Motor vehicle and pedal cycle conspicuity: part 3 - retroreflective and fluorescent materials, final report.

Final Report: 9/33/13

Motor Vehicle and Pedal Cycle Conspicuity

Part 3: Retro-reflective and fluorescent materials

Undertaken on behalf of

The Department of the Environment, Transport and the Regions

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Summary

This is the final report for the project investigating the conspicuity benefits to be obtained from the application of retro-reflective and fluorescent materials to heavy and long vehicles and their trailers.

A series of controlled scientific studies were undertaken to determine:-

- the conspicuity benefits and disbenefits of the retro-reflective markings formats proposed in Draft Regulation XA and now outlined in ECE Regulation 104[1];
- the need for, and implications of, applying such markings in red to the rear of vehicles;
- the contribution to be made by fluorescent materials.

The findings of these studies were considered in conjunction with:-

- the Human Factors principles of conspicuity;
- a review of previous vehicle conspicuity research;
- an assessment of current on-the-road practice concerning improved vehicle conspicuity;
- a literature review of truck accidents;
- an appraisal of suitable conspicuity enhancing materials.

The recommendations which resulted from a full consideration of all the above factors are as follows:-

ECE Regulation 104 marking formats

- The ECE Regulation 104 formats are likely to improve conspicuity and so should be accepted.
- The effects of the disbenefits of discomfort glare and colour recognition are likely to be minimal.

[1] At initiation of this project, the ECE 104 formats were formerly proposed in Draft Regulation XA. Note: there are no technical differences between ECE 104 and Draft Regulation XA.

The use of red markings to the rear

- ECE Regulation 104 (formerly Draft Regulation XA) suggests the use of yellow or white markings to the rear of the vehicle without any use of red. This will mark a significant departure from current practice in which red is always associated with the rear of the vehicle.
- On the basis of the current research we would strongly recommend the retention of red to the rear of the vehicle in terms of colour markings, as this offers an important safety benefit in enabling other road users to judge the orientation of the truck: 90% of drivers associated red with the rear of a vehicle compared to the small minority who associated yellow and white to the rear (less than 10% and 2% respectively).
- Whilst yellow and white are more visible than red in their respective ECE104 formats, when viewed at 135m (well in excess of the 70mph stopping distance of 96m), all drivers were able to immediately see the red full contour format, but not the red dashed line markings. There was found to be no difference in the reaction times of drivers to the red markings compared to the yellow or white markings. This was also the case when comparing the number of correct detections. Thus any visibility or conspicuity differences between yellow/white and red are of no practical significance.
- The research also shows that the potential of any red markings to obscure the red vehicle rear lights is avoided if a minimum separation of 200mm between the stop lamps and the markings is maintained.

Recommendations

- It is therefore strongly recommended that red should be retained to the rear of vehicles. The red markings should be applied in the contour formats specified by ECE104 (either full or partial), with a separation distance of 200mm from the stop lamp. This will ensure red rear markings provide adequate safety for vehicles.
- Additionally, to preserve daytime conspicuity, the ECE Regulation 104 marking formats should be applied in conjunction with the ECE70 marking formats which includes the fluorescent red.

The contribution of fluorescent materials

- Combined performance fluorescent-retro-reflective materials should be permitted under ECE104 since they are likely to be of benefit to daytime conspicuity and some night-time aspects, whilst imposing no significant disbenefits.

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1.0 Project objectives

As traffic volume increases, improved measures to assist the government in achieving its target for road safety need to be introduced. One means is to present road users with clearer information regarding their driving environment. This would be especially beneficial with respect to assisting drivers in the early detection and identification of other types of road users e.g. pedal cyclists, recovery vehicles and trucks, in order that they can adjust their own driving behaviour as appropriate.

With regard to large vehicle conspicuity, the objectives of the study are to:-

- determine how best to use retro-reflective and fluorescent materials to improve the conspicuity of large vehicles;
- evaluate current international proposals which aim to improve vehicle conspicuity;
- determine whether existing legislation is adequate and propose improvements where necessary.

This document is the Final Report relating to this study and details the wide range of considerations given to answer the above objectives.

Contextual background information is discussed first and includes:-

- a description of the human factors principles relevant to improved conspicuity;
- the need for improved large vehicle conspicuity as evidenced by accident data;
- the role of retro-reflective materials.

The scientific test work undertaken is then described and the findings discussed. Full details of each specific aspect of the work are given in the relevant sub-reports contained in the appendices. These findings, along with results of the cost-benefit analysis, are then used as the basis for the recommendations upon which changes to the Regulations are based.

It should be noted that conspicuity is the ability of an object to draw attention to itself even if a person is not actively looking for it. Since it is difficult to ask a participant to report seeing an item of interest without prompting them to look for it, measures of conspicuity in this study have been approximated by other means such as visibility, image and reaction time.

2.0 Human factors relating to vehicle conspicuity

The central issue to this study is vehicle conspicuity. This refers to the ability of a vehicle to draw attention to its presence, even when other road users are not actively looking for it. Improving vehicle conspicuity is essentially an ergonomics issue, since an understanding of the factors which road users find attention-getting is central to the development of successful conspicuity treatments. The main human factors aspects of relevance to vehicle conspicuity are described in this section which provides a valuable context for the rest of the report.

2.1 Contrast

Conspicuity can be improved by increasing the luminance and colour contrast of the vehicle against its background.

2.1.1 Luminance contrast

This refers to the difference in brightness between the vehicle and its background and is a major cue for detection (Cole, 1972). In general the older one gets, the more luminance is required to differentiate an object from the background it is viewed against (Sekuler, 1982). Considering the greater number of older drivers, and their projected future increase, making large vehicles brighter would be a suitable means of increasing their conspicuity. Increased luminance contrast can be achieved through the use of special materials, including those which have fluorescent and retro-reflective properties, as well as through the use of lighting. Successive changes in luminance contrast, such as flashing lights, are particularly good at getting attention if they are in the peripheral field of view since this region is especially sensitive to changes in state.

2.1.2 Colour contrast

This is best achieved through the use of colours which are not commonly found in the environment in which the vehicle will be viewed. (A grey vehicle will not be very conspicuous against a tarmac road environment!) It is also important to use colours to which the human eye is most sensitive. The Spectral Luminosity Curve, which represents the sensitivity of the human eye to light of different wavelengths (see Fig.1), shows that photopic (day) vision is most sensitive to wavelengths of 550nm, corresponding to yellow-green hues, whilst scotopic (night) vision is most sensitive to wavelengths of 510nm corresponding to green hues in terms of human efficiency. Therefore, yellow-green hues would offer the greatest benefit to improved vehicle conspicuity. This principle is well understood, hence high visibility clothing is this colour.

2.2 Size and form

The size and form of the conspicuity treatments are also important to the benefits which can be obtained. Generally the greater the area of the treatment, the greater the conspicuity and the greater the distances over which the vehicle can be seen. In addition the larger an object appears to the observer, the smaller the change in apparent size necessary to detect motion (Steedman and Barker, 1961). This is particularly important in the motorway environment where, due to high vehicle speeds, other road users need as much forewarning as possible in order to modify their driving behaviour.

In terms of conspicuous materials, research into daytime conspicuity has shown that:-

- there are benefits to employing blocks of colour close to a square form rather than a narrow stripe (Siegel and Federman, 1965);
- 'stimuli of a given area tended to be more effective the less rectangular and the more square-like they were in shape' (Siegel and Federman, 1965);
- striped markings can be analogous to camouflage in that they break up the vehicle form.

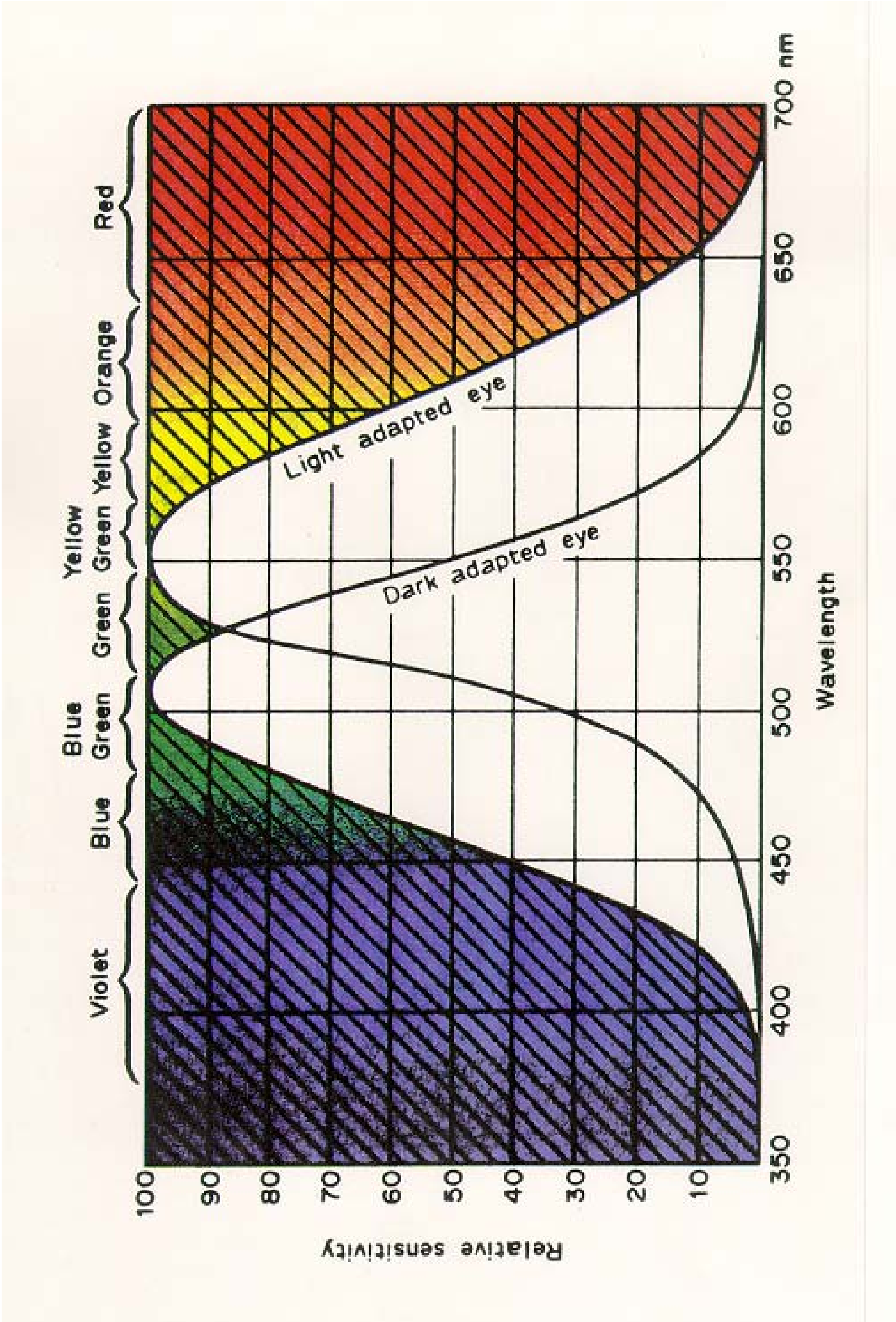


Fig 1: The Spectral Luminosity Curve

2.3 Shape/Pattern Recognition

The information transmitted by the eye to the brain is processed in order to make sense of what is being viewed. The stronger and more familiar the visual cues associated with an object, the quicker and more reliably the information about it will be processed. Burg and Beers (1976) established that for the night-time conspicuity of motorcyclists the unique shape of the stimulus is of considerable importance in attracting attention and establishing recognition. Henderson, R.L. et al (1983) has reviewed the area of vehicle conspicuity and in his discussion of work by Ziedman et al (1981) on 'truck reflectorisation' he notes that the best of all options, based on time to detect the vehicle presence, was when the vehicle body was outlined with reflective material (side and rear profiles were treated and separately tested). Henderson et al (1983) notes that 'Although comparable data for passenger cars do not exist, it is reasonable to expect that they would show similar relationships.'

2.4 Glare

It was mentioned in the previous section that night-time conspicuity can be increased through the use of retro-reflective materials. Retro-reflective materials have a special property by which virtually all the incident light falling on them, for instance from a vehicle’s headlights, is reflected directly back to the light source. For the car driver, whose eye height is relatively close to the headlights (the vertical separation is about 60cm), the reflected light is perceived to be quite bright. It is the superior luminance of these materials compared to, say the reflective performance of the paintwork of the vehicle which makes them such an asset at night. There are different types of retro-reflective materials which reflect light at different intensities and similarly there are colours which reflect with different efficiencies. It might be supposed that improving conspicuity is merely a case of applying the maximum performing material in the maximum performance colour thereby achieving the greatest possible luminance contrast between the vehicle and its background. However, the idea that more is better may not necessarily hold since the reflected light could become so intense that it is perceived as too bright by other road users. If this is the case, then the material may be said to be causing glare. There are two forms of glare - disability glare and discomfort glare.

2.4.1 Disability glare

This is the phenomenon by which bright light source(s) in the visual field reduce an individual's ability to see objects. It is caused by light entering the eye being scattered as it passes through the lens and the vitreous humor. In the driving environment additional scatter may result from the windscreen, especially in the rain, and from spectacles. This scattered light superimposes itself onto the object under view as a veiling luminance and reduces its contrast such that it appears 'washed out'. The extent of the effect on vision is dependent upon the intensity of the glare source and the angle of the source from the line of sight - in general the smaller the angle, the greater the effect of the glare on visibility. For further information refer to Appendix 1.

2.4.2 Discomfort glare

If glare is annoying or painful, but does not cause disability in the visual field, it is referred to as discomfort glare. In the road environment discomfort glare may arise from the reflection of the headlights of following vehicles in the rear view mirrors or from the rear fog lights of vehicles ahead. Discomfort glare could potentially have safety implications since it may cause drivers to avert their gaze thereby reducing their attention to that area of the driving scene. However no data has been found to confirm or refute this assertion. For further information refer to Appendix 1.

2.5 The Driving Population

2.5.1 Population trends

Demographic forecasts predict that between 1991 and 2011 there will be a 7% increase in people over the age of 65, rising to 38% by 2031. These changes will be reflected in the UK driving population resulting in a 89% increase in male drivers and a 212% increase in female drivers, aged over 65, between 1985/6 and 2005/6. The increase in the number of older drivers on the road is of particular relevance to this work since, as a group in general, they are likely to have a poorer visual performance brought about by age related factors.

2.5.2 The effects of ageing

Some of the difficulties faced by older drivers are briefly described below and conspicuity schemes should aim to assist the older driver in overcoming these effects rather than adding to them.

Older drivers suffer from:-

- reduced contrast sensitivity making them less able to detect dim lights;
- increased time to adapt to different lighting conditions;
- increased time to re-focus on objects at different distances;
- increased light scatter within the eye making them more susceptible to glare. Broadly there is approximately 50% deterioration in resistance to glare for every increase of 12 years in age;
- increased recovery time from glare. This has been measured at 3.9 seconds for 20-24 year olds and 6.8 seconds for 75-79 year olds (Burg, 1967 in Southall & Ward, 1994);
- reduced dynamic vision i.e. being able to see and interpret moving images;
- reduced perception of angular movement which assists drivers in determining the relative speed between their vehicle and the one in front. In certain conditions this can result in an increase of half a second in the decision times of 70 year olds compared to 20 year olds;
- increased reaction times which are approximately 20-30% slower for older drivers.

2.6 Conclusions

From the discussion above, it is possible to conclude that the following factors are important to improving vehicle conspicuity.

Contrast:

Luminance

- Daytime - improve conspicuity by using fluorescent materials,
- Night-time - improve conspicuity by using retro-reflective materials.

Colour

- Improve conspicuity by using those colours not commonly applied to vehicles,
- The human eye is most sensitive to yellow-green hues.

Size/Form:

- Improve conspicuity by covering as large an area as possible.
- Improve conspicuity by employing square-like forms rather than stripes.

Shape/Pattern:

- Improve conspicuity by defining the vehicle outline at night.

However, in order to develop a suitable conspicuity marking scheme for vehicles, the above factors need to be applied with full consideration given to other Human Factors requirements.

The scheme should aim to provide as much contextual information as possible in order to assist drivers in making timely and accurate decisions. For instance as well as being conspicuous, the marking scheme should strive to assist drivers in determining vehicle orientation, separation distance, closing speed, etc. The scheme should also be as effective as possible for all drivers including those in the older age groups and it should not give rise to disbenefits such as disability or discomfort glare.

3.0 Definition of the vehicle conspicuity problem

3.1 Accident scenarios

It has been estimated by the Transport Research Laboratory (TRL) that each year in Great Britain 30-34 car occupants are killed in collisions with the rear of HGVs and 40-44 are killed in collisions with the side of HGVs (Robinson, 1994).

Data collected by the National Highways and Transport Safety Administration (NHTSA) revealed that in 1993, large trucks were three times as likely to be struck in the rear as other vehicles in two-vehicle fatal accidents. Further evidence of the over involvement of HGVs in fatal accidents is suggested by the statistics that whilst large trucks account for 3% of registered vehicles, they account for 8% of vehicles involved in fatal crashes (NHTSA, 1993).

Similar patterns have been found in Europe. Danner et al (1989) noted that trucks constitute 4% of registered vehicles in Federal Republic of Germany but are involved in 6.5% of all injury accidents and 12.6% of all fatal accidents. Earlier work by Langwieder and Danner (1987) reviewed 1,200 truck accidents in Germany. Analysis showed that, aside from head-on collisions, accident reduction measures are most desirable to prevent the front of cars striking the side of trucks since this configuration results in the highest proportion of injuries and also to prevent the front of cars from striking the rear of trucks since this results in a greater proportion of severe and fatal accidents.

3.2 Accident causation

3.2.1 Conspicuity issues

In the early 1980s the Motor Industry Research Association (MIRA) undertook a two year study of commercial vehicle accidents. Of the 200 accidents recorded and analysed, 26 were considered to be conspicuity related; defined as those accidents which ‘might have been lessened in severity or eliminated altogether had another road user seen the commercial vehicle earlier’. Of these 26 accidents, half (equivalent to 6.5% of the total sample) occurred in conditions of poor visibility (twilight or night) where improvements to truck conspicuity would have helped and, of these, eight resulted from trucks manoeuvring across the road e.g. undertaking U-turns or reversing into or out of drives (Zlotnicki & Kendall, 1982).

In 1988 an OECD inquiry arrived at similar conclusions; that failure to recognise the presence of a vehicle is a contributory factor in a considerable proportion of collisions involving heavy vehicles. This was further borne out by Sweatman et al (1990), who concluded from their study of heavy vehicle crashes in Australia, that conspicuity issues may have featured in up to 5% of accidents and this reflects the earlier work of Minahan & O'Day (1977) who noted that many car-truck collisions result from the car driver failing to see the truck in time.

3.2.2 Perceptual issues

The remaining half of the 26 conspicuity accidents reported above by the MIRA study were instances where the driver should have seen the truck but for some reason did not appear to do so. (In two of these thirteen instances the truck was parked with its hazard warning lights on, and in another a van ran into the rear of a mobile crane painted bright yellow with black markings travelling on a motorway at 25-30mph). MIRA suggest that some of these accidents may have been caused by the lack of perception of the speed of the lead vehicle by the driver of the following vehicle and they remark on the work of Noble (1969) who considered that those vehicles travelling slower than the general traffic flow should in some way have attention drawn to them to advise other drivers of this fact.

Langwieder and Danner (1987), in their study of 1,200 truck accidents, noted that rear-end truck to truck accidents appear to be caused by the driver not appreciating the speed of the vehicle ahead. This supports the earlier work of Solomen, as reported by Mortimer (1969), which indicated that drivers are poor at judging relative velocities and that where the disparity in speed between vehicles travelling in the same direction exceeded 20mph there is a sharp rise in the probability of rear end collisions. Later work by Mortimer (1977) further validates this opinion since he concludes that in 80% of rear end collisions, the struck vehicle was travelling at 20mph or less. Obviously the slower the speed of the lead vehicle, the greater the disparity in speed with the following vehicle and, according to Solomen, the greater the opportunity for collision.

3.2.3 Summary

In summary, it can be concluded from the above work that in the order of 5-10% of accidents involving heavy vehicles have conspicuity related causes. These accidents result from the truck not being seen at all, the truck not being recognised for what it is or the relative speed between the truck and following vehicle being incorrectly interpreted. If the lead vehicle is a slow moving vehicle then such a disparity will be exaggerated.

However, the misperception of speed may be a simplified means of accounting for such misjudgements. Ittleson (1951*)* noted that whilst the change in size of an object gives some clues as to its motion, accurate judgement of distance is dependent upon a correct understanding of the subject based upon relevant experience. That is to say, it is not sufficient to know that the vehicle ahead is moving but that drivers need to identify what type of vehicle it is and thereby obtain more clues as to how it is likely to be moving. Refer to Fig.2.

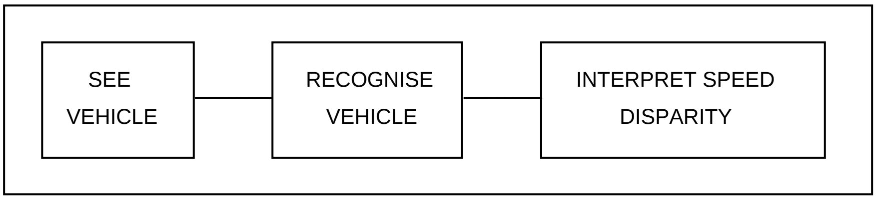


Fig.2: Drivers visual processing

Generally speaking, in terms of the failure of the driver's visual processing, collisions with the rear of large vehicles can be a result of a failing in any one of the 'see', 'recognise' and 'interpret' stages. Collisions with the sides of such vehicles, especially where they have arisen from the large vehicle being effectively stationary across the path of the following vehicle, most probably arise from a failure of the first two stages.

3.3 Solutions

Just as previous research can help to define the problem, so can it provide indicators as to the solutions.

3.3.1 Conspicuity

In terms of alerting other road users to the presence of such vehicles, various treatments have been suggested:-

- the fitment of daytime running lamps, especially to improve the frontal conspicuity (Sweatman, 1991, OECD 1988);
- the use of brilliant colour schemes (Sweatman, 1991) and high-contrast colour patterns (OECD, 1988);
- the use of reflectorisation (OECD, 1988), better reflective markings on trailer sides (MIRA, 1982*)* and reflectorised markings and graphics to the side and rear (Sweatman, 1991);
- more illumination designed to be seen in a direction perpendicular to trailer sides (MIRA, 1982) and to improve the side lighting of lorry trailers to clearly indicate length and position (Noble, 1969).

Klingenberg (1989) describes the application of such treatments to the concept vehicle FACT (The Freightliner/Heil Advanced Concept Truck). To improve its daytime conspicuity the FACT tractor unit and the lower centre section of the trailer were painted bright yellow and to address night-time conspicuity it incorporated reflectorised graphics along the side of the cab and the sides and rear of the trailer.

3.3.2 Perception

Treatments to address the remaining two stages i.e. to assist drivers in identifying what they see and to help them to understand the consequences of what they are seeing, have been less widely investigated.

- For public utility vehicles travelling at speeds slower than the general traffic Noble (1969) suggests the use of rear lights which are independent of the rear tail lamp and signalling lights. He notes that such vehicles travelling on the throughways of New York are legally obliged to use their hazard warning lights.

- In their study Langwieder and Danner (1987) showed that improving the form of rear marking signals to indicate the unusually slow speed of the truck could help to achieve better estimation of distance or arouse a higher level of attention particularly in poor lighting conditions.
- Prolux (1959) found that the perception of change in relative motion required less time and was considered to be easier with a reflectorised rear than with four taillights. Mean perception times were reduced by more than 1 second for reflectorised rears, equating to 73ft at 50mph. The reason given for this improved performance is that the subjects could triangulate more effectively with the reflectorised rear and hence determine changes in distance.

3.4 Conclusions

This section has discussed some of the main accident configurations involving trucks and other large vehicles which predominantly involve other vehicles striking their sides or rears. Some of these accidents can be accounted for by failures in the driver’s visual processing system such as failure to see the vehicle, failure to recognise it and failure to understand the implications of it, primarily to adjust to its speed in sufficient time.

Various methods have been suggested as a means for improving the driver’s visual processing and these can be summarised as: improved illumination, the use of bright colours and high contrast patterns and the use of reflective markings. These treatments are realisations of the human factors principles discussed in section 2.1. Conspicuity can be enhanced by improving luminance contrast through the use of lighting, reflective materials and fluorescent materials and by improving colour contrast through the use of yellow-green with blue (high contrast patterns).

The aim of this and the previous sections has been to identify where vehicle conspicuity enhancements are needed and conceptually what form these would be most appropriate to take. The aim of the next section is to discuss in more detail the relative merits of the various technologies which can be employed to this end.

4.0 Retro-reflective materials as a solution

ECE Regulation 104 proposes the use of additional retro-reflective markings to improve the conspicuity of heavy and large vehicles and their trailers. The appropriateness of this technology to improve vehicle conspicuity is discussed below.

4.1 Review of materials

Retro-reflective materials are those which reflect all light falling on them directly back in the direction from which it came. An example of the application of retro-reflective materials is roadsigns. These appear bright to oncoming drivers because the light from the drivers headlamps which illuminates the sign is reflected directly back to driver. The performance of retro-reflective materials is therefore dependent upon them being illuminated by another source and also by the angles at which they are viewed. Other factors such as the material technology i.e. whether it is glass bead or prismatic, and colour also influence the material's performance.

The properties of other materials were also investigated in the course of this study.

Fluorescent materials provide the benefit that they can appear extremely bright and so provide high luminance contrast with their background making them relatively more conspicuous. However because fluorescent materials rely on the phosphors within the materials being stimulated by ultra-violet light they offer no conspicuity benefits at night.

Photo-luminescent materials are materials which become charged from a light source, daylight or artificial, and release the stored energy over time in the form of emitted light. Unlike retro-reflective materials, photo-luminescent materials, once charged, do not need a light source in order to be seen and their performance is not dependent upon viewing angle. However the luminance of photo-luminescent materials is much lower than retro-reflective materials and this declines over time. If a photo-luminescent material is not charged within three to five hours its luminous performance will be negligible.

Combined performance materials are those which combine two of the material attributes described above. The combined performance material most relevant to this work is the fluorescent-retro-reflective material which appears fluorescent by day and is retro-reflective by night. Thus, one material is able to appear bright (increase its luminance contrast with its background) both day and night.

For a more detailed review of materials, refer to Appendix 2.

4.2 Review of research

An extensive literature search of both in-house and external databases was undertaken covering vehicle conspicuity research, accident surveys, experimental methodologies and human factors.

Three major research studies were identified which were of direct relevance to this work.

Darmstadt Institute of Technology (European research)

Accident data suggested that night-time accidents involving trucks tended to result in higher levels of injuries and that improving truck conspicuity may be of benefit to those accidents scenarios where the truck is impacted in the side or rear. Laboratory trials suggested that retro-reflective markings to improve truck conspicuity should take the form of a horizontal line marking to the side and a contour marking to the rear. Field trials verified the benefits of such markings particularly if applied in yellow or white.

Vector Enterprise Inc (USA research)

Accident data suggested that large trucks were over-represented in fatal accidents. This issue was addressed by applying a horizontal line marking to the side and a contour markings to the rear in alternating red and white. Field trials verified the benefits of such markings.

University of Michigan (USA research)

This was a follow-up to the Vector study which aimed to define the range of minimally acceptable truck conspicuity enhancements. Their studies confirmed the benefits of using alternating red and white to convey the impression of hazard and the use of a horizontal line to the side and a full or partial contour to the rear. (Contour markings to the rear were favoured because their two-dimensional form was found to assist in judgements of separation distance).

From the above studies it may be concluded retro-reflective materials are useful in improving the night-time conspicuity of trucks and that they are effective in reducing accidents when compared with vehicles operating at levels equivalent to, or somewhat higher than, the country's minimum required standard. All studies show that two-dimensional markings to the rear provide the added benefit of enabling following drivers to more accurately judge their closing speed to a truck.

With regard to colour there appears to be an Atlantic divide with US research favouring the use of alternate red and white and European work favouring the use of single colours (predominantly white or yellow) to each face.

For a more detailed review of the research, refer to Appendix 3.

4.3 Review of current practice

In addition to looking to published research, other groups for whom vehicle conspicuity was considered to be an issue were contacted for their views.

Police

The Police Scientific Brach at the Home Office wished to develop a conspicuous marking scheme for its motorway patrol vehicles in order to increase the forewarning to other drivers of their presence on the road and also to provide a unique and recognisable image to other road users. This was achieved through the use of fluorescent-retro-reflective and retro-reflective materials which were applied in colours which maximised conspicuity and associated with the police.

Emergency rescue

The Chief and Assistant Chief Fire Officers Association (CACFOA) had produced research which showed that red appliances and blue flashing lights are not the most effective colours in terms of conspicuity. They were therefore working to develop a scheme of lighting, markings and sirens to improve conspicuity and without detracting from identity. The choice of materials and colours used were ones which would address both day and night-time conspicuity.

Fleet transport

Observation of the trucks on the UK's roads suggests that some fleet operators are willing to invest more in retro-reflective markings than the minimum requirements laid down in the Road Vehicle Lighting Regulations. The markings generally took the form of red full or partial contours to the rear and the main reason given for their application was safety. (This will be discussed more fully in section 8.2.1).

In conclusion it can be said that the truck markings adopted by operators, as described above, appear to have originated through a combination of research recommendations, concerning outlining, and UK Regulations, concerning colour. Similar influences can be seen regarding the use of outlining by the police and fire and rescue service. A major difference between the markings employed by the police and fire and rescue services, and those proposed by the ECE104 and research recommendations, is that the former actively address the issue of daytime conspicuity by incorporating fluorescent materials whilst the latter addresses night-time conspicuity only, acknowledging that the markings may be of benefit during the day.

For a more detailed review of current practices, refer to Appendix 4.

4.4 Conclusions

- The material review and the research review confirms that retro-reflective materials can be beneficial in addressing heavy and large vehicle conspicuity.
- The research review suggests that conspicuity is likely to be optimised if the retro-reflective materials are applied as a horizontal line to the side and a full or partial contour marking to the rear. (A two-dimensional form is needed to the rear to assist in determining separation distances not just on-the-road presence).
- The material review and current practice review suggest that if daytime conspicuity is also to be addressed some form of fluorescent markings must be used.

In terms of the implications of this review for the remainder of the study, it may be concluded that:-

- Retro-reflective and fluorescent retro-reflective materials are the only materials which need to be assessed.
- There are no marking formats additional to line and contour formats which need to be included in the testwork.
- Some assessment of the effect of fluorescent materials should be included in the testwork in the form of fluorescent-retro-reflective markings.

5.0 Assessment of marking formats

In order to meet the objectives of the project, three aspects relating to vehicle markings needed to be addressed:-

- the performance of the ECE104 markings;
- the use of red markings;
- the use of fluorescent materials.

A series of studies were undertaken to investigate the above factors and these, along with a full description of the markings used, are briefly described below. The results of these studies are tabulated for ease of comprehension and presented in section 5.3.

5.1 Description of the marking formats used in the assessments

5.1.1 The ECE104 marking formats

ECE104 defines two types of markings - contour markings and graphics markings.

Contour markings are ‘a series of rectangular strips intended to be placed in such a way that it shows the contour of the vehicle to the side or rear’. Contour markings can be either white or yellow and their colorimetric and photometric requirements are given in Appendix 5.

Graphics markings are ‘additional coloured markings intended to be placed within the contour marking’. Graphics markings are optional and can be any colour. However they have a lower photometric performance than the contour markings. Refer to Appendix 5.

The forms of these markings are shown in Figure 3 below.

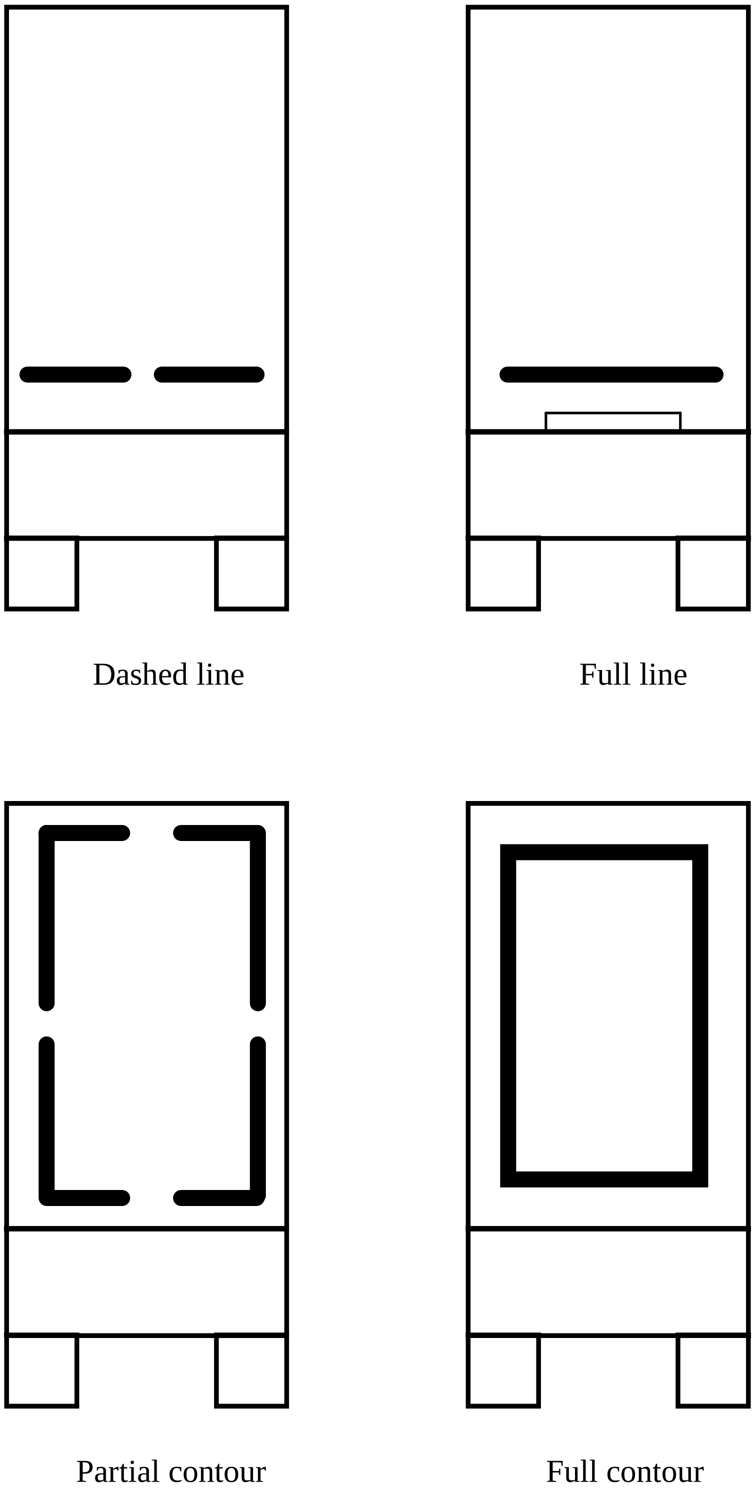
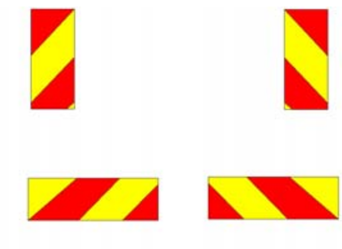


Fig. 3: Forms of the ECE104 markings

The colorimetric and photometric performance levels of the materials used in the study met the requirements specified by ECE104 and are given in Appendix 5 for comparison.

5.1.2 ECE70 marking formats

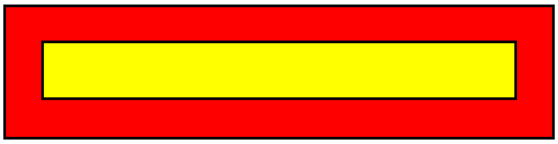
The ECE104 markings were compared to the ECE70 markings currently in use on the road. The forms of the ECE70 markings are shown below in Fig. 4.



CLASS 1

← Fluorescent red

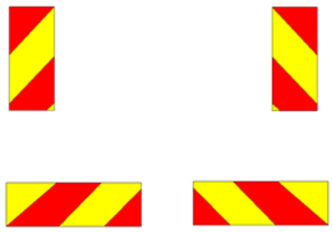
← Retro-reflective yellow



CLASS 2

← Fluorescent red

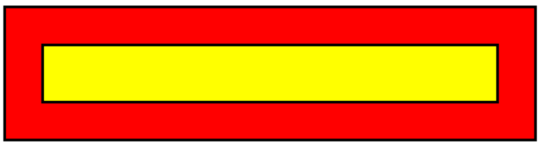
← Retro-reflective yellow



CLASS 3

← Retro-reflective red

← Retro-reflective yellow



CLASS 4

← Retro-reflective red

← Retro-reflective yellow

Fig 4: Forms of the ECE70 markings

5.2 Description of the assessments conducted

5.2.1 The visibility assessment

In this assessment visibility was used as an approximation to conspicuity. The aim of the assessment was to rank the different ECE104 forms and colours along with the ECE70 formats in terms of their visibility. Visibility was assessed using a visibility meter. This necessitated the participant viewing the truck rig through the eyepiece of the visibility meter and reducing the contrast until the truck became obscured from view. The degree of obscuration required to conceal the truck from view was recorded by a three-digit read-out. The higher the reading, the greater the extent of obscuration needed, and therefore the more visible the image being viewed.

For a more detailed explanation of the visibility meter, refer to Appendix 6. This was undertaken for both day and night-time conditions. For further information concerning the visibility trials refer to Appendix 7: report entitled Conspicuity of Markings.

5.2.2 The image assessment

In this assessment image was used as an approximation of conspicuity. Image was defined as 'the extent to which the markings indicate that there is something ahead on the road'. It was assessed using a 7-point rating scale where 1 was defined as markings which could barely be seen, and 7 as markings which clearly indicated that there was something ahead on the road. This measure of image was used to assess the impact, or on-the-road presence, the different forms of markings may portray. For further information concerning the image trials refer to Appendix 7, report entitled Conspicuity of Markings.

5.2.3 The reaction time assessment

This assessment was conducted to determine whether the ECE104 markings applied in red perform as well as those applied in yellow and also to investigate how these variations perform compared to the ECE70 markings. The aim was to use measures which would provide a guide to on-the-road performance such as the number of occasions the truck is identified as present on the roadway and the time taken to make this decision which could then be calculated as a stopping distance. This assessment was conducted as a worst-case scenario in which dirtied materials were viewed as a truck driver would see them. The task for the participants was to identify as quickly and accurately as possible if there was a truck ahead of them when only given 0.4secs glimpse of the road ahead. For further information concerning the reaction time trials refer to Appendix 8, entitled Validation Report.

5.2.4 Disability glare

Two assessments of disability glare were undertaken.

Disability glare of contour markings

This assessment was undertaken to investigate the concern that high performance red contour markings to the rear of vehicles may mask the detection of the vehicle’s stop lamps. In addition, if this was found to be the case, the study was to identify the vertical separation distance required between the markings and the lamps to minimise the effects of masking. Measures were taken of the probability of correct detections, i.e. the number of times the stop lamp was correctly reported as ‘on’ or ‘off’, and the time taken to make these responses when there was no material present on the rear of the vehicle and when the materials was placed at successive separation distances from the stop lamps. For further information concerning these time trials refer to Appendix 9: report entitled Disability Glare of Red Markings.

Disability glare of contour and graphics markings

This assessment was undertaken to determine if the application of contour and graphics materials to the side face of heavy and long vehicles and their trailers could result in disability glare. A worst case scenario was replicated in which the contour and graphics markings would appear at their brightest. This was achieved by using a full white contour and the maximum area of the highest performing graphics material permissible under the Regulation. The test was for the participants to identify as quickly and accurately as possible whether there was a pedestrian between them and the truck, when viewing from behind main beam headlamps. For further information concerning these time trials refer to Appendix 10: report entitled Disability Glare of Graphics Markings.

5.2.5 Discomfort glare

A further assessment was undertaken to determine if the application of retro-reflective material to the side and rear faces of heavy and long vehicles could result in discomfort glare. Discomfort glare occurs when a source of high luminance, is found to be painful or annoying but does not result in the loss of visual information. Discomfort glare was assessed for full contour markings and dashed lines markings, both with and without the additional graphics markings. Since discomfort glare is a subjective phenomenon, it cannot be measured directly or calculated. Instead those exposed to the glare sources are required to make and report their own judgements as to the level of discomfort they are experiencing. These judgements were made using the deBoer rating scale which, despite some short comings, is the industry standard. For further information concerning the discomfort glare trials, refer to Appendix 11: report entitled Discomfort Glare of Markings.

5.2.6 Colour association

Colour association was assessed to determine if certain colours of markings are more likely to be associated with certain faces of a vehicle. Five colours of retro-reflective materials (red, yellow, white, fluorescent yellow and fluorescent red-orange) were viewed under dipped and main beam headlamps at viewing angles of 45°. For each condition the participants had to state which face of a vehicle they most associated with the viewed colour, and also state the strength of that association ranging from probable to definite. For further information concerning the colour association trials, refer to Appendix 12: report entitled Colour Association.

5.2.7 Colour recognition

Five colours of retro-reflective materials were viewed as described in section 5.2.6 above. The participants were allowed to view each condition for 2-3 seconds, after which they had to state which colour they had just seen. As well as assessing misperceptions of yellow as white, the effect of fluorescence on colour perception was also examined.

Concern was expressed by the client that retro-reflective yellow material may be perceived as white and a study was undertaken to investigate this. For further information concerning the colour recognition trials, refer to Appendix 13: report entitled Colour Recognition.

5.3 Results of the assessments

5.3.1 The performance of the ECE104 markings formats

- **Visibility** The only difference between the ECE104 and ECE70 markings is that the ECE104 full and partial contour formats are more visible at night.
- **Image** Generally all the proposed ECE104 markings present a stronger image of ‘something on the road ahead’ than the ECE70 marking formats, both day and night.
- **Reaction time** Trucks marked with the ECE104 formats and the ECE70 formats are detected with equal probability and in equal time.
- **Disability glare** The worst case condition of a full white contour markings and the white graphic area is of benefit to the probability of, and the time taken to, detect a pedestrian in front of the truck.
- **Discomfort glare** This may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. This is not particularly realistic of conventional driving situations.
- **Recognition** Yellow may be perceived as white by a small minority of drivers.
- **Association** There is strong association that yellow relates to the side of a vehicle, white to the front and red to the rear.

Table 1: The performance of the ECE104 marking formats

Visibility	Image	Reaction time	Disability glare	Discomfort glare	Recognition	Association
Night-time - In general, ECE104 full and partial contours are significantly more visible than ECE70 markings. -No significant difference between ECE104 (full or dashed) lines and ECE70 markings. - Yellow ECE104 (full or partial) contours are significantly more visible than dashed line formats; no difference for white.	**Night-time** - All ECE104 markings (except yellow full and dashed lines) have a significantly stronger image than the ECE70 markings. - ECE104 (full and partial) contours have a significantly stronger image than full and dashed lines. No significant differ-ence between full and partial contours.	**Night-time** - No significant difference in terms of number of correct detections and detection time, between ECE104 yellow (full contour or dashed line) markings, or ECE70 markings and lights only condition.	**Night-time** - Worst case condition of maximally bright contour and graphics markings improved the probability and time taken to detect a pedestrian standing between a truck and an oncoming car.	**Night-time** - Discomfort glare is only likely to arise when newly applied full contours are viewed under main beam for more than a minute. (Driver has option to adjust to dipped beam to alleviate this problem).	**Night-time** - Retro-reflective yellow is likely to be perceived as white by a small minority of drivers (13%).	**Night-time** - There is consensus amongst drivers that red signifies he rear of a vehicle, yellow the side and white the front.

- No significant difference between ECE104 full and partial contours. - No significant difference between full and dashed lines. **Daytime** - No consistent differences in visibility of ECE104 (full contours and dashed line) markings and ECE70 markings. - ECE104 full contours are significantly more visible than dashed lines markings formats.	- No significant difference between full and dashed lines. **Daytime** - ECE104 full contours have a significantly stronger image than ECE70 markings. - ECE104 full contours have a significantly stronger image than dashed lines.	**Reaction distances** - ECE104 yellow full contour 8.40m - ECE70 Diagonal 9.24m - ECE70 Rectangle 9.27m - Lights only 9.69m - ECE104 yellow dashed lines 9.74m		- ECE104 and ECE70 markings applied together are unlikely to cause discomfort glare. - The addition of graphics markings does not lead to discomfort glare. - Full contours are significantly brighter than dashed lines.		

5.3.2 The use of red markings

- **Visibility** Night-time: Red ECE104 contour formats are as visible as ECE70 markings and equal to, or better than, the minimum ECE104 yellow dashed line format. Red line formats are significantly less visible than both the ECE70 and ECE104 yellow dashed lines formats. Day-time: All red formats are significantly less visible than the ECE70 markings. Red ECE104 markings and yellow ECE104 dashed lines markings perform equally.
- **Image** Night-time: All forms of the red ECE104 formats present a stronger image than the ECE70 markings. They also present a stronger image than the ECE104 yellow dashed lines format except for the red dashed lines. Day-time: Red ECE104 contour formats perform equally as well as ECE104 yellow dashed line formats. However, red ECE104 dashed lines perform worse than ECE104 yellow dashed lines.
- **Reaction time** All red ECE104 formats perform as well as ECE70 and ECE104 yellow dashed lines formats.
- **Disability glare** Providing that the red ECE104 markings have a minimum vertical separation from the stoplamps of 200mm, disability glare should be minimal.
- **Discomfort glare** This may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. This is not particularly realistic of conventional driving situations.
- **Recognition** Red is the most accurately perceived colour achieving 99% accuracy in its recognition.
- **Association** Strong association of red signifying the rear of vehicles. This is stronger than white to the front and yellow to the side.

Table 2: The use of red markings

NB The ECE70 and the ECE104 yellow dashed line formats represent the minimum performance levels which the red markings must reach to be acceptable for on-road use.

Visibility	Image	Reaction time	Disability glare	Discomfort glare	Recognition	Association
Night-time - No significant difference between ECE104 (red full or partial contours) and ECE70 markings. - ECE104 red (full and dashed line) significantly less visible than ECE70 markings. - ECE104 red full contour is significantly more visible than yellow dashed lines.	**Night-time** - All ECE104 red markings have a significantly stronger image than the ECE70 markings. - All forms of ECE104 red markings, except the dashed lines, have a significantly stronger image than the yellow dashed lines. - No significant difference between red and yellow dashed lines.	**Night-time** - No significant differences between the ECE104 red (full contour or dashed line) formats and the ECE70 or lights only conditions. - No significant differences between the ECE104 red and yellow, full contour and dashed lines markings.	**Night-time** - Minimum separation distance of ECE104 red markings from stop lamps should be 200mm.	**Night-time** - Discomfort glare is only likely to arise when newly applied ECE104 red full contours are viewed under main beam for more than a minute. (Driver has option to adjust to dipped beam to alleviate this problem).	**Night-time** - Red retro-reflective material is the most correctly perceived colour, achieving 99% accuracy in its recognition.	**Night-time** - Confirmed that there is a strongly held convention that red is associated with the rear of vehicles.

- ECE104 red full line is significantly less visible than yellow dashed lines. **Daytime** - ECE104 red (full contour or dashed line) markings are significantly less visible than ECE70 markings. - No significant difference between red (full contours or dashed line) markings, and yellow dashed lines.	**Daytime** - No significant difference between ECE104 red full contour and ECE70 markings. - ECE104 red dashed lines have a significantly weaker image than ECE70 markings. - ECE104 red dashed lines have a significantly weaker image than yellow dashed lines. - No significant difference in ECE104 red full contour and yellow dashed lines formats.	**Reaction distances** - ECE104 yellow full contour 8.40m. - ECE104 red full contour 8.83m. - ECE70 Diagonal 9.24m. - ECE70 Rectangle 9.27m. - Lights only 9.69m. - ECE104 yellow dashed lines 9.74m. - ECE104 red dashed lines10.07m.				

5.3.3 The use of fluorescent materials

- **Visibility** Night-time: Fluorescent ECE104 (full and partial) contours are significantly more visible than ECE70 markings; line formats perform the same as ECE70. Fluorescent red-orange is generally more visible than its non-fluorescent counterpart, fluorescent yellow is generally not. Day-time: ECE104 fluorescent yellow full contours are significantly more visible than the ECE70 markings formats, the fluorescent red-orange full contours are not. Fluorescent yellow and red-orange ECE104 markings are more visible than their non-fluorescent counterparts.

- **Image** Generally the fluorescent yellow and red-orange ECE104 full markings present a stronger image than the ECE70 markings for both day and night. In addition they present a stronger image than their non-fluorescent counterparts by day but not at night.

- **Disability glare** Based on the disability glare assessment of contour and graphics markings, described in section 5.2.4, it is unlikely that fluorescent ECE104 markings formats will give rise to disability glare.

- **Discomfort glare** Fluorescent markings are no more likely to result in discomfort glare than their non-fluorescent counterparts. Discomfort glare may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. This is not particularly realistic of conventional driving situations.

- **Recognition** Fluorescent red-orange was identified as red on 95% of the occasions it was presented for viewing. Fluorescent yellow was misinterpreted for white on 25% of the occasions it was presented for viewing. This was double the number of misinterpretations of yellow for white.

- **Association** Fluorescent yellow is strongly associated with the sides of vehicles, fluorescent red-orange with the rears. Refer to Table 3 below for full details.

Table 3: The use of fluorescent materials

Visibility	Image	Disability glare	Discomfort glare	Recognition	Association
Night-time - ECE104 fluorescent (full or partial) contours are significantly more visible than ECE70 markings. - No significant difference between ECE104 fluorescent (full or dashed) lines and ECE70 markings. - Fluorescent yellow is significantly more visible than yellow for ECE104 dashed lines only. For other ECE104 formats there is no significant difference. - Fluorescent red-orange is significantly more visible than red for all ECE104 formats except dashed lines where there is no significant difference. **Daytime** - ECE104 fluorescent yellow full contours are	**Night-time** - All fluorescent forms of ECE104 markings portray a significantly stronger image than the ECE70 markings. - Generally there is no significant difference in the image portrayed by ECE104 fluorescent and non-fluorescent forms. **Daytime** - ECE104 fluorescent full contours present a significantly stronger image than the ECE70 markings.	**Night-time** - Fluorescent yellow is more likely to give rise to disability glare than fluorescent red-orange based on its photometric performance. However since the photometric performance of fluorescent yellow is less than that of white and white contour markings in conjunction with graphics	**Night-time** - Fluorescent materials did not generally result in greater discomfort glare than their non-fluorescent counterparts. - Discomfort glare is only likely to arise when newly applied ECE104 fluorescent full contours are viewed under main beam for more than a	**Night-time** - Fluorescent yellow was mis-interpreted for white on about 25% of the occasions it was presented for viewing. This was double the number of misinterpret-ations of yellow for white.	**Night-time** - Strong consensus that fluorescent yellow is associated with the sides of vehicles. - Fluorescent red-orange was strongly associated with the rear of vehicles.

significantly more visible than ECE70 markings. - No significant difference between ECE104 fluorescent red-orange full contours and ECE70 markings. - Class 1&2 (fluorescent and retro-reflective) ECE70 formats are significantly more visible than the ECE104 fluorescent red-orange dashed lines formats; there is no significant difference for these ECE70 formats and the fluorescent yellow dashed lines. - Class 3&4 (retro-reflective only) ECE70 formats are generally less visible than the fluorescent yellow and fluorescent red-orange dashed lines. - ECE104 full contour and dashed lines formats are significantly more visible in their fluorescent forms than their non-fluorescent forms.	- ECE104 dashed lines present a significantly stronger image than ECE70 Class 3&4 (retro-reflective only) markings but there is no significant difference for ECE70 Class 1&2 (fluorescent and retro-reflective) markings. - ECE104 fluorescent yellow and red-orange full contour and dashed lines present a significantly stronger image than their non-fluorescent counterparts.	markings did not give rise to disability glare, see table 2 above, it can be considered unlikely that fluorescent yellow or red-orange contour markings will give rise to disability glare.	minute. (Driver has the option to adjust to dipped beam to alleviate this problem).	- Fluorescent red-orange was identified as red on 95% of the occasions it was presented for viewing.	- There is no significant difference in the association with the rear of vehicles of red and fluorescent red-orange.

6.0 Recommendations

6.1 The ECE104 markings formats

The results detailed in the previous section can be summarised as follows.

6.1.1 Benefits of the ECE104 markings formats

- Aside from the night-time visibility benefits of applying the ECE104 markings in full and partial contour formats, there is no significant benefit of the ECE104 marking formats over the ECE70 marking formats as measured by visibility and reaction time. However, the results of the image study suggest that there are significant benefits to be obtained both day and night, by the application of the ECE104 markings. Part of this discrepancy may be accounted for by the fact that the reaction time assessment pre-cued the participants to look for something i.e. they had to detect whether or not a truck was present. Whilst detectability is associated with conspicuity, conspicuity is more complex since it involves the object drawing attention to itself. Therefore, if drivers are not fully alert and aware of what is on the road around them, the image presented by truck markings may need to be quite strong to obtain their attention. Therefore, considering all these factors together it is likely that the ECE104 markings will offer some conspicuity benefits, particularly if applied in the full and partial contours formats.
- When the ECE104 markings were viewed in the worst case scenario for disability glare, they were found to assist pedestrian detection i.e. there was no masking effect.

6.1.2 Disbenefits of the ECE104 markings formats

- Discomfort glare may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. However this is not particularly realistic of conventional driving situations.
- There is strongly held colour association that white relates to the front of a vehicle, yellow to the side and red to the rear. The application of yellow or white materials to the rear of trucks, as proposed by ECE Regulation 104,

violates this association, particularly to the rear. It may be postulated therefore, that the application of yellow or white material to the rear of a truck, may lead some drivers to believe that they are looking at the side or front of the truck rather than its rear. However judgements of vehicle orientation are unlikely to be made on colour alone since there will be other cues available to the driver regarding which face of the vehicle is being viewed. These include the horizontal span of the material and the size, colour and spacing of the vehicle lighting.

- A point specifically raised for investigation in this study was the propensity of yellow retro-reflective material to be perceived as white. This was found to occur in a sizeable minority of cases. (In 13% of the occasions it was presented for viewing, yellow retro-reflective material was perceived as white). For those participants who saw yellow as white, the majority of them went on to associate the colour with the front rather than the side of a vehicle. Therefore it seems likely that misrecognition can lead to misassociation. However it should be noted that on 26% of occasions that white was presented for viewing, it was misperceived as yellow. A Senior Crash Avoidance Standards engineer at the Department of Transport, Canada confirmed the effect that yellow can appear as white but believed that colour was less important than the fact that drivers would be receiving a message that “There is something large in your path - drive appropriately”.

6.1.3 Recommendations for the ECE104 markings formats

- **The ECE104 formats are likely to improve conspicuity and so should be accepted.**
- **The effects of the disbenefits of discomfort glare and colour recognition are likely to be minimal.**
- **To take advantage of colour association, the potential to use red to the rear should be considered.**

6.2 The use of red markings

6.2.1 Benefits of red markings

- Generally the red ECE104 marking formats present an equivalent or stronger image than the ECE70 and the yellow ECE104 dashed lines marking formats both by day and night. The exception to this is the red ECE104 dashed lines format.
- Red is the most accurately perceived colour achieving 99% accuracy in its recognition.
- Red is strongly associated with the rear of vehicles and this association is stronger than white to the front and yellow to the side.
- All red ECE104 marking formats perform as well as ECE70 and ECE104 yellow dashed lines formats in terms of reaction time.

6.2.2 Disbenefits of red markings

- At night the red contour formats are equivalent or more visible than the ECE70 and yellow ECE104 dashed lines formats, but this is not true for the line formats.
- By day there is no difference in the visibility of the red ECE104 markings and the yellow ECE104 dashed lines formats but the red ECE104 markings are significantly less visible than the ECE70 markings.
- Red ECE104 markings can cause disability glare as measured by probability of, and time to, detect a stop lamp is on. However, if the vertical separation between the red retro-reflective materials and the stop lamp is 200mm this effect should be minimised.
- Discomfort glare may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. However this is not particularly realistic of conventional driving situations.

6.2.3 Recommendations for red markings

- **The use of red ECE104 marking formats will allow full advantage to be taken of the strong recognition and vehicle orientation association held by this colour.**
- **To ensure that the performance of the red ECE104 markings at least match the performance of the ECE70 and yellow ECE104 dashed lines format (worst case), they should be applied in the full or partial contour formats.**
- **Additionally to preserve daytime conspicuity the red ECE104 marking formats should be applied in conjunction with the ECE70 marking formats.**
- **The minimum separation between the red retro-reflective ECE104 markings and the vehicle stop lamps should be 200mm.**

6.3 The use of fluorescent materials

6.3.1 The benefits of fluorescent materials

- Generally, for day and night, the fluorescent ECE104 formats are as visible as, and in some instances more visible than, both their non-fluorescent ECE104 counterparts and the ECE70 marking formats.
- Generally the fluorescent ECE104 formats present a stronger image than the ECE70 marking formats and perform as well, if not better than, their non-fluorescent ECE104 counterparts.
- Fluorescent ECE104 marking formats are unlikely to give rise to disability glare.
- Fluorescent red-orange is perceived as red and so should not lead to misassociations or confusion regarding vehicle orientation.

6.3.2 The disbenefits of fluorescent materials

- Discomfort glare may potentially be a problem when new material is applied in a full contour format and viewed under main beam for more than one minute. However this is not particularly realistic of conventional driving situations.

- Fluorescent yellow is twice as likely as non-fluorescent yellow to be misperceived as white. Since there is strong association that white represents the front of a vehicle this means that fluorescent yellow is more likely to give rise to a misinterpretation of vehicle orientation based on colour perception alone. However additional cues such as vehicle lighting and the horizontal span of the material will also assist oncoming drivers in interpreting the vehicle ahead of them.

6.3.3 Recommendations for fluorescent markings

- **Combined performance fluorescent-retro-reflective materials should be permitted under ECE104 since they are likely to be of benefit to daytime conspicuity and some night-time aspects whilst imposing no severe disbenefits.**

7.0 Amendments to Regulations

If the results and recommendations of this work are accepted, then the following changes to legislation would need to be made.

7.1 ECE Regulation 104

7.1.1 Colour

The colour specifications of ECE104 should be amended to include:

- retro-reflective red,
- fluorescent-retro-reflective yellow,
- fluorescent-retro-reflective red-orange.

7.1.2 Formats

The specification of the format of the markings needs to be extended to require that the retro-reflective red markings are used in partial or full contour formats only; line formats should not be permitted.

7.1.3 Location

The specification of the location of the markings needs to be extended to require that the retro-reflective red and fluorescent-retro-reflective red-orange markings are only permitted to the rear of the vehicle.

7.2 The Road Vehicle Lighting Regulations 1989

Two new schedules may be required within these Regulations to accommodate the ECE104 requirements and the findings of this work. One classification would cover the use of retro-reflective materials as conspicuity markings i.e. markings whose primary function is to denote the presence of the vehicle on the road to other drivers e.g. the red full contour marking used by some UK operators to the rear of trucks. A further classification would cover the use of retro-reflective materials as graphics or advertising markings i.e. markings whose primary function is to convey a corporate identity e.g. the logos used by organisations such as BT and Golden Wonder. Such classifications may take the form of:

7.2.1 Conspicuity markings

Class of vehicle

As per ECE Regulation 104.

Position

As per ECE Regulation 104 with the following exception:

- red and fluorescent red-orange to the rear only.

Size

As per ECE Regulation 104 for dimensions and formats with the following exception:

- red to be applied in full or partial contour formats only.

Colour

- White and yellow - as per ECE Regulation 104.
- Red.
- Fluorescent yellow and fluorescent red-orange.

7.2.2 Graphics markings

Class of vehicle

As per ECE Regulation 104.

Positioning

As per ECE Regulation 104

Size

As per ECE Regulation 104.

Colour

As per ECE Regulation 104.

8.0 Cost-benefit analysis

8.1 Costs

The following costings assume a full contour marking to the rear and a single line to either side of the truck This is based on the work of this study which suggests that this is a suitable compromise between the ‘ideal’ marking requirement for full contours to the side and rear, and the minimum marking required of a single line to the side and rear. It is also representative of the formats adopted by UK operators to date, refer to Appendix 1, and is in line with the formats used in the Darmstadt and Vector Studies.

8.1.1 Material costs

Per vehicle material costs have been estimated at £150. These estimates are based on:-

- Operator consultations (see Appendix 1),
- The need for approximately 120ft of material to mark up the above described format at a cost of £1/ft (based on 3M’s Diamond Grade).

8.1.2 Labour fitment costs

The time taken to fit the markings has been estimated at four hours which, based on an hourly rate of £20, equates to £80. The total per vehicle cost is therefore £230 (material and labour costs).

8.1.3 Number of trucks to mark up

Data from the Society of Motor Manufacturers and traders (SMMT) has been used to provide figures for the size of the current national fleet of trucks. SMMT figures take into account vehicles which are in use but are not currently licensed and are therefore higher than those shown in the DoT publication Transport Statistics Great Britain.

According to SMMT statistics, in 1995 there were 548,674 registered heavy commercial vehicles in the UK and 52,261 new registrations.

Retro-fitting

Based on 1995 figures, the cost to retro-fit the national truck fleet would be £126,195,020. (National truck fleet of 548,674 vehicles x total per vehicle costs of £230).

Per annum costs

New truck registrations are 52,261 per annum. Therefore for new trucks to be marked each year, the cost will be £12,020,030. (52,261 vehicles x total per vehicle costs of £230). Since retro-reflective materials have a life of seven years and the Freight Transport Association estimate that the majority of trucks have a life of 3-6 years, replacement costs due to the materials reaching the end of their life should not be incurred.

Note. Replacement costs will be greater for fluorescent-retro-reflective materials since these have a life of five years compared to seven.

8.2 Benefits

8.2.1 User opinions

A number of fleet managers were contacted for their opinions of additional retro-reflective markings for trucks. The main reason given for using retro-reflective markings over and above those currently required by UK Regulations was safety. For one organisation the adoption of the markings was accident driven, for others it was because they perceived it to be in their best interest in terms of reducing potential accidents and being seen to be a responsible operator by both the public and employees. Benefits, in terms of costs saved due to reduced accidents, were difficult to quantify. Most organisations did not collect the relevant data or if they did it was compounded by other factors. The closest one organisation came to quantification was to say that although accidents were infrequent before the markings were introduced, in the three years since they had been applied they had not had any rear shunts.

Due to the lack of accident information available from operators, the likely benefits of the conspicuity markings have been estimated from national statistics and research as described below.

8.2.2 Casualty estimates - all accidents

Data from Road Accidents Great Britain 1995 records the number of casualties in vehicles involved in collisions with a truck. However, Robinson 1994 found that only 84.4% of the fatal accidents identified by STATS 19 actually directly involved a heavy goods vehicle. Therefore (assuming this also holds for serious and slight injuries), the data needs to be reduced by 15% for all categories. This adjusted total is shown in Table 4.

Table 4: Casualties involved in collision with a truck - 1995

Other vehicle involved in truck collision	Fatal	Serious	Slight
Car	183	990	5951
Light Goods Vehicle	16	126	418
Heavy Goods Vehicle	15	117	454
Total	214	1233	6823
Total (Robinson, 15% reduction)	182	1048	5800

8.2.3 Casualty estimates - point of impact

Since conspicuity accidents tend to involve the sides and rears of trucks it is necessary to adjust the data for ‘all’ trucks casualties, given in Table 4 above, to account for this. Robinson 1994 estimated the car-into-truck fatalities according to HGV point of impact and it will be assumed that these percentages also hold true for all casualty categories and all vehicle types. If this data is combined with the casualty types identified in Table 4, the number of casualties involved in relevant point-of-contact collisions can be calculated. This is shown in Table 5.

Table 5: Casualties involved in collision with a truck

Face of vehicle impacted			Number of casualties		
	%	**Mean%**	**Fatal**	**Serious**	**Slight**
Rear	07-09	8	15	84	464
Side	10-12	11	20	115	638
Total			35	199	1102

8.2.4 Casualty estimates - conspicuity related accidents

However not all side and rear impacts with trucks can be attributed to conspicuity. MIRA undertook an analysis of 200 accidents in the early 1980s and found 13% of commercial vehicle accidents to be conspicuity related i.e. accidents which ‘might have been lessened in severity or eliminated altogether had another road user seen the commercial vehicle earlier’. Using this data it is possible to estimate the number of fatalities and serious injuries which may be conspicuity related. This is shown in Table 6 where the total casualties given in table 5 have been reduced to 13%.

Table 6: Conspicuity related casualties

	Fatal	**Serious**	**Slight**
Total casualties	5	26	143

8.2.5 Estimate of effectiveness of conspicuity enhancements

Even though conspicuity treatments are applied to trucks, it cannot be assumed that their effectiveness in preventing conspicuity related accidents will be 100%. Two major studies to date have assessed the effectiveness of conspicuity treatments. Both compared the accident rates of trucks with and without conspicuity markings over a two year period. The Vector trials, which assessed 4,000 vehicles, found an 18% reduction in collisions. The Darmstadt study, which assessed 2,000 vehicles, found a 93% reduction in accidents. The discrepancy in these reduction rates is in part due to the base vehicles against which the marked vehicles were compared. In the Vector study many of the comparator vehicles already had some form of reflective graphic on them whereas in the Darmstadt study the comparator vehicles had 'conventional' markings, although it is not clear what these are. However the assessment work associated with this study has shown that the contour formats offer significant conspicuity benefits at night over the existing ECE70 marking formats and so an assumed percentage of effectiveness of 75% may not be unreasonable. Using this level, the number of casualties saved are given in Table 7.

Table 7: Total casualties saved

	Fatal	**Serious**	**Slight**
Total casualties saved	4	20	107

8.2.6 Estimate of monetary savings due to casualty reduction

Road Accidents GB 1995 estimates that the average costs per casualty were £812,010 for a fatality, £92,570 for a serious injury and £7,170 for a slight injury. If these values are combined with the casualties identified in Table 7, the total monetary savings in terms of casualty reduction can be calculated.

Table 8: Monetary savings

	Fatal	**Serious**	**Slight**	**Total**
Total casualties saved	4	20	107	
Cost per casualty	812,010	92,570	7,170	
Total monetary saving	3,248,040	1,851,400	767,190	**5,866,630**

8.2.7 Estimates of truck repair and off-the-road costs

In addition to the monetary savings due to casualty reduction, there are also savings to be gained from the reduction of repair and off-the-road costs. If the number of truck accidents (as opposed to casualties in truck accidents) is adjusted in the same way as the casualty data, monetary estimates can be obtained.

From Road Accidents Great Britain, data for 1995 indicates that there were a total of 6,896 car-to-truck, Light Goods Vehicle-to-truck and truck-to-truck accidents. The relevant adjustments, as made for the casualty accidents, are shown in Table 9.

Table 9: Reduction of truck accidents due to conspicuity treatments

Total accidents involving trucks	6896	
15% reduction identified by Robinson	5862	
Face of truck impacted	Rear 8% 469	Side 11% 645
Conspicuity related - 13%	61	84
Effectiveness - 75%	46	63

The casualty data in Table 4 suggests that fatal and serious casualties jointly account for 17% of all casualties. This percentage will be used to refine accidents costs by assuming that 17% of the accidents likely to be prevented by conspicuity treatments would have been severe and the remaining 83% minor. Discussions with commercial vehicle repairers suggest that major repairs may take in the order of two days whilst minor repairs may take half a day. If these figures are combined with the daily off-the-road cost estimated by the Freight Transport Association at £256.41, then the off-the-road cost for a severe accident is in the order of £512.82 and for a slight accident it is £128.21. The total costs associated with these accidents are given in Table 10.

Table 10: Monetary savings

	Rear		**Side**		**Total**
	Severe	**Slight**	**Severe**	**Slight**	
Repair costs	2,000	350	2,000	300	
Off-the-road costs	512.82	128.21	512.82	128.21	
Total costs	2,512.82	478.21	2,512.82	478.21	
Number of accidents prevented	8	38	11	52	
Total savings (Total cost x accidents)	20,102.56	18,171.98	27,641.02	22,266.92	**88,182.48**

8.3 Conclusions

The table below summarises the financial costs and benefits discussed above.

Table 11: Summary of financial cost-benefits

Costs			12,020,030.00
Benefits	Casualty saving	5,866,630.00	
	Repair and off-the-road costs	88,182.48	
	Total savings	5,954,812.48	
Net annual cost			**6,065,217.52**

These costs may be reduced if operators can take advantage of economies of scale in the application of the materials to their vehicles. Since several large fleet operators are already employing some form of marking, encouragement to voluntarily comply with the Regulation may be beneficial.

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