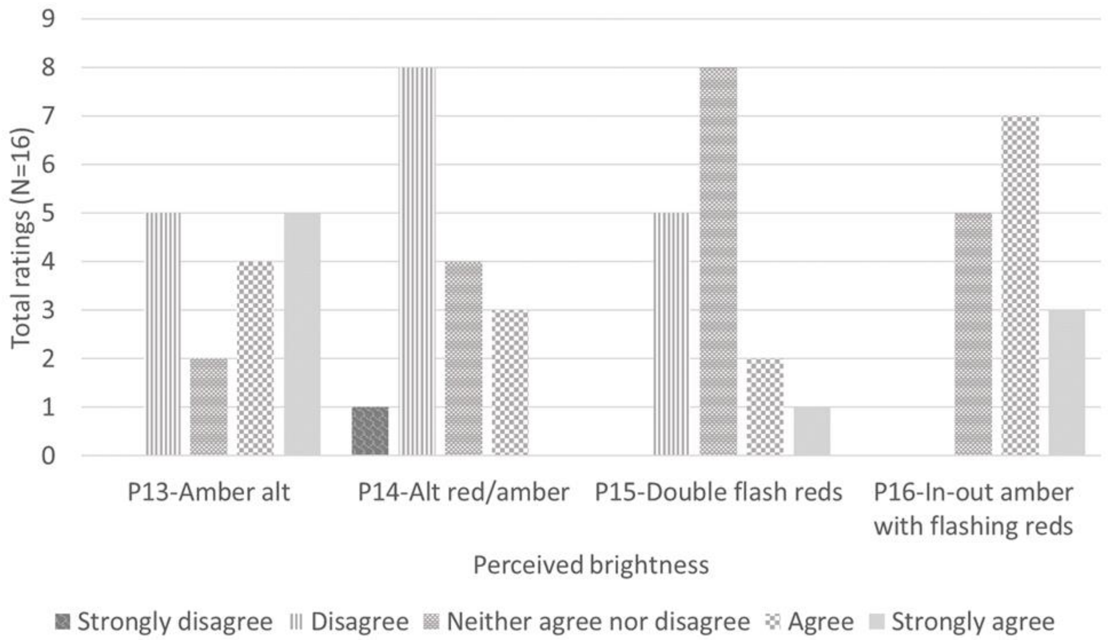

Figure 158: Graph to show the perceived brightness of the lighting at 300 metres at night

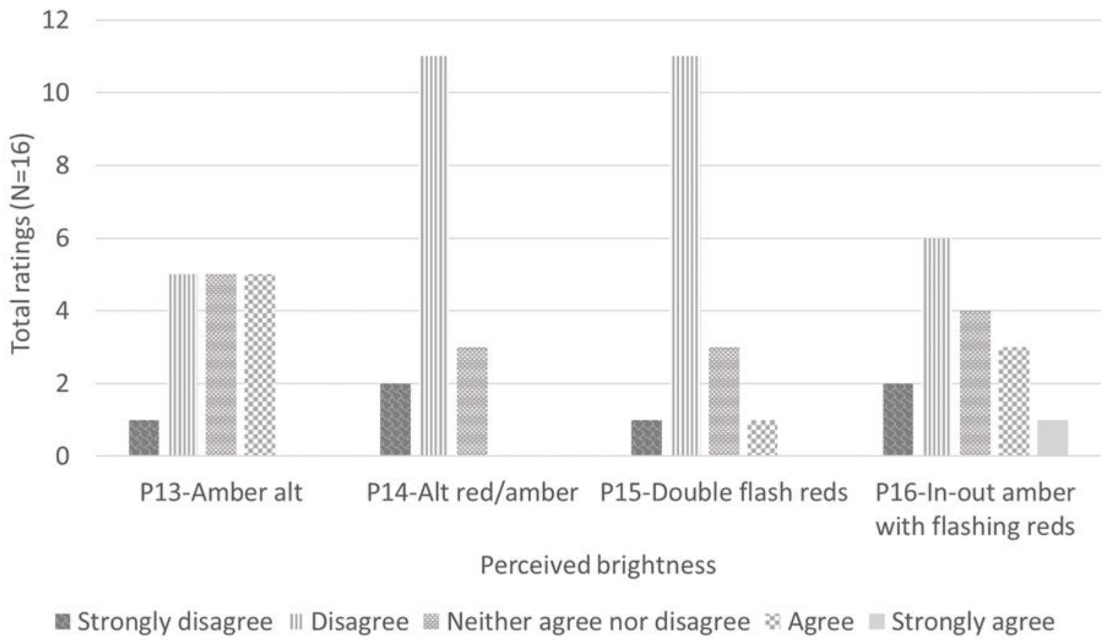

Figure 159: Graph to show the perceived brightness of the lighting at 200 metres at night

H.5 Perceived distraction

How distracting the light was perceived to be was measured on a scale from A-E, with A being strongly disagree and E being strongly agree.

H.5.1 Patterns P1-P6 – Dday and night

The following section presents the comparisons of lighting patterns P1–P6. The flashes per minute of these patterns varied and all flashes were either amber alternating or amber flash.

When comparing the perceived distraction of the lighting at 300 metres in the day vs night, disagreement was generally noted across both scenarios. Stronger disagreement was noted in the day data, particularly across both 75 fpm patterns and the 120 fpm alternating pattern (see Figure 160 and Figure 161). This suggests that attendees did not perceive these patterns to be distracting.

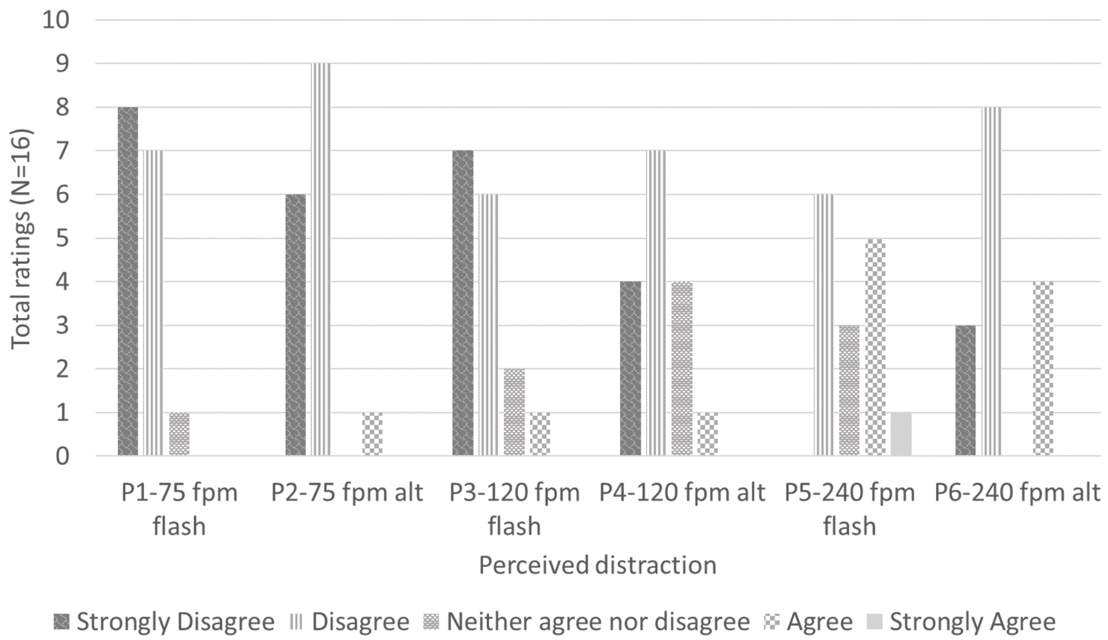

Figure 160: Graph to show the perceived distraction of the lighting at 300 metres in the day

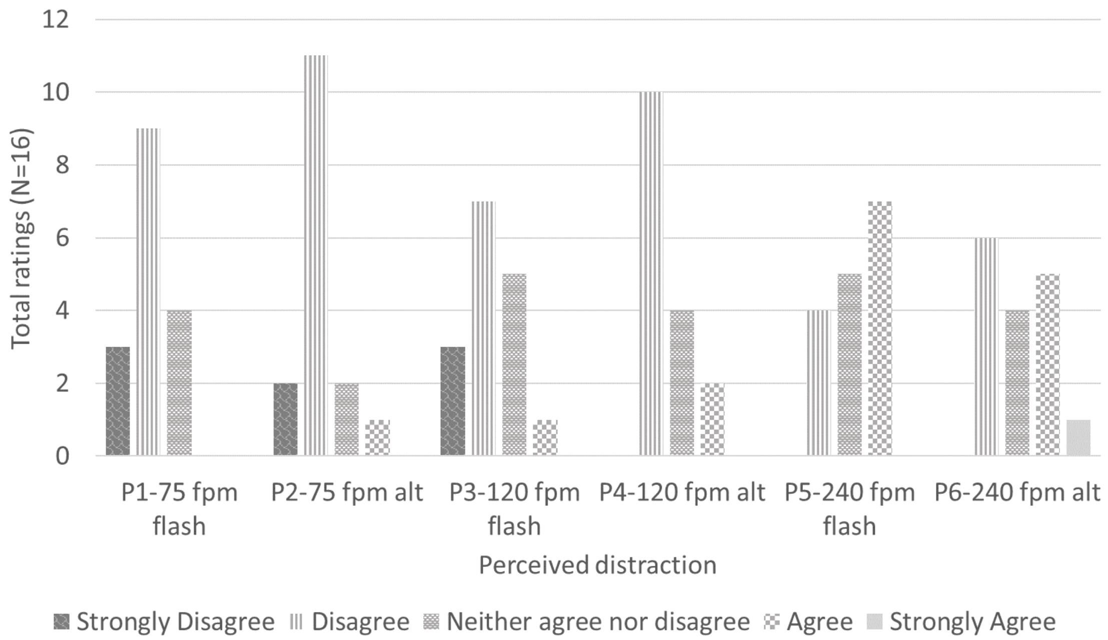

Figure 161: Graph to show the perceived distraction of the lighting at 300 metres at night

When comparing the perceived distraction of the lighting at 200 metres in the day vs night, disagreement was generally noted across both scenarios (see Figure 162 and Figure 163). However, in the 200 metres night data, nine of the attendees responded to the 120 fpm flash with ‘neither agree nor disagree’. Additionally, in the night data, agreement was noted when the attendees were presented with the 240 fpm flash pattern, which suggests that this pattern was perceived to be distracting

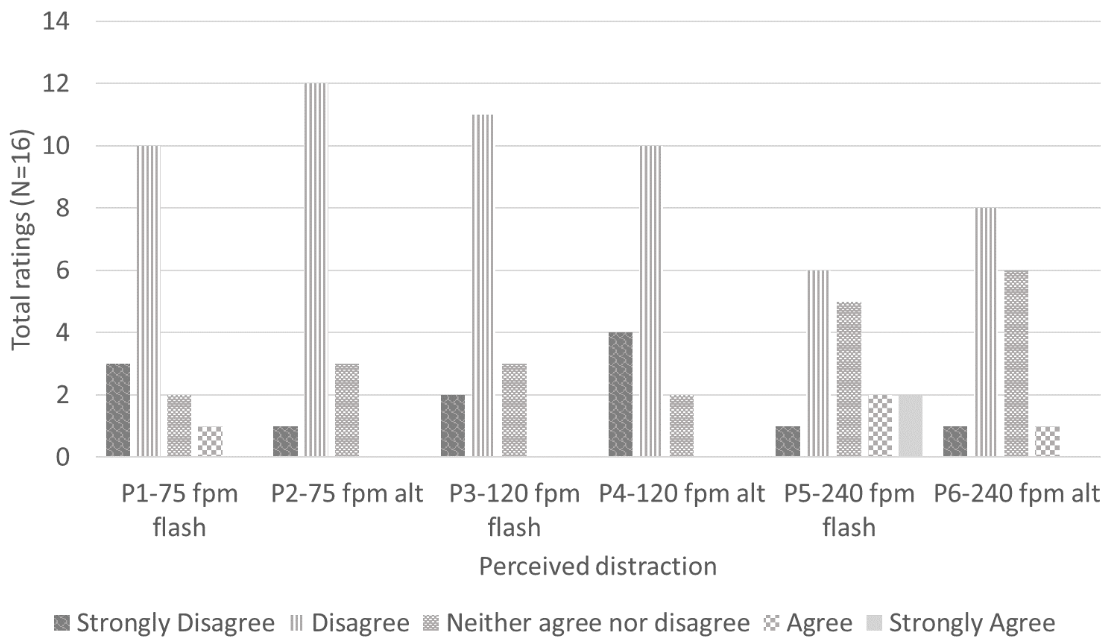

Figure 162: Graph to show the perceived distraction of the lighting at 200 metres in the day

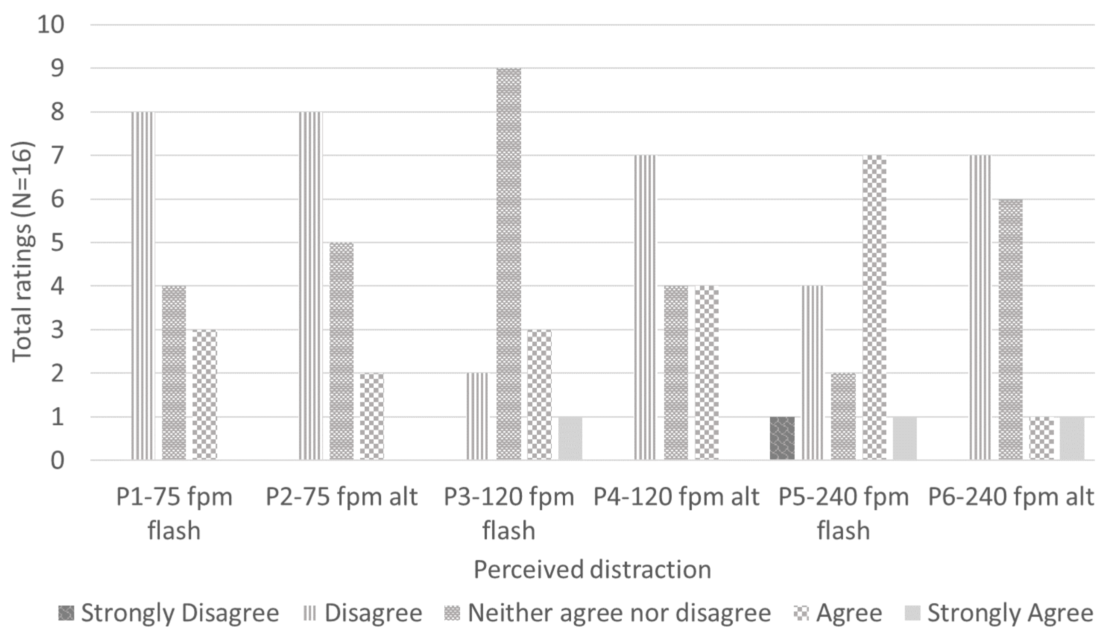

Figure 163: Graph to show the perceived distraction of the lighting at 200 metres at night

H.5.2 Patterns P1-P6 – distance

As Figure 164 and Figure 165 show, disagreement with the statement was found when comparing both the day 300 and day 200 metres data. Strong disagreement was particularly noticeable in the day 300 metres data, suggesting that the lighting patterns were not distracting at this distance.

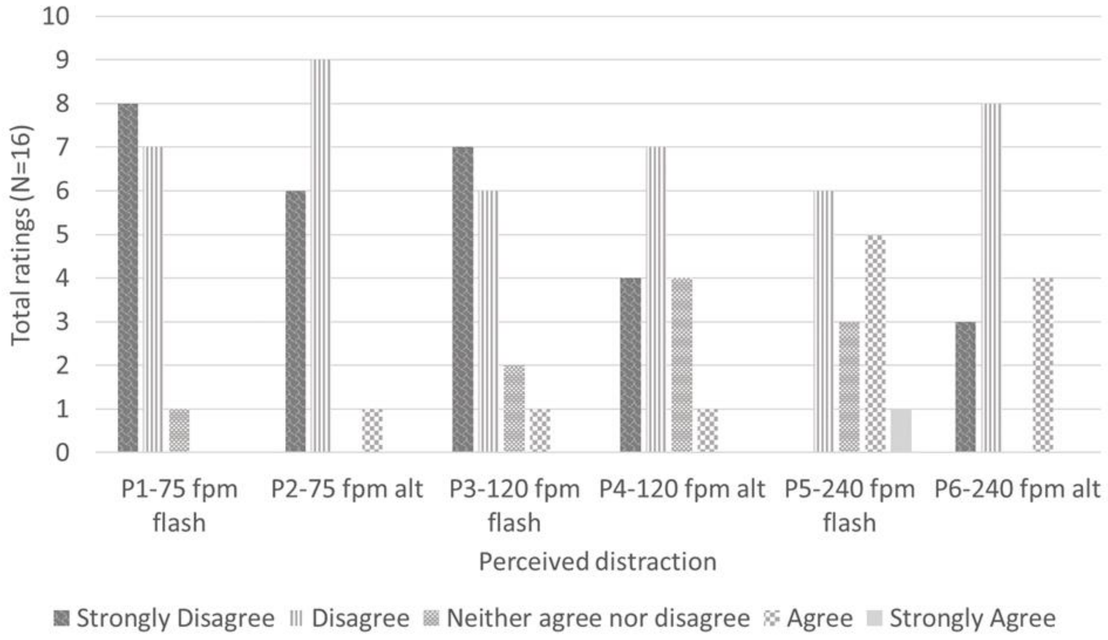

Figure 164: Graph to show the perceived distraction of the lighting at 300 metres in the day

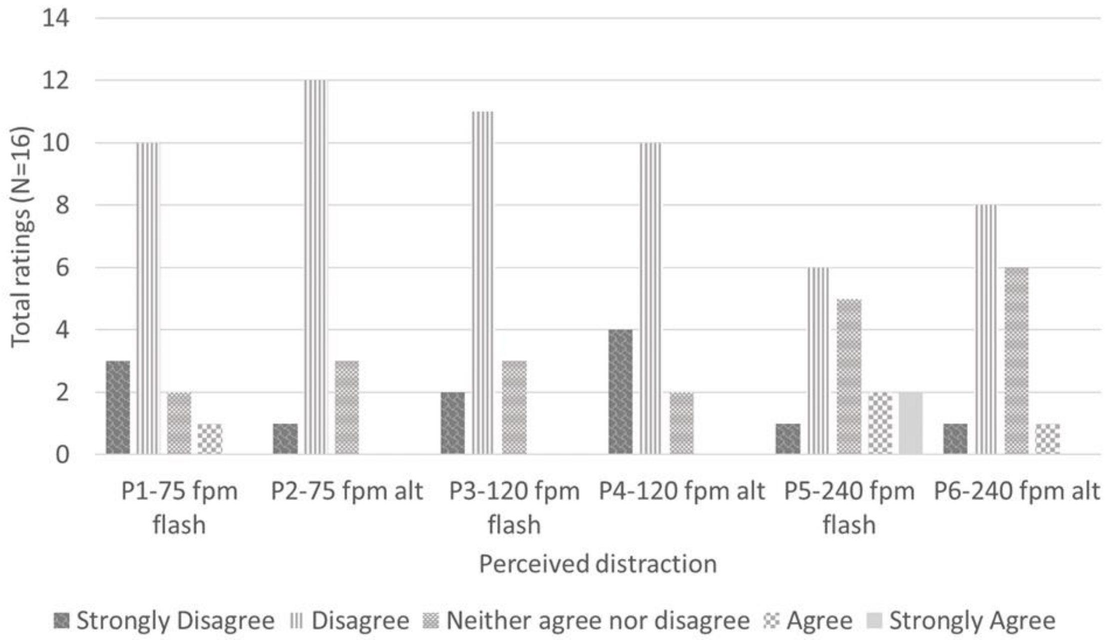

Figure 165: Graph to show the perceived distraction of the lighting at 200 metres in the day

When comparing the perceived distraction at 200 metres and 300 metres at night, clear differences emerge (see Figure 166 and Figure 167). As noted previously, attendees responded to the 120 fpm flash with ‘neither agree nor disagree’. Agreement was noted when the attendees were presented with the 240 fpm flash pattern, which suggests that this pattern was perceived to be distracting. In contrast, these effects were not noted in the 300 metres data, where disagreement with the statement for 120 fpm flash pattern was found. This suggests that, at a longer distance, the pattern was perceived to be less distracting by the attendees.

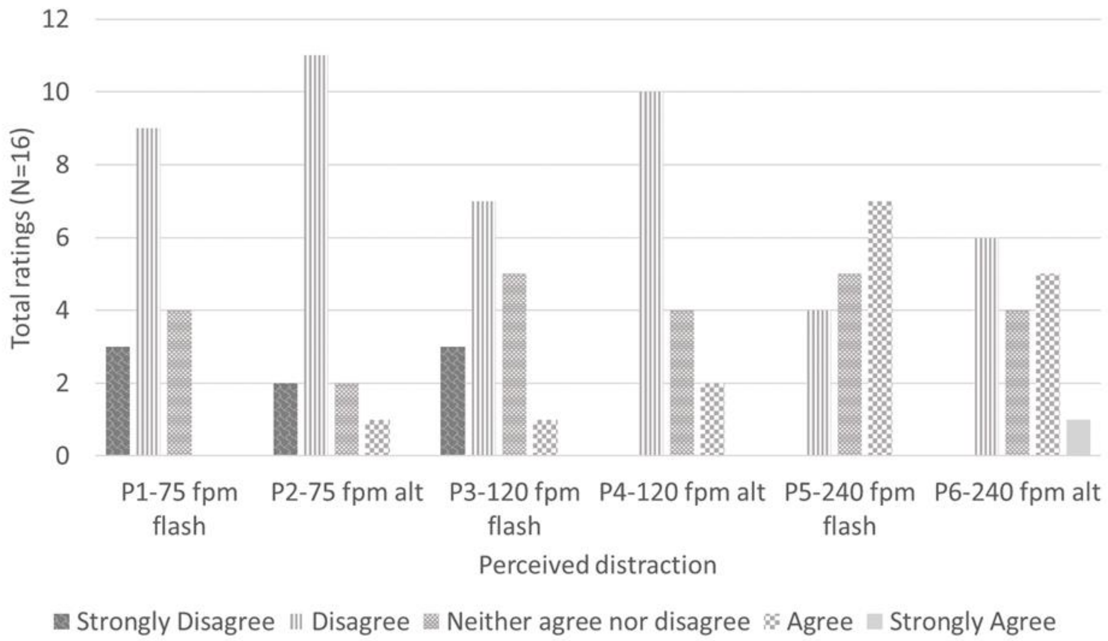

Figure 166: Graph to show the perceived distraction of the lighting at 300 metres at night

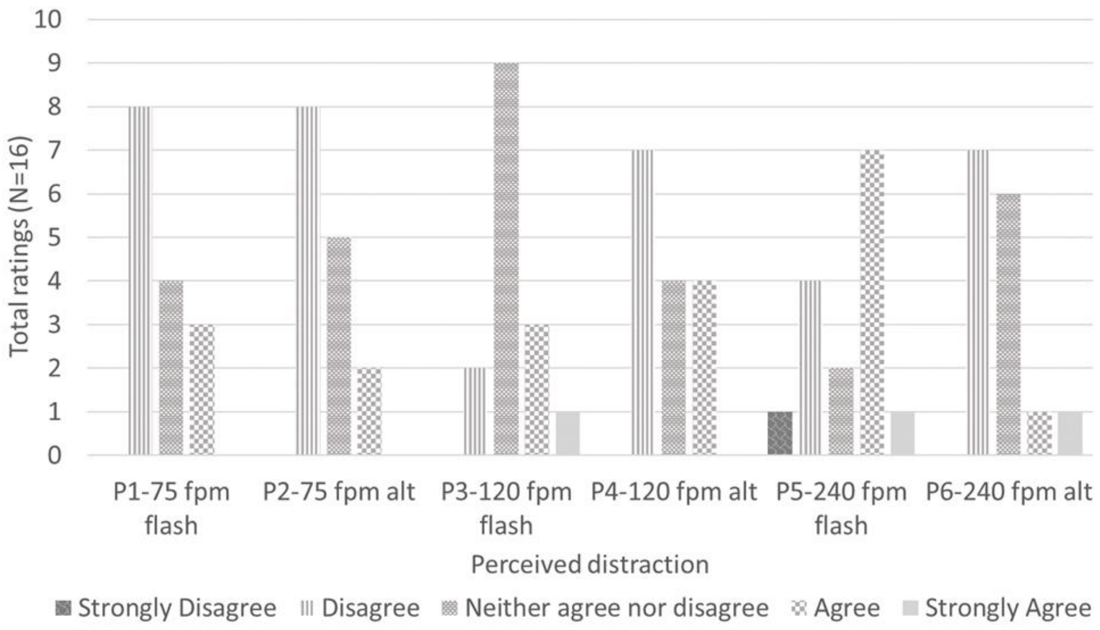

Figure 167: Graph to show the perceived distraction of the lighting at 200 metres at night

H.5.3 Patterns P7-P12 – day and night

When comparing the perceived distraction at 300 metres in the day vs night, clear differences emerge (see Figure 168 and Figure 169). Though both distances had fairly even levels of disagreement towards the perceived distraction of the lighting, attendees appeared to strongly disagree more when presented with the lighting at 300 metres in the day compared to at night.

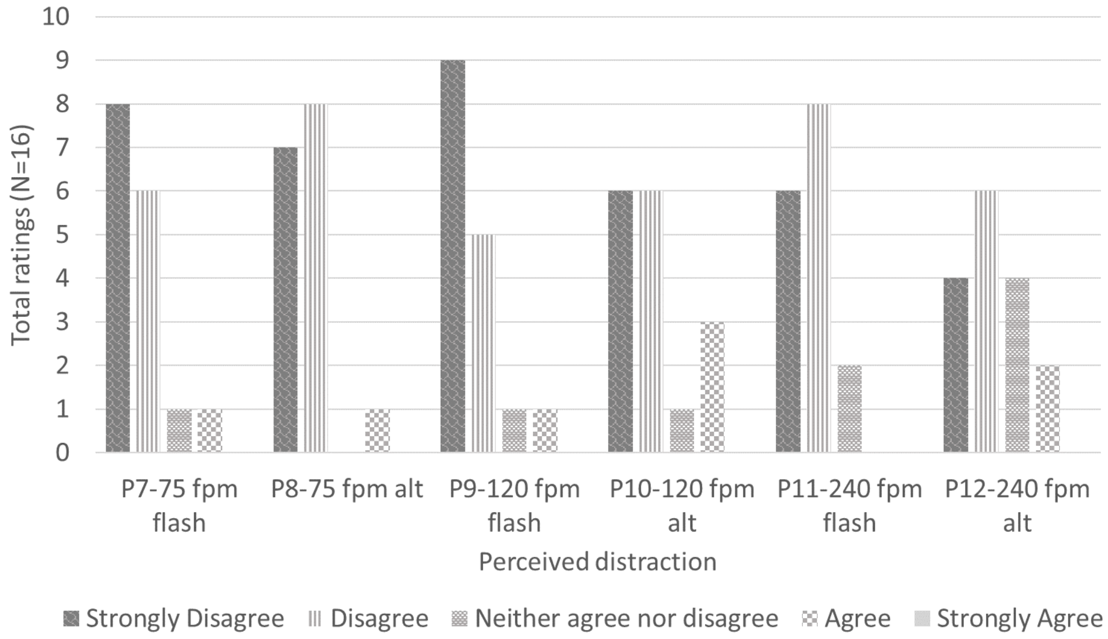

Figure 168: Graph to show the perceived distraction of the lighting at 300 metres in the day

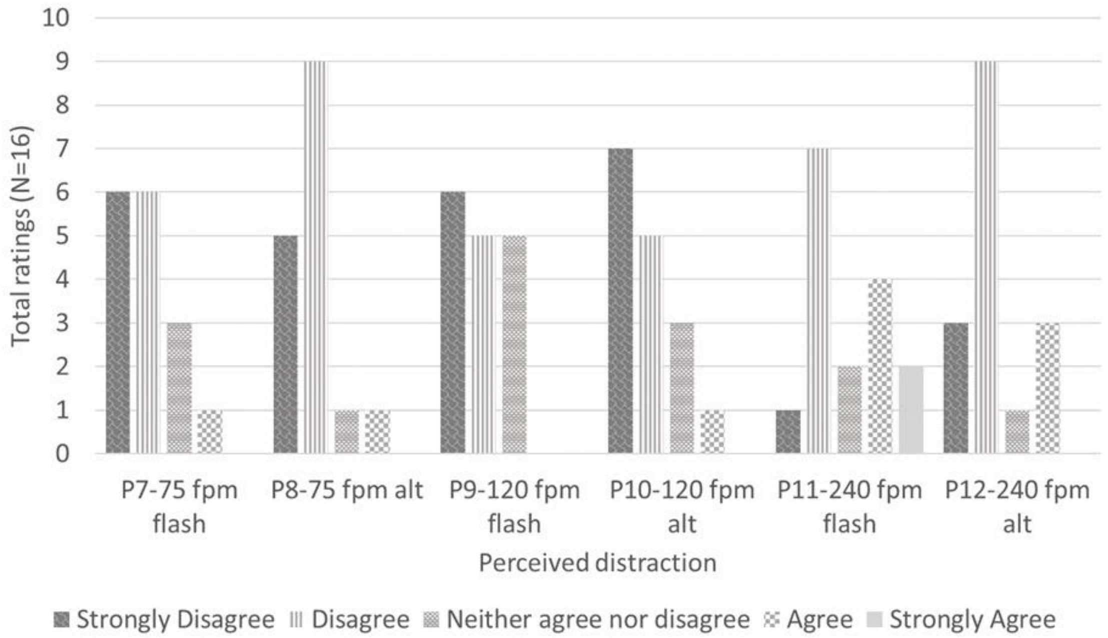

Figure 169: Graph to show the perceived distraction of the lighting at 300 metres at night

When comparing the perceived distraction at 200 metres in the day vs night, both distances had even levels of disagreement regarding the perceived distraction of the lighting patterns. Interestingly, more agreement and neutral responses were noted for the 240 fpm flash and

240 fpm alternating lighting patterns at night. This may suggest that these patterns were viewed as more distracting at night versus the day (see Figure 170 and Figure 171).

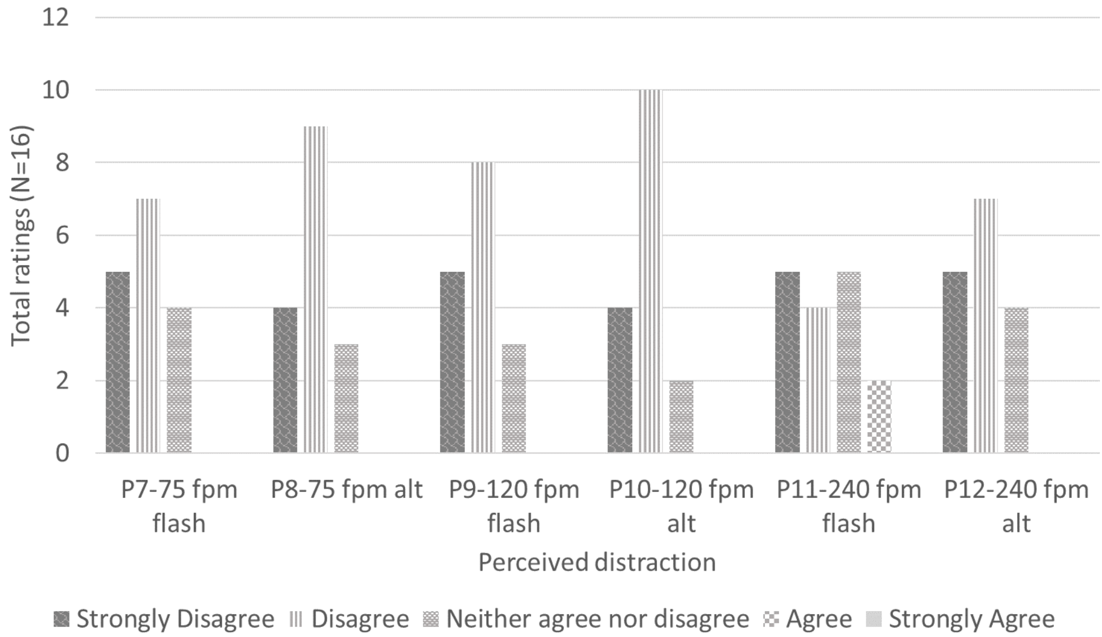

Figure 170: Graph to show the perceived distraction of the lighting at 200 metres in the day

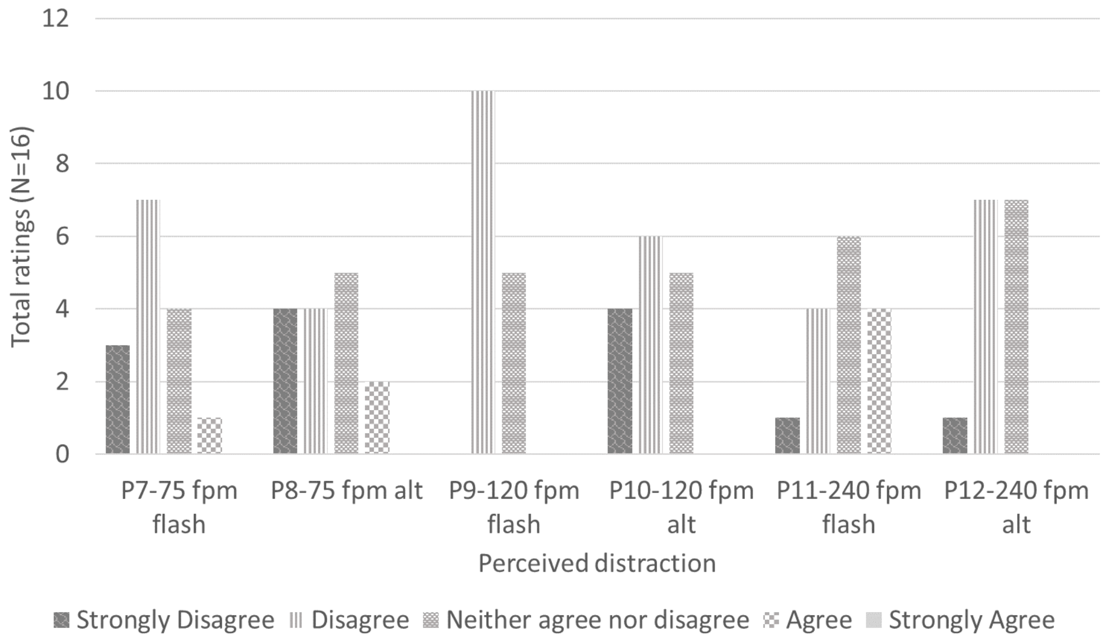

Figure 171: Graph to show the perceived distraction of the lighting at 200 metres at night

H.5.4 Patterns P7-P12 – distance

When comparing the perceived distraction at 300 metres and 200 metres in the day, the levels of disagreement with the statement were roughly even, with greater responses of strongly disagree reported for the 300 metres day data (Figure 172 and Figure 173).

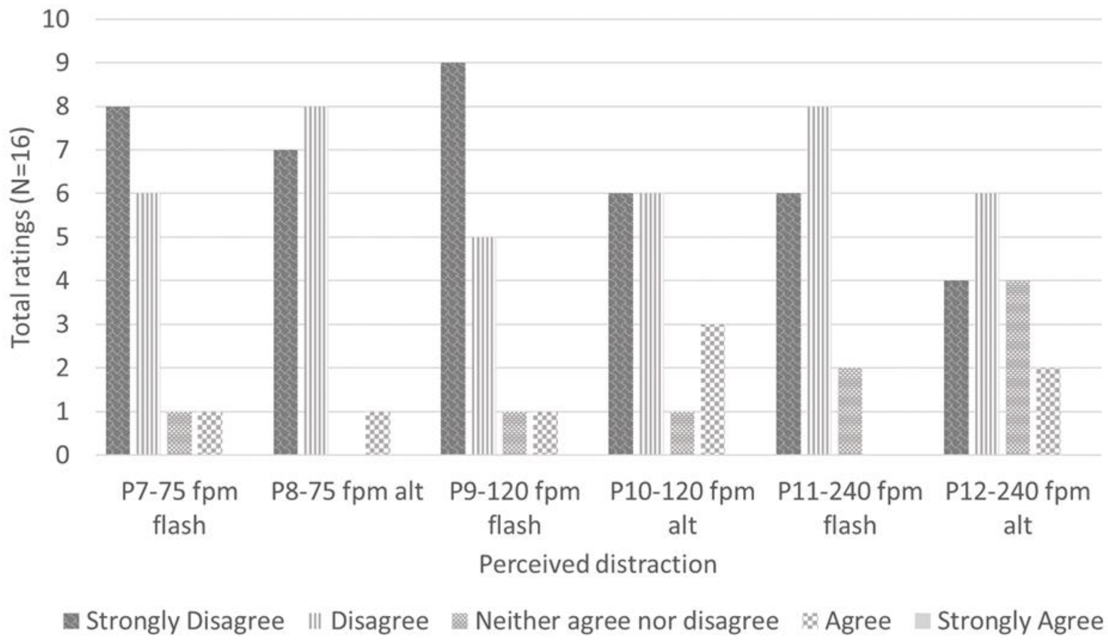

Figure 172: Graph to show the perceived distraction of the lighting at 300 metres in the day

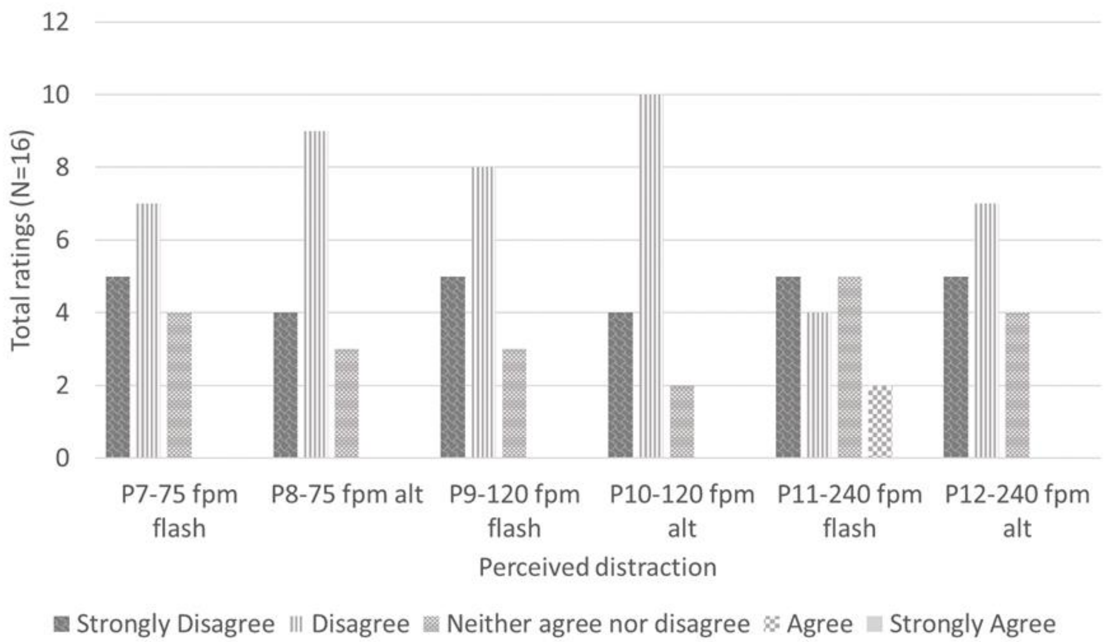

Figure 173: Graph to show the perceived distraction of the lighting at 200 metres in the day

When comparing the perceived distraction at 200 metres at night versus the day, more disagreement was noted at 300 metres at night, compared to at 200 metres (see Figure 174 and Figure 175).

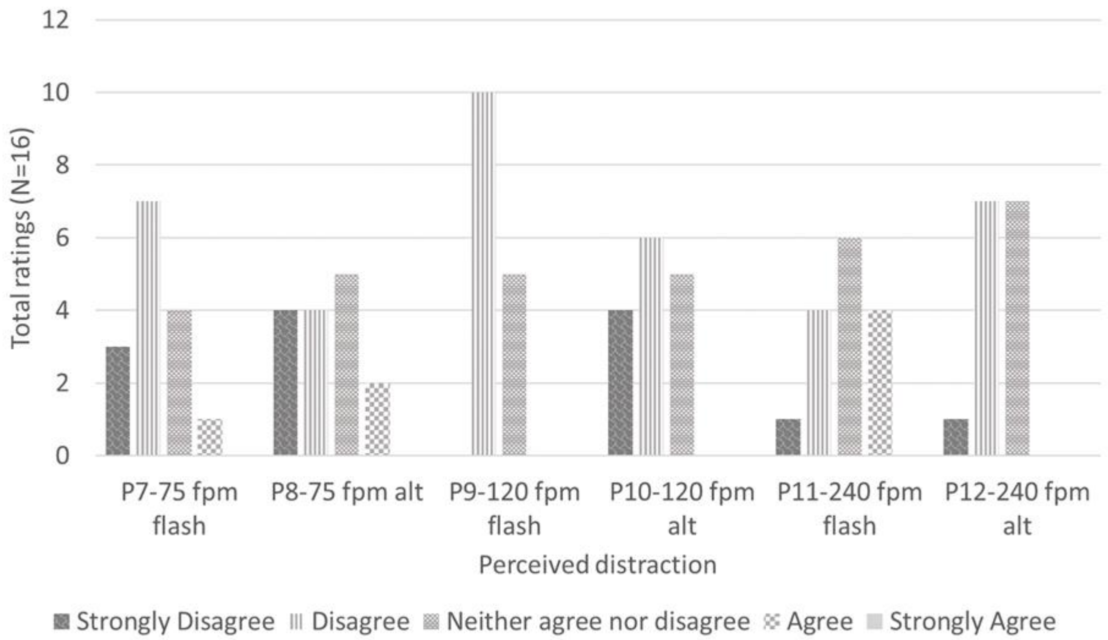

Figure 174: Graph to show the perceived distraction of the lighting at 200 metres at night

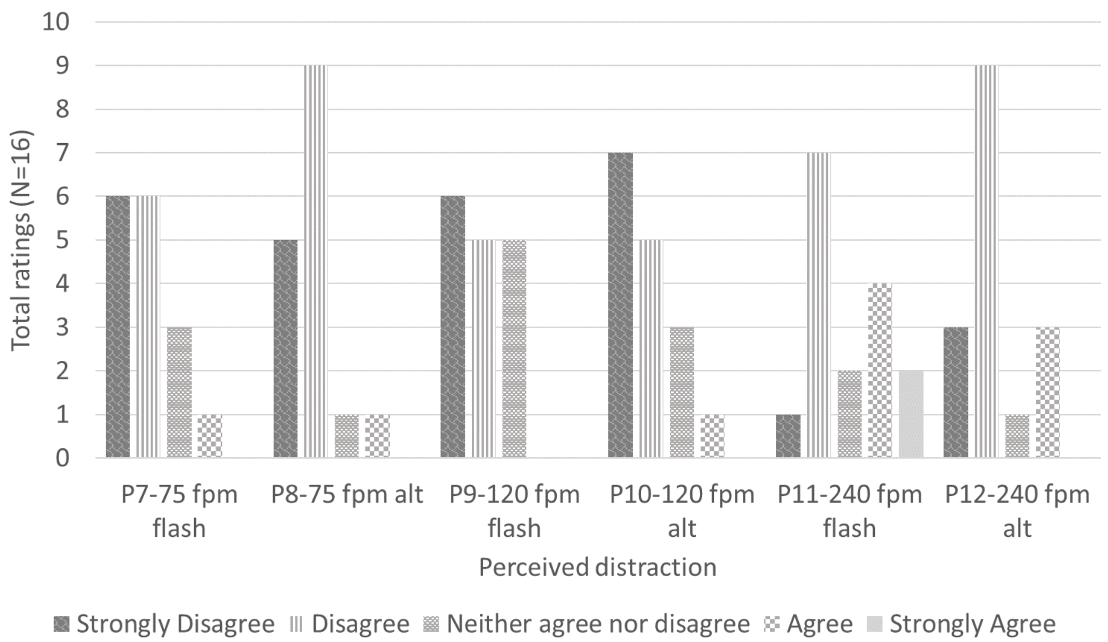

Figure 175: Graph to show the perceived distraction of the lighting at 300 metres at night

H.5.5 Patterns P13-P16 – day and night, and distance

When comparing the perceived distraction at 300 metres in the day versus 200 metres at night, disagreement appeared to be higher at night, compared to the day (see Figure 176 and Figure 177). Agreement was noted across both scenarios for the in out amber with flashing reds pattern, which suggests that this lighting pattern may have been perceived as distracting by the attendees. Slightly different results were found when comparing the perceived distraction observed at 200 metres and 300 metres at night. In the 200 metres night data, most attendees rated the in out amber with flashing lights pattern as neither agree nor disagree; in the 300 metres night data, nearly half agreed with the statement. This may suggest that this pattern was distracting for the attendees.

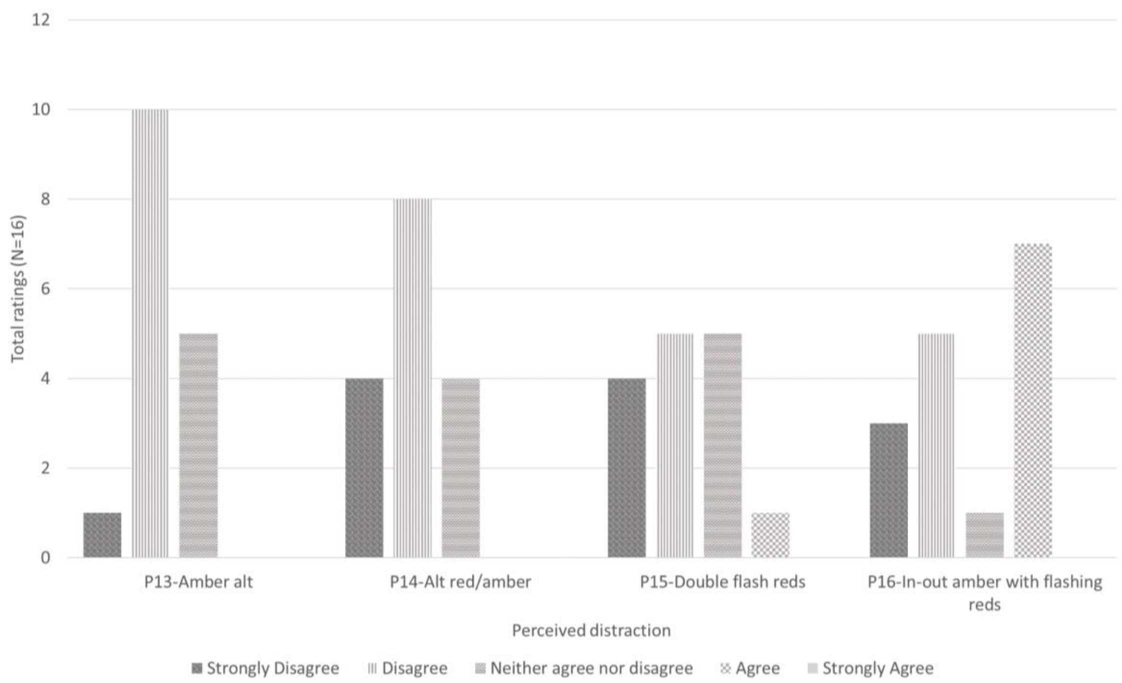

Figure 176: Graph to show the perceived distraction of the lighting at 300 metres in the day

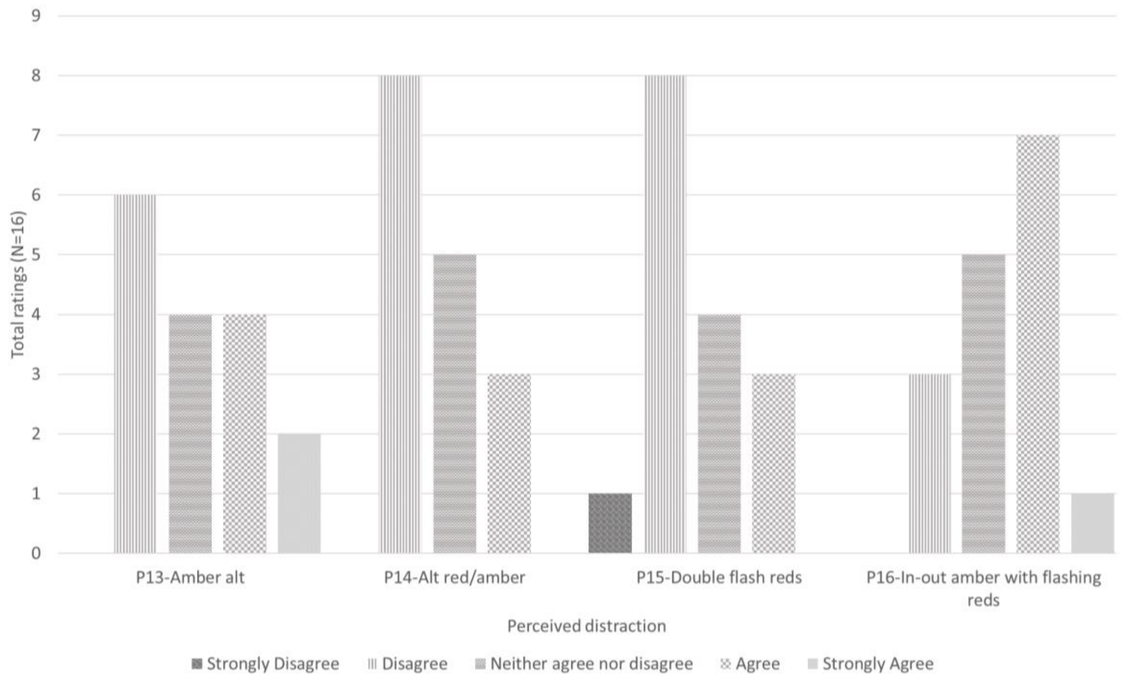

Figure 177: Graph to show the perceived distraction of the lighting at 300 metres at night

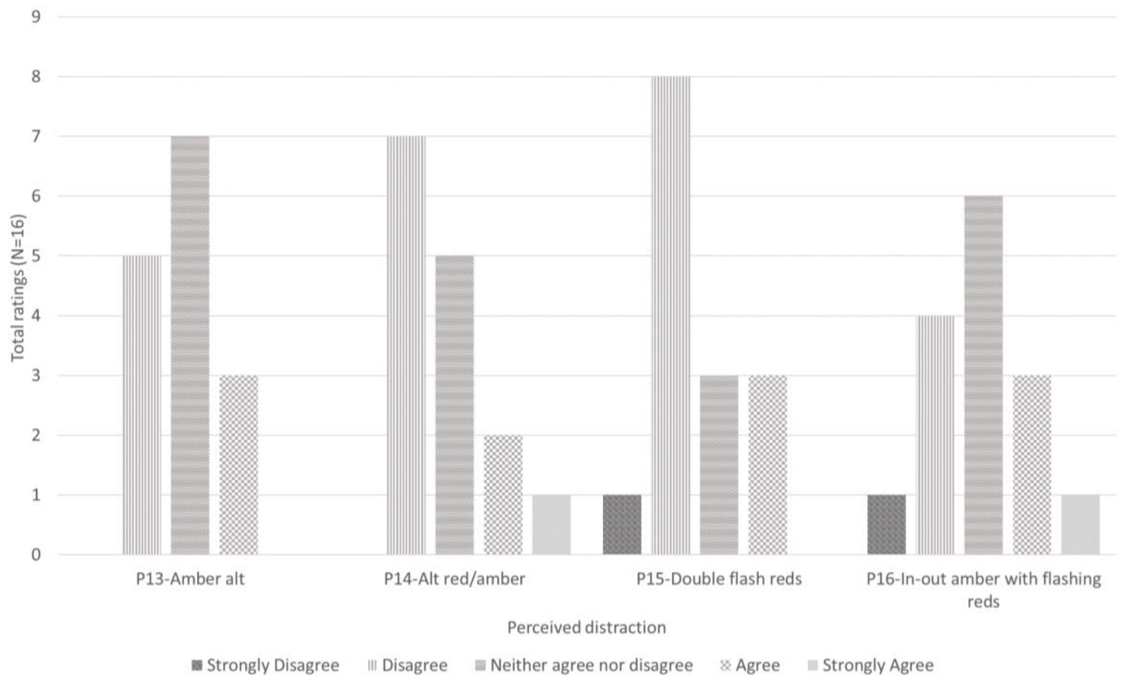

Figure 178: Graph to show the perceived distraction of the lighting at 200 metres at night

H.6 Perceived comfort

How comfortable the lighting was to look at was measured on a scale from A–E, with A being strongly disagree and E being strongly agree.

H.6.1 Patterns P1-P6 – day and night

The following section presents the comparisons of lighting patterns P1–P6. The flashes per minute of these patterns varied and all flashes were either amber alternating or amber flash.

When comparing how uncomfortable the lighting patterns were perceived to be at a distance of 300 metres in the day versus night, more disagreement was noted in the day compared to the night(see Figure 179 and Figure 180). This suggests that the lighting patterns were viewed overall as more comfortable in the day, compared to at night. Agreement, particularly when viewed at 300 metres at night, was also noted for the 240 fpm flash and 240 fpm alternating lighting patterns, suggesting that participants found these patterns uncomfortable to view.

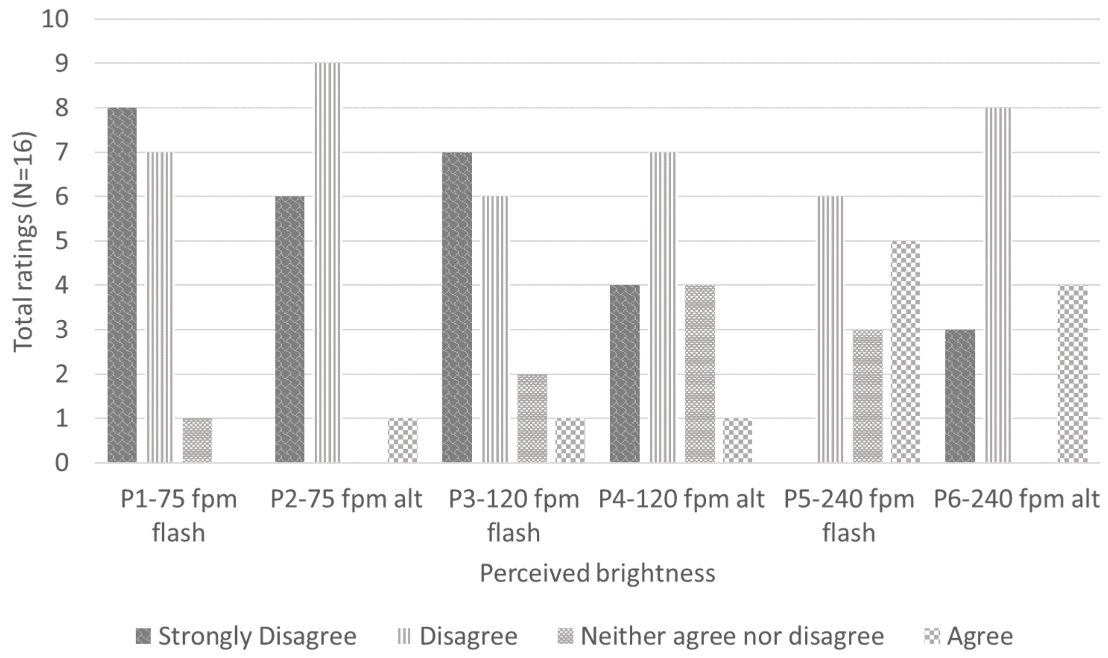

Figure 179: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres in the day

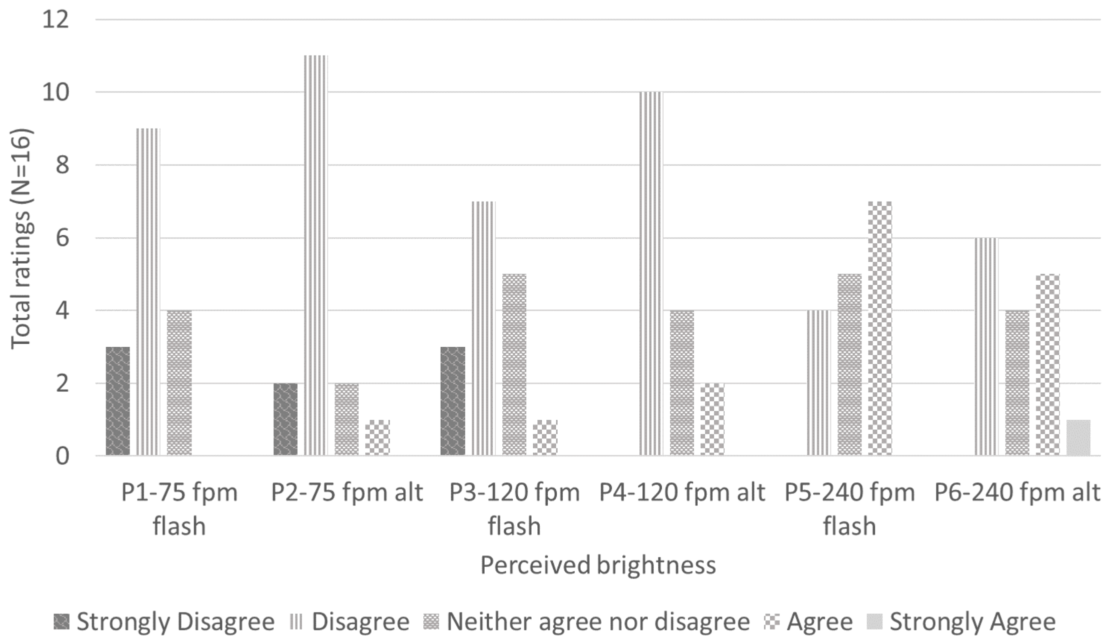

Figure 180: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres at night

When comparing how uncomfortable the lighting patterns were perceived to be at 200 metres in the day versus night, disagreement was noted across both scenarios. Interestingly, when viewed at 200 metres at night, agreement with the statement was noted across several of the patterns, particularly the 240 fpm flash.

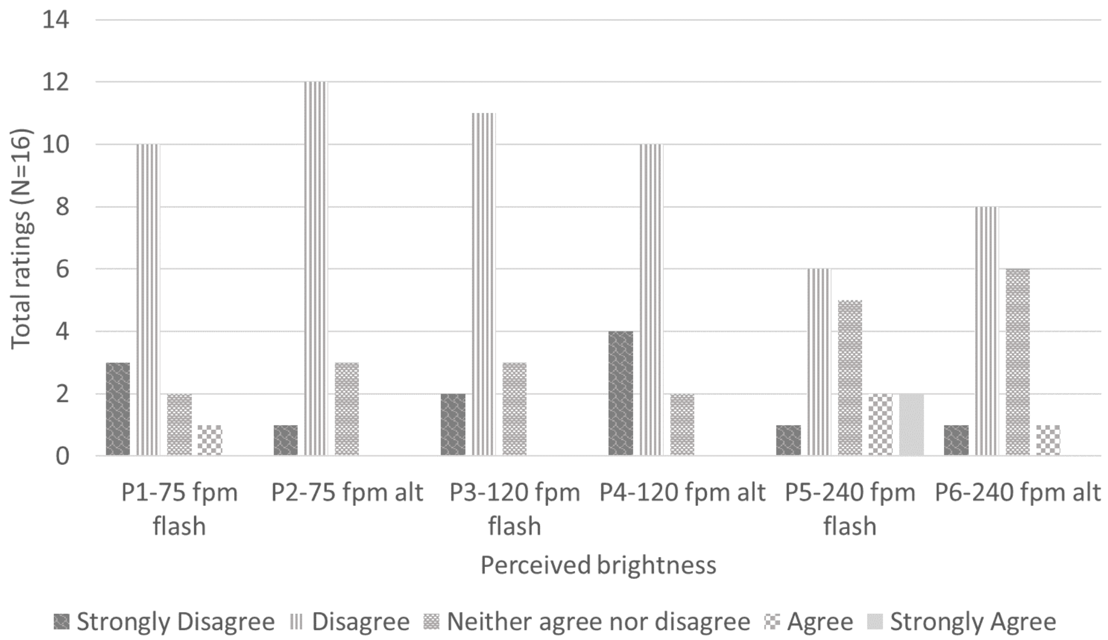

Figure 181: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres in the day

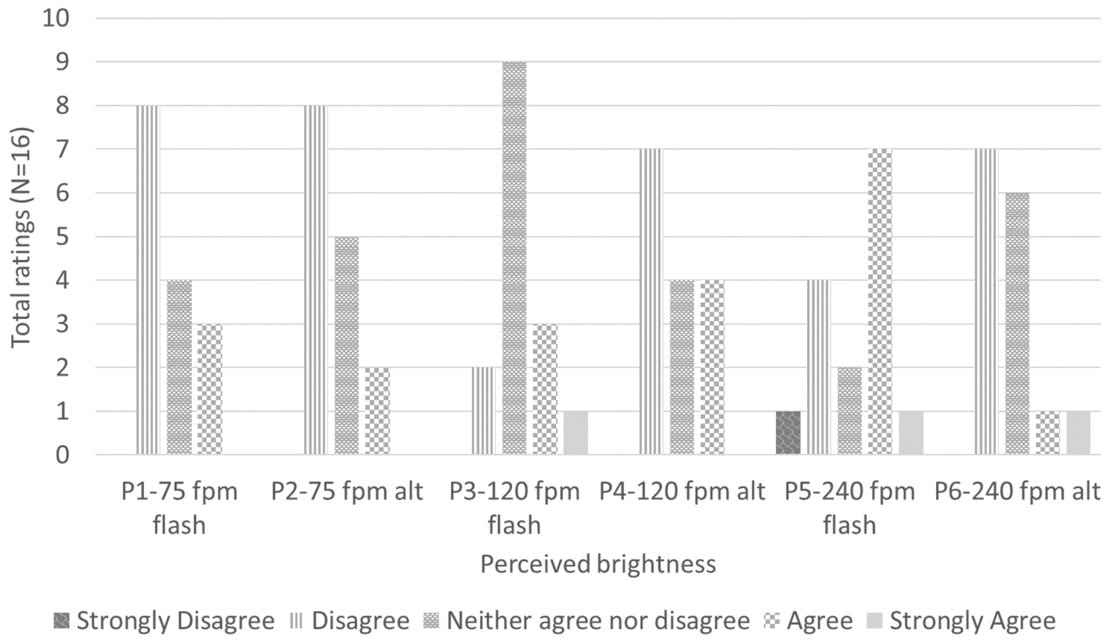

Figure 182: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres at night

H.6.2 Patterns P1-P6 – distance

When comparing how uncomfortable the lighting patterns were perceived to be at 200 and 300 metres in the day, disagreement was noted across both scenarios. Slightly more strong disagreement noted in the day compared to at night (see Figure 183 and Figure 184).

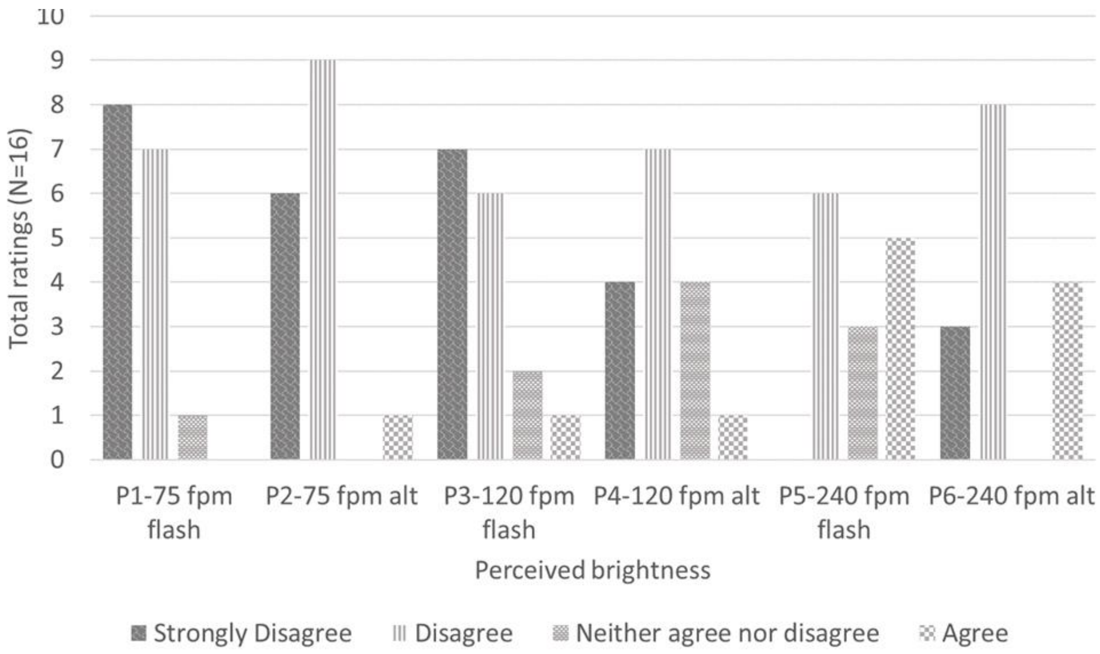

Figure 183: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres in the day

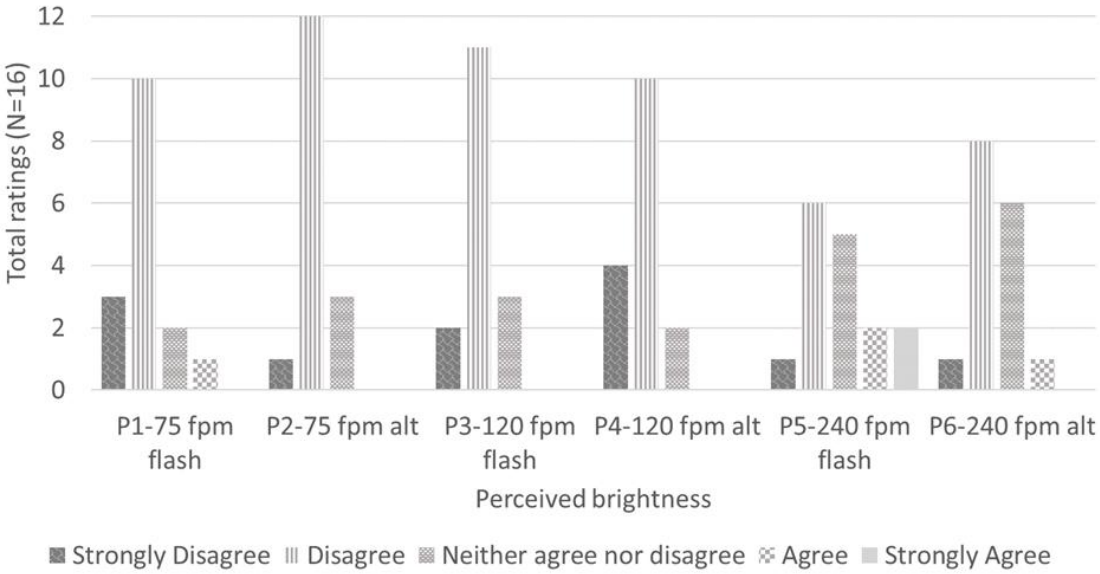

Figure 184: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres in the day

When comparing how uncomfortable the lighting patterns were perceived to be at 200 and 300 metres at night, consistent disagreement was noted across both scenarios. Nonetheless, more agreement was noted at 200 metres at night (see Figure 185 and Figure 186).

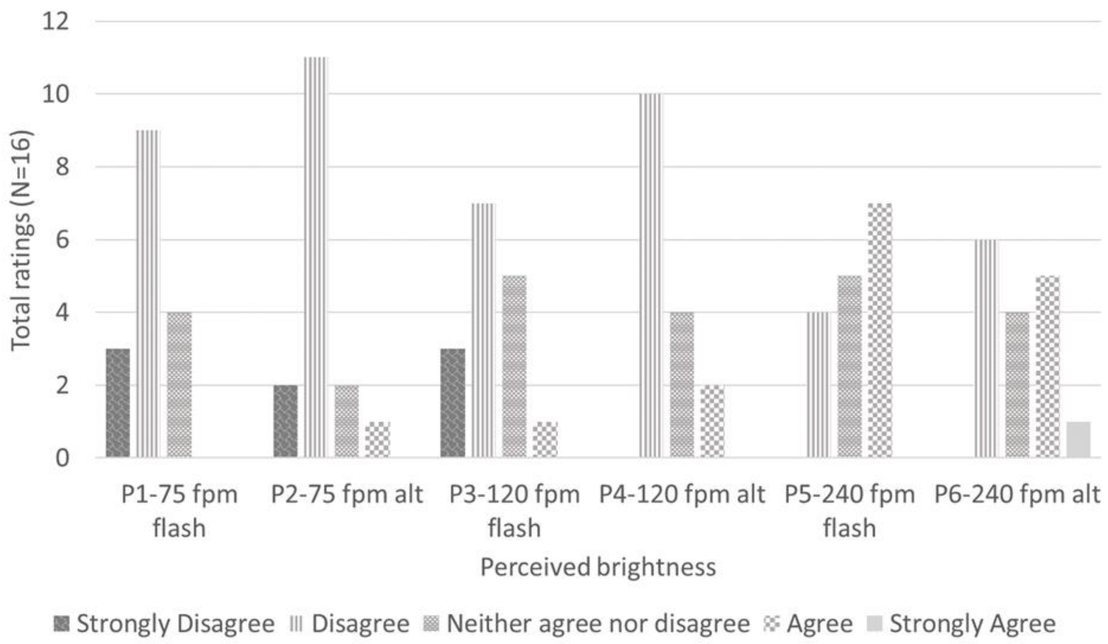

Figure 185: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres at night

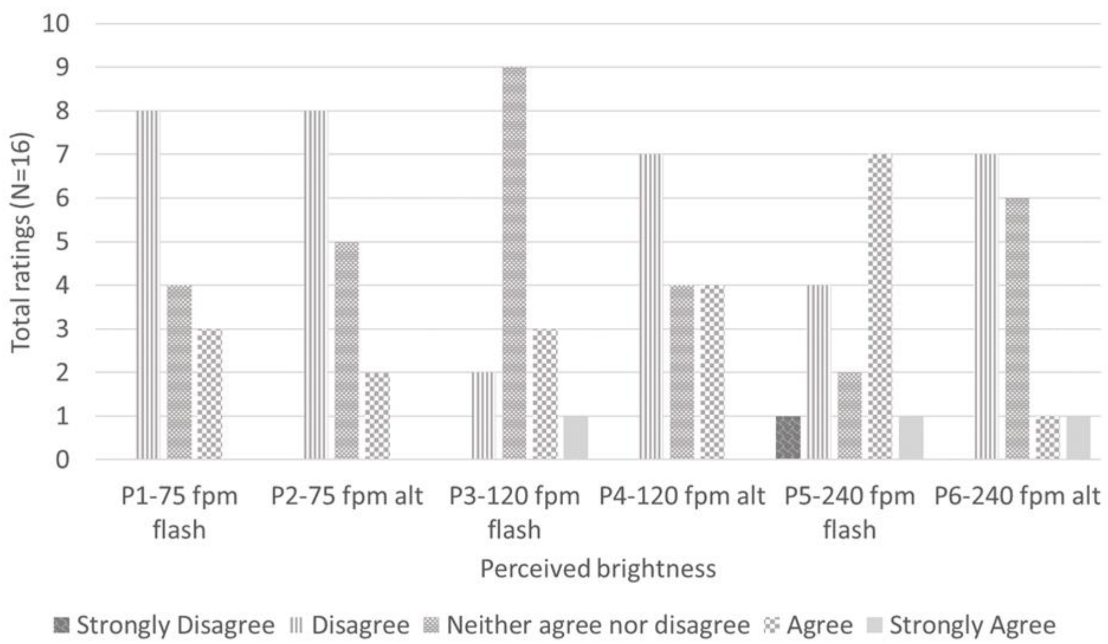

Figure 186: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres at night

H.6.3 Patterns P7-P12 – day and night

When comparing how uncomfortable the lighting patterns were perceived to be at 300 metres in the day versus night, the disagreement observed was even between the two scenarios. The ratings of strongly disagree were higher for the 300 metres day data, for the 120 fpm flash pattern (see Figure 187 and Figure 188).

When comparing the perceived comfort of the lighting patterns at 200 metres in the day versus night, the disagreement was roughly even between the two scenarios. More strong disagreement was noted for the 240 fpm alternating and 240 fpm flashing patterns in the day (see Figure 189 and Figure 190).

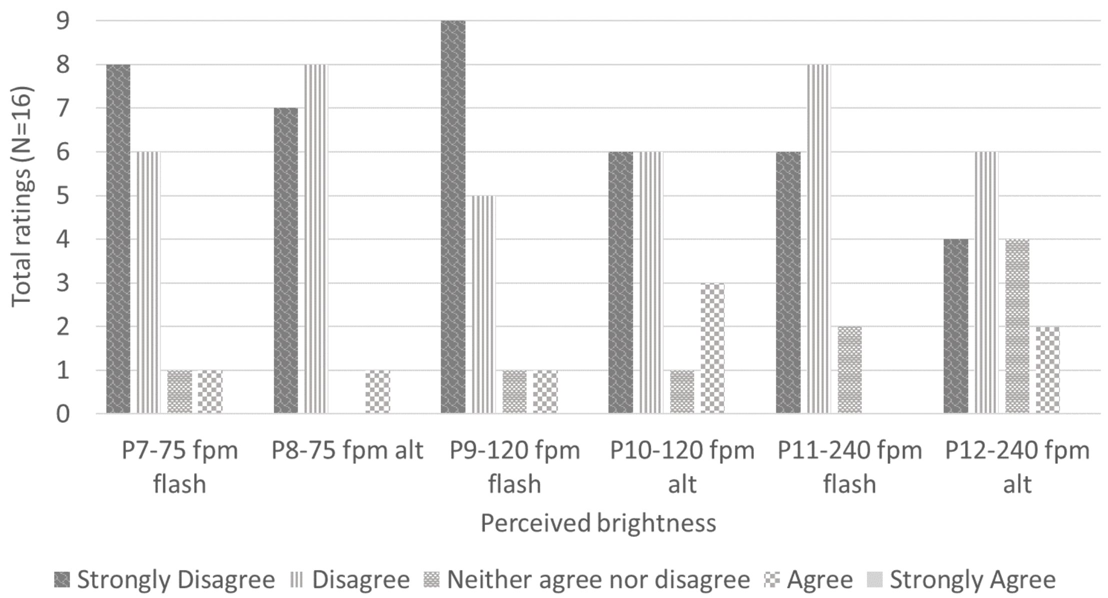

Figure 187: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres in the day

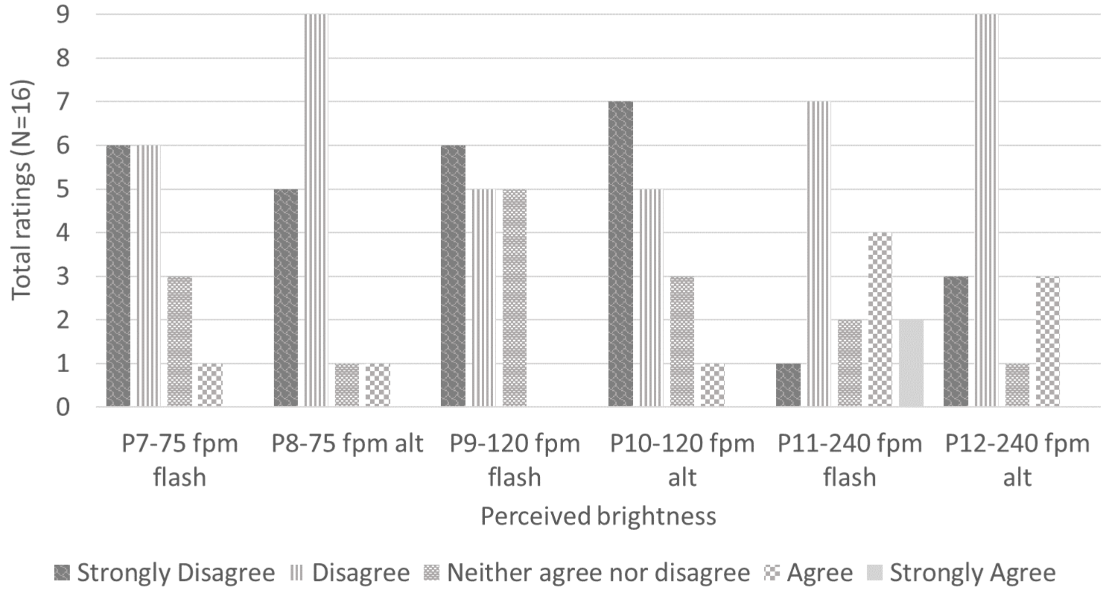

Figure 188: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres at night

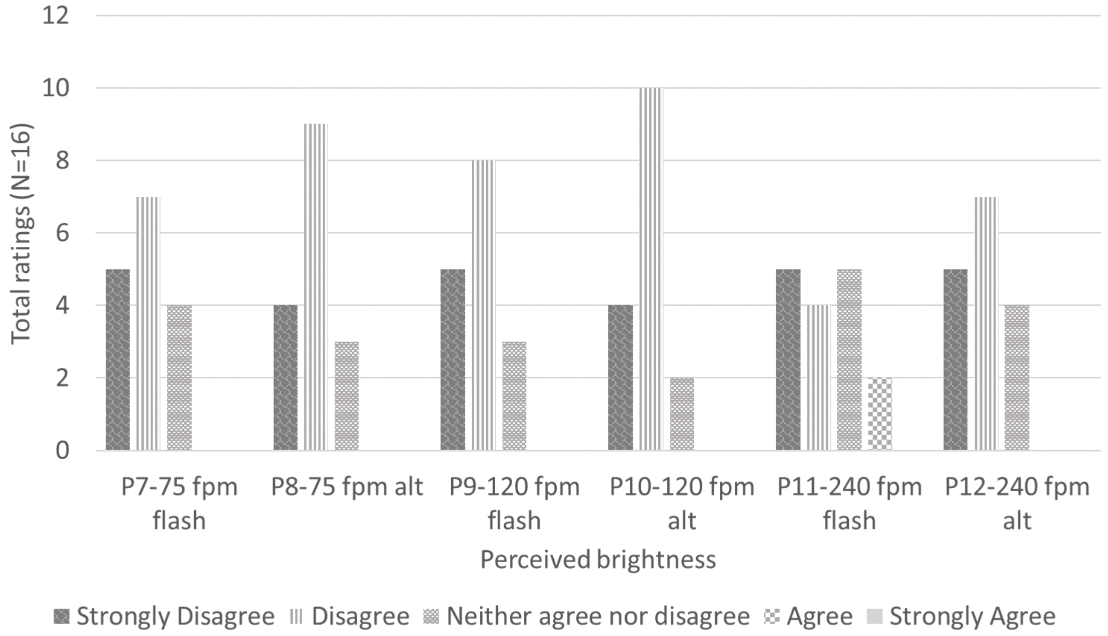

Figure 189: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres in the day

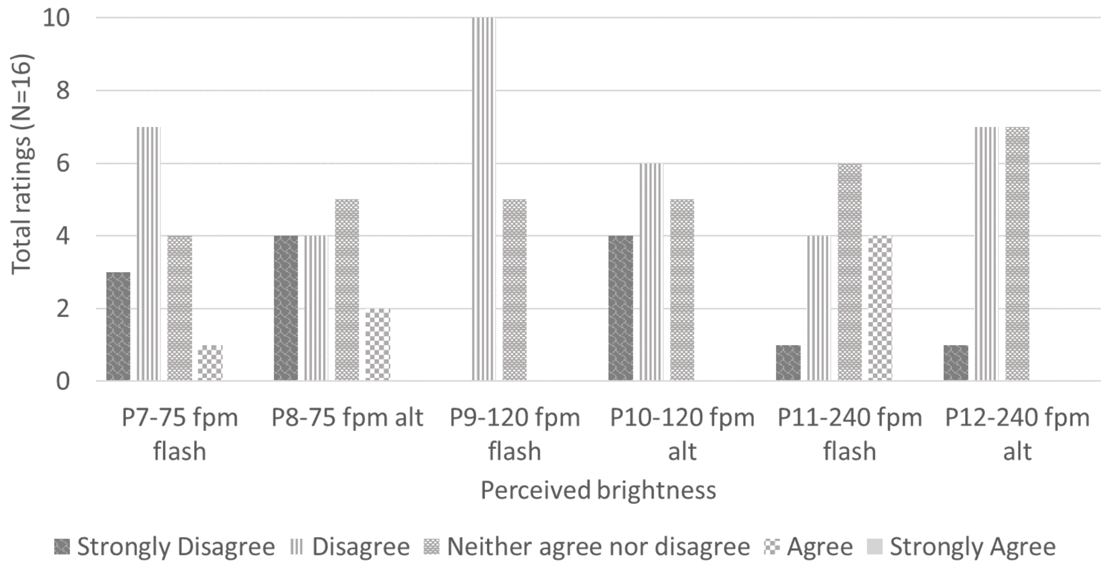

Figure 190: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres at night

H.6.4 Patterns P7-P12 – distance

When comparing the perceived comfort of the lighting patterns at 300 metres and 200 metres in the day, as Figure 191 and Figure 192 show, more disagreement was found overall at 300 metres. When comparing the perceived comfort of the lighting patterns at 300 metres and 200 metres at night day, as Figure 193 and Figure 194 show, more disagreement was found overall at 300 metres.

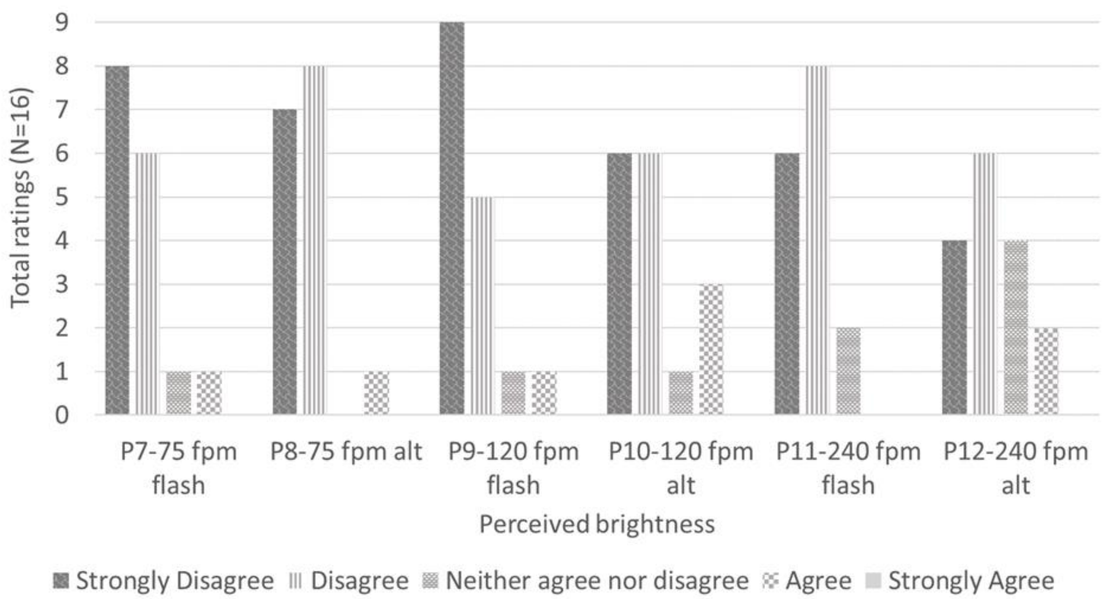

Figure 191: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres in the day

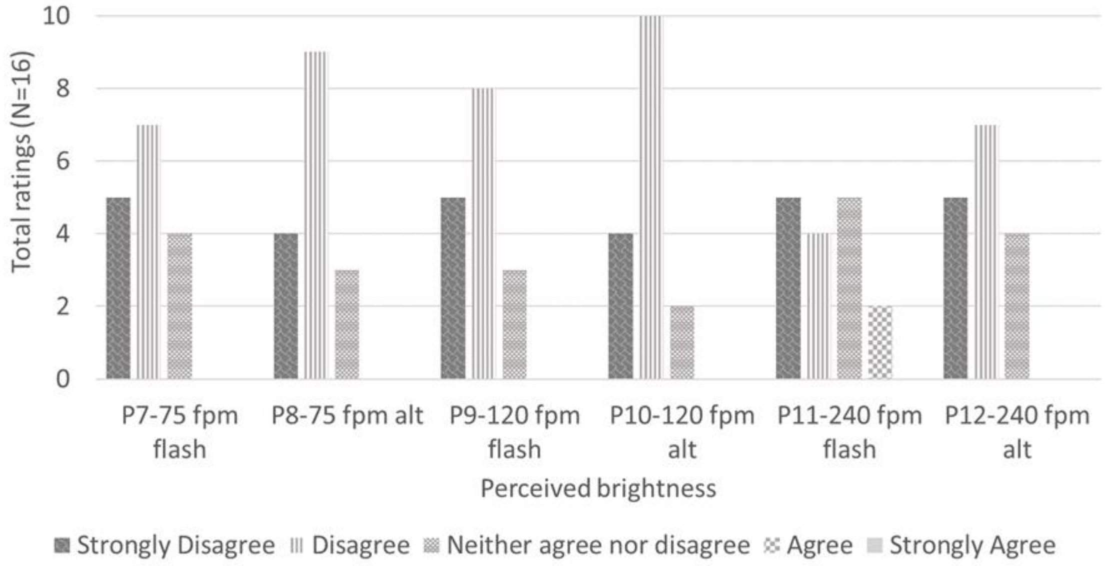

Figure 192: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres in the day

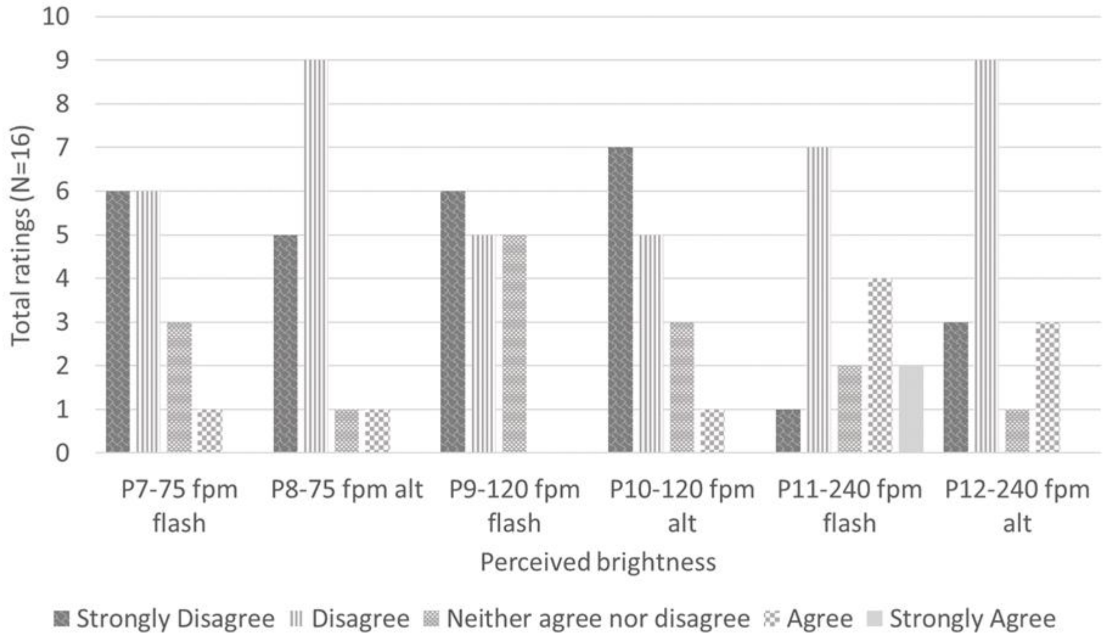

Figure 193: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres at night

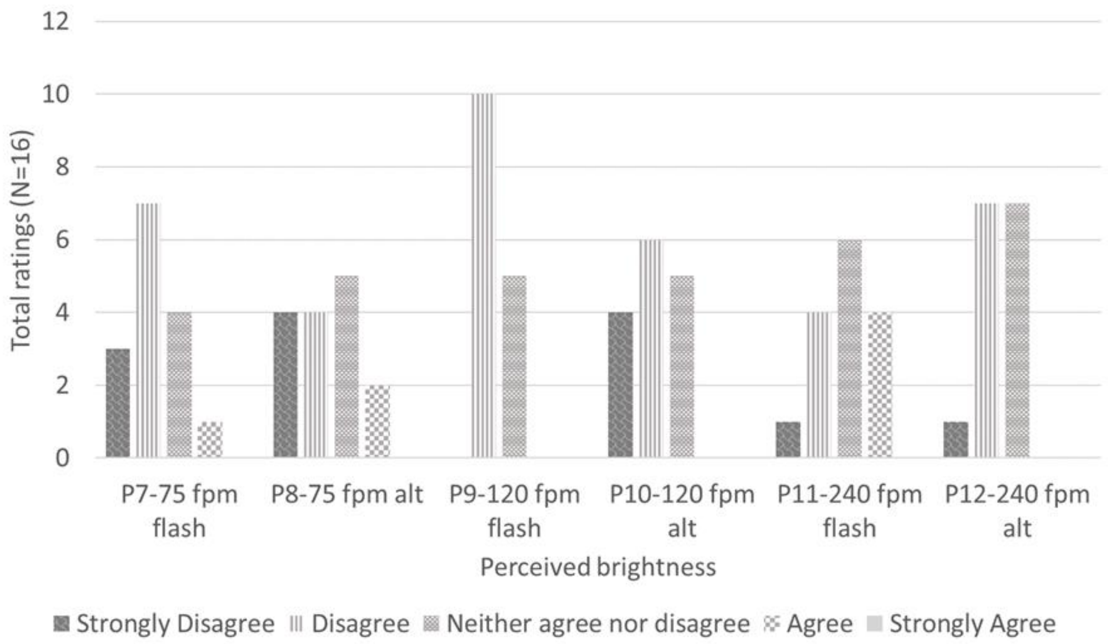

Figure 194: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres at night

H.6.5 Patterns P13-P16 – time of day

When comparing the perceived comfort of the lighting patterns at 300 metres in the day versus night, as Figure 195 and Figure 196 show, more disagreement was found overall at 300 metres in the day. Attendees were either neutral or agreed with the statement when presented with the in-out amber with flashing reds lighting pattern, suggesting that this pattern was uncomfortable to look at. No noticeable differences were observed for perceived comfort when comparing lighting patterns at 300 metres at night (Figure 196) with 200 metres at night (Figure 197).

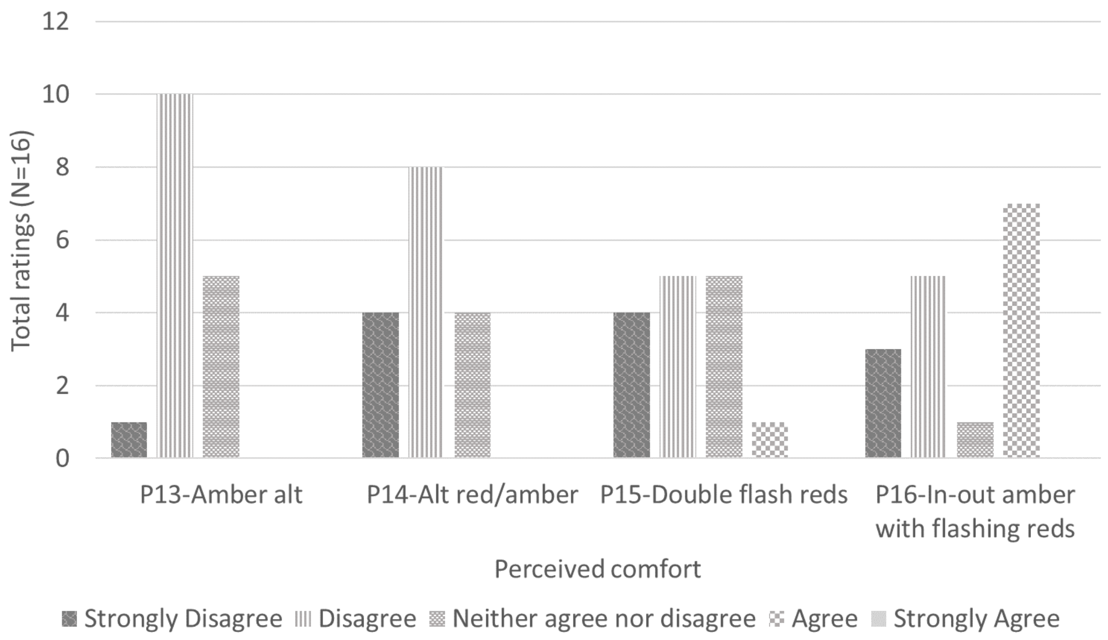

Figure 195: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres in the day

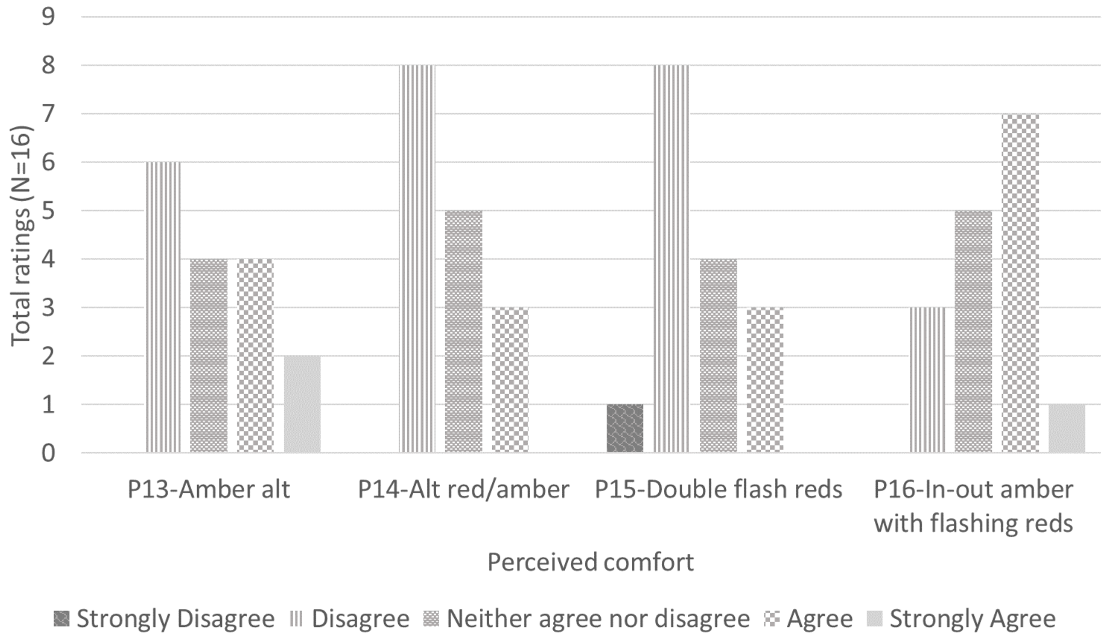

Figure 196: Graph to show how comfortable the lighting patterns were perceived to be at 300 metres at night

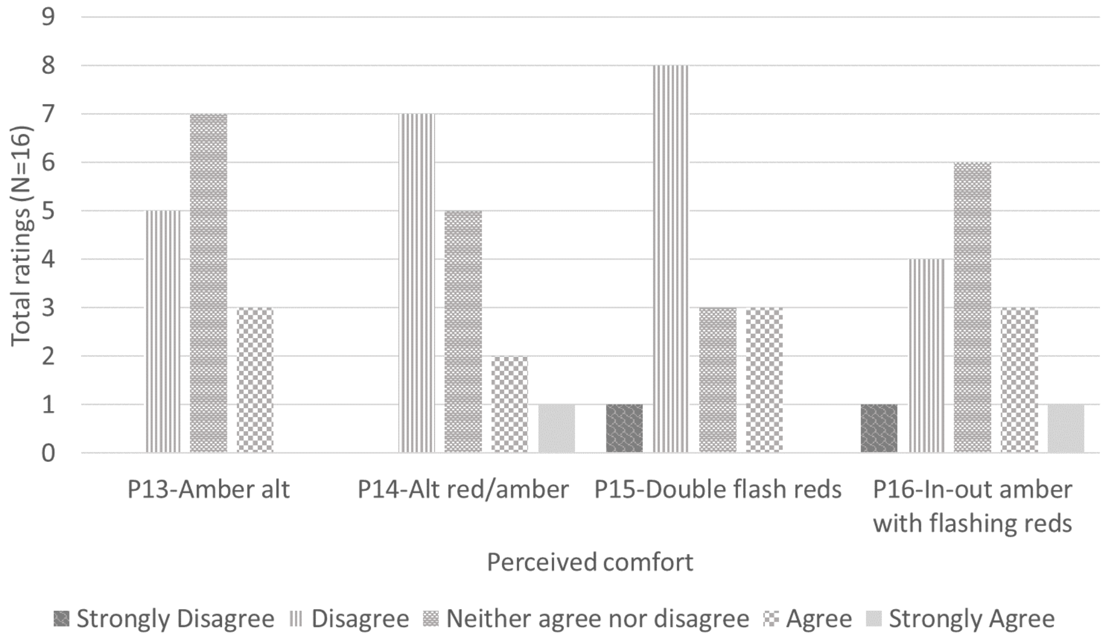

Figure 197: Graph to show how comfortable the lighting patterns were perceived to be at 200 metres at night

H.7 Perceived visual impairment

The extent to which the attendee perceived that the lighting would prevent them seeing around the vehicle was measured on a scale from A–E; A being strongly disagree and E being strongly agree.

H.7.1 Patterns P1-P6 – day and night

When comparing the perceived visual impairment at 300 metres in the day versus night, as Figure 198and Figure 199show, disagreement was generally noted across both scenarios. More strong disagreement was noted in the 300 metres day data. Agreement was noticeable in the night data for the 240 fpm flash data.

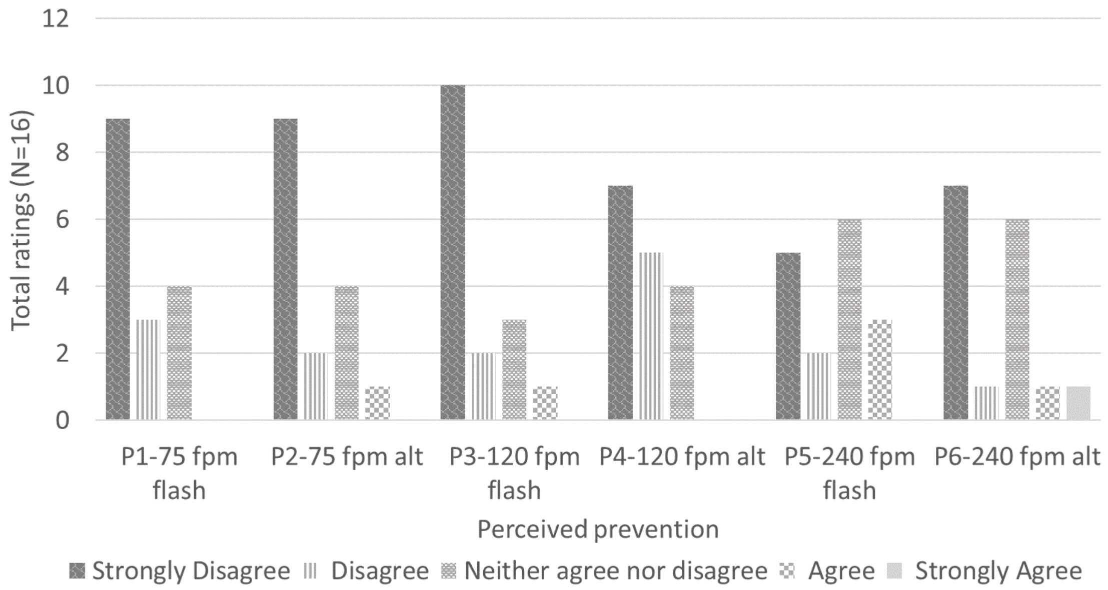

Figure 198: Graph to show the perceived prevention at 300 metres in the day

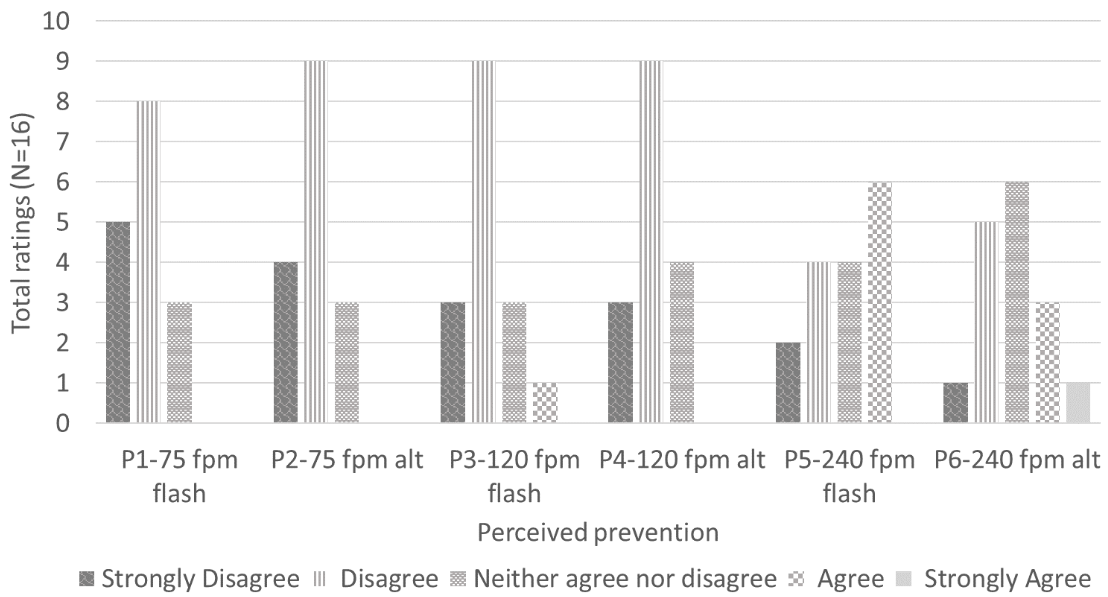

Figure 199: Graph to show the perceived prevention at 300 metres at night

When comparing the perceived visual impairment at 200 metres at night versus the day, there were substantial differences found between the scenarios. As Figure 200 and Figure 201 show, agreement was overwhelmingly expressed in the 200 metres night data, compared to the day data. This was particularly noticeable in the 75 fpm alternating and 240 fpm flashing patterns. This suggests that attendees viewed the patterns as more likely to prevent them from seeing around the vehicle at night compared to the day.

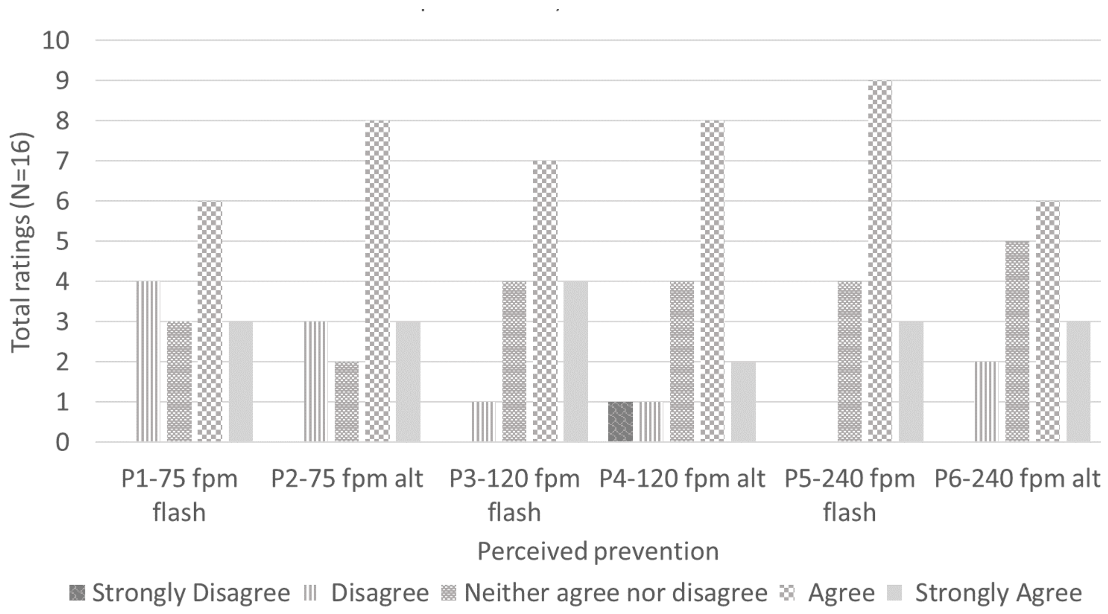

Figure 200: Graph to show the perceived prevention at 200 metres at night

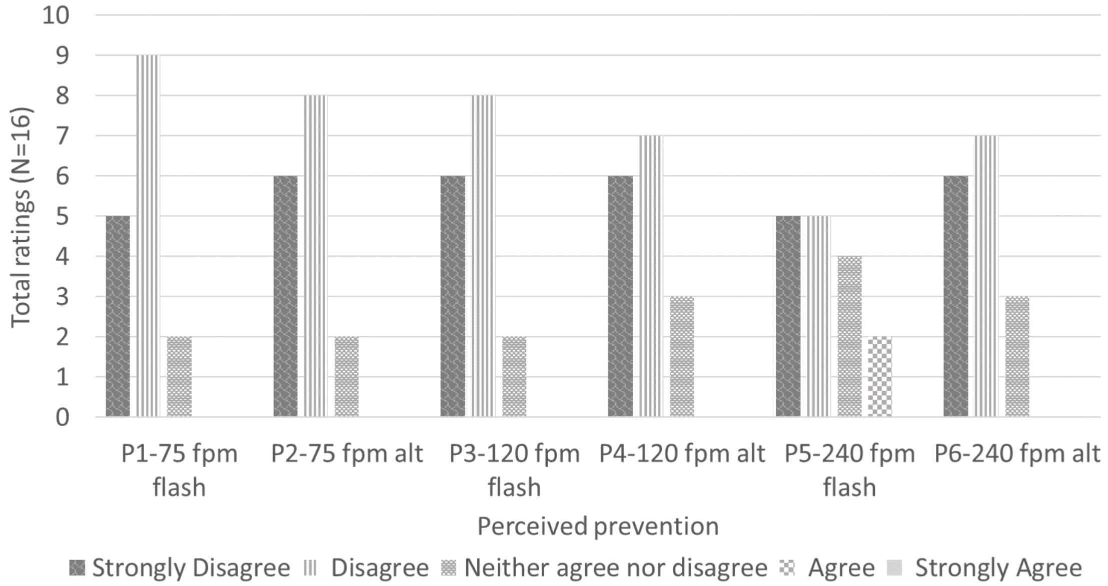

Figure 201: Graph to show the perceived prevention at 200 metres in the day

H.7.2 Patterns P1-P6 – distance

When comparing the perceived visual impairment at 200 and 300 metres in the day, disagreement was fairly even between the two scenarios, with strong disagreement noted in 300 metres day data (see Figure 202 and Figure 203).

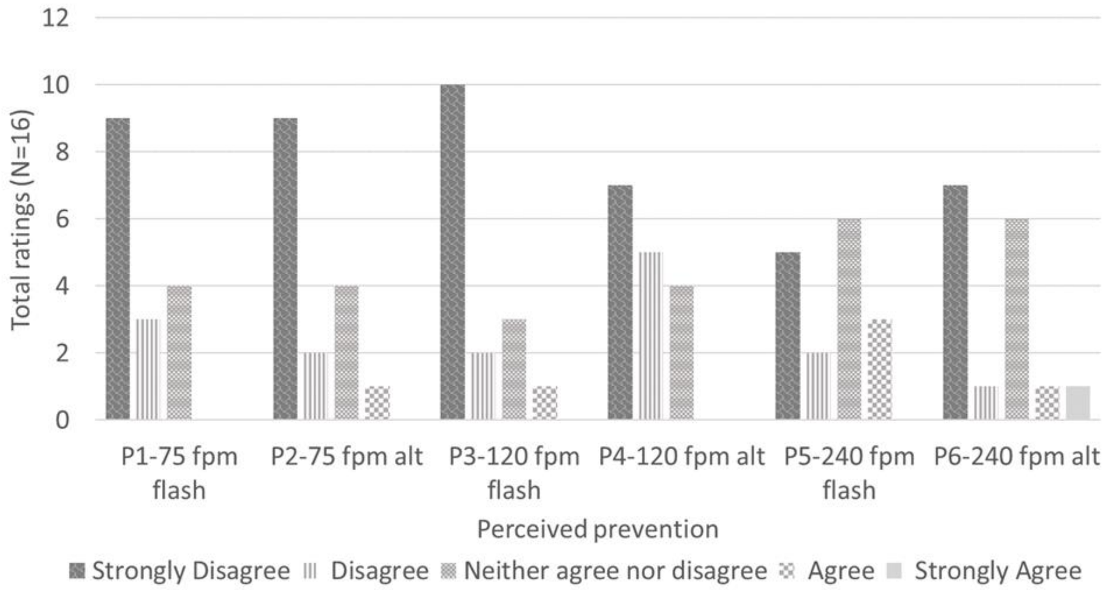

Figure 202: Graph to show the perceived prevention at 300 metres in the day

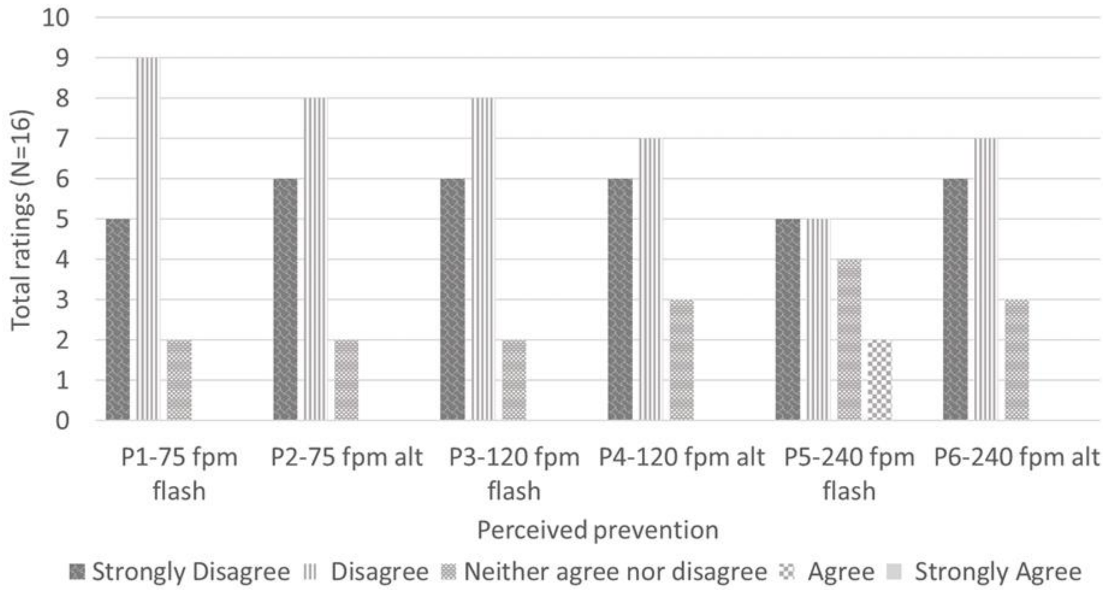

Figure 203: Graph to show the perceived prevention at 200 metres in the day

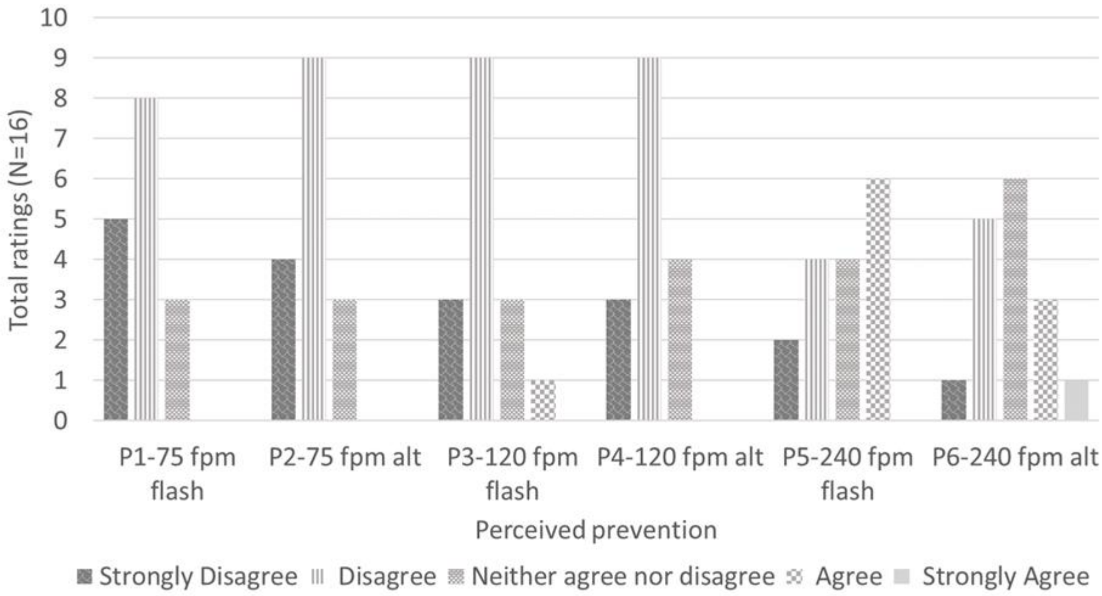

Figure 204: Graph to show the perceived prevention at 300 metres at night

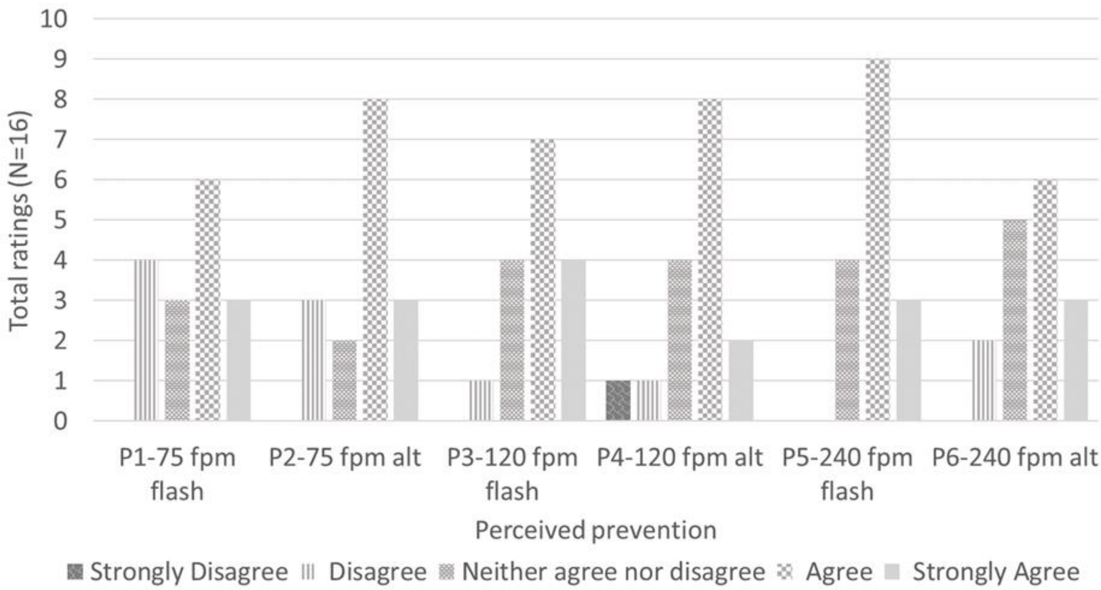

Figure 205: Graph to show the perceived prevention at 200 metres at night

When comparing the perceived visual impairment at 300 versus 200 metres at night, there were substantial differences found between the scenarios. As shown by Figure 204 and Figure 205, agreement was much stronger at 200 metres at night, especially for the 75 fpm alternating and 240 fpm flash patterns. This suggests that the distance from the lighting patterns may affect the attendees' perceptions of whether they could see around the vehicle or not.

H.7.3 Patterns P7-P12 – day and night

When comparing the perceived impairment at 300 metres in the day versus night, as Figure 206 and Figure 207 show, disagreement was generally noted across both scenarios. More strong disagreement was noted in the 300 metres day data. Agreement was noticeable in the night data for the 240 fpm flash data.

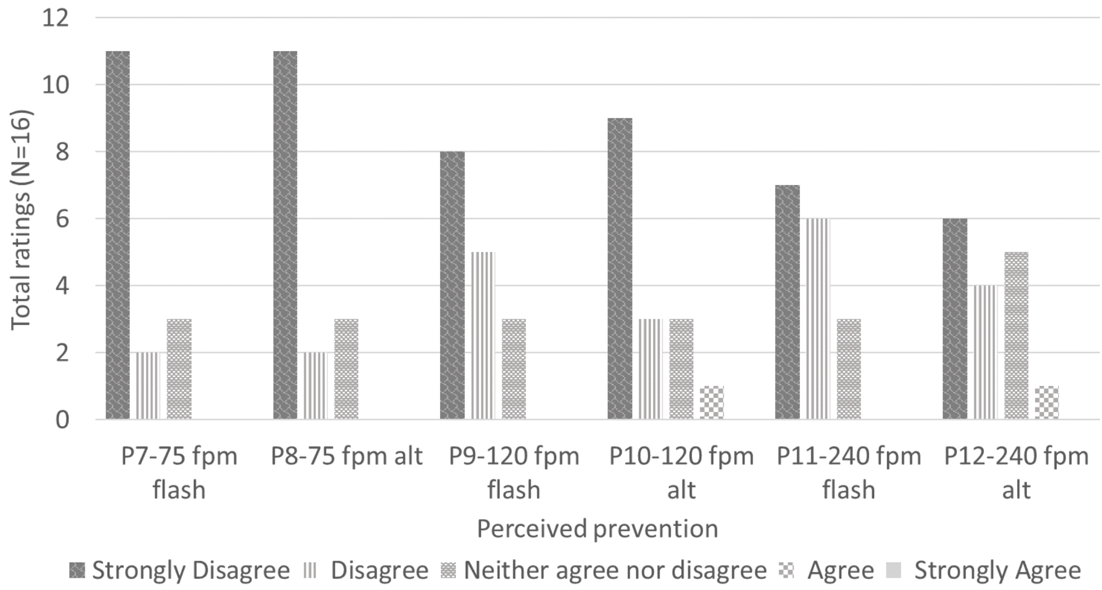

Figure 206: Graph to show the perceived prevention at 300 metres in the day

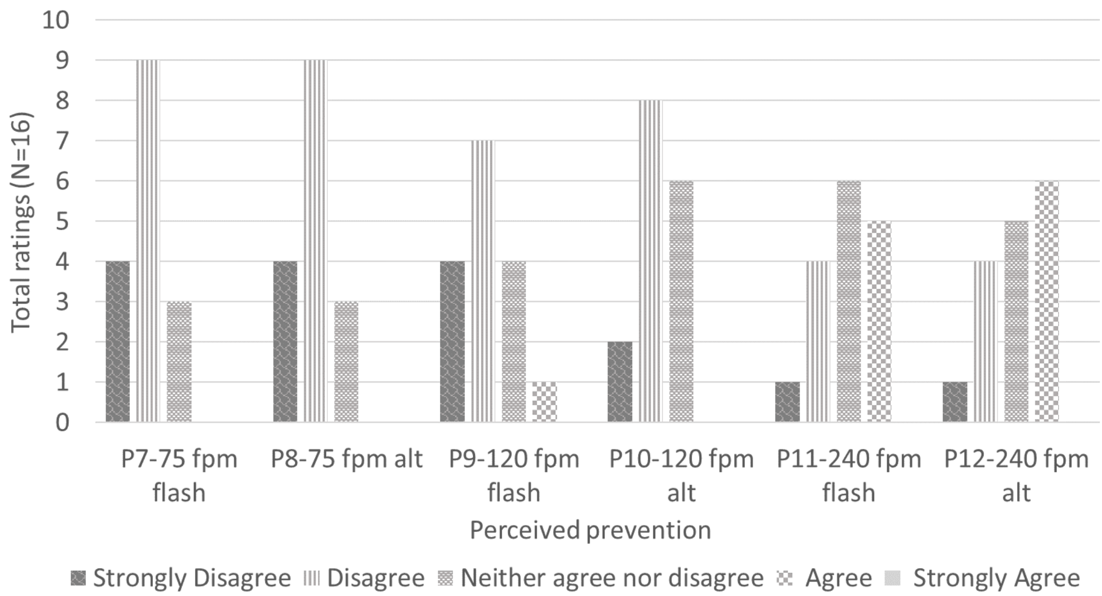

Figure 207: Graph to show the perceived prevention at 300 metres at night

When comparing the perceived impairment at 200 metres in the day versus night, as Figure 209 and Figure 208 show, both agreement and neither agree nor disagree was found at night, but not in the day.

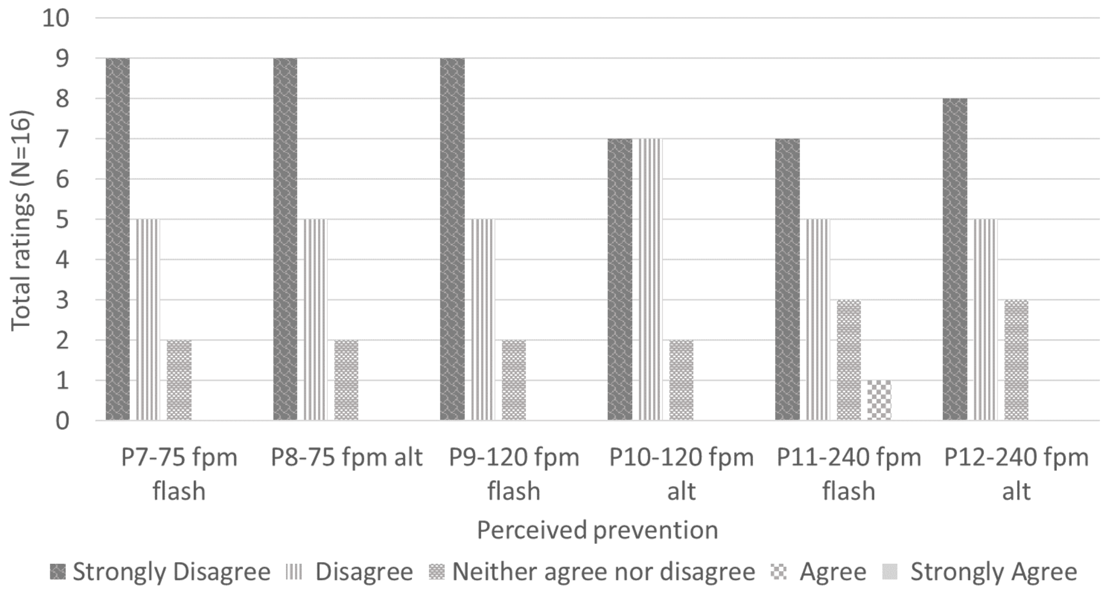

Figure 208: Graph to show the perceived prevention at 200 metres in the day

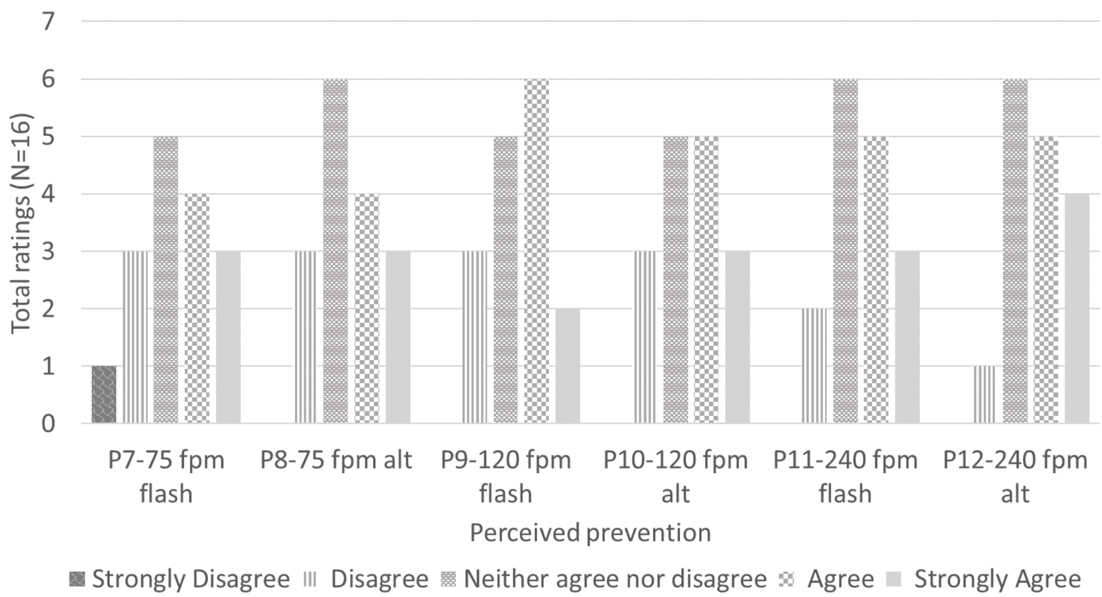

Figure 209: Graph to show the perceived prevention at 200 metres at night

H.7.4 Patterns P7-P12 – distance

When comparing the perceived visual impairment at 300 and 200 metres in the day, as Figure 210 and Figure 211 show, no clear differences were observed between the two scenarios for disagreement/ strong disagreement.

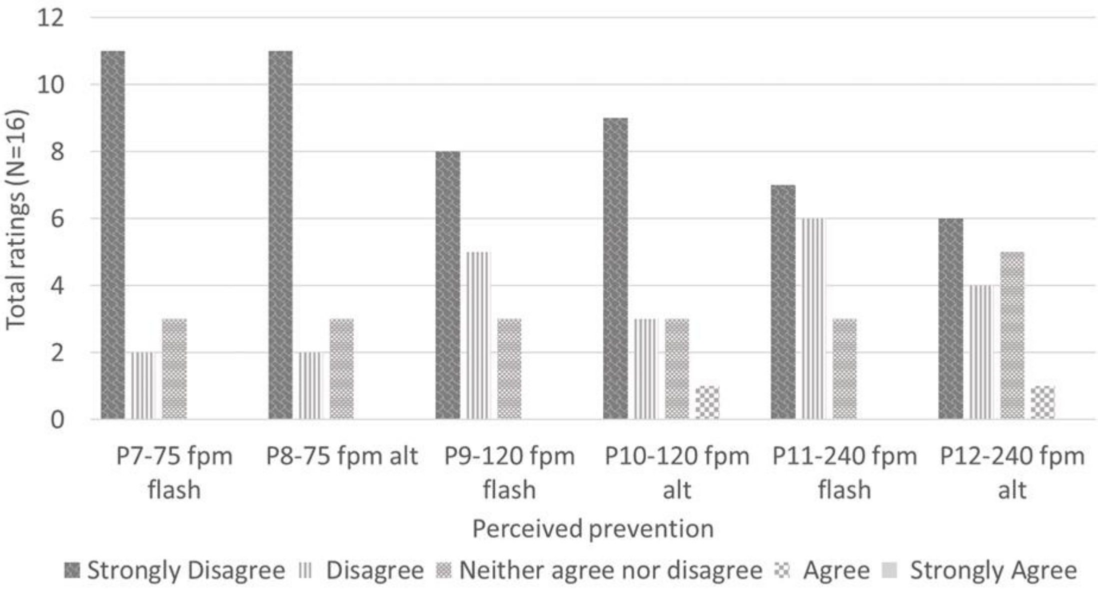

Figure 210: Graph to show the perceived prevention at 300 metres in the day

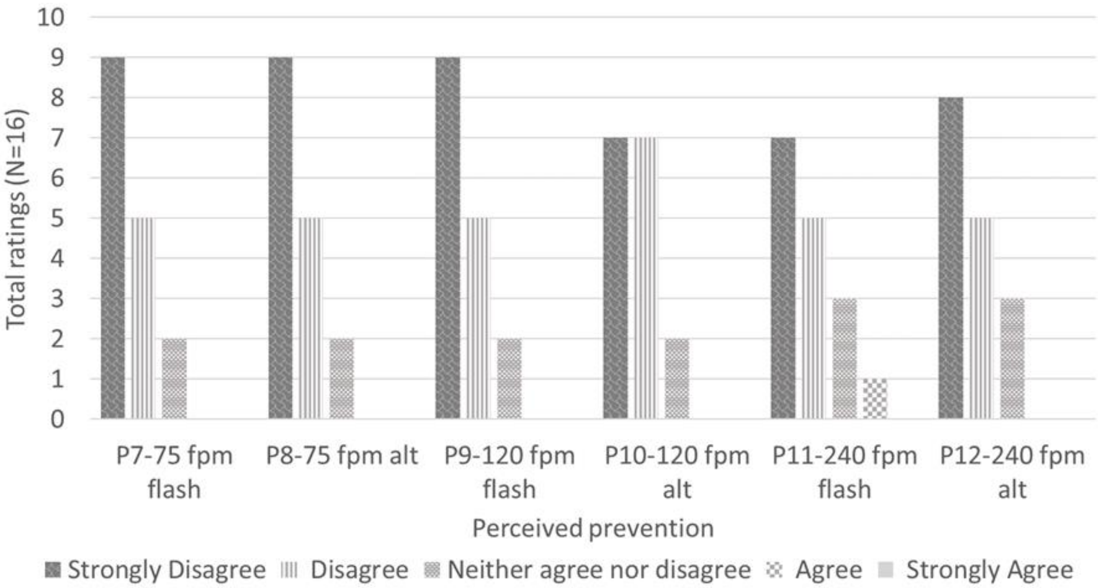

Figure 211: Graph to show the perceived prevention at 200 metres in the day

When comparing the perceived visual impairment at 300 and 200 metres at night, as Figure 212 and Figure 213 show, around half of the attendees expressed agreement or were neutral at 200 metres at night, across the patterns presented. In contrast, at 300 metres at night, more disagreement was noted across the patterns presented, though agreement and neutrality was observed for the 240 fpm flash and 240 fpm alternating patterns. These findings may suggest that attendees viewed the patterns as more obstructive at 200 metres at night, compared to at 300 metres.

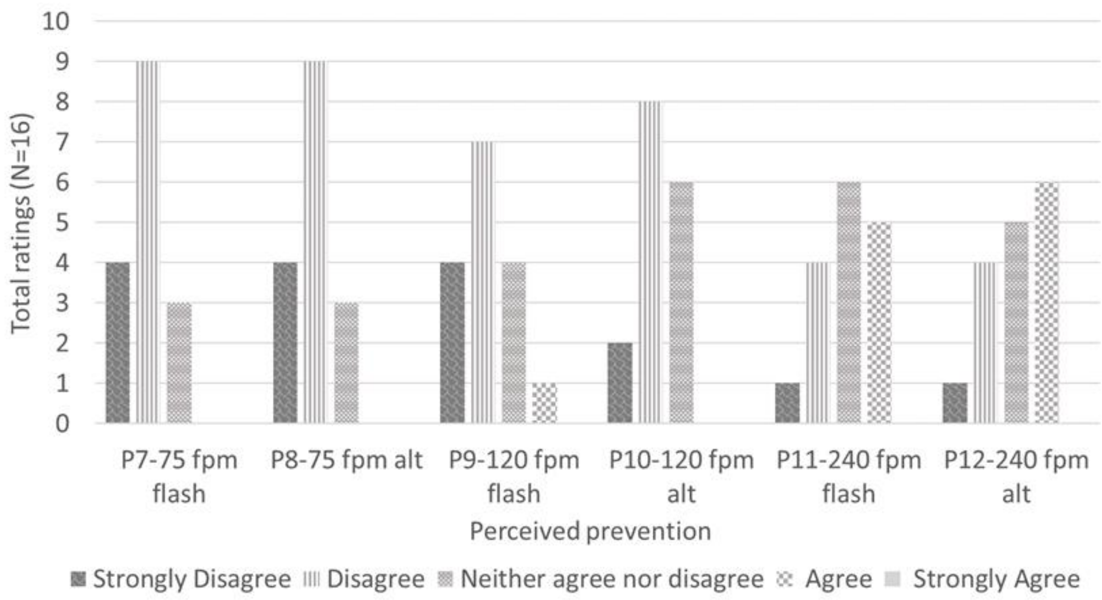

Figure 212: Graph to show the perceived prevention at 300 metres at night

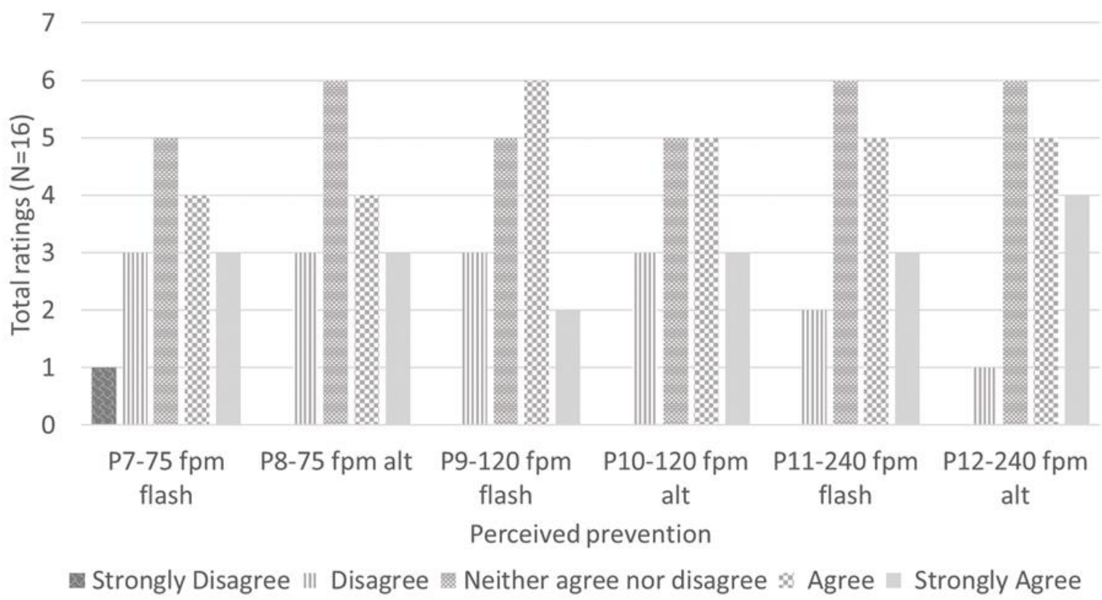

Figure 213: Graph to show the perceived prevention at 200 metres at night

H.7.5 Patterns P13-P16 – day and night, and distance

When comparing the perceived visual impairment at 300 metres at night with 300 metres in the day, as Figure 214 and Figure 215 show, disagreement was generally noted for all the lighting patterns at 300 metres in the day. The 300 metres night data contrasted this; attendees expressed either neutrality or agreement with the statement, suggesting that they may have perceived the lighting patterns to be potentially obstructing their view around the vehicle.

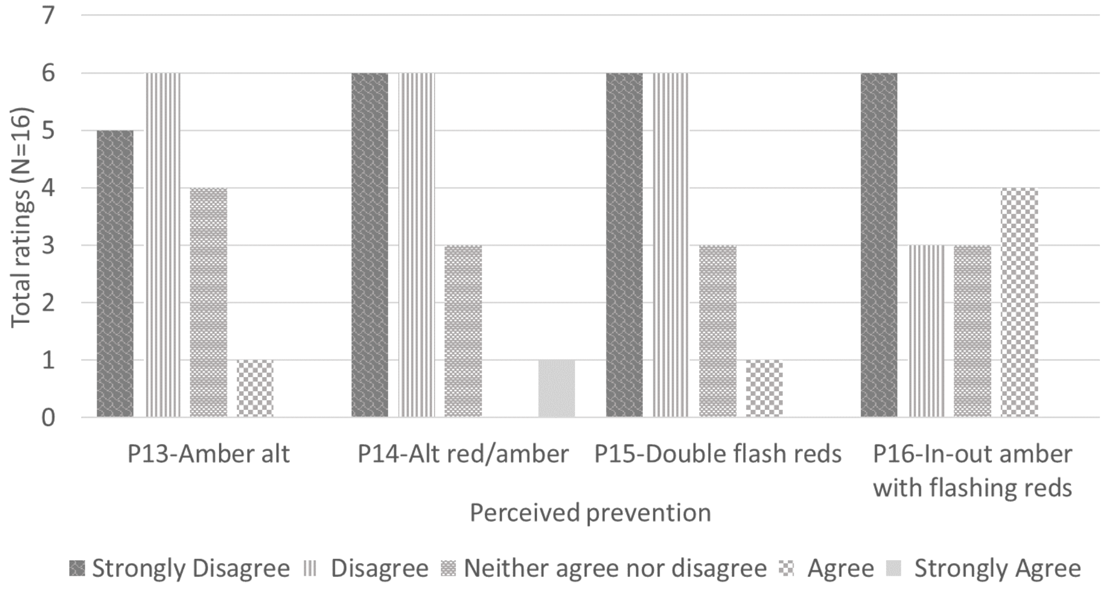

Figure 214: Graph to show the perceived prevention at 300 metres in the day

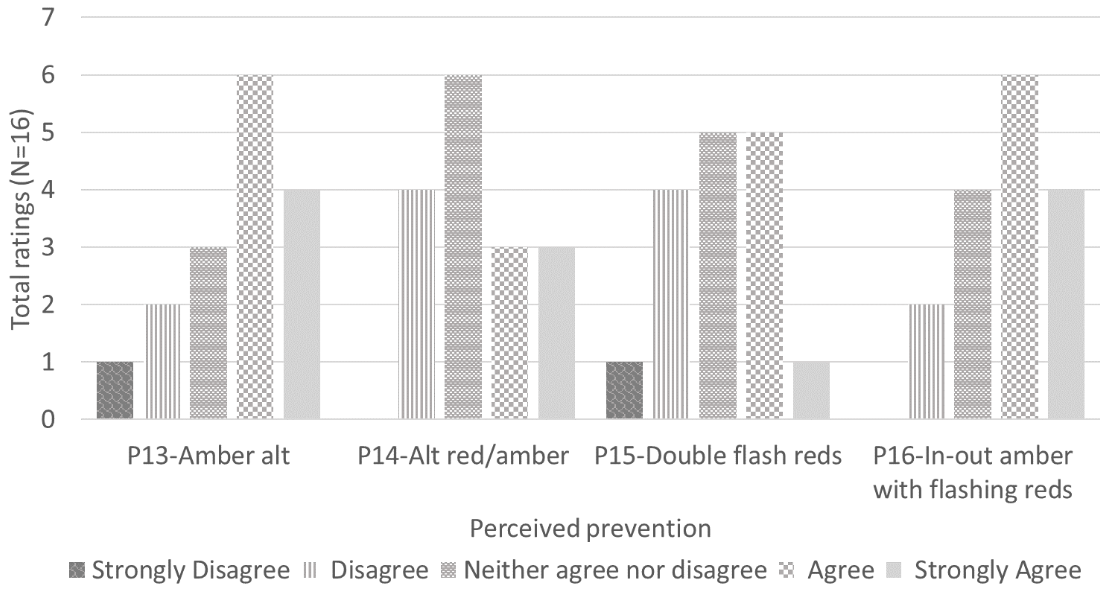

Figure 215: Graph to show the perceived prevention at 300 metres at night

When comparing the perceived visual impairment at 200 metres at night with 200 metres in the day, disagreement was noted across the 200 metres day data (see Figure 216). In contrast, attendees expressed either agreement or were neutral in the night data (see Figure 217).

When comparing the perceived visual impairment at 300 metres and 200 metres at night, the ratings of agreement and neutrality were roughly even across the two scenarios (see Figure 215 and Figure 217).

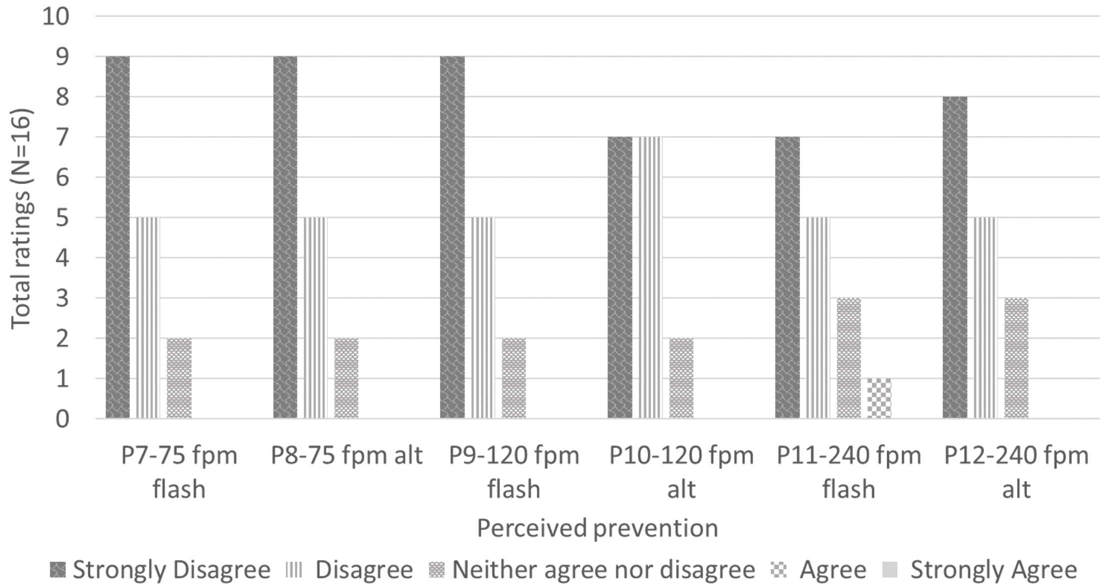

Figure 216: Graph to show the perceived prevention at 200 metres in the day

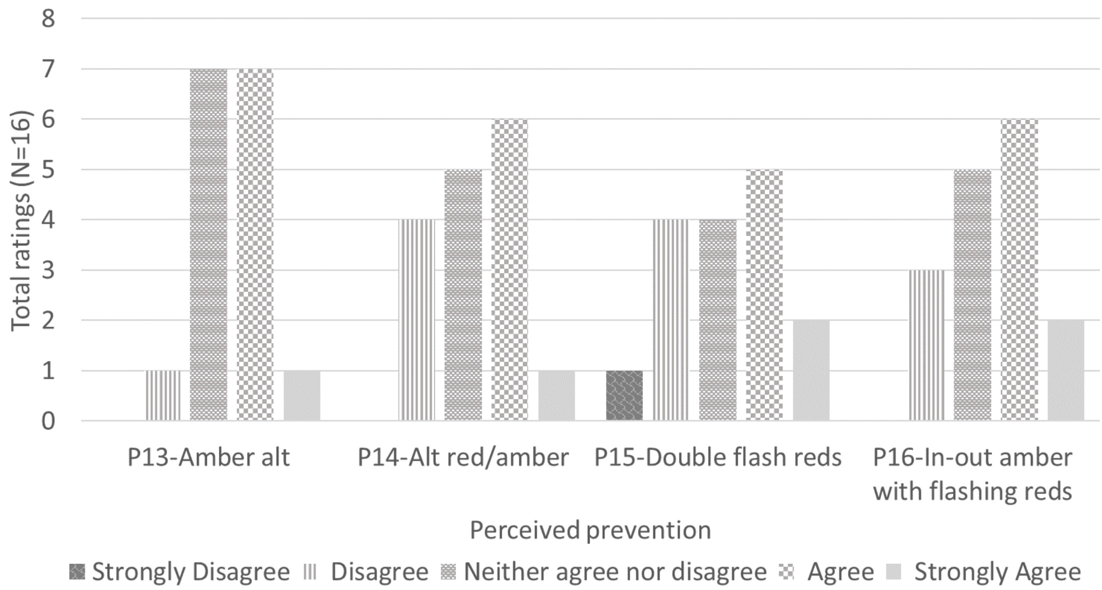

Figure 217: Graph to show the perceived prevention at 200 metres at night

H.8 Summary

Considered together, the following conclusions can be reached (although note a full psychophysical test design would be needed to confirm such findings).

- Patterns displayed with a faster flashes per minute are attention grabbing but also potentially too bright, depending on the distance and time of day.
- Whilst rated as attention grabbing, patterns displayed with a faster rate of flashes per minute may also be rated as distracting.
- No patterns were viewed as particularly likely to prevent an attendee viewing around the vehicle.

When considered alongside the results from the online survey detailed in F.2.2, some consistent findings are noted:

- The online survey found a good proportion of respondents stated that the vehicle was parked, rather than moving for FP1. This is mirrored by the findings around the 75 fpm flashing pattern (pattern 1) in the Expert Review.
- The online survey found that respondents expected the vehicle to be moving, rather than parked for FP2, FP4 and FP6, this is mirrored by the expert review findings around the lighting patterns P2-P6.

Appendix I Expert seminar submissions

This section contains submissions made by stakeholders and other experts, either within the Expert Seminar 'chat' log of the online seminar held on Tuesday, November 22nd, 2022, or submitted separately. All those submitting comments were offered confidentiality. Where this was waived, their details are provided.

Submissions are in four sections:

- 'Chat' Log. This has been anonymised
- Questions which were asked in the 'chat', including those relating to project delivery against the DfT's ITT document. These are answered separately, with TRL responses in blue
- Submitted comments, anonymous
    - Where the comment raised a point or question relating to project delivery or TRL's involvement, these are answered in blue
- Submitted comments, attributed
    - Where the comment raised a point or question relating to project delivery or TRL's involvement, these are answered in blue

It should be noted that the comments in these sections are largely opinions, but they are reported here as a legitimate reflection of the perceptions of the industry on this topic.

I.1 Expert seminar Microsoft Teams meeting 'chat' log

This section contains comments extracted from the meeting 'chat' Log. These have been anonymised.

- The intention is to publish the report together with the report from the current research.

- Will what the public perceived the purpose of the vehicle to be mentioned in this meeting or will it be released as part of the report?

- My question was to ask if the research covered the impact of a change to other operators such as highway maintenance

- [Redacted] - we can discuss later - an interesting question. We certainly will discuss data on understanding of what the lights mean in the report.

- [Redacted] - please ask this question in the next comments pause - I will come to you

- [Redacted] - will come to you in the next pause - after I have covered rest of project - a few minutes from now.

- Listening to this call I am seriously concerned that we seem to be considering a change without considering the impact on others.

- Answering that statement we have to establish that lane closure. So similar situation exists. Be clear we support regulation of warning lamps and beacons.

- OK [Redacted] - you have joined for the main discussion bit. You missed the description of all the work that has happened in the 2022 and earlier 2020 reports. I can catch you up after if this is helpful

- [Redacted] - your point about impact on others - will be highly relevant to first question framing the discussion I expect - I'll come to this first.

  like 1

- Others - please contribute anything you wish to ask or comment on by raising your hand. It is best for this kind of thing if we hear multiple focus areas.

- Thinking it may be easier to design an authorised traffic sign than use red beacons and lamps regs... difficult with authorisations but not impossible

- "If" we were granted red lights? would this be only PAS43/Sector17 companies working with Police and Highways on there schemes to only be aloud to use them? My concern is "IF" they were granted anyone would be able to use them and we will be in the situation we are in now with over use of Amber lights.

  like 1

- Hi [Redacted]. The independent recovery already has mechanisms in place to limit the appropriate use of lighting together with suitable training. Happy to expand on this. Thanks, [Redacted].

  like 1

- Hi [Redacted]. The independent recovery already has mechanisms in place to limit the appropriate use of lighting together with suitable training. Happy to expand on this. Thanks, [Redacted].

- Should red lights be authorised, strict controls should be put in place governing their use, only to be used when stationary, in situations deemed high risk. Technicians will need to be trained and SOP’s put in place. I believe the use of red lights must be authorised individually, perhaps PAS 43 certification could be used to licence their use? Lighting regulations will need to change, and incorrect use of red lights will need to policed by the authorities.

  like 1

- Should red lights be authorised, strict controls should be put in place governing their use, only to be used when stationary, in situations deemed high risk. Technicians will need to be trained and SOP’s…

- And needs to be coordinated with all stopped in a live traffic lane

- For report... we need a coordinated approach and regulation of amber

- Answering that statement we have to establish that lane closure. So similar situation exists. Be clear we support regulation of warning lamps and beacons.

  For report

- Driver attention.. drug use, customer speed... distracted driving....

- You are asking us to compensate for poor road user behaviour, we will never be able to keep up unless we start tackling that alongside

- For report - agree that the use of amber lights need regulation and control.

  like 1

- For the report: While UK Search and Rescue have been invited to this meeting, it does not seem appropriate to dilute or detract from this important discussion around recovery vehicles by raising issues around Search and Rescue vehicles. There are a number of potential benefits offered by red lights to emergency vehicles who are stopped and working on main roads, dual carriage ways, motorways etc. Not all emergency services currently have permissions. Any use would need to be governed by the same useful discussion this meeting is having. I feel there is merit in feeding these needs into this wider discussion outside of this meeting.

- For the report. I wouldn't be able to support a change if it looked only at the recovery industry alone

- Good question [Redacted]

- FOR REPORT I believe the use of red lights is only part of the solution, the industry needs to adopt commonality to its vehicles, PPE, parking and customer care, there is scientific data suggesting the best colours and livery for vehicles, this is already laid out within PAS 43, yet very few organisations follow this guidance. Conspicuity is not just about making something visible, it should also aid in making it identifiable, the faster an approaching motorist sees and identifies a vehicle at the roadside the faster they are able to understand the likely situation, and act accordingly. Regardless of red lights being allowed or not, the industry could do more to help itself. The industry currently has widely differing standards, the level of professionalism differs greatly, an improvement here would help with safety and potentially reduce accidents of all types with the industry. I also believe a change in thinking is required, instead of thinking “I hope this never happens” we should be thinking “it will happen”. Control measures and protocols should be based around the worst happening, not trying to control something which may ultimately be outside the operator's control.

- I believe the use of red lights will have a bigger psychological effect for the industry than any evidence will show. When we consider the instances of vehicles being struck at the roadside, lighting has little effect, the driver which strikes a stationary breakdown vehicle did so because they did not see it. Will red lights improve the instances of vehicle strikes? I suspect not; however, they will help the industry feel its safety is being taken seriously, currently many feel, that the industry is considered a second-class citizen, our safety doesn't matter. Parity with other emergency roadside workers would be welcomed, even if the data suggests there is no benefit to using red lights.

- Please understand there is a significant risk of the industry withdrawing their services for a period of time to prove they are essential providers

I.2 Questions asked within the 'chat', including relating to delivery of work against the DfT's 'Statement of Requirements'

- TRL answers interspersed
- Much of this information is covered in the final project report, although that will not specifically comment on content of the TRL proposal document.

I.2.1 STATS19

STATS 19 reports, shows the Killed and Seriously Injured (KSI) on the strategic road network, have you looked at specific examples from the KSI report over any given period, and if so what if any case studies have been done on vehicle recovery operators killed or seriously injured and then considered how "Red Warning Lights" may have prevented the incident.

- An attempt to identify what might have prevented any individual incident would require an in-depth investigation
- The 2020 project final report discussed use of STATS19, Road Accident In-Depth Studies (RAIDS) and Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) information

I.2.2 Trials location

Statement of Requirements. Contract Title: The use of red flashing lamps by road recovery operators – Phase 2. Contract Reference: TETI1027

Asks the following:

8.2 One of the reported benefits of road-recovery vehicles fitted with red flashing lamps is an implicit association between the colour red and the concept of danger. It has been suggested that this association of red with danger could benefit road recovery operators if it causes drivers approaching a scene to take more care. Therefore, a key objective for the off-road trials is to generate sufficient data to statistically quantify this association under "real road" conditions and determine whether there is expected to be demonstrable road safety benefits to recovery operators and other road users.

How was this trial undertaken? And where?

- Trials were undertaken as described during the seminar. Full details are provided in the report. The participant track trials were held at Wroughton airfield.
- See later answers for additional details of site selection
- Several test tracks were investigated
- Due to access difficulties, the original 'rural' site was not used for trials
- Two further sites were identified as suitable for the 'rural' environment

- No sites were identified as suitable to deliver the three other road environments

I.2.3 Trials design

How and where was each of [these] undertaken and tested, who, what industry experts were involved. There is an inclusive list of recovery vehicle types listed [below], what and who's vehicles were used.

8.4, 8.5, 8.6 from the Tender Terms of Reference, states the following:

8.4The key tasks of work package 3 will include but is not limited to:

8.5 Develop a suitable off-road vehicle trial methodology to ensure the extent of the vehicle trials activity generates a representative and statistically robust data set, considering, for example, the following conditions:

i) A range of weather conditions and variation in traffic density

- In our proposal we recommended that variations in weather conditions and traffic density should not be included. Both would have restricted participants' views ahead towards the static vehicle so would have altered participants' behaviour
- Also, each additional condition tested (e.g., traffic, no traffic) would have required doubling the number of trials participants
- For a track-based trial, it is not possible to control ambient weather conditions
- For a track-based trial, it would be difficult to ensure repeatable 'other traffic', so not consistent between-participants, adversely affecting results
- In a simulator trial, other, AI-controlled, traffic would respond to the actions of the participant-driven vehicle, so might not be consistent between-participants, adversely affecting results
- In the urban environment, any oncoming vehicles might restrict participants' demerge decisions, adversely affecting results, so other AI-controlled traffic was not introduced
- In the high-speed road environment, other AI-controlled traffic might restrict participants from demerging, adversely affecting results, so was not introduced
- A limited number of AI-controlled vehicles were introduced in the motorway environment. In this environment a demerge action was not required to avoid the parked vehicle on the hard shoulder. HGVs were not included as, being restricted to lanes 1 and 2, they might obstruct participants' view

ii) Day and night conditions

- Covered in both track and simulator trials, using different participants for each condition

iii) Red flashing only, red + amber, and amber flashing lamps

- Covered in both track and simulator trials

iv) Effects of colour combinations vs red flashing lamp on its own.

- Track and simulator trials covered: amber only, red only, amber and red together. The client's requirement was described:

  8.3 The trial would help to understand drivers' behaviour, and whether there is a difference in drivers' likely behaviour when they see stationary vehicles in the carriageway displaying rear-facing flashing red lamps only, amber plus rear-facing flashing red lamps, and amber warning beacons only.

v) Stationary and dynamic conditions (hard shoulder)

- Simulator trial included vehicles stopped in live lanes (high-speed dual carriageway and urban) and on the hard shoulder (motorway) conditions

vi) The off-road trials should replicate real-world environment and different road types (SRN, urban and rural roads). The criteria for the trial location shall be clearly defined.

- Although the ITT specified three road types, in our proposal we recommended increasing this to four: motorway with hard shoulder, high-speed dual carriageway, urban, rural
- Trials could not be undertaken on public roads
- No test track facilities in the UK can provide the full set of required road environments
- Several of those facilities which could provide a single environment would not permit sole use hire for trials duration
- Trials used naïve public participants, requiring that sufficient participants were available close to any selected trials location and that within-site travel is possible to access the test area from public areas
- For the purposes of trials, it was essential that participants did not have a view ahead to the test scenarios. Most off-road test track facilities do not have obstructed views
- 'Rural' track trials were undertaken at the Science Museum National Collections Centre, Wroughton, a decommissioned airfield, which provided sole use, a suitable naturalistic environment and reasonable local catchment for participant recruitment
- Our proposal recommended that TRL's DigiCar simulator was used to deliver the three other road environments

8.6 Identify and select suitable vehicle trial participants. Selection and evaluation criteria for participants should ensure a broad representation across age, gender, driving experience, professional/non-professional drivers, etc. Consideration should also be given to different recovery vehicle types such as flatbed, recovery truck, tow truck, van, etc.

- Track trials participants were recruited from TRL's participants register and responses to advertising targeted on a radius 20 miles around Swindon (the nearest large town to the trials site). All were over 18 and UK driving licence holders
- Simulator trial participants were recruited from TRL's participant register. All were over 18 and UK driving licence holders

- Each additional single condition tested (e.g., different industry vehicle) would require doubling the number of trials participants. To run trials using four vehicle types would have extensively extended trials duration and costs. Five simulator trials were undertaken each day, with 72 participants taking part in total. As occasional equipment failures occur and some participants do not arrive for booked trials, it is likely that, to use four vehicle types, the trials would have extended over three months. Therefore, we recommended in our proposal that a single vehicle type should be used
- Using a single vehicle type for each of the two sets of trials meant that the only variable was the lighting displayed, therefore it was participants' reactions to these changes that were recorded and analysed
- The vehicle used (and staff) were provided by the RAC. TRL had an existing relationship with the RAC. In case of difficulties with vehicle provision, two other organisations had offered support

I.3 Submitted comments, anonymous

Where the comment raised a point or question relating to project delivery, these are answered in blue.

For clarity, each anonymous submission has been listed separately.

If the recommendation from the research is to grant authorisation for the use of red lamps, what are your priorities on maximising their effectiveness? For example, in consultation, views were expressed from some industry representatives about over-use of red lamps, how could this be managed?

> The system MUST be controlled, there are a number of mechanisms in place including PAS 43 and ID cards to do this, but others are better equipped to comment on them. The vehicle must be fitted with a device to turn the light off when the vehicle moves off. This device is already available. The operative must have attended the appropriate course on their use

If the recommendation is to not grant authorisation, what else could the industry pursue to improve safety?

> An alternative way to make it clear to people there is danger ahead must be found as the proliferation of Amber Lights has now made them almost pointless.
>
> There is also a chance that VRO's will start to use RED lights illegally and the chance to control their introduction for maximum efficiency with minimum dilution to all Red Light Users will be gone

If there is not firm evidence either way, how would the industry make the decision about what to do next?

> After 30 years the industry has had enough of delays and being fobbed off while other who are less likely to need its protection are allowed their use. As stated before there is also a chance that VRO's will start to use RED lights illegally and the chance to control their introduction for maximum efficiency with minimum dilution to all Red Light Users will be gone

We are legally and duty bound to protect our people under the Health and Safety at work Act 1974 and supporting legislation and guidance. As part of the risk parameters and logic we are able to apply to mitigate risk we are permitted (when not an absolute duty) to use a hierarchy of controls to mitigate risk to our people. Naturally we agree that there are many physical, technical and system controls that sit with government and road safety related bodies and enforcement agencies that form part of this hierarchy. We believe conspicuity and lighting is a critical control within this hierarchy and we are therefore grateful to have this opportunity to contribute to this review.

At the [redacted], we have a long legacy and are proud to support these organisations and feel we play a pivotal role in driving road safety. We have a fantastic set of professional and very capable (breakdown and recovery) employees and contracted parties who keep our national critical road infrastructure moving and support our members' and customers' day get back on track. Every organisation on today's call has their own safe systems of work to promote and maintain a safe working environment for our people. We all care and are passionate about this subject hence the emotive discussion. I trust that passion is received in this manner.

In relation to this consultation, on the use of red over amber lights, I believe the following should be considered:

1. The breakdown and recovery industry attend incidents at high speed and dangerous locations alongside, and often without the support of, those with blue/ red light support. It should be noted we attend smart and non smart motorways and dual carriage ways but also other high speed roads. The police and highways agency will not, and do not, attend a number of these locations. Often these locations can be more dangerous for our people, our customers/ members and other road users.
2. It is deemed necessary for police/ highways to have red light support to undertake their role safely. Yet, without permitting the use of red lights for these operators, TRL and government would be wilfully and intentionally condoning different, and a lower standard of controls, for our people when attending such dangerous locations. These controls are available and would be reasonably practical to introduce. In addition to this, it is clear, with resounding unity, that the industry strongly believe red light use would strengthen the safety of those working at our roadsides. NB: It should be noted that these people are subjected to many of the same hazards to which it is already deemed that a higher standard of protection is required.

TRL is not involved in the decision to allow, disallow, or otherwise. TRL is an independent social enterprise research company that has been tasked with collecting evidence in a number of areas to inform the decision on red flashing lamps to be made by the DfT.

3. We wholeheartedly agree appropriate controls and conditions would need to be implemented to ensure controlled use of red lights. We would of course be happy to support and participate in the development of such standards.
4. I cannot therefore support exploring an alternative and substandard level of controls (i.e. amber) as requested in the meeting given the reasons above. I feel we would not be meeting the duty of care to our people in doing so.

This question was asked as a way of understanding positions and thoughts on the topic – not because anything has been decided by the DfT. It achieved this even if only through people reacting in the way they did (understandable, given the strength of feeling about red vs. amber). The discussion off the back of this was very useful, as it underlined this strength of feeling. TRL's starting position on this is not to assume that red flashing lamps are safer, it is to ask the (main) question "how much can red lamps help improve the safety of road recovery operatives, relative to what is used now".

5. In recommending this difference in standards I would suggest that the supporting parties would be grossly negligent and vicariously liable for future related road deaths and associated life changing injuries that emerge from such relevant and potentially avoidable incidents.

I would also implore TRL/ government to consult with the Health and Safety Executive (HSE) as a key stakeholder on this matter as I believe there a disconnect in relation to this approach and the HSEs (and therefore Department for Work and Pensions) legislation and updated driving and riding safely for work.

Consultation with the HSE is outside of the scope for the current project so not something that we can undertake. However, this has been included the report's Conclusion and Recommendations section.

Forgetting the legal argument. I know everyone involved in todays call is passionate about road safety. Morally, we have a responsibility to get all of our people home safely everyday. The collective industry has made many improvements and its imperative that we continue to work collectively to drive standards and make improvements; vast or incremental. Road users are individuals shaped by learning, reinforced behaviour and wider feedback. We are all conditioned to know that red means stop or danger and amber means readiness/ alert. As such I make a plea that we do not make this anymore complex than required. Our people work in dangerous high speed locations, often as lone workers, in areas where they are not supported by some of the controls available on smart/ non smart motorways (overhead messaging/ lane closures etc). They are the sole responders. We therefore ask that our breakdown and recovery industry is permitted to be equipped with the same controls granted to other agencies. We ask this to ensure we can keep them safe and get them and other road users back to their family and friends at the end of the shifts after supporting our critical road infrastructure.

When looks at previously there were concerns that the example given to justify the use of red beacons may be related to risks associated with operating outside a safe method of working. Secondly the number and intensity of beacons and other lamps often means vehicles are over conspicuous and road users tend to not easily comprehend the nature of the hazard until much closer to the vehicles than they could/should; I assume that this was tested /considered as part of the demonstration you mentioned. Finally, linked with this is the consideration of the impact on visibility of workers on foot; the extra veiling luminance from all the active light sources was calculated to reduce the visibility to approaching traffic of workers hi-vis by up to 20%, not helped by some operators using colours with lower luminance factors (e.g. orange vs yellow).

While not excluding the use of red lamps, it is important to ensure that the benchmark is the most effective use of existing options.

Red beacons are visible from a shorter distance than amber / yellow for the same intensity. That’s for somebody with normal vision, never mind the various optical disabilities (not limited to the impact of red/green colour-blindness).

I.4 Submitted comments, attributed

Where the comment raised a point or question relating to project delivery, these are answered in blue.

For clarity, each attributed submission has been listed separately.

I.4.1 Paul Anstee, Slow Down Move Over (SDMO)

Red lights

- Experience
- Concerns
- Solutions

Experience:

In thirty-one years of doing Rescue and Recovery there has been a need more now than ever for protection to unprotected road operators.

The changes have been vehicles have become sounder proofed in cocooning the people inside them making them more de sensitised to the surroundings outside.

Job migration and population expansion, the local factories of employment have disappeared causing more people to take to the road to get to their job, forcing them to start early and finish late making the day longer hours than if they worked local. This is then changing the reaction times and attitudes of people driving with modern day stress.

This came to my notice when one of my own vehicle operators got hit on the 21st June 2016 working on an A road in the Chelmsford area. The person that hit my operator was text messaging and drove up the right-hand side of the recovery deck as he was on the deck half in and out of the car, fortunately it did not kill him.

Being a Road Operator, the traffic noise is lost over the years working next to the road I had become de sensitised to its full dangers and from the accident it made the traffic become very loud. I have always been a safe worker and employer! But safety became very loud and brought to my attention that changes that have to be made with more training to the rescue recovery operator and public awareness.

This is where Slow Down Move Over UK was born from

Concerns:

What I have experienced in the real live road situations that people do not respect unprotected road workers weather it has amber or emergency lights including red in them.

If people cannot see an eight-foot arrow sign directing them there is a work force in front of them or driving around police cars protecting a situation there has to be more to just giving red lights to unprotected road workers like us in the Rescue Recovery Industry.

I agree that we should be given all the tools in the toolbox to secure our safety! But I have a concern it will come back to diluting the safety of others if they are not used in the correct way or policed. I know there is very comprehensive training in the Institute Vehicle Recovery. But control should be implied and understanding (a criteria to follow to get these authorised to be used by each company) If a protocol isn't in place! People will just use them anyway and take the telling off.

Solutions

This is my request from leading a safety campaign to raise awareness

- UK wide training on how to use amber lights backed by government in DCPC training and a national information package that can be shared by all the industries
- Driver awareness courses (from the speed awareness courses) to refresh people's knowledge of amber and emergency lighting.
- Bring in the hazard perception training an image of a rescue recovery vehicle working in the video. (This was suggested in 2018)

Without education this is just another flashing light that no one cares about

The suggestion regarding UK wide training is welcomed and is already captured in our recommendations. The suggestion regarding the hazard perception test is again welcomed and has been included in our second recommendation.

I.4.2 Mark Crawley – Chairman, The London Association of Recovery Operators (LARO)

Accident will happen by their very nature but having the use of red flashing lights in the armoury of the professional recovery operator and used in the appropriate circumstance will undoubtedly save lives. The independent recovery industry wants regulation in the use of red lights and is equally keen to avoid their over use and any subsequent dilution. The Institute of Vehicle Recovery has proactively developed a lengthy training module detailing there appropriate use and restrictions. The recovery industry attends hundred's of incidents daily in all weather conditions, not just on the Strategic Road Network but on high speed 'A' and varying 'B' roads where the use of red lights should be an option afforded to the operator under existing Health and Safety legislation as it is currently for other selected emergency services.

I.4.3 Simon Hill – Deputy General Secretary, Metropolitan Police Federation

I have some concerns and observations regarding the prospect of granting authorisation for the use of Red Flashing lamps for the vehicle recovery industry.

To make my position clear from the outset, I am very supportive of any measure that provides a safer environment, working or otherwise, for any person. However, I don't believe that making a safer environment for some, should be to the detriment of a safer environment for others.

The main areas of observation that I have;

- It was acknowledged within the seminar that there is limited/no regulation or control over the use of amber lights. This is an area that needs further exploration to determine if proper regulation and control would contribute to a safer working environment for the recovery industry.
- I am fully supportive of the comments made by [redacted] when it comes to the recovery industry needing to adopt commonality, colours & livery, the recovery industry doing more to help itself and generally having a more professionalised approached. There tends to be a consistent approach within the emergency service industry when it comes to vehicles with lighting & livery, thus making the vehicles more distinctive
- It was referenced on more than one occasion during the seminar that red flashing lights would not ultimately be sufficient to remove all the dangers faced by the recovery industry (my words). This weakens the argument for more widespread rollout away from emergency service vehicles.
- Roads being 'awash' with amber flashing lights was mentioned which is not a point I disagree with. It seems somewhat perverse to replace roads being 'awash' with amber flashing lights to roads being 'awash' with red flashing lights.
- Recovery vehicles predominantly perform a singular role, and that is to recover vehicles. Emergency service vehicles perform a multitude of roles such as recovery of not only vehicles but debris, pedestrians and animals. Closing roads by way of a 'rolling road' is a task completed by Police vehicles but not recovery vehicles as is the stopping of vehicles via techniques such as Tactical Pursuit & Containment. There are going to be other tactics that are deployed by Police vehicles on roads that are specific to that department including enforcement and techniques deployed by Special Escort Group who are responsible for the escorting of dignitaries.

I did not find there to be a compelling argument for red flashing lights to be used by the recovery industry especially when considering the above observations and additional safety measures that could be implemented by the recovery industry that are currently not.

My fear is that to do so would cause confusion to the general public whilst driving as they would not be able to differentiate between an emergency service vehicle or not, this would dilute the impact of red flashing lights. This in turn leads to a greater level of danger for my members whilst working on the roads.

My position is to not support the recovery industry being granted authority to use red flashing lights on their vehicles.

I.4.4 Keith Smith, IEng, FIHE, FCIHT, MIET, TechIOSH, RegTTME(IHE) – The Chevron Group Chief Engineer, TMCA Technical Officer

- The TMCA having listened to the Recovery Industries representatives comments at the expert meeting are not supportive of the recovery industries isolated request for red lights. The member who put up an image of a red beavertail lorry that had been hit, that was in no way conspicuous was an example of how their industry is arguing for action but the basics are not correct.
- The TMCA are against a specific change to benefit of recovery companies without the task considering the wider implications on all aspects of warning and beacon use, traffic management, incident support, Impact protection, ab load escort, Traffic officers etc.
- The TMCA is as concerned as the recovery industry at the number of recovery operators, traffic management personnel and vehicles that we are both having hit on the hard shoulder and support the imperative to deal with this.
- The TMCA is as concerned as the recovery industry at the number of recovery operators, traffic management personnel and vehicles that we are both having hit when stationary in live traffic lanes and support the imperative to deal with this.
- The TMCA however does not consider that red lights are the solution as it will not address driver inattention and awareness which are the root cause of both our industries to suffer the fatalities and incidents levels that are wholly unacceptable. We will still get hit irrespective of the colour of our lights is our opinion. Red lights may also have a negative impact on others
- The TMCA does supports greater regulation of amber warning lights including the suggestion of amber lights having to be permitted and standardised. E.g.
    - Vehicles that park / stop with a safety zone have a simple roof mounted beacon
    - Traffic management and recovery vehicles parked in live lanes having full width Amber LED beacons and lower mounted Amber LED traffic Directors
    - Ab load escorts being regulated and a sign standardised for them
    - Greater prescription of roof mounted LED light up signs on authorised and permitted vehicles to a standard colour/ design
- The TMCA is concerned about the poor application and easy availability of amber beacons and lamps.
- The TMCA understands the recovery industries frustration and request for action but the requests made and language used at the meeting by some representatives is considered counterproductive to their desire to achieve improvement.

I.4.5 Simon Thresher – MREW Vehicle Officer, UKSAR DTAG Member. Mountain Rescue England & Wales

If the recommendation from the research is to grant authorisation for the use of red lamps, what are your priorities on maximising their effectiveness? For example, in consultation, views were expressed from some industry representatives about over-use of red lamps, how could this be managed?

- Only to be used whilst stationary, at the scene of an incident that cannot be pre planned or anticipated.
- Only to be used by those practicably trained in there use and application.
- Only to be used on roads where the national speed limit applies or the width / speed of the road places emergency workers at risk
- Only to be used on the rear most vehicle and not every emergency vehicle in attendance.
- Only to be used where other risk mitigation cannot be implemented by nature of the response required ie a risk to life. (vehicle recovery is a pre planned activity, as long as the vehicle to be recovered is not on a live running lane of a carriageway with a national speed limit and where the occupants can leave the vehicle)

If the recommendation is to not grant authorisation, what else could the industry pursue to improve safety?

- Deployment of warning signs – where practical.
- Use of amber beacons.
- Continued use of hazard warning lights.

If there is not firm evidence either way, how would the industry make the decision about what to do next?

- Further clarify the purpose of alternating rear red lights as to their presence and need in relation to a recognised life risk.
- Challenge the use by individuals in relation to risk management other than the use of alternating rear red lights.
- Adopt a legislative / regulatory standard as to when, who and how they should be used with a means of enforcement for the removal from vehicles or users where the continued incorrect use is demonstrated.

MREW doesn't believe that they should be used as the default go to option for on road activities, we believe that any user should be able to demonstrate that they are unable to adopt other risk management strategies before there use and only in relating to a life risk. In that people seeing rear reds know that someone's life is in immediate danger – Thinking along the lines of F1 flags.

In our view the public are saturated with blue light use and as such it doesn't always provide the safety net required, likewise with Amber lights (used on everything these days), Red lights however are used sparsely and as such people concentrate on them closer due to not knowing exactly what they are there for. Blue lights can also be overwhelming when on scene, a vehicle with 360 flashing blues can distract drivers passing the scene from both directions.

This is the reason MREW look to fitting rear reds and will ensure there use is limited to the above to ensure they do not become an everyday occurrence for people.

I.4.6 Mac Hobbs – Professional Recovery Operators Federation (PROF)

Sadly I have only just been made aware that the recorded meeting will not be transcribed and is therefore unlikely to be viewed or considered by the 'decision makers' in the way we believed it would. for the record I would urge those who are making those decisions to look and/or listen to the reasons the industry feels it not only deserves the protection afforded to others but in fact is is entitled to the same protection. It is clear there is an element of reluctance from some quarters to afford VRO's this protection for reasons only known to them. The procedures are already in place and the industry is again ahead of the curve and ready to regulate their use. I hope we are afforded the respect and protection our vital service deserves.

There was never any intention of transcribing the meeting for subsequent distribution or to distribute the recording. The event invitation advised that the recording would only be used for reference, if needed, by researchers and would subsequently be deleted. TRL had, however, informed attendees ahead of the meeting that there would be the opportunity to submit comments and that these would be compiled for the report. As a courtesy, after requests during the meeting (no objections were made), the chat log was distributed to attendees (not for distribution in part or whole outside of that group) after the call.

I.4.7 Derek Firminger – Chairman the European Rescue and Recovery Initiative (ERRI)

The recovery industry is unique in the way it operates, 24 hours a day, 365 days per year.

The whole industry is also required to work within the most challenging of conditions, namely; all weather conditions, rain, wind, storms. Every season no matter what, winter, frost, snow, fog, mist, blizzard. Summer extreme heat, etc.

The industry operates on all road types from rural landscapes, including A roads and B roads, to all motorway types, conventional, with hard shoulder, smart motorway, ALR or managed motorway.

For reason unknown the recovery industry is expected to operate with NO specialist safety precautions, such as lane closures, Impact Protection Vehicles, and most of the time no additional protection from any government agency, such as National Highways Traffic Officer or Police. On occasions a recovery operator can be working within a metre of traffic passing at the national speed limit without any additional or specialist protection other than standard PPE and an amber light.

There is No Other Industry expected to work in these conditions, in fact ALL other industries would refuse to work in these conditions without specialist protection.

Those other agencies, namely National Highways Traffic Officer, and the Police operate in similar conditions with the added protection of "RED Flashing Lights", these are used to increase their conspicuousness and to make them safer.

The recovery industry has been refused this additional protection for reasons previously described as dilution and to maintain the status quo, this rejection of a basic conspicuity enhancement must be classed as discrimination.

Quoted from the Oxford English Dictionary "Discrimination is the act of making unjustified distinctions between people based on the groups, classes, or other categories to which they belong or are perceived to belong. Discrimination especially occurs when individuals or groups are unfairly treated in a way which is worse than other people are treated, on the basis of their actual or perceived membership in certain groups or social categories. It involves restricting members of one group from opportunities or privileges that are available to members of another group".

This refusal of the basic human right under rules associated with the health and safety at work must go on record through the reporting mechanism of the TRL Expert Seminar 'Chat' Log that will form part of the appendices file attached to the full 2022 TRL report.

Safety is a requirement and not a privilege, and should not be treated as one, even when government agencies are concerned.

For clarity: TRL is not a government agency, TRL is an independent social enterprise research company that has been tasked with collecting evidence in a number of areas to inform the decision on red flashing lamps to be made by DfT.

I.4.8 Mary Edwards – Institute of Vehicle Recovery (IVR)

I realise the Newbury day was not purely about red lights but my disappointment at the red lights/flash patterns was that there was not a direct comparison between is this red light and flash pattern better than this amber light using the same flash pattern. They were mixed up and that meant those observing could not draw a direct comparison. I think that would have been a powerful way to compare which was most effective.

The IVR puts in place the training standards for the recovery industry and would put in place the standards for the use of red lights. It is already fully prepared within our training should the industry be awarded red lights.

The role of the recovery operator is roadside, all roads, all weathers, all visibility. In some ways they are in a more dangerous position, more often than those who already have red lights.

You have an industry that is predominately controlled via police contracts, highways contracts and which has an industry national training scheme (IVR). All of the infrastructure (RQM cards) is there to check at the roadside if a VRO has attended the correct training if red lights were to be awarded. Also, it could be added to the auditing process of a vehicle recovery operator via their training records to ensure those who drive a vehicle with red lights has the right training.

The industry is ready for it. So, what is the difference between others who already have it and the vehicle recovery operator? A life is a life, and we see this as another tool to the industry's toolbox We should continue to use every tool available to us to help keep our workers as safe as they can be roadside.

I.4.9 Nick Ovenden – Institute of Vehicle Recovery (IVR)

Red Lights for the recovery industry has long been spoken about; will it help or won't it, how would we police it, would it dilute the importance for others etc etc. I believe that they would help recovery operators to be safer at the roadside. I also believe that the motoring public would be safer, hitting a stationary lgv in a car is often fatal for the car occupants. The dilution that has been spoken about is mostly from the traffic officer service and police patrols. I recently saw a police driver during a pursuit training exercise flashing red lamps at high speeds. This is definitely dilution! The recovery industry has already put stringent rules in place in readiness for being granted the use. My belief is that the wider recovery industry will use them anyway, granted or not, as they believe that their safety is as important as the other services that are allowed extra safety measures. If that happens, we will lose control. It would be much better if it was regulated than if it was a free for all.

I.4.10 Richard Goddard – President, Professional Recovery Operators Federation (PROF)

Taking nothing away from TRL, because they are doing exactly what they've been commissioned to do.

Unfortunately, I firmly believe that on current evidence of the farcical trials, the steadfast lack of communication or interaction of the DFT, the unwillingness to share the data from the seminar, or engage in it, is a sad indication of that this review has been a for gone conclusion from the re-start!

This review has set out to find another reason not to grant red lights!

Dilution! Dilution! has never been discussed or evidence based, yet it was the reason given by the minister of transport for not allowing them!

National Highways were given as the reason dilution was a problem!

We know now that is simply not the case!

Retrials of conspicuity have been a distraction, irrelevant because other public services use them, and do not affect dilution!

I have to say that the DFT, are still playing games with the recovery industry.

[Redacted] and the other [redacted] chose to skulk in the back ground rather than engage with relevant questions! And they should be ashamed of themselves!

I have no confidence in them or this disgrace of a review!

Why have an evidence seminar then restrict the participants from the recordings or the transcripts?

Because it's a farce, we are being patronised by a government department responsible for Smart Motorways and a basic lack of responsibility for their own duty of care!!

Whatever evolves from all this so called evidence research, will be more legal mumbo jumbo Styled to waste more time public money and possibly more of our lives!

It's a disgrace!!

TRL strongly refutes any suggestion that the trials conducted in this research project have been any other than correctly planned, delivered, and analysed. When Mr Goddard was asked to provide evidence for statements of "…farcical trials" and "…this disgrace of a review" his reply via email to SH on 08/12/2022 provided nothing tangible on the quality of the research.

SH's **interpretation** is that by "…farcical trials" Mr Goddard may have been referring to the event at Newbury Showground (which he chose not to attend) at which mistakes in procedures led to the loss of 10 of 64 datapoints. These errors are outlined in this report, and as noted have had no material impact on findings. SH's **interpretation** is that by "…this disgrace of a review" Mr Goddard may be referring to the wider activities that the DfT has undertaken over the last decade, the outcomes of which he has been very open on disagreeing with.

TRL's role has been to deliver a number of high-quality, independent research projects focusing on specific research questions, to provide evidence to support the DfT in making any decisions. TRL refutes any suggestion that it is anything other than independent in this matter.

Regarding sharing (or restricting) data and recordings from the seminar:

- There was no intention of transcribing the meeting for subsequent distribution, or to distribute the recording. The event invitation advised that the recording would only be used for reference, if needed, by researchers and would subsequently be deleted.
- TRL had informed attendees ahead of the meeting that there would be the opportunity to submit comments and that these would be compiled for the report.
- As a courtesy, after requests during the meeting (no objections were made), the chat log was distributed to attendees (not for distribution in part or whole outside of that group) after the call.

Appendix J National Highways Traffic Officer Work Instructions

The table below is an extract from the work instruction 'Activity Tools'; 'Vehicle mounted warning lights and their use'. Reproduced with permission from National Highways.

Lights Illuminated	Permitted Usage on TOV
Rear Ambers and Rear Reds	• When carrying out an RRB • Stationary whilst dealing with an incident in a live lane • While setting out or removing ETM, including reversing, or if the TOV itself is used as part of live lane ETM • Stationary on a hard shoulder where hard shoulder abuse is a known issue • Moving to a place of relative safety, such as a hard shoulder. Once in the place of relative safety rear reds will **normally** be extinguished
Rear Ambers and Rear Reds plus Front Ambers	• When carrying out an RRB and approaching another resource that needs to be aware of the TOV approach and position • When signalling a vehicle to stop for a safety intervention • Operating within a section of carriageway where rearward relief is being managed
Rear Ambers	• Stationary in a place of relative safety • Stationary whilst directing traffic on foot at a junction or roundabout • Escorting abnormal loads (front ambers are also to be illuminated when approaching and passing junctions and interchanges) • Escorting other vehicles such as slow ambulances • Reversing on a hard shoulder
Rear and Front Ambers	• Driving within an incident sterile area • Driving within a road section where Reverse Access is operating • Clearing a vehicle from the carriageway to the nearest place of relative safety which is not the hard shoulder • Conducting CCTV maintenance checks (smart motorway – hard shoulder running sections only)
Rear and Front Ambers plus dipped or alternate flashing headlights	In order to conform with the current Special Order, alternate flashing headlights may only be used in the following circumstances: When driving on the carriageway through stationary or slow-moving traffic -on-route to an incident • Driving along the hard shoulder on-route to an incident • Driving past exempted signals on-route to an incident • On the immediate approach to a tailback of traffic resulting from an incident in a carriageway or other congestion impeding progress to an incident

Appendix K Guidance Document on Conspicuity and Warning Lamps

For reference, all content of the industry conspicuity guidance document is reproduced below. Document format and presentation may be adjusted for publication.

Conspicuity and Warning Lamps Guidance

1 Introduction

This guide is intended to be used by:

- Recovery industry Technicians, to improve their understanding of the benefits and limitations of conspicuity aids
- Recovery industry trainers, to ensure that new Technicians are aware of how their safety may be improved by the correct use of conspicuity aids
- Recovery industry managers, when specifying conspicuity aids for vehicles

Purpose

This guidance has been developed for the road recovery industry to help improve the safety of technicians, customers, and other road users. Working at the roadside, or in live lanes, is hazardous and improving conspicuity may help approaching drivers be more aware of the vehicle and the technician working near it.

Benefits

Following the guidance in this document, being aware of how conspicuity can improve safety, but also knowing the limitations and potential adverse effects of conspicuity equipment, may help technicians to improve their personal safety. Improving conspicuity, of the vehicle or technician, is not a replacement for following good working practices, but using both together can help reduce the chance of a collision.

Contents

This guide will explain:

- Conspicuity and visibility are terms that are commonly used but often confused
- How conspicuity aids may improve safety for Technicians, customers, and other drivers
- Potential adverse effects and how they may be reduced or allowed for
- How drivers need to react when approaching an incident
- What conspicuity equipment can be fitted to vehicles (and where to find further information)
- Things to consider before using warning beacons
- Risks of working around conspicuous vehicles
- Additional conspicuity equipment that can be fitted

Use of warning beacons in specific situations is covered in the SURVIVE Best Practice Guidelines.

Note: this guide is not intended for other operators, such as with abnormal loads, where additional guidance and different regulations may apply.

2 Definitions

This guide uses several terms, including:

Warning Beacon	A warning lamp that is visible from 360° around the vehicle
Chapter 8	Traffic Signs Manual Chapter 8, Part 2 Operations and Part 3 Update
Conspicuity	How well something stands out from its surroundings
ECE 104	UN Regulations No 104 - Uniform provisions concerning the approval of retro-reflective markings for vehicles of category M, N and O
Electroluminescent	Material, typically a panel, which emits light when electricity is connected
ETM	Emergency Traffic Management, signs and cones used to provide short-term protection for an incident and give directions to approaching traffic
Fluorescent	Material, typically paint or dye, which converts UV light into visible light, so appearing 'brighter'
Lamp	Equipment which emits light in certain directions only
PAS 43	PAS 43:2018 - Safe working of vehicle breakdown, recovery and removal operations. Management system specification
Position lamp	A lamp used to indicate the presence and width of a vehicle when viewed from the front or rear
PPE	Personal Protective Equipment. For this guidance, this is conspicuous clothing.
Retroreflective	Material which reflects light back towards its source.
Stop lamp	A lamp used to indicate to road users that the brakes of a vehicle or combination of vehicles are being applied
Side marker lamp	A lamp fitted to the side of a vehicle or its load and used to render the vehicle more visible to other road users
UNECE R65	UN Regulations No 65 - Uniform provisions concerning the approval of special warning lamps for power-driven vehicles and their trailers
Visibility	How easily you can see something when you know it is there
Work lamp	A lamp used to illuminate a working area or the scene of a breakdown in the vicinity of the vehicle to which the lamp is fitted

3 Improving safety – what is 'conspicuity'

Conspicuity and *visibility* are terms that are often confused. They each have a specific meaning, and there are several types of conspicuity. This section will explain the most important terms and how they can be used to improve safety for Technicians working at the roadside.

- *Visibility* is how easily you can see something when you know its location
- *Conspicuity* is how well something stands out from its surroundings

When working at the roadside, the two most important aspects of conspicuity are:

- *Attention conspicuity*, the extent to which something 'grabs' someone's attention when they are not looking for it
- *Cognitive conspicuity*, the extent to which an object is expected by the observer

Another important concept is how well understood something is by an observer, such as an approaching driver.

When a recovery vehicle is at the roadside attending a breakdown, it is unlikely that approaching drivers will expect to see it or that they will actively be looking for it. Conspicuity 'aids', such as warning lamps and fluorescent and retroreflective materials can make the vehicle stand out from its surroundings and 'grab' the driver's attention. Typically, conspicuity aids are used to make the recovery vehicle brighter than its surroundings.

Recovery vehicles are relatively rare on the road, so drivers will not usually be expecting to see them or encounter them obstructing a live lane. When a recovery vehicle is present, drivers may not understand what they are seeing or how they should react. Conspicuity equipment may help drivers to identify the vehicle and help them understand what they need to do.

Novelty

New markings or lighting schemes may sometimes seem successful through being 'novel', i.e. different to what a road user is used to seeing. However, there is a risk that novel schemes might be confusing and could increase the time taken for a driver to respond.

Brighter, or different colours?

Making an object brighter will potentially help approaching drivers see something, but it may not help them understand what they are seeing. Different colours might make a small difference to visibility if the light is difficult to see, but the main purpose and advantage is to help distinguish between types of vehicles or hazards, for example blue lights on emergency vehicles. However, this requires understanding of the meaning of the colour being used.

3.1 Limitations

Conspicuity equipment can only help approaching drivers if they have a clear line of sight to the recovery vehicle. If their view is obstructed, for example by the recovery taking place around a bend, or by other traffic, then drivers may not identify the recovery vehicle and be able to react to it.

The time of day may affect how easily a driver can identify the recovery vehicle. Low sun, at sunrise and sunset may affect drivers' vision. Very bright sunlight, or reflections, may prevent drivers from identifying the recovery vehicle.

If the recovery vehicle is in the driver's line of sight, but does not stand out from its surroundings, the driver may not be able to identify it. And, if they are not expecting the recovery vehicle, then their reaction to it may be delayed.

The term 'looked, but failed to see' has been used to describe collisions in which drivers claim not to have seen something that they have then collided with. However, this term does not adequately describe all of the ways in which drivers might not 'see', which include:

- Did not look at all
- Inadequate looking
- Looked, saw, but failed to identify or take correct avoiding action

The first of these is unlikely if a driver is approaching something on the road ahead, but if a driver isn't looking at all (for example if they are looking inside their vehicle) or if the driver's view is obstructed, then no conspicuity aid can improve the driver's awareness of the recovery vehicle.

When a driver has not looked adequately (perhaps looking for too short a time or failing to look in exactly the place where the recovery vehicle is located), increased *attention conspicuity* (or *cognitive conspicuity – through expectation*) may help the recovery vehicle to 'grab attention'.

Taking correct avoiding action might be influenced by conspicuity aids, but only if the driver is already aware of the actions that need to be taken, through an understanding of what they are seeing.

Another issue is that conspicuity aids, particularly the glare from warning lamps, can create difficulties for drivers, either by causing distraction (the driver looks towards the recovery vehicle rather than looking elsewhere) or disability (the driver is unable to see what is beyond the recovery vehicle).

The glare from warning lamps and retroreflective markings may also make it difficult for drivers to see pedestrians who are close to the recovery vehicle, even when they are wearing high visibility PPE.

4 How drivers react

When looking at a scene, what drivers "see" is partly influenced by what they expect to see. This means that approaching drivers are often not actively looking for vehicles, such as breakdown and recovery vehicles, stopped in live lanes. This is the "looked, but failed to see" error, where the driver looks directly at a vehicle but then subconsciously dismisses it as a hazard or threat because it does not fit with their expectations.

If approaching drivers are aware of the recovery vehicle (potentially because their attention has been 'grabbed' by the vehicle's warning lamps and conspicuity markings), and are to react appropriately, they must be able to:

- Identify and understand what the hazard is
- Understand what action they need to take and decide whether they have a reasonable time to do so
- Carry out the manoeuvre
- Ensure their vehicle is steady and stable, then pass the obstruction

This sequence is shown in Figure 2. To achieve this requires early recognition of whether the hazard is in a live lane (particularly if obstructing the lane in which the driver is travelling) or on the hard shoulder and emphasises that the importance of conspicuity is not just to attract attention but is also about enhancing understanding.

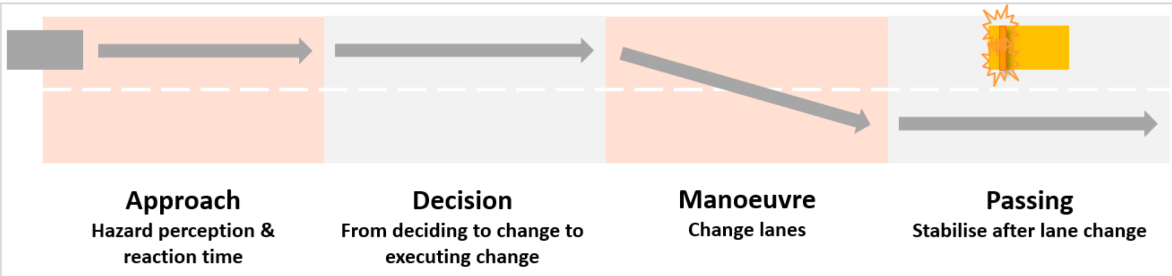

Figure 218: Approaching an obstruction

5 What equipment can be used (allowed by regulations and authorisations)

Current regulations permit a range of conspicuity equipment to be used on recovery vehicles.

5.1 Lighting

5.1.1 Warning beacon

- A recovery vehicle should be fitted with at least one amber coloured warning beacon.
- Warning beacons must be capable of emitting a flashing or rotating beam of light throughout 360° horizontally so they should be mounted to the rear of the cabin or gantry.
- Warning beacons must be mounted above 1.2 metres from the ground to ensure visibility to other road users – greater height will provide more visibility to other road users.
- The flash of a warning beacon must happen at least once a second but no more than 4 times a second. Each flash must be equal and have constant intervals between.
- Warning beacons should only be illuminated either at the scene of an emergency, to warn other road users of the presence of the vehicle or while a broken-down vehicle is being recovered.

5.1.2 Side marker lamps

- Recovery vehicles with a greater length than 6m must have side marker lamps fitted (2 each side or more depending on the vehicle size) but voluntary fitment is allowed for shorter vehicles.
- Side marker lamps must only be fitted to the side of the recovery vehicle; when illuminated, the lamp must only be visible from the side of the vehicle.
- Side marker lamps must show amber light (or red at the rearmost lamp).
- The distance between lamps must be no greater than 3 metres, one must be located within 4 metres of the front and 1 metre from the rear of the vehicle.
- Side marker lamps must be fitted no more than 2.3 metres from ground level.
- The light emitted from side marker lamps is permitted to be only steady light (not flashing).
- Side marker lamps are not allowed to move (by swivelling, deflecting or otherwise) relative to the vehicle while the vehicle is in motion.
- Side marker lamps must be turned on/off with the position lamps, rear registration lamp, etc.

5.1.3 Position lamps

- Recovery vehicles must be fitted with at least two position lamps, one on each side, at the front and the rear.
- These must be white at the front and red at the rear and they must emit a steady beam of light (not flashing).
- Any number of additional front or rear position lamps may be fitted to increase conspicuity to other road users.

5.1.4 Direction indicators

- Recovery vehicles must have at least one direction indicator on each side showing to the front, side and rear of the vehicle.
- No additional direction indicators are permitted to the front, but one additional pair of approved direction indicators is permitted to the rear (on each side). Any number of additional approved side direction indicators are permitted to be fitted to the vehicle.
- All direction indicators must be marked with the required approval markings.
- Direction indicators must be amber and signal to the driver while they're in operation via a tell-tale.
- A single switch will operate all the direction indicators as the hazard warning signal device. This is when all direction indicators with which a vehicle or combination of vehicles is equipped must flash in phase.

5.1.5 Work lamps

- A work lamp is a white lamp used to illuminate a broken-down vehicle or working area in the vicinity of the recovery vehicle.
- A work lamp is only permitted to be used for the purpose of illuminating a breakdown and therefore must not be illuminated while the recovery vehicle is in motion.
- It is illegal to cause undue dazzle or discomfort, etc., to other road users while work lamps are illuminated. This could have dangerous consequences, particularly if approaching drivers cannot see clearly to pass the recovery vehicle or are unable to see pedestrians around it.

5.2 Retro reflectors & Markings

5.2.1 Side retro reflectors

- Side retro reflectors are required for recovery vehicles that have a length that exceeds 6 metres.
- They must be located along the length of the side of the recovery vehicle (like the side marker lamps).
- Side retro reflectors must be amber (or red at the rear).

5.2.2 Rear markings

- Rear markings are permitted on all types of recovery vehicle.
- Rear markings must be fitted to recovery vehicles with a maximum gross weight greater than 7500 kg (7.5 tonnes):
    - Rear markings must consist of red and yellow stripes as prescribed by, and as shown in the diagrams in, the Road Vehicle Lighting Regulations 1989.
    - Any number rear markings can be fitted to a vehicle with a GVW > 7500 kg or unladen weight of 3000 kg.
- Optional rear markings are permitted to Recovery vehicles with a maximum gross weight that does not exceed 7500 kg.
    - Retroreflective yellow stripes are not permitted for vehicle with a maximum gross mass below this threshold.

5.2.3 UN Regulation No. 104 Conspicuity marking

- Retroreflective markings must be fitted to recovery vehicles with a maximum gross weight greater than 7500 kg (7.5 tonnes) and trailers over 3500 kg (3.5 tonnes).
- The markings must have a width of 50 mm and be positioned in a way to outline the dimensions of the vehicle at the rear and along the side.
- Red markings must be placed at the rear and amber markings on the side.

Additional conspicuity guidance for vehicles used on carriageways is given in:

- Traffic Signs Manual Chapter 8

6 Conspicuity equipment options

This section details how conspicuity equipment can be selected for vehicles. Two types of vehicles are shown, similar equipment may be selected for other types.

Three levels are illustrated:

- Standard vehicle equipment
- Basic conspicuity
- Enhanced conspicuity

6.1 Standard vehicle equipment

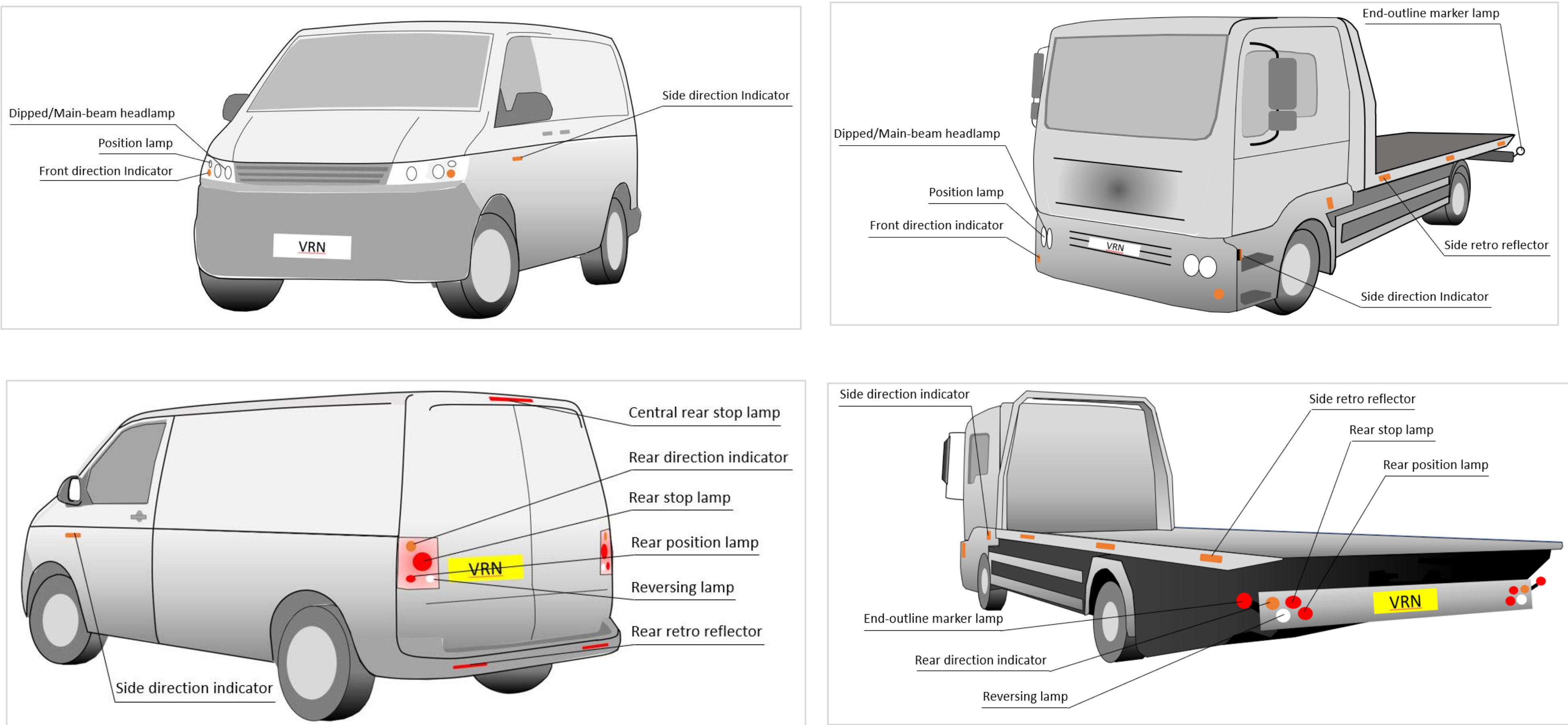

Figure 219: Standard vehicle fitment

Depending on its type, a new vehicle will typically be equipped with:

- Dipped and main beam headlamps
- Front and rear position lamps
- Front, rear and side indicator lamps
- Rear stop lamps
- Central rear stop lamp
- Rear retro reflectors
- Reversing lamp
- End outline marker lamps
- Side retro reflectors
- Side marker lamps

6.2 Basic conspicuity

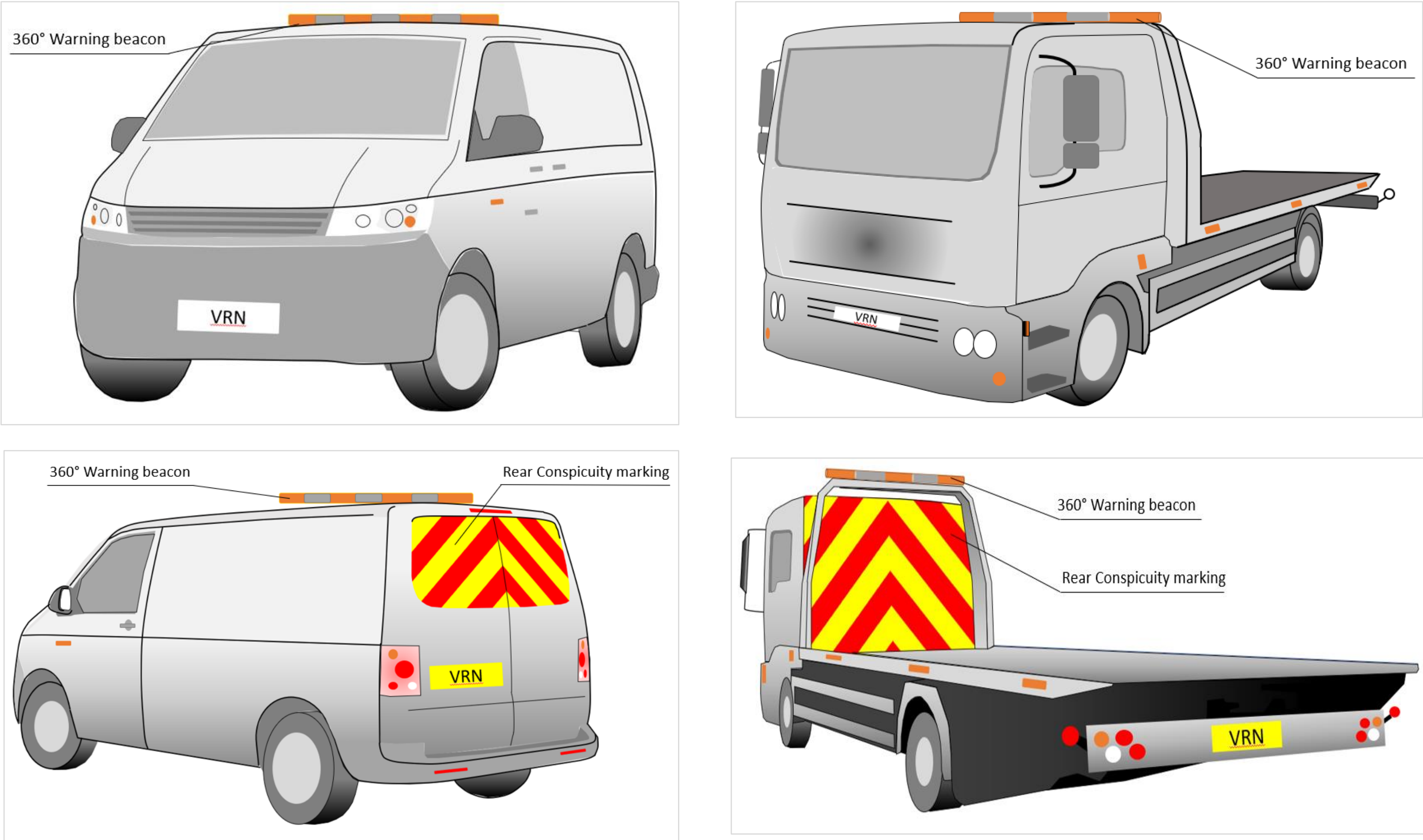

Figure 220: Basic conspicuity

Basic conspicuity equipment is described by:

- UK vehicle lighting regulations
    - Warning beacons
    - Light colours
    - Work lamps
- Chapter 8
    - Warning beacons
    - Vehicle colour
    - Retroreflective markings (side, lockers, doors, etc.)
    - Rear chevrons, or red panel markings
- PAS 43
    - Specifies a minimum of two high level amber coloured warning lights or beacons
    - Vehicle colour
    - Retroreflective markings
- UNECE R65
    - Beacon colour, beam pattern, etc.
- ECE 104
    - Retroreflective contour marking, required on new goods vehicles over 7.5 tonnes and new trailers over 3.5 tonnes.
        - Red to rear is preferred in the UK
        - Yellow to the side is preferred in the UK

6.3 Enhanced conspicuity

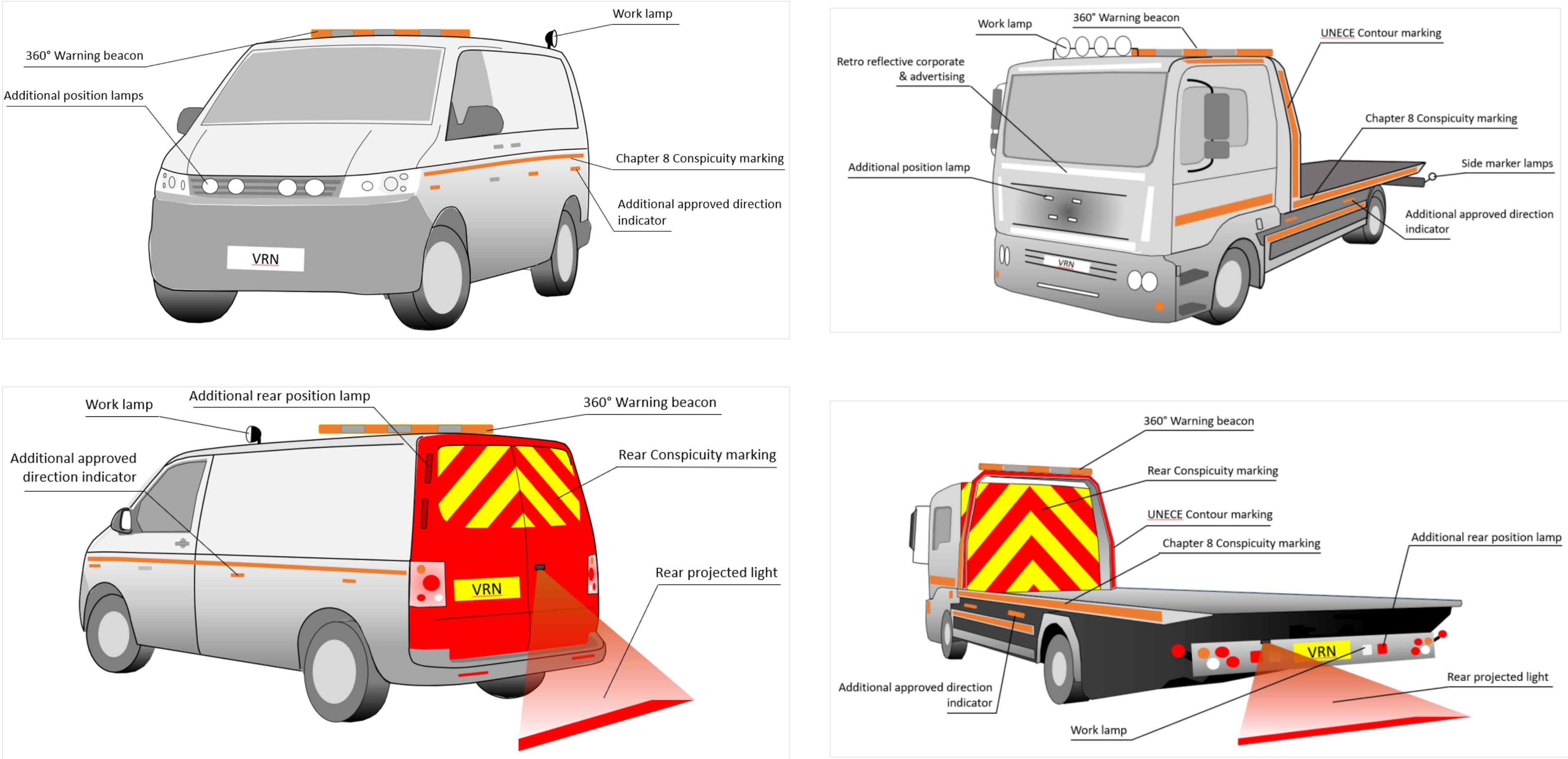

Figure 221: Enhanced conspicuity

Enhanced conspicuity may be achieved by installation of:

- UK lighting regulations
    - Side marker lamp
    - Side reflectors
    - Additional front and rear marker lamps
    - Additional side approved direction indicators
- ECE 104
    - Conspicuity markings may also be fitted to other vehicles but not passenger cars, goods vehicles with a gross vehicle weight of 3,500 kg or less or trailers with a gross vehicle weight of 3,500 kg or less.
    - Retroreflective corporate and advertising markings, colours permitted are:
        - White to the front
        - Yellow to the side preferred for UK
        - Red to the rear preferred for UK
    - Retroreflective contour marking – optional for some vehicles and trailers
- Retroreflective material
    - Additional retroreflective material can be added:
        - White to the front
        - Amber to the side
        - Red to the rear
- Projection systems
    - Light projected from the vehicle onto the ground around the vehicle
    - Appropriate colours for location on vehicle
    - It is illegal to cause undue dazzle or discomfort to other road users.
- Electroluminescent panels
    - Can be considered as optional positions lamps
    - Appropriate colours for location on vehicle
    - It is illegal to cause undue dazzle or discomfort to other road users

7 Using warning beacons

Key points when considering whether to use warning beacons are:

- **Use your warning beacons when they could provide effective warning**
- **Misuse (or over-use) of warning beacons will diminishes their effectiveness**
- **Do not illuminate them if there's no hazard to you or other road users**

Detailed guidance on the use of warning beacons in specific situations is covered in the SURVIVE Best Practice Guidelines. There are several aspects to consider:

- Approaching an incident scene:
    - Could slowing or manoeuvring your vehicle affect other traffic?
- When stopped:
    - Does your vehicle or your actions present a hazard to other road users?
    - Is approaching and passing traffic a direct risk to you?
    - Could your warning beacons confuse or mislead other road users?
- When stopped:
    - How long will you be at the incident?
        - Consider placing signs and cones for longer attendance
- When leaving the scene:
    - Could manoeuvring your vehicle affect other traffic?
- When travelling in traffic:
    - Can you maintain a speed appropriate for the road?
        - If yes, warning beacons may not provide any benefit to other road users
    - Are your warning beacons visible to traffic approaching from behind?
        - If not, your warning beacons cannot provide them any benefit
    - If visible to the front, will your warning beacons provide any benefit to other road users?
        - If you are on a motorway, it is unlikely that they could

8 Working around your vehicle

Figure 222: Examples of how pedestrians can be difficult to identify

If you are working near your vehicle, be aware that your own conspicuous PPE may be 'overwhelmed' by your vehicle's lighting and its fluorescent and retroreflective markings. There are two main ways that drivers may find it difficult to see you:

- Your vehicle's markings and warning lamps may be 'brighter' than your PPE
- If they are a similar colour, your PPE may 'blend' with your vehicle, a form of camouflage

Also, drivers may not be expecting to see pedestrians around parked vehicles. Combining camouflage effects with lack of driver expectation may delay drivers in identifying you and slow their reactions to you.

Wearing conspicuous clothing (fluorescent in daylight, retroreflective in darkness) can help approaching drivers identify you. However, be aware that if you are stepping out from around your vehicle, they may be unable to identify you until they are very close. Retroreflective and fluorescent markings on your lower legs show well when the wearer is walking, this will help identify you as a person. In darkness, these markings can work particularly well when an approaching vehicle is using only dipped beam headlamps.

Figure 223: Conspicuous markings on lower legs can be beneficial

9 Additional conspicuity equipment

This section outlines some conspicuity technologies which could supplement the equipment typically fitted to breakdown and recovery vehicles. The equipment outlined here is compliant with current regulations. Other technologies and future possibilities not yet fully developed or applied to vehicle conspicuity are detailed in the project report, although these would require amendments to existing regulations for them to be compliant.

9.1 Projected light

Light projection systems can create illuminated warning for other road users by projecting light from the recovery vehicle onto the ground around the vehicle, potentially identifying safety zones. Also, they could improve road user awareness of the presence of recovery vehicles and their operators.

If the technology is in appropriate colours, then light projection systems will comply with regulations. It is illegal to cause undue dazzle or discomfort to other road users.

9.2 Lightbars

Lightbars are a versatile conspicuity technology as they can be configured to display a range of different colours and flashing patterns.

With its ability to be freely customised, the lightbar could be set up to function as a range of lighting and colours. Depending on the configuration of the equipment:

- If the signal is front-facing then it may be either amber (when flashing as part of a warning beacon) or white in colour (non-flashing, as work area lighting)
- If side-facing, this is limited to amber (non-flashing)
- If the lamp is rear-facing then it may only be red (non-flashing) in colour.

10 Acknowledgements

This guidance was written following consultation with the road recovery industry. Draft versions were sent for review and responses were received from:

- The Institute of Vehicle Recovery (The IVR Group)
- Association of Vehicle Recovery Operators (AVRO)
- National Highways

The authors are grateful for their support

11 Resources

- The lighting that may be fitted must be within that permitted by UK Road Vehicle Lighting Regulations 1989:
    - https://www.legislation.gov.uk/uksi/1989/1796/made
- The Traffic Signs Manual Chapter 8 provides additional conspicuity guidance for vehicles to be used on high-speed roads, including installation of signs and cones for Emergency Traffic Management (ETM) and use of vehicle-mounted signs, Part 2 Operations and Part 3 Update, can be downloaded from:
    - https://www.gov.uk/government/publications/traffic-signs-manual
- Details of warning beacons are given in UNECE Regulation No. 65: Uniform provisions concerning the approval of special warning lamps for power-driven vehicles and their trailers. A copy can be downloaded here:
    - https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2011/r065r2e.pdf
- Information on installation of retroreflective material (such as contour marking and corporate branding) is provided in UNECE Regulation No. 104: Uniform provisions concerning the approval of retro-reflective markings. Details here:
    - https://www.gov.uk/government/publications/conspicuity-marking-requirements-on-goods-vehicles
- Detailed information on appropriate use of warning beacons in typical breakdown and recovery scenarios is given in the SURVIVE Best Practice Guidelines v4/18. The guidelines can be downloaded from here:
    - http://www.survivegroup.org/download_files/SURVIVE%20Best%20Practice%20Guidelines%20v418.pdf
- A guide addressing some basic questions to help recovery vehicle operators and drivers is available on the Gov.uk website: Guidance: Running a vehicle recovery business: driver and vehicle safety rules.
    - https://www.gov.uk/government/publications/guide-for-recovery-operations/running-a-vehicle-recovery-business-driver-and-vehicle-safety-rules
- PAS 43 is the specification for the safe working of vehicle breakdown and recovery operations. It is available from the British Standards Institution (BSI):
    - https://knowledge.bsigroup.com/products/safe-working-of-vehicle-breakdown-recovery-and-removal-operations-management-system-specification-3/tracked-changes

The Use of Red Flashing Lamps by Road Recovery Operators

The road recovery industry has proposed that regulations are changed to allow fitting and use of rear-facing red flashing lamps, to improve conspicuity and safety of recovery operators attending incidents. This project undertook activities to assist the DfT in deciding a way forward on this issue.

Studies were run on a track, and in a driving simulator, to test driver response to red flashing lamps, red plus amber flashing lamps, and amber lamps. No evidence was found to support the idea that red, or red plus amber, flashing lamps, would change driver response relative to amber. Surveys did suggest that people had a slight increase in perceiving red and red plus amber flashing lamps as meaning 'danger' or 'prepare to stop', compared with amber. Any decision to change regulations to allow the use of red flashing lamps by road recovery industry vehicles should be supported by extensive engagement with the industry to ensure that recovery operators are not led to expect direct safety benefits from this change alone.

Recommendations were also made for other actions the recovery industry can undertake in attempting to improve safety, and notes that any change in regulations should be accompanied by public education around the meaning of different warning signals.

A conspicuity guidance document was produced to provide information that can be used by industry trainers and can inform technicians on their personal conspicuity.

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