Motor vehicle and pedal cycle conspicuity. part 3: retroflective and fluorescent materials. Summary report.

Motor vehicle and pedal cycle conspicuity - 9/33/13

Part 3: Retro-reflective and fluorescent materials

Summary report

Prepared for:

The Department of the Environment, Transport and the Regions

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1.0 Summary

Accident data suggests that the conspicuity of large vehicles, and the perception of closing speed to them, are contributory factors in accident causation. Ergonomic principles indicate that improved luminance and colour contrast, as well as outlining the vehicle form, are likely to increase conspicuity. A review of previous research, current on-the-road practices and the materials available shows that retro-reflective and fluorescent materials can be applied to vehicles to increase their night-time and daytime conspicuity. If applied in outline form, such materials may also assist in judgements of separation distance.

Experimental work confirmed the benefits of retro-reflective and fluorescent materials, particularly if applied in outline form. The ECE104 marking formats performed at least as well as, and frequently better than, the current ECE70 markings in terms of conspicuity. The markings assisted in the detection of a pedestrian located beside the vehicle and visual discomfort, caused by the luminance of the materials, was minimal. The introduction of the ECE104 marking formats was therefore recommended.

Public opinion indicated that the colour red was recognised with 99% accuracy and was strongly associated with signifying the rear of a vehicle. It would therefore be beneficial to use red markings to the rear of vehicles but only if the following recommendations are met: they must be employed as full or partial contours, applied in conjunction with the ECE70 markings and be located no closer than 200mm to the vehicle's brake lights.

It is also recommended that combined fluorescent-retro-reflective materials should be permitted under ECE104, subject to their meeting the colorimetric requirements, since they are likely to be of benefit to daytime conspicuity and some night-time aspects, whilst imposing no severe disbenefits.

2.0 Introduction

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.

Retro-reflective and fluorescent material is widely used to enhance motor vehicle conspicuity. Proposals have been put forward in Europe on the use of such material to improve the conspicuity of larger vehicles.

The objectives of the study are therefore 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.

3.0 Information review

3.1 Ergonomics of 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 ergonomics aspects of relevance to vehicle conspicuity are described below.

3.1.1 Contrast

Increased contrast can increase conspicuity and can be achieved by:

Luminance contrast: This refers to the difference in brightness between the vehicle and its background and is a major cue for detection (Cole, 1972). Increased luminance contrast can be achieved through the use of special materials, including those which have fluorescent and retro-reflective properties.

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 an asphalt 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, shows that photopic (day) vision is most sensitive to yellow-green hues, whilst scotopic (night) vision is most sensitive green. Therefore colours in this region are likely to most benefit vehicle conspicuity and is the rationale behind high visibility clothing.

3.1.2 Size and form

Generally the larger the area of the conspicuity treatment, the better the conspicuity and the greater the distances over which the vehicle can be seen. 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 incite camouflage since they break up the vehicle form.

3.1.3 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. Henderson, R.L. et al (1983) in his discussion of work by Ziedman et al (1981) on 'truck reflectorisation' 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.

3.2 The vehicle conspicuity problem

3.2.1 Truck accident statistics

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

3.2.2 Accident causation

Conspicuity and perceptual issues may contribute to large vehicle accidents.

Conspicuity issues: In the early 1980s the Motor Industry Research Association (MIRA) undertook a two year study of commercial vehicle accidents. Of 200 accidents, 13 occurred in conditions of poor visibility (twilight or night) where improvements to truck conspicuity would have helped. A study by Sweatman et al (1990) in Australia concluded that conspicuity issues may have featured in up to 5% of accidents; 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.

Perceptual issues: The MIRA study also identified 13 accidents where the driver should have seen the truck but for some reason did not appear to do so. It is suggested that these may in part be due to a lack of perception of the speed of the by the driver of the following vehicle. 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.

3.2.3 Suggested preventative measures

The following measures are possible means for reducing large vehicle accidents due to conspicuity and perceptual issues.

Conspicuity measures: Vehicles can be made more conspicuous by the use of: brilliant colour schemes (Sweatman, 1991), high-contrast colour patterns (OECD, 1988), reflectorisation (OECD, 1988), better reflective markings on trailer sides (MIRA, 1982*)* and reflectorised markings and graphics to the side and rear (Sweatman, 1991).

Perceptual measures: 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 (22m) 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.

3.3 Review of previous research

3.3.1 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.

3.3.2 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.

3.3.3 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).

3.3.4 Conclusions to previous research

From the above studies it may be concluded retro-reflective materials are useful in improving the night-time conspicuity of trucks. All studies showed 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.

3.4 Material review

3.4.1 Retro-reflective materials

Retro-reflective materials are those which reflect the majority of light falling on them 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 illuminate 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.

3.4.2 Fluorescent materials

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. Furthermore fluorescent materials have an average life of three to five years after which time their performance decreases.

3.4.3 Photo-luminescent materials

Photo-luminescent materials that become charged from a natural or artificial light source, 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.

3.4.4 Combined performance materials

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.

3.4.5 Conclusions to material review

Retro-reflective materials offer superior night-time conspicuity benefits over photoluminescent materials due to their high luminance and the availability of vehicle headlights to act as illumination sources. Daytime conspicuity can be addressed through the use of fluorescent materials in either a single or combined form.

3.5 Current on the road 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.

3.5.1 Police

The Police Scientific Branch 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 retro-reflective and combined performance materials that were applied in colours and forms which maximised conspicuity.

3.5.2 Emergency rescue

The Chief and Assistant Chief Fire Officers Association (CACFOA) had undertaken 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 without detracting from identity. The choice of materials and colours used were ones which would address both day and night-time conspicuity.

3.5.3 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. The main reason given for their application was safety.

3.5.4 Conclusions to current practices

In conclusion it can be said that the current practices employed by the parties above appear to have originated through a combination of research recommendations, resulting in the use of an outlining formation, and the UK Regulations, resulting in the use of red materials. A major difference between the police and emergency rescue markings and those defined by the EC 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 have some consequential benefit during the day.

3.6 Conclusion to the information review

Accident data confirms that trucks are over-represented in accidents and result in severe injuries. The main accident scenarios are other road users driving into the rear of trucks or driving into the side of a truck which is perpendicular to their direction of travel whilst manoeuvring. These accidents are in part due to conspicuity issues, where the vehicle was not seen, or perceptual issues, where the closing speed has been misjudged. There is therefore a need for measures to be introduced to mitigate these effects of conspicuity and perception.

Ergonomic principles indicate that improving the brightness and/or colour contrast of a vehicle against its background can increase its conspicuity. The material review concluded that retro-reflective materials, which increase luminance contrast at night, and fluorescent materials, which increase luminance and colour contrast by day, offer the best conspicuity benefits when applied to vehicles.

Ergonomic principles also indicate that maximising the area over which contrast is increased, or outlining the vehicle, would also be beneficial. The results of previous research suggest that contour (outline) markings, particularly to the rear, are of benefit in reducing accidents.

However definitive measures of the conspicuous performance of the EC markings, including an assessment of their benefits and disbenefits, needs to be investigated through experimental work. In addition the need for, and performance of, red materials to the rear will be similarly investigated.

4.0 Experimental work

4.1 Aim of the experimental work

The aim of the experimental work was to:

- Assess the performance of the ECE 104 marking formats and compare them with the vehicle markings currently in use as specified by ECE 70 in terms of their conspicuity benefits and disbenefits,
- Investigate the need for and performance of red markings used to rear of vehicles,
- Investigate the use of fluorescent materials.

The marking formats were assessed in conjunction with vehicle lighting.

4.2 Description of the marking formats

4.2.1 ECE 104 marking formats

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, yellow or red. Refer to figure 1.

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.

4.2.2 ECE 70 marking formats

These are shown in figure 2.

4.3 Assessment of the marking formats

The marking formats were assessed by male and female members of the public (participants), who were aged 20-75 years, using the following methods:

4.3.1 Detection rate and time

The participants were given 0.4 secs to view the road ahead and to identify as quickly and accurately as possible if there was a truck present. The more accurate the detection rate and the faster the detection time, the greater the conspicuity of the markings.

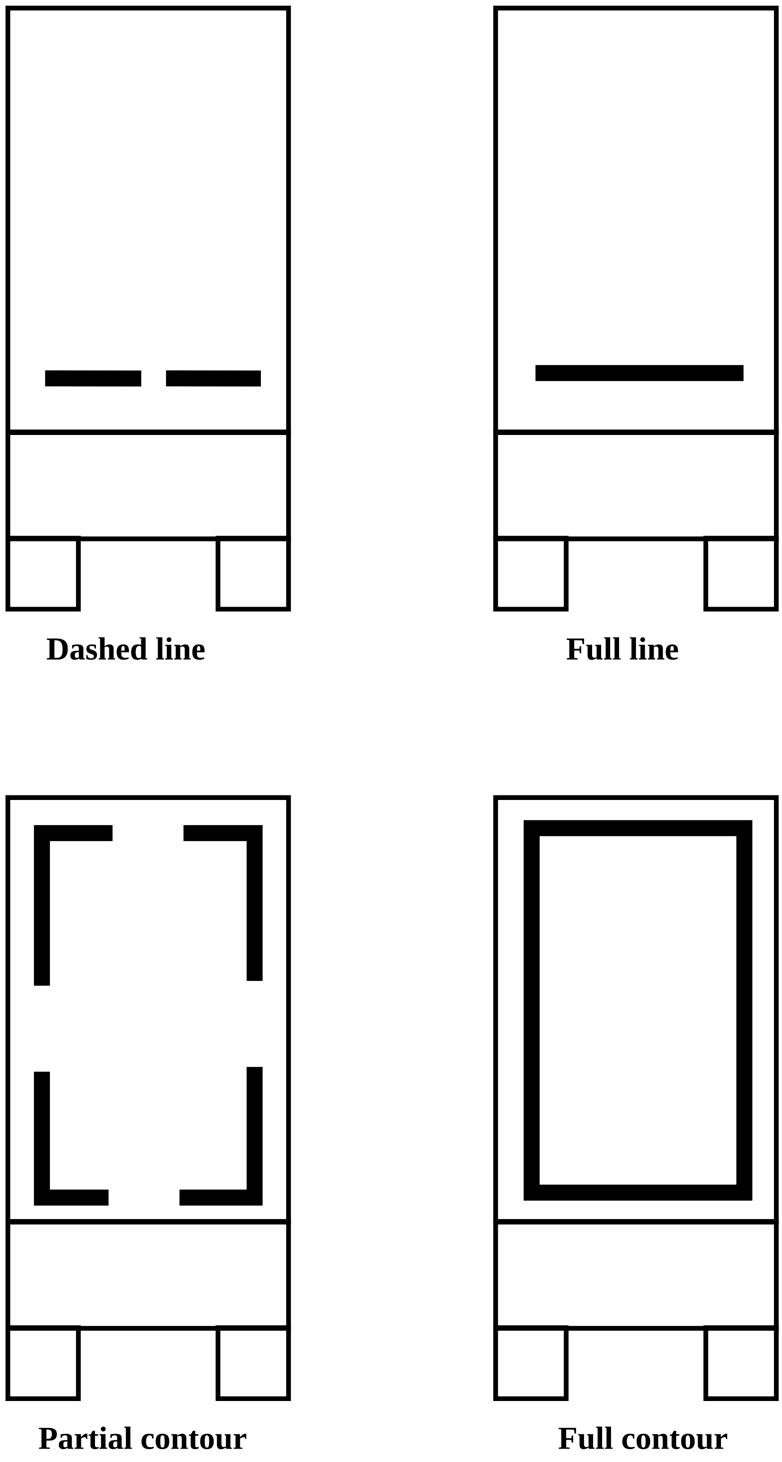
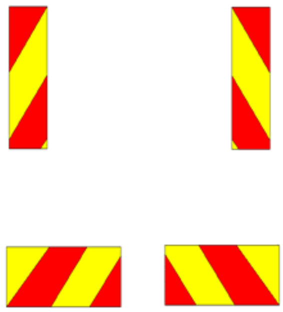


Figure 1: The marking formats defined by ECE104

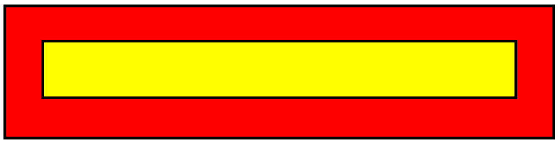
(White, yellow or red)



CLASS 1

Fluorescent red

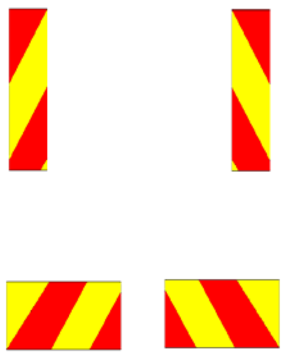
Retro-reflective yellow



CLASS 2

Fluorescent red

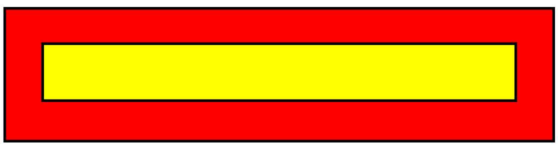
Retro-reflective yellow



CLASS 3

Retro-reflective red

Retro-reflective yellow



CLASS 4

Retro-reflective red

Retro-reflective yellow

Figure 2: The marking formats defined by ECE70

Retro-reflective / fluorescent red

Retro-reflective / fluorescent yellow

4.3.2 Visibility

The participants used a visibility meter to reduce the contrast of the truck against its background until it was completely obscured from view. The degree of obscuration required for total concealment was measured by a three-digit readout. The higher the read-out, the greater the obscuration required and the more visible the markings.

4.3.3 Image

Image was defined as ‘the extent to which the markings indicate that there is something ahead on the road’. It was measured by a seven-point rating scale. The higher the rating score, the stronger the image.

4.3.4 Masking of pedestrians

ECE104 full white contour and graphics markings were viewed under main beam conditions to determine if this maximal brightness masked the view of a pedestrian to oncoming drivers. The more accurate the detection rate and the faster the detection time of the pedestrian, the less the affect of disability glare from the markings.

4.3.5 Masking of vehicles’ brake lights

ECE104 full red contour markings were viewed under main beam conditions to determine how close the markings could be located to the brake lights without masking their detection. The more accurate the detection rate and the faster the detection times of the brake lights being on, the less the affect of disability glare from the markings.

4.3.6 Discomfort glare

Discomfort glare occurs when something is bright enough to be painful or cause annoyance but does not obscure objects from view. Discomfort glare was measured using the established seven-point de Boer rating scale. Scores close to 1 indicated that the markings were too bright; scores close to 7 indicated that they were not visible enough.

4.3.7 Colour association

Participants viewed different coloured materials and stated what face of a vehicle they associated with that colour.

4.3.8 Colour recognition

To determine if confusion could arise between certain colours, participants viewed different coloured materials and stated what colour they saw.

4.4 The conspicuity benefits and disbenefits of EC marking formats

The conspicuity benefits and disbenefits of the ECE104 and ECE70 markings formats were assessed by the following means:

4.4.1 Detection rate and time

ECE104 and ECE70 marking formats were detected at similar rates and times.

4.4.2 Visibility

Night-time: ECE104 contour formats were found to be more visible than ECE70 and ECE104 line formats. ECE104 line formats were of similar visibility to ECE70.
Daytime: ECE104 full contours were more visible than dashed lines and ECE70.

4.4.3 Image

Night-time: Generally all forms of ECE 104 presented a greater image than ECE70. ECE104 contour formats were better than line formats.
Daytime: ECE104 full contours presented a better image than dashed lines and ECE70.

4.4.4 Masking of pedestrians (Disability glare)

ECE104 full contour marking and graphics markings improved the detection rate and time of a pedestrian standing between the truck and the approaching vehicle.

4.4.5 Discomfort glare

ECE 104 full contour markings when newly applied and viewed under main beam for more than a minute may give rise to discomfort glare but this is an extreme and infrequent circumstance. Otherwise ECE 104 and ECE70 markings did not give rise to unacceptable levels of discomfort glare.

4.4.6 Recommendations

- **Introduce the ECE104 markings.**
- **Use contour formats in preference to lines since these outperform the ECE70 markings in terms of visibility and image under both day and night conditions.**

4.5 The need for and performance of red markings used to rear of vehicles

The following assessments were undertaken to determine if there was a need, due to colour association, for red markings to be used to the rear of vehicles and how red could be used in conjunction with the ECE104 markings formats.

4.5.1 Colour recognition

Red was the most accurately perceived colour with 99% correct recognition.

4.5.2 Colour association

There was a strong association of red signifying the rear of vehicles. This was stronger than the associations of white to the front and amber/yellow to the side.

4.5.3 Detection rate and time

All red ECE104 formats performed as well as ECE70 and ECE104 yellow dashed lines (the least visible format combination).

4.5.4 Visibility

Night-time: Red ECE104 full and partial contour formats are at least as visible as ECE70 markings and ECE104 yellow dashed lines.
Daytime: All red formats are significantly less visible than the ECE70 markings.

4.5.5 Image

Night-time: All red ECE104 marking formats are better than ECE70, however only the contour formats are better than ECE104 yellow dashed lines.
Daytime: Only the red contour formats perform on a par with ECE70 and ECE104 yellow dashed lines, line formats are poorer.

4.5.6 Masking of vehicles' brake lights (Disability glare)

Masking of brake lights will be minimal if a 200mm separation distance is used between the markings and the lights.

4.5.7 Discomfort glare

Red ECE 104 full contour markings when newly applied and viewed under main beam for more than a minute may give rise to discomfort glare.

4.5.8 Recommendations

- **Permit the use of red materials to the rear of vehicles. (Now implemented).**
- **Apply red material as full or partial contours in conjunction with ECE70 markings to achieve a minimum level of daytime and night-time conspicuity.**
- **Ensure a minimum brake light to marking separation of 200mm.**

4.6 The contribution of fluorescent materials

Combined fluorescent and retro-reflective materials (yellow and red-orange) were evaluated to determine their contribution to day and night-time conspicuity.

4.6.1 Colour recognition

Red-orange was identified as red on 95% of occasions it was viewed. Yellow was mis-interpreted for white on 25% of occasions.

4.6.2 Colour association

Red-orange was strongly associated with vehicle rears and yellow with the sides.

4.6.3 Visibility

Night-time: Red-orange and yellow contour formats are better than ECE70. Red-orange formats are generally more visible than red; fluorescent yellow formats are on a par with yellow.
Daytime: Both fluorescent variants are more visible than their non-fluorescent counterparts. Fluorescent yellow full contour is better than ECE70; red-orange is equivalent to ECE70.

4.6.4 Image

Night-time: All forms of fluorescent ECE104 markings are better than ECE70. There is no difference between fluorescent and non-fluorescent forms.
Daytime: Both fluorescent variants outperfrom non-fluorescent materials and ECE70.

4.6.5 Masking of pedestrians (Disability glare)

Based on their photometric specification, fluorescent materials are not as bright as white which has been shown not to mask the presence of pedestrians.

4.6.6 Discomfort glare

Fluorescent variants did not generally result in greater discomfort glare than their non-fluorescent counterparts. However non-fluorescent ECE 104 full contour markings when newly applied and viewed under main beam for more than a minute may give rise to discomfort glare.

4.6.7 Recommendations

- **Permit the use of fluorescent materials to increase daytime conspicuity subject to their meeting ECE 104 colorimetric requirements.**

5.0 Cost-benefit analysis

5.1 Calculation of costs

The estimated total costs to mark-up new vehicles is **£12,020,030** per annum.
This is derived from:

(material cost per vehicle + fitting cost per vehicle) * number of vehicles

(£150.00 + £80.00) * 52,261 = £12,020,030.00

5.2 Calculation of benefits

The benefits have been estimated at **£5,955,147** per annum. This is derived from:

(reduction in casualty costs + reduction in vehicle costs) as calculated below:

5.2.1 Reduction in casualty costs

	Injury severity		
	Fatal	**Serious**	**Slight**
Number of casualties involved in collision with an HGV (Source: Road Accidents Great Britain 1995)	214	1,233	6,823
Adjustment for direct involvement by HGV (Reduction of 15%)	182	1,048	5,800
Adjustment for side and rear impacts only (Reduction of 81%)	35	199	1,102
Adjustment for conspicuity as cause of accident (Reduction of 87%)	5	26	143
Adjustment for effectiveness of conspicuity treatments (Reduction of 25%)	4	20	107
Costs per casualty	812,010	92,570	7,170
Total casualty costs saved	3,248,040	1,851,400	767,190
Total	**5,866,630**		

5.2.2 Reduction in vehicle costs

Number of vehicles involved in collision with an HGV (Source: Road Accidents Great Britain 1995)	6,896	
Adjustment for direct involvement by HGV (Reduction of 15%)	5,862	
Adjustment for side and rear impacts only (Reduction of 81%)	1,114	
Adjustment for conspicuity as cause of accident (Reduction of 87%)	145	
Adjustment for effectiveness of conspicuity treatments (Reduction of 25%)	109	
Adjustment for accident severity (Assume: Severe = 17% and slight = 83%)	Severe 19	Slight 90
Repair costs per vehicle	2,000	325
Off-the-road costs per vehicle	513	128
Total costs per vehicle	2,513	453
	47,747	40,770
Total	**88,517**	

5.3 Conclusions to cost-benefit analysis

The data suggests a net annual cost of **£6,064,883.**

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- ICE has been repeatedly invited to work closely with the following clients: the Home Office, the Department of the Environment, Transport and the Regions, Ford Motor Company and the Police Scientific Development Branch amongst others.

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