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Assessment of the safety benefit of retro reflective markings on HGVs and buses.

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Assessment of the safety benefit of retro reflective markings on HGVs and buses

Undertaken on behalf of

Department for Transport

Prepared by

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May 2005

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Executive Summary

Recently a proposal has been made to the UNECE working party on lighting and signalling to amend Regulation 48 to mandate R104 specification markings on all new heavy trucks and buses. At the same time, the EC is considering introducing a requirement to fit R104 tape to all new heavy trucks, and possibly to retro-fit the tape to existing heavy trucks as well.

The DfT has therefore commissioned this study to reconsider the potential benefits of mandating R104 markings to new and existing HGVs in the UK and to consider the advantages of extending the requirement to a broader range of vehicles. Specifically, this would comprise commercial vehicles exceeding 3.5, 7.5 and 12 tonnes and to buses exceeding 5 tonnes or fitted with more than 9 seats.

In this study two cost benefit analyses have been conducted; one considers the costs/benefits associated with retro fitting retro reflective tape to the current existing vehicle parc and the second considers fitting the tape annually to just new vehicles. The study combines estimates for the cost of applying retro reflective tape in either line of full contour marking (as per ECE 104) and an estimate of the benefits arising from the number of accidents that the use of retro reflective tape may have prevented based on 2003 accident data. And on the accident reduction experience with retro reflective tape in the USA.

The study highlights the difficulties in obtaining accurate data and the drawbacks of using data from the USA. Vehicles in the USA typically show some differences to vehicles in the UK as regards lighting and signalling equipment.

Results of the cost benefit analysis show that;

- Retro fitting tape to the total existing vehicle parc in line or contour marking formats incurs a cost for all vehicle types.
- The costs of fitting tape to new vehicles is considerably lower than the costs incurred when retro fitting tape to vehicles. This is due to the reduced time

taken to fit the tape and that no off road costs are incurred. It should also be noted that as the years progress the proportion of the total vehicle parc fitted with retro reflective tape will also increase and therefore this will increase the number of accidents prevented. However it should also be noted that after 7 years the costs will also increase due to the need to start replacing tape on the earlier marked vehicles and this will incur the higher costs associated with retro fitting.

- There is a cost benefit for fitting line markings to newly registered HGVs greater than 7.5t, minibuses and coaches/buses.
- Fitting line markings to newly registered vehicles over an 8 year period shows that a benefit arises for HGVs >7.5t, minibuses and coaches/buses with benefits occurring after the 3rd and 4th years respectively.
- A benefit for fitting contour markings to new HGVs >7.5t occurs in the 5th year.

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1 Introduction

Large vehicles that are either stationary or moving relatively slowly compared with the speed of following traffic represent a traffic hazard and a possible cause of accidents. Similarly, large vehicles crossing a stream of traffic (slowly) also presents a hazard for drivers who do not accurately perceive their size or speed. The Road Vehicles Lighting Regulations (1989) attempt to address this problem by requiring certain classes of large vehicles to be fitted with retro-reflectors to improve their conspicuity. In addition UNECE Regulation 104 (R104) provides a technical specification for high-quality retro-reflective tape, which can be used to emphasize the contours of large vehicles. Currently, under both RVLR and UNECE Regulation 48 (which regulates installation of lighting and reflective devices on vehicles), tape complying with R104 is allowed to be fitted to large vehicles but it is not mandatory. Installation is at the discretion of the manufacturer or user.

In 1998 the DfT commissioned research to investigate the benefits of requiring all new UK Heavy goods vehicles (HGVs) to comply with the R104 specification ICE (1998). The results of the research indicated that there would be no cost benefit.

Recently a proposal has been made to the UNECE working party on lighting and signalling to amend Regulation 48 to mandate R104 specification markings on all new heavy trucks and buses. At the same time, the EC is considering introducing a requirement to fit R104 tape to all new heavy trucks, and possibly to retro-fit the tape to existing heavy trucks as well.

The DfT has therefore commissioned this study to reconsider the potential benefits of mandating R104 markings to new and existing HGVs in the UK and to consider the advantages of extending the requirement to broader range of vehicles. Specifically, this would comprise commercial vehicles exceeding 3.5, 7.5 and 12 tonnes and to buses exceeding 5 tonnes or fitted with more than 17 seats.

The main method in which estimates regarding accident reduction have been calculated in this report will use STATS 19 data. However due to how vehicles are classed and coded in STATS 19 it has not been possible to split the class of HGV

to incorporate a class of HGV greater than 12t. Instead all costs have been calculated for classes of vehicle as currently defined and coded for in STATS 19. These are listed in Table 1.

Table 1. Vehicle classes as defined in STATS 19 coding system

Vehicle type	Description
Heavy goods vehicles	3.5 to 7.5t
Heavy goods vehicles	>7.5 t
Minibus	8-16 passenger seats
Bus and coach	> 17 passenger seats

2 Literature review

A literature search of both in-house and external databases was undertaken covering vehicle conspicuity research and accident surveys. This section presents a summary of previous research studies and their findings regarding;

- The circumstances in which accidents involving trucks occur including conspicuity and perceptual issues
- The effectiveness of retro reflective tape in relation to various layout configurations, circumstances of its use and its effectiveness in terms of accident reduction.

2.1 Accident scenarios

In a study by The Highways Agency (2004) a detailed high level analysis of STATS 19 data was conducted to determine key characteristics of HGV accidents. The report states that the risk of an HGV accident is on average, greater than the risk of an accident involving other vehicle types, stating that this is particularly the case on motorways. Compared to other vehicle type accidents the consequences of crashes involving HGVs can be greater in terms of the number and severity of casualties, vehicles involved, the duration of the incident and impact on delays. Frequently occurring scenarios described in the report include side impacts which often occur when the lorry is turning or is astride lanes, i.e. reversing or making a ‘U’ turn and many HGV incidents are related to lane changing manoeuvres. However the report states that the extent to which visibility of the actual vehicle is a factor in these accidents is uncertain. Although it goes on to state that “Improved

conspicuity of large trucks could help users gauge their distance and rate of approach".

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). UK accident data for 2003 shows that of all accidents where at least one other vehicle collided with a HGV, approximately 41% struck the front of the HGV, 30.2% struck the side and 12.7% struck the rear of the HGV.

Accident data for 2003 suggests that large trucks are over-represented in fatal accidents. In 2003 Heavy goods vehicle represented about 1.7% of the vehicles on UK roads yet they were involved in 15% of accidents that resulted in fatal casualties. This pattern is consistent throughout 2000-2003.However HGVs travel 6 times the average distance travelled per year by a car.

Similar patterns have been found in Europe and America. Danner et al (1989) in Federal Republic of Germany noted that trucks constitute 4% of registered vehicles but are involved in 6.5% of all injury accidents and 12.6% of all fatal accidents.

Data collected by the National Highways and Transport Safety Administration (NHTSA) in America 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).

2.2 Accident causation

2.2.1 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.

US research (NHTSA 2001) has indicated that, in a number of accidents involving trucks, the driver of the other vehicle may not have seen the truck in time to avoid the collision. The report states that such accidents are more likely to occur in dark conditions or under other conditions of reduced visibility i.e. adverse weather conditions such as rain, snow or fog.

In a study by Mosedale et al (2004) a trial data collection system was developed in which data was collected in relation to precipitating factors and contributory factors in addition to data collected for the STATS 19 database. For each contributory factor the reporting officer indicated their confidence in the judgement by coding it as 'definite', 'probable' or 'possible'. The trial provided information on contributory factors for approximately a quarter of all reported road accidents (involving all type of vehicles) in Great Britain since 1999. For contributory factors the most commonly reported factor was 'inattention' (25%) followed by 'fail to judge other person's path or speed' (23%), and 'looked but did not see' (19%). This finding suggests a significant role for poor visibility but also highlights the difficulty of distinguishing conspicuity and perceptual failure.

A study by The Highways Agency (2004) states that "Improved conspicuity of large trucks could help users gauge their distance and rate of approach. This may include evaluation of the benefits of such measures as improved rear light clusters, higher level brake lights and indicators and consideration of other aids that will highlight the vehicle's profile such as the fitting of retro-reflective tape".

A study by Craft et al (1996) investigated rear end crashes looking at the different circumstances of accidents where vehicles collided with trucks and where trucks had collided with other vehicles. The study used data gained from TIFA (comprises data collected from a telephone survey supplementing FARS data) and GES (a nationally representative sample of police-reported traffic crashes) and Fatal Accident Complaint Team (FACT) from the Michigan state police. Data files used in this study were constructed using TIFA and GES data covering 1994-1999 and FACT from 1996 to 2001. In the study the following key differences between truck struck and truck striking crashes were noted.

- Lighting conditions

  When another vehicle collides with the rear of a truck, it is almost twice as likely to be in the dark or in the dark but lit conditions, as opposed to when a truck strikes another vehicle, where almost 90 percent of all crashes occurred in daylight.

  Furthermore, fatal rear-end crashes are even more associated with dark or dark but lit conditions. In fatal rear-end crashes where the truck is the striking vehicle about 31% occurred in dark or dark but lit conditions. In comparison, when the truck is struck by a vehicle, the proportion of dark or dark but lit rises to 46%. The study concludes that when another vehicle hits the rear of a truck, it is almost twice as likely to occur when visibility is diminished.

- Vehicle lighting

  40% of trucks struck by other vehicles in rear-end crashes had at least one lighting violation, compared with less than half that number (13%) of the trucks that were the striking vehicle.

- Alcohol

  In fatal crashes where the truck is struck by another vehicle in dark but lit conditions, 35% of the other drivers had been drinking. For daylight the number is 9% and dawn or dusk it is 13%. Craft states that alcohol use and light conditions are exacerbating factors when considered together. Night time means less light to perceive vehicles ahead, and drinking further slows recognition and reaction time thereby increasing the risk of late or no

detection of the truck. The same consequences will also apply to drivers experiencing pronounced fatigue or need for sleep.

2.2.2 Perceptual issues

Of the 26 conspicuity accidents reported in the MIRA study (previously outlined in section 2.2.1) 13 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.

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 previous experience of different classes of vehicle and their speed characteristics. That is to say, it is not sufficient to know that the vehicle ahead is moving but that the driver needs to identify what type of vehicle it is and thereby predict how it is likely to be moving.

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.

2.2.3 Summary

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 its speed characteristics. All three factors are associated with a failure to adjust vehicle 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.

2.3 Effectiveness of retro-reflective tape

This section summarises previous research studies and their findings regarding the effectiveness of retro reflective tape in relation to various layout configurations used on trucks, conditions of its use and its effectiveness in terms of accident reduction.

2.3.1 Configuration and colour of tape

In a study by Darmstadt Institute of Technology (1992) 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 struck 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.

Similarly a study by Tansley and Petrusic (1992) reports that full contour, solid white provided the best detection rate. The study assessed 19 different configurations of treatments by trial using video footage. 30 subjects viewed a video while simultaneously conducting a second task. Findings from these two studies are supported by more recent research in which contour markings were found to be more visible than single line markings (Grant et al,1993, Hilderbrand and Fullarton, 1997 and ICE,1998).

ICE (1998) investigated the relative performances of ECE 104 and ECE 70. Findings showed that contour markings, as presented in ECE 104, are most visible. In addition research shows that full contour markings (Figure 3 and Figure 4) are the most effective when compared to line markings (Figure 1 and Figure 2).

Contour marking also assists in the perception of a HGV. In a paper by Prolux (1959) red dot confusion is discussed. This is when the small red tail lights in the dark do not readily convey the perception that there is a slower moving truck ahead. The red lights on the rear of the truck can be misperceived as two separate vehicles at different distances. Prolux suggests that the use of retro reflective tape on the side and rear of large trucks and trailers may help resolve this problem. It is thought that tape joining the red lights will link the lights and more clearly present the image of a single object thereby aiding recognition.

ECE 104 defines three types of markings – line markings, contour markings and graphical markings. It states that the width of the marking material shall be 50mm +10/-0 mm.

- Line markings are made up of an element or several elements preferably continuous, parallel or as close as possible to the ground. The mounting of the markings should identify, as closely as possible, the entire length and width of the vehicle.

- 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.

- Graphical 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.

The forms of line and contour markings are shown in Figure 1 to Figure 4.

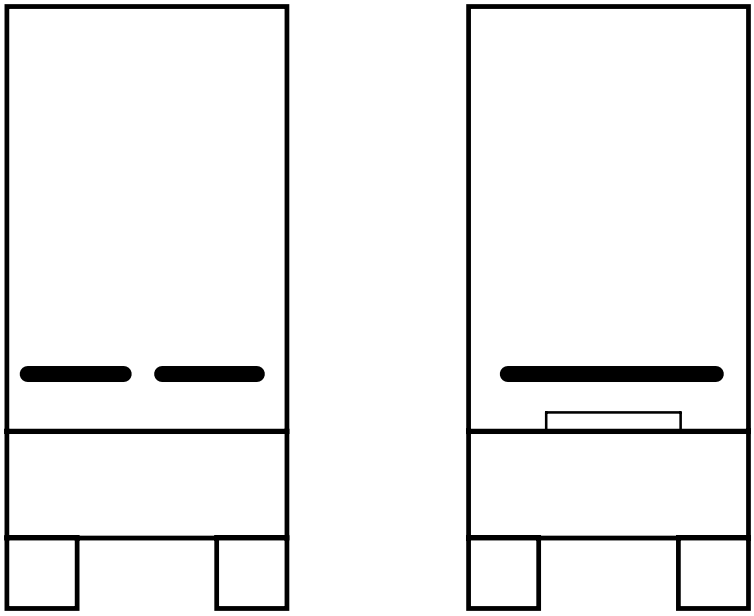


Figure 1. Forms of the line ECE 104 markings for the rear

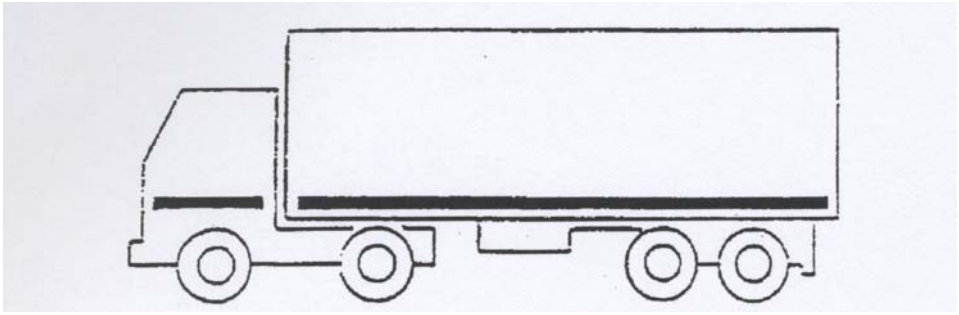
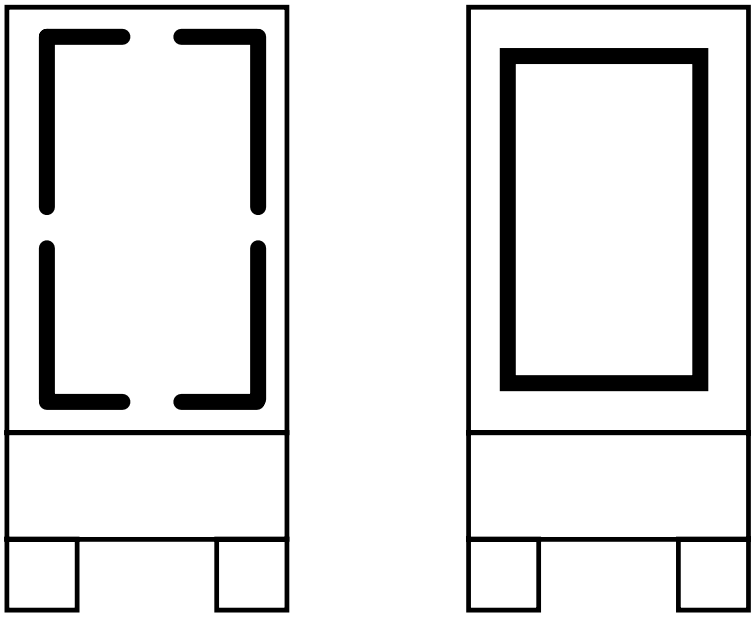


Figure 2. Forms of the line ECE 104 markings for the side



Partial contour Full contour

Figure 3. Forms of the contour ECE 104 markings for the rear

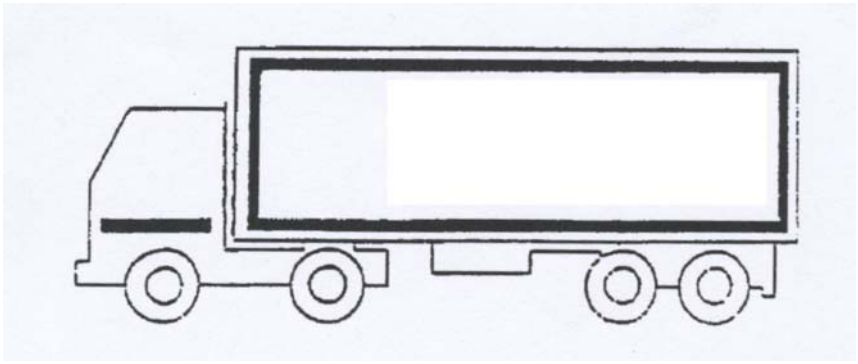


Figure 4. Forms of the contour ECE 104 markings for the side

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.

In 1993 the Federal Highway Administration (FHWA) amended the Federal Motor Carrier Safety Regulations (FMCSRs) to require that motor carriers engaged in interstate commerce install retro reflective tape that is striped red and white alternately (like candy). However research by New Brunswick University of Canada

(1997) and Tansley et al (1992) showed that solid line markings of a single colour have greater visibility thresholds (viewing distances).

2.3.2 Circumstances where retro reflective tape is likely to be effective

There has been some research investigating different circumstances such as various lighting conditions, weather conditions, dirt and characteristics of the observer in which retro reflective tape maybe most/least effective and therefore when its use may be most beneficial. Studies have made conclusions based on experimental studies and through the analysis of accident data. This section presents a short review of the research.

Hildebrand and Fullerton, 1997.
Effectiveness of heavy truck conspicuity treatments under different weather conditions.

Weather conditions

Hildebrand and Fullerton (1997) conducted a study to investigate the effectiveness of heavy truck conspicuity treatments under different weather conditions. Subjects viewed video recordings of approaching trucks with various configurations of tape under four different weather conditions. Each configuration was evaluated on the basis of visibility threshold, ability to distinguish dimension /size and subjective comparative rating. All retro reflective tape treatments substantially increased the threshold of visibility for the rear of the trailer.

There was a significant reduction in visibility thresholds for the rear of the trailer with the changes in weather. Relative to clear conditions it was found that the presence of snow or rain reduced thresholds by approximately 50 to 70%, while fog decreased visibility by as much as 90%. Retro reflective tape seems to have little value in fog.

NHTSA HS 809 222. The effectiveness of retro reflective tape on heavy trucks, 2001.

In 1993 the FHWA amended the Federal Motor Carrier Safety Regulations (FMCSRs) to require motor carriers engaged in interstate commerce to install retro reflective tape or reflex reflectors on the side and rear of semi-trailers that were

manufactured on or after December 1st 1993, have an overall width of 2032mm or more and a gross weight rating (GVWR) of 10,000 pounds or more. The FHWA required that motor carriers install retro-reflective tape or reflex reflectors within two years of the effective date of this rule. The agency allowed motor carriers a certain amount of flexibility in terms of the colours or colour combinations during a 10 year period beginning on the effective date of this regulation. But required that all older trailers be equipped with conspicuity treatments identical to those mandated for new trailers at the end of the ten year period.

To ascertain an indication of the effectiveness of this regulation the NHTSA conducted a study (NHTSA 2001) to compare the accident rate and circumstances of HGVs with and without contour tape markings. The study collected accident data for Pennsylvania and Florida from 1997 to 1999 (10,959 accident cases). In addition, for each crash that occurred during the assessment period the crash / police investigator had to complete an investigator's supplementary truck–tractor trailer accident report. This form probed for additional information which may not necessarily normally be recorded i.e. if lights were on/functioning, if tape present what was the layout, colour, was the tape damaged/ undamaged, clean/dirty, weather conditions, lighting conditions, and point of impact etc.

The basic analysis tabulated tractor-trailer combination involvements in crashes by trailer treatment (treated / untreated), and damage area (single vehicle and front, side and rear) and light conditions (light / dark). Single vehicle or frontal impact accidents acted as control groups. Their findings regarding lighting, dirt, area of impact and age of the observer are presented below.

Lighting conditions

The results indicated that the tape was the most effective in dark-not-lighted conditions. In these conditions the tape reduced side and rear impacts into heavy trailers by 41%. The reduction was statistically significant. In dark lighted, dawn and dusk conditions the tape did not significantly reduce crashes. It was also found that the tape did not significantly reduce crashes during daylight.

Dirt

Dirt on the tape significantly diminished its effectiveness in rear impacts. This finding is also supported by Schmidt-Clausen (1998), who looked at the retro

reflective performance of tape under varying degrees of dirt. Markings near the lower part of the vehicle i.e. closest to the road are more prone to the build up of dirt and therefore likely to be less effective.

Impact area

The tape maybe somewhat more effective in preventing rear impacts than side impacts. But this was not a consistent finding in the two states for which data was analysed.

Age of driver

The study concludes that the tape is effective when the driver of the impacting vehicle is less than 50 years old. A possible explanation of this is that older drivers are less able to see, recognise and /or react to the tape in time to avoid hitting the trailer. This is of particular relevance given that 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, they are likely to have a poorer visual performance brought about by age related factors.

2.3.3 Accident reduction

Four major research studies were found to be of direct relevance to this work.

Vector study (1985)

A field study was undertaken in America to compare the accident rate of 2,000 trucks fitted with retro-reflective materials against a control group of non-reflectorised trucks. The study lasted two years during which the trucks accumulated a total of 106.44 million miles, 68% of which were travelled at night. A horizontal line marking to the side and a contour marking to the rear in alternating red and white were applied to half the trucks. Field trials verified the benefits of such markings. Of 612 relevant accidents (where another vehicle collided with the truck) 273 (45%) were considered to be conspicuity related. Comparing two groups

(treated and untreated) which had equal mileage and journey types, it was concluded that in daytime the retro-reflective group had fewer accidents (where something hit the truck) than non reflective group (with 16.3 % fewer accidents-daytime). In night time, there were 21.2 % fewer accidents. The results indicated that overall there was an 18% reduction in collisions in which the truck was struck and that this was statistically significant. Following this research the FHWA amended the Federal Motor Carrier Safety Regulations (FMCSRs) – see above.

University of Michigan, USA research (no date given)

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).

NHTSA HS 809 222. The effectiveness of retro reflective tape on heavy trucks, 2001.

The study, previously described above in section 2.3.2 collected accident data for Pennsylvania and Florida from 1997 to 1999. The study concludes that tape is highly effective in preventing crashes in all dark conditions (Lit and unlit by street lighting) reducing accidents by 29% and especially in dark-unlit conditions in which tape is effective in reducing accidents by 41%. When the two sets of data (Pennsylvania and Florida) are pooled the tape does not have a significant effect on preventing crashes in dark but lit, dawn or dusk conditions, resulting in 3% increase in accidents in these conditions (positive values in table 2 present the reduction in accidents and negative values present the percentage increase in accidents, refer to Table 2).

Table 2. Retro reflective tape effectiveness in different light conditions (% reduction in accidents)

Lighting conditions	Pennsylvania	Florida	Pooled data
Dark	38 %	18 %	29%
Dark-not-lighted	44 %	37 %	41%
Dark but lighted, dawn and dusk	19 %	-18 %	-3%

SWOV research 2002

SWOV in the Netherlands conducted a cost benefits analysis of the large scale introduction of retro reflective contour or line markings. Their study showed that the introduction of the tape would have a positive road safety effect, but that this estimated road safety effect was smaller than anticipated due to the relatively small number of accidents involving conspicuity as a primary causal factor. Every year there are about 9 deaths and 83 serious injury casualties in the Netherlands as a result of collisions against the flank or rear of trucks during twilight and night-time hours. The report states that complete introduction of retro-reflecting contour marking is expected to result in 2-3 fewer deaths and 20-30 fewer in-patients per year. It states that the cost effectiveness, in the terms of the reduction of the number of casualties per amount invested, in comparison with other potential measures is rather low. They conclude that other measures which involve the same investment have a greater expected safety profit.

2.3.4 Summary

Research and accident statistics show that the use of tape is effective in terms of increasing visibility thresholds and reducing the number of accidents. From the literature review it can be concluded that the use of retro reflective tape marking is effective in preventing crashes in dark conditions (Vector study 21.2% and NHTSA study 29% reduction in accidents). The tape does not appear to significantly reduce crashes in dawn or dusk conditions. Contradictory results are reported in the literature for the effectiveness of retro reflective tape on HGVs in daylight conditions. In the NHTSA 2001 study it states that retro reflective tape will not significantly reduce crashes during daylight. Whereas the Vector 1985 study

reported that the use of retro reflective tape on the rear of trucks resulted in a 16.3% reduction in rear and side impact accidents that occurred in daylight.

Relative to clear conditions it was found that the presence of snow or rain reduced thresholds by approximately 50 to 70%, while fog decreased visibility by as much as 90%. There is consensus in the literature that retro reflective tape seems to have little value in fog. In addition, dirt will reduce the performance of the tape and only observers younger than 50 years are likely to gain benefit from viewing the tape at sufficient distances to prevent or reduce the severity of accidents.

ICE (1998) compared the relative performances of markings as specified in ECE 104 and ECE 70. Findings showed that contour marking as presented in ECE 104 are most visible. In addition their research shows that full contour markings are more effective than line markings.

The literature search did not find any relevant references regarding the use of retro reflective tape on the rear and side of minibuses, coaches or buses and its effects on accident figures. However, it is suggested that the overall effectiveness of retro reflective tape on buses or coaches in reducing accidents may be reduced due to buses and coaches being generally more visible than HGVs through the presence of internal lighting illuminating and making the vehicle more visible. However, such internal lighting may not be used on coaches/buses used for long distance journeys. Therefore although the characteristics of PSVs are different to HGVs it can be argued that tape on PSVs would have similar effects in dark conditions where internal lighting is not in use.

3 Method

3.1 Costs

Estimates for the cost of applying retro reflective tape in either line or full contour marking (as per ECE 104) on the side and rear of trucks between 3.5-7.5 tonnes, >7 tonnes, minibus and coaches/buses have been calculated based on quotes from relevant parties and 2003 vehicle parc data.

Costs calculated include;

- Fitting the tape (material and labour costs)
- Cost for applying tape to existing vehicles
- Annual costs for fitting tape to new vehicles

3.2 Benefits

To ascertain whether the use of retro reflective tape in conjunction with existing conspicuity aids on trucks, minibuses, and coach/buses in the UK is cost effective there is a need to gain data on the number of accidents that currently occur that are;

1. Conspicuity related, and

2. May have been prevented or enjoyed reduced severity from the use of line or contour retro reflective tape markings.

The literature review has established a specific set of poor conspicuity accident definition criteria. This study will use these criteria to filter accidents at the UK national level for 2003. This will give estimates of the number of relevant accidents in which poor conspicuity may have been a contributory factor. The literature review has also provided a second set of criteria which relate to the circumstances in which retro-reflective markings could provide a benefit. The application of the second level filter will further refine the estimation for the number of accidents that would have been prevented. This approach provides an important advance on all the previous estimates that have been reviewed.

From the literature review scenarios associated with poor conspicuity have been identified as those listed in Table 3

Table 3. Aspects associated with poor conspicuity

Area of impact	Driving manoeuvres	Weather conditions	Lighting conditions
• Rear impact • Side impact	• HGV making a U turn • Trucks reversing into or out of drives • HGV turning across traffic • Driving slowly in faster moving traffic • Parked stationary	• Rain • Fog • Snow	• Daylight • Dawn • Dusk • Dark

From the literature review circumstances where retro reflective tape will be effective have been identified as those listed in Table 4.

Table 4. Circumstances where retro reflective tape is effective

Area of impact	Weather conditions	Lighting conditions	Observer characteristics
• Slightly more effective at preventing rear than side impacts	• Clear • Rain	• Daylight • Dark	• Driver of colliding vehicle less than 50 years of age.

In addition the literature review provided data regarding the effectiveness of retro-reflective tape in different lighting conditions in terms of accident reduction values. These figures are summarised in Table 5.

Table 5.The percentage of accidents prevented by the use of retro reflective tape in certain lighting conditions

Lighting conditions	**Percentage of accidents prevented by the use of retro reflective tape markings**		
	Vector study 1985	NHTSA study 2001	Mean average percentage values
• Daylight	16.3%	0%	8.15%
• Dark	21.2%	29%	25.1%

The above criteria will be used in section 4.2 to filter and identify relevant cases from STATS 19 data. Calculations for the number of accidents and casualties that the introduction of tape may have prevented can then be made and subsequent calculations made regarding the cost / benefits of national introduction of ECE 104.

The use of the percentage level of the effectiveness of tape in certain conditions (gained from previous research,Table 5) only provides a rough guide and could lead to a slight over estimation of the number of accidents that may have been prevented by the use of retro reflective tape markings. This is because it assumes a conspicuity related cause in all accidents where the relevant conditions applied. In reality this will not have been the case. The percentage values for accident reduction are a result of American studies. It should be noted that there are differences between the US and the UK in terms of vehicles, road conditions, and HGV marking practices.

Accident reduction figures arising from studies analysing American data involve comparison of vehicles with contour marking (red and white tape) and without any retro reflective markings. Whereas in the UK use of reflectors and lighting on the rear and sides of HGV and rear retro reflective marking as prescribed in ECE 70 are already required for some class of vehicles to improve their conspicuity. Therefore the effect of the addition of retro reflective tape markings may not result in similar reduction rates as those observed in America.

However the literature search did not find any studies / figures regarding the effectiveness of retro-reflective tape for UK vehicles. Furthermore, there appear to be no studies pertaining to accident reduction rates following the introduction of

ECE 70. However, empirical research conducted by ICE in 1998 found that ECE 104 contour markings did perform significantly better than ECE 70 markings.

Therefore it is proposed that the percentage reduction rates from the American studies be used to provide a best estimate for the effectiveness of the tape, with the acknowledgement that this may result in an over estimation in the number of accidents that the use of retro reflective tape markings may prevent.

To account for a possible over estimation a more detailed analysis of a small subset of STATS 19 data was conducted. This consisted of retrieving individual cases from Nottingham police accident records that satisfy the conspicuity criteria. An assessment of each individual case was made as to whether retro-reflective would have prevented the accident or not. This judgment was based on reviewing information that may be additional to that provided by STATS 19, i.e. information from witness statements and police statements. Findings from this small sample of detailed case studies was then used to ascertain to what extent the accident reduction figures (as described in Table 5) are over or under estimating accident reduction rates through the use of retro reflective tape markings.

4 Cost benefits analysis

The following estimates for cost benefits consider both line and full contour marking forms (as per ECE 104) on the side and rear of trucks between 3.5 -7.5 tonnes, >7.5 tonnes, minibus and coaches/buses. It calculates the cost benefits for reducing accidents that occurred in 2003.

It has not been possible to split the class of HGV further to incorporate a class of HGV defined as greater than 12t as STATS 19 does not have a code for this classification (it only has a code for greater than 7.5t). Therefore all costs have been calculated for class of vehicle as currently defined and coded for in STATS 19. These are listed in Table 6.

Table 6. Vehicle classes as defined in STATS 19 coding system

Vehicle type	Description
Heavy commercial vehicles	3.5 to 7.5t
Heavy commercial vehicles	>7.5 t
Minibus	8-16 passenger seats
Bus and coach	> 17 passenger seats

4.1 Estimation of costs of applying markings

4.1.1 Material costs

Material costs have been estimated for each vehicle type and are based on consultations with operators, fitters and manufacturers of vehicle conspicuity retro reflective tape. The prices quoted for retro reflective vehicle conspicuity tape of 50mm width ranged from £2.05 to £3.80 per metre. The average cost for tape is £3.18 per metre. The length of tape required for each vehicle type has been calculated using average vehicle lengths. The vehicle dimensions used for each vehicle class are listed below in Table 7.

Table 7. Material costs for line and full contour markings for different class of vehicle.

Vehicle type		3.5–7.5 t	>7.5t	Minibus	Coach / Bus
Vehicle dimensions	Length (l)	5m	12.2m	5m	11m
	Width (w)	2.5m	2.5m	2.5m	2.5m
	Height (h)	3m	3m	3m	3m
Total length of tape required	Line markings (2l+1w)	12.5m	26.9m	12.5m	24.5m
	Full contour markings (4l+2w +6h)	43m	71.8m	43m	67m
Total cost of materials (based on £3.18 per metre)	Line markings	£39.8	£85.65	£39.8	£78
	Full contour markings	£136.74	£228.32	£136.91	213.33

4.1.2 Labour fitment costs

New vehicles

The time taken to fit the markings to NEW vehicles has been assumed will take place as part of the production process and has been estimated at

- 2 hours for line marking for all sizes of vehicle
- 4 hours for full contour marking for all sizes of vehicle

The aforementioned labour costs are based on consultations with fitters, manufacturers of vehicle conspicuity retro reflective tape.

The prices quoted ranged from £25 per hour to £60 per hour. The average hourly rate is £40. This equates to £80 to fit line markings and £160 to fit full contour markings to new vehicles.

Existing vehicles - Retro fitting

Quotes from tape fitters-

- There is a significant difference in cost and fitting of new fit and retro fitting of tape. But this varies from vehicle to vehicle. Retro fitting requires cleaning off of residue glue.

- There is a time and cost difference for retro fitting tape, but can not advise as depends on individual vehicles. The stripping and removal of residual glue requires solvent as adhesive from old tape can be very strong.

- There is little difference in new fit or retro fitting other than the need to ensure that the area to receive the marking is thoroughly clean and therefore old vehicles may take a little longer.

It appears that retro fit will be slightly more expensive to do. This is mainly due to increased time required to prepare the vehicles' surface. For example, in instances where old tape has to be removed or the vehicle needs a thorough clean (this is particularly likely when the vehicle is old).

Therefore an additional hour has been allocated for retro fitting line markings and an additional 2 hours to fit contour markings to allow for additional costs in time and materials. This equates to £120 to retro fit line markings and £240 to retro fit contour markings.

4.1.3 Lost operational usage

New vehicles

It is assumed that the fitting of tape to a new vehicle would occur as an additional part of the production process. Therefore, overall, the lost operational usage of the vehicle while tape is being fitted is likely to be minimal and has not been included in this cost estimate.

Existing vehicles - Retro fitting

An estimate of the commercial costs associated with loss of vehicle operation during fitting tape have been made based on figures gained from the Road Haulage Association for costs incurred during time off road due to repairs. Figures presented in Table 8 represent depreciation, wages, licences, insurance, goods in transit, interest on capital and overhead per vehicle per day. The average off road costs that are used in further calculations are presented inTable 9.

Table 8. Off road costs (Road Haulage Association)

Vehicle type	3.5t	7.5t	13t	18t 3 axle	26t rigid	32t rigid	38t combi	44t combi
Cost per day	£126	£152	£170	£187	£213	£234	£249	£282

Table 9. Estimated average off road costs

Vehicle type	3.5 to 7t	< 7t	Minibus	Coach/bus
Estimated average off-the-road costs for fitting retro fitting line markings (half a day)	£69.5	£106	£69.5	£106
Estimated average off-the-road costs for retro fitting contour marking of tape (1 day)	£139	£212	£139	£212

4.1.4 Number of vehicles to mark up

Data from Transport Statistics Great Britain 2004 has been used to provide figures for the size of the current national fleet of trucks. The number of registered vehicles for 2003 (parc figures) within each vehicle class are presented in Table 10. These figures comprise rigid vehicles and the number of trailers used on articulated units in 2003. Data from the Society of Motor Manufacturers and Traders (SMMT) has been used to provide figures for the number of newly registered vehicles for 2001-2003. Table 11 presents the figures for newly registered HGVs and Table 12 presents the figures for newly registered minibus and coaches/buses.

Table 10. The parc figures for 2003

Vehicle type	GVW	2003
Heavy commercial vehicles	3.5 to 7.5t	155,600
Heavy commercial vehicles	>7.5 t	402,701
Minibus	up to 17 passenger seats	91,357
Bus and coach	> 17 passenger seats	97,815

Table 11. Newly registered vehicles per year (2001-2003)

Vehicle type	GVW	2001	2002	2003	Mean average
Heavy commercial vehicles (Rigid and articulated vehicles)	3.5t to 7.5t	19,577	17,755	18,289	18,540
Heavy commercial vehicles (Rigid and articulated vehicles)	>7.5t	35,996	34,165	37,301	35,821
	Total	**55,573**	**51,920**	**55,590**	**54,361**

Table 12. Newly registered vehicles per year (2002 – 2003)

Vehicle type	Number of passengers	2002	2003	Mean average
Mini bus	Up to 17 passenger seats	638	974	806
Bus and coach	> 17 passenger seats	3,974	4,290	4,132

To enable cost comparison between marking vehicles with line markings to the side and rear to contour markings to the side and rear, HGV vehicles have been split into two categories based on body type. Body type category A consists of vehicles with a shape that will only enable line markings to be applied and category B consists of vehicles with a shape that would enable either line markings or

contour markings to be fitted. Figures presented in Table 13 have been compiled from Transport Statistics Great Britain 2004 - currently licensed vehicles in 2003.Table 14 presents the number of newly registered vehicles within each body type category.

Table 13. The number of existing vehicles in 2003 of each body type category

Body type categories	A	B
	Only line marking possible	Both line or contour markings possible
3.5- 7.5t	56,700	98,900
>7.5t	258,486	144,215
Minibus	0	91,357
Coach / bus	0	97,815

Table 14. The average number of newly registered vehicles per year of each body type category

Body type categories	A	B
	Only line marking possible	Both line or contour markings possible
3.5- 7.5t	6,749	11,791
>7.5t	22,997	12,824
Minibus	0	806
Coach/bus	0	4,132

4.1.5 Replacement costs

Since retro-reflective materials have an average life of seven years and the Freight Transport Association estimate that the majority of trucks have a '1st' life of 7 years, before being sold on. Replacement costs due to the materials reaching the end of their life will be incurred by 2nd users. These costs have been considered in section 5 for retro fitting tape.

4.1.6 Total costs of applying tape to vehicles

Two comparative calculations of fitting costs have been conducted. One presents the costs for fitting all vehicle body types (A and B) with line markings. The second presents the costs for fitting contour marking to B category vehicles that are suitable to have contour markings and the remaining vehicles being fitted with line markings. These two different calculations have been undertaken for retro fitting tape to the existing vehicle parc of 2003 (Table 15 and Table 16) and for fitting tape to 1 years worth of newly registered vehicles (Table 17 and Table 18).

4.1.7 Total costs for retro fitting tape to existing vehicle parc

Estimated costs incurred to fit existing vehicles in 2003 are presented in

Table 15 (Line markings) and Table 16 (Full contour markings).

Table 15. Estimate for costs to retro fit line markings to existing vehicles in 2003

Line markings						
Vehicle type	**Body type**	**Materials**	**Labour**	**Off road costs**	**Number of vehicles 2003**	**Total cost for fitting new vehicles** (Material + labour) number of vehicles
3.5 to 7.5t	A and B	£39.8	£120	£69.5	155,600	£35,679,080
>7.5 t	A and B	£85.65	£120	£106	402,701	£125,501,767
Minibus		£39.8	£120	£69.5	91,357	£20,948,160
Coach/ bus		£78	£120	£106	97,815	£29,735,760

Table 16. Estimate for costs to retro fitting full contour markings to all existing vehicles in 2003

Contour (where possible) and Line markings (where contour not possible)						
	Body type and markings	**Materials**	**Labour**	**Off road costs**	**Number of vehicles 2003**	**Total cost for fitting new vehicles** (Material + labour) number of vehicles
3.5 to 7.5t	B (contour)	£136.74	£240	£139	98,900	£67,948,646
	A (line)	£39.8	£120	£139	56,700	
>7.5 t	B (contour)	£228.32	£240	£212	144,215	£206,069,027
	A (line)	£85.65	£120	£212	258,486	
Minibus	(All contour)	£136.91	£240	£139	91,357	£47,131,990
Coach/bus	(All contour)	£213.33	£240	£212	97,815	£65,079,254

4.1.8 Total costs for fitting tape to newly registered vehicles

Table 17. Estimated total costs of applying line markings to newly registered vehicles per year.

Line markings						
Vehicle type	**Body type**	**Materials**	**Labour**	**Off road costs**	**Average number of new vehicles per year (TSGB)**	**Total cost for fitting new vehicles** (Material + labour) number of vehicles
3.5 to 7.5t	A and B	£39.8	80	0	18,540	£2,221,092
>7.5 t	A and B	£85.65	80	0	35,821	£5,933,749
Minibus		£39.8	80	0	806 (SMMT)	£96,559
Coach/ bus		£78	80	0	4,132 (SMMT)	£652,856

Table 18. Estimated total costs of applying full contour markings to newly registered vehicles of body types where contour marking is possible and to vehicle where only line markings are possible per year

Contour (where possible) and Line markings (where contour not possible)						
Vehicle type	**Body type**	**Materials**	**Labour**	**Off road costs**	**Average number of new vehicles per year (TSGB)**	**Total cost for fitting new vehicles** (Material + labour) number of vehicles
3.5 to 7.5t	B (Contour)	£136.74	£160	0	11,791	£4,307,391
	A (Line)	£39.8	£80	0	6,749	
>7.5 t	B (Contour)	£228.32	£160	0	12,824	£8,789,269
	A (Line)	£85.65	£80	0	22,997	
Minibus	(All contour)	£136.91	£160	0	806 (SMMT)	£239,309
Coach/ bus	(All contour)	£213.33	£160	0	4132 (SMMT)	£1,542,599

4.2 Estimation of accident costs

4.2.1 Accident involvement of vehicle by class

For the purposes of this report we are interested in accident cases that occurred in 2003 where a vehicle collided into the side or rear of a truck, minibus or coach/bus. However this may include like vehicle colliding with like i.e. a truck colliding into another truck, and this would lead to duplication in the data set. Therefore to avoid the duplication of accident cases used in the analysis, the cases included have been restricted to accidents involving only 1 HGV and at least one other vehicle, resulting in an analysis of 8,282 HGV (reduced from 12,205 HGV accident cases), 1,011 minibus and 5,109 coach/bus accident cases (all cases where the HGV, minibus or coach/bus was the vehicle being struck). Table 19 shows the breakdown of these accidents in terms of areas of impact and resultant number of casualties by severity of their injury. Accidents of particular relevance to this study are side and rear impacts.

Table 19. Number of single HGV accidents (where another vehicle struck the truck) and casualty figures in relation to vehicle type and area of impact

Vehicle type	Area of impact	Number of cases	Number of injuries - 2003		
			Fatal	Serious	Slight
3.5t to 7.5t	Front	734	25	117	963
	Side	426	7	58	521
	Rear	246	3	26	310
	Total	**1715**	**40**	**260**	**2154**
> 7.5 t	Front	3319	173	530	4298
	Side	2551	71	369	2942
	Rear	1006	40	191	1216
	Total	**8135**	**337**	**1317**	**9932**
Minibus	Front	467	10	102	817
	Side	223	11	34	359
	Rear	140	3	19	234
	Total	**1011**	**27**	**186**	**1660**
Bus and coach	Front	1990	34	280	3261
	Side	1184	9	108	1548
	Rear	424	1	108	1548
	Total	5109	54	612	7632

4.2.2 Estimate of the number of accidents and causalities where poor conspicuity is a possible casual factor.

In the previous cost benefit analysis conducted by ICE (1998) figures for calculating the number of conspicuity related accidents and casualties were based on findings from a study conducted by MIRA in 1980. However the MIRA study looked at a small sample of 200 accidents that occurred in 1980.

To further increase the reliability of estimates made regarding the number of conspicuity related accidents and casualties in this report, the following filtering method for accident case identification has been employed. This filtering process applies findings from more recent studies (1985, 1997 and 2001 as described in section 2) and has been applied to UK accident data for 2003.

The first filter pulls out cases where conspicuity may have been a causal factor. The second filter further refines these to identify cases where retro-reflective tape is likely to have been effective had it been applied.

Filter method

Filter 1
Identification of conspicuity related accidents

Accidents cases from STATS 19 that are likely to be conspicuity related have been selected based on the area of impact (side and rear) and whether the case involves any of the following factors (Table 20).

Table 20. Factors associated with poor conspicuity

Weather conditions	Lighting conditions
• Rain • Fog • Snow	• Daylight • Dawn • Dusk • Dark

Filter 2
Identification of conspicuity related cases where retro reflective tape may have been effective.

A second filter using criteria for when retro-reflective tape is likely to be effective (Table 21) provides the number of accident cases in which tape may have prevented the accident.

Table 21. Circumstances where retro reflective tape is effective

Weather conditions	Lighting conditions	Observer characteristics
• Clear • Rain	• Daylight • Dark	• Driver of colliding vehicle less than 50 years of age

Combination of the findings from filters 1 and 2

The matrix below (Table 22) summarises how cases have been identified as possibly having conspicuity as a casual factor and whether retro reflective tape would have been effective (cells highlighted in grey). This method of identification has been used to filter all side and rear impacts that may have been conspicuity related and where retro-reflective tape may have been effective in preventing the accident.

Table 22. Matrix highlighting combinations of lighting and weather conditions where accidents likely to be conspicuity related may occur and whether retro-reflective tape markings in these instances is likely to be effective.

	Daylight	Dark
Fine	Possibly conspicuity related (tape effective)	Possibly conspicuity related (tape effective)
Rain	Possibly conspicuity related (tape effective)	Possibly conspicuity related (tape effective)
Snow	Possibly conspicuity related (tape not effective)	Possibly conspicuity related (tape not effective)
Fog	Possibly conspicuity related (tape not effective)	Possibly conspicuity related (tape not effective)

Results

Table 23 to Table 26 present the number of accidents that occurred in 2003 that fell within the relevant categories for each vehicle type.

Table 23. Number of accidents involving impacts into side and rear of 3.5 to 7.5 t HGVs in 2003

	Lighting conditions	Daylight	Dark
Severity of accident	**Weather conditions**		
Fatal	**Fine**	7	1
	Rain	0	0
Serious	**Fine**	48	10
	Rain	5	3
Slight	**Fine**	424	64
	Rain	60	21

Table 24. Number of accidents involving impacts into side and rear of >7.5t HGV in 2003

	Lighting conditions	Daylight	Dark
Severity of accident	**Weather conditions**		
Fatal	**Fine**	60	29
	Rain	7	6
Serious	**Fine**	301	101
	Rain	45	13
Slight	**Fine**	2109	419
	Rain	247	76

Table 25. Number of accidents involving impacts into side and rear of minibus in 2003

	Lighting conditions	Daylight	Dark
Severity of accident	**Weather conditions**		
Fatal	**Fine**	5	2
	Rain	0	0
Serious	**Fine**	24	7
	Rain	3	4
Slight	**Fine**	207	54
	Rain	27	14

Table 26. Number of accidents involving impacts into side and rear of coach/bus in 2003

	Lighting conditions	**Daylight**	**Dark**
Severity of accident	**Weather conditions**		
Fatal	**Fine**	5	5
	Rain	0	0
Serious	**Fine**	96	27
	Rain	4	2
Slight	**Fine**	1085	191
	Rain	111	33

Table 27. Total number of side and rear impact accidents that fall within conspicuity and effective tape categories in 2003.

Vehicle type	Number of accidents by severity class			
	Fatal	Serious	Slight	Total number of accident cases
3.5t - 7t	8	66	569	643
> 7 t	102	460	2851	3413
Minibus	7	38	302	347
Coach/bus	10	129	1420	1559
Total	127	693	5142	

Applying accident reduction factor

The literature review provided figures for the percentage of accidents that retro-reflective tape would prevent in certain lighting conditions (Table 28). These values also take account of driver age. Table 29 presents the resultant estimated number of accidents that retro reflective tape would have prevented. These have been calculated by applying the mean values of the reduction percentages reported in the two studies.

Table 28.The percentage of accidents prevented by the use of retro reflective tape in certain lighting conditions

Lighting conditions	**Percentage of accidents prevented by the use of retro reflective tape markings**		
	Vector study 1985	NHTSA study 2001	Mean average percentage values
• Daylight	16.3%	0%	8.15%
• Dark	21.2%	29%	25.1%

Table 29. Estimated number of accidents that would have been prevented by the use of retro reflective tape markings.

Vehicle type	Number of accidents by severity class			
	Fatal	Serious	Slight	Total number of accidents
3.5t - 7t	0.8	7.6	60.8	69.2
> 7 t	14.3	56.8	316.3	387.4
Minibus	0.9	5	36.14	42.04
Coach/bus	1.7	15.4	145.9	163
Total	17.7	84.8	559.14	

The above figures for the number of accidents prevented each year from the use of retro reflective tape have been calculated from accident data arising from a full vehicle parc. Therefore these figures present an estimate for the number of accidents that would be prevented if the whole fleet of vehicles (i.e. Total vehicle parc) were treated with retro reflective tape. Therefore a further reduction factor needs to be applied to calculate the number of accidents prevented through the partial introduction of retro reflective marking i.e. to just new vehicles. To provide an estimate that reflects the number of treated vehicles the following procedure has been applied.

Accident figures in Table 29 (representing accident estimates for the whole vehicle parc of 2003) have been reduced in proportion to the number of vehicles that would be treated. Table 30 presents the calculation of the second reduction factor

for each class of vehicle when only newly registered vehicles are considered and the subsequent number of estimated accidents that would be prevented.

Table 30. Number of accidents prevented when only new vehicles are fitted with retro reflective tape

	3.5 – 7.5 t	>7.5t	Minibus	Coach / bus
Percentage of new vehicles in vehicle parc	11.9	8.9	0.88	4.22
Number of accident cases prevented in year one				
Fatal	0.1	1.27	0.007	0.07
Serious	0.9	5.06	0.04	0.65
Slight	7.2	28.15	0.32	6.16

4.2.3 Estimates of casualty and accident related savings

In order to assess the benefits of the introduction of the use of retro reflective tape markings an estimate on the value of savings in terms of casualties and other accident related costs is required. Since 1988 the Department for Transport has valued road accident fatalities using a willingness to pay approach. Subsequently there are set values for calculating the costs for the different level of accident severity, fatal, serious and slight. Costs are estimated for casualties and injury accidents reported by the police, and for an estimated number of damage only accidents. A report by TRL (Hopkins and Simpson, 1995) outlines what these costs include and how the costs are estimated. A breakdown of the aspects of relevance to this study are presented below (taken from Hopkins and Simpson, 1995).

Casualty related costs

Casualty related costs include;

- Human costs which reflect the non resource element of the cost i.e. the pain and distress suffered by accident victims, their relatives and friends, and in the case of fatalities, the intrinsic loss of enjoyment of life, beyond the consumption of food and services.
- Lost output
- Medical costs

Accident related costs

Accident related costs are estimated for each level of severity; the accident severity is defined as the severity of the most severely injured casualty in that accident.

Accident related costs include;

- Damage to vehicle or vehicles involved and to other third party members. Damage costs include related costs such as engineers and assessor fees, the amount of excess on the insurance policy and payment made to loss of use of the vehicle and for hire of a replacement vehicle.
- Insurance and administration costs.
- The cost of police time in dealing with and investigating the accident. The costs also take account of the time spent by administrative support teams.

The two types of cost (casualty related and accident related) are considered together to provide average cost per accident (refer to Table 31). Figures presented in Table 31 are taken from Road Accidents Great Britain 2003 which provides estimates for the average costs per accident. The costs per accident are based on the average number of casualties in an accident. Hopkins (1995) states that the value cost per accident should be used to calculate the potential benefits to society of reducing the risk of accidents and injuries. Therefore these values have been used as the basis for calculating estimated saving from the use of retro reflective tape.

Table 31. Costs per accident (Road Accidents Great Britain 2003)

Accident / Casualty type	Costs per accident
Fatal	1,492,910
Serious	174,520
Slight	17,520

Potential saving per year in terms of accident costs (based on 2003 accident data) are presented for each vehicle class in Table 32 (based on total vehicle parc) and Table 33 (based on newly registered vehicle parc).

Table 32. Accident savings based on total vehicle parc

Accident severity	Vehicle type			
	3.5 – 7.5t	**>7.5**	**Minibus**	**Coach / bus**
Fatal				
Estimated number of accidents prevented per year	0.8	14.3	0.9	1.7
Cost per accident	£1,492,910	£1,492,910	£1,492,910	£1,492,910
Estimated accident savings per year	£1,194,328	£21,348,613	£1,343,619	£2,537,947
Serious				
Estimated number of accidents prevented per year	7.6	56.8	5	15.4
Cost per accident	£174,520	£174,520	£174,520	£174,520
Estimated accident savings per year	£1,326,352	£9,912,736	£872,600	£2,687,608
Slight				
Estimated number of accidents prevented per year	60.8	316.3	36.14	145.9
Cost per accident	£17,520	£17,520	£17,520	£17,520
Estimated accident savings per year	£1,065,216	£5,541,576	£633,173	£2,556,168
Total accident savings per year				
Estimate saving	£3,585,896	36,802,925	£2,849,392	£7,781,723

Table 33. Accident savings based on partial vehicle parc (1 year of newly registered vehicles)

Accident severity	Vehicle type			
	3.5 – 7.5 t	**>7.5t**	**Minibus**	**Coach / bus**
Fatal				
Estimated number of accidents prevented per year	0.1	1.27	0.007	0.07
Cost per accident	£1,492,910	£1,492,910	£1,492,910	£1,492,910
Estimated accident savings per year	£149,291	£1,895,996	£10,450	£104,504
Serious				
Estimated number of accidents prevented per year	0.9	5.06	0.04	0.65
Cost per accident	£174,520	£174,520	£174,520	£174,520
Estimated accident savings per year	£157,068	£883,071	£6,980	£113,438
Slight				
Estimated number of accidents prevented per year	7.2	28.15	0.32	6.16
Cost per accident	£17,520	£17,520	£17,520	£17,520
Estimated accident savings per year	£126,144	£493,188	£5,606	£107,923
Total accident savings per year				
Estimate savings	£432,503	£3,272,255	£23,036	£325,865

5 Cost benefit calculations

Assumptions

Research has shown that line and full contour markings differ in their degree of effectiveness, with full contour markings having a higher performance. However there is currently insufficient data to provide an estimate on how this difference will affect the number of accidents prevented by line markings compared to contour markings. Due to this lack of data, savings from the use of line markings have been calculated based on the assumption that line markings perform equally as well as contour markings i.e. preventing the same estimated number of accidents. The estimated savings presented here for line markings are therefore likely to be an over estimate.

The cost benefits for retrospectively applying retro reflective markings to all HGV, minibuses and coaches have been calculated for a period spanning 7 years (the life span of the tape) and is based on the following three assumptions.

- Retro reflective tape has a life span of 7 years.
- Vehicle parc figures will remain constant (number of newly registered vehicle = number of decommissioned vehicle each year).
- Newly registered vehicle numbers will remain constant at figures presented in tables 7 and 8, section 4.1.4 (based on average figures of 2000-2003)
- Accident figures estimated for 2003 are sustained for the following 7 years (based on costs that would occur if tape not introduced).

5.1 Line markings – cost benefit

5.1.1 Fitting line markings to existing vehicle parc 2003

Table 34. Line marking –cost benefits for retro fitting tape to existing vehicle parc of 2003

Vehicle type	3.5 – 7.5 t	>7.5 t	Minibus	Coach / bus
Costs	-35,679,080	-125,501,767	-20,948,160	-29,735,760
Benefits	3,585,896	36,802,925	2,849,392	7,781,723
Total	-£32,093,184	-£88,698,842	-£18,098,768	-£21,954,037
Overall monetary	Cost	Cost	Cost	Cost

5.1.2 Fitting line markings to newly registered vehicles

The costs of fitting tape to new vehicles is considerably lower than the costs incurred when retro fitting tape. This is due to the reduced time taken to fit the tape and lack of off road costs. It should also be noted that as the years progress and the proportion of vehicles fitted with retro reflective tape increases the number of accidents prevented will also increase therefore showing an increase in benefits. However it should be noted that after 7 years the costs will also increase due to the need to start replacing tape on the earlier marked vehicles and this will incur the costs of retro fitting.

Table 35. Line marking – HGVs 3.5 – 7.5t cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Total	Cumulative total and overall cost or benefit?
Year 1	-2,221,092	432,503	-1,788,589	
Year 2	-2,221,092	865,006	-1,356,086	-£3,144,675
Year 3	-2,221,092	1,297,509	-923,583	-£4,068,258
Year 4	-2,221,092	1,730,012	-491,080	-£4,559,338
Year 5	-2,221,092	2,162,515	-58,577	-£4,617,915
Year 6	-2,221,092	2,595,018	373,926	-£4,243,989
Year 7	-2,221,092	3,027,521	806,429	-£3,437,560
Year 8	-2,221,092	3,460,024	1,238,932	-£2,198,628 (+costs to start replacing tape on year 1 vehicles = -£4,251,222)

Table 36. Line marking – HGVs > 7.5t cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Total	Cumulative overall monetary cost or benefit?
Year 1	-5,933,749	3,272,255	-2,661,494	
Year 2	-5,933,749	6,544,510	610,761	-£2,050,733
Year 3	-5,933,749	9,816,765	3,883,016	£1,832,283
Year 4	-5,933,749	13,089,020	7,155,271	£8,987,554
Year 5	-5,933,749	16,361,275	10,427,526	£19,415,080
Year 6	-5,933,749	19,633,530	13,699,781	£33,114,861
Year 7	-5,933,749	22,905,785	16,972,036	£50,086,897
Year 8	-5,933,749	26,178,040	20,244,291	+£70,331,188 BENEFIT (Although at this point onwards will need to deduct costs to start replacing tape on year 1 vehicles= £11,163,615)

Table 37. Line marking – Minibuses cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Total	Cumulative overall monetary cost or benefit
Year 1	-96,559	23,036	-73,523	
Year 2	-96,559	46,072	-50,487	-£124,010
Year 3	-96,559	69,108	-27,451	-£151,461
Year 4	-96,559	92,144	-4,415	-£155,876
Year 5	-96,559	115,180	18,621	-£137,255
Year 6	-96,559	138,216	41,657	-£95,598
Year 7	-96,559	161,252	64,693	-£30,905
Year 8	-96,559	184,288	87,729	+£56,824 BENEFIT (Although at this point will need to deduct costs to start replacing tape on year 1 vehicles = £184,816)

Table 38. Line marking – Coaches/buses. cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Total	Cumulative overall monetary cost or benefit
Year 1	-652,856	325,865	-326,991	
Year 2	-652,856	651,730	-1,126	-£328,117
Year 3	-652,856	977,595	324,739	-£3,378
Year 4	-652,856	1,303,460	650,604	£647,226
Year 5	-652,856	1,629,325	976,469	£1,623,695
Year 6	-652,856	1,955,190	1,302,334	£2,926,029
Year 7	-652,856	2,281,055	1,628,199	£4,554,228
Year 8	-652,856	2,606,920	1,954,064	£6,508,292 BENEFIT (Although at this point will need to deduct costs to start replacing tape on year 1 vehicles= £1,256,128)

5.2 Contour marking – cost benefit

5.2.1 Fitting contour markings to existing vehicle parc 2003

Table 39. Contour marking – cost benefits for fitting tape to existing vehicle parc of 2003

Vehicle type	**3.5 – 7 t**	**>7 t**	**Minibus**	**Coach / bus**
Costs - Existing parc	-£67,948,646	-£206,069,027	-£47,131,990	-£65,079,254
Benefits	£3,585,896	£36,802,925	£2,849,392	£7,781,723
Total	-£64,362,750	-£169,266,102	-£4,428,598	-£57,297,531
Overall monetary	COST	COST	COST	COST

5.2.2 Fitting full contour markings to newly registered vehicles

Table 40. Contour marking – HGVs 3.5 – 7.5t cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Cumulative total	Cumulative overall monetary cost or benefit
Year 1	-4,307,391	432,503	-3,874,888	
Year 2	-4,307,391	865,006	-3,442,385	-£7,317,273
Year 3	-4,307,391	1,297,509	-3,009,882	-£10,327,155
Year 4	-4,307,391	1,730,012	-2,577,379	-£12,904,534
Year 5	-4,307,391	2,162,515	-2,144,876	-£15,049,410
Year 6	-4,307,391	2,595,018	-1,712,373	-£16,761,783
Year 7	-4,307,391	3,027,521	-1,279,870	-£18,041,653
Year 8	-4,307,391	3,460,024	-847,367	-£18,889,020
				(+costs to start replacing tape on year 1 vehicles = -£8,097,691)

Table 41. Contour marking – HGVs > 7.5t cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Cumulative total	Cumulative overall monetary cost or benefit
Year 1	-8,789,269	3,272,255	-5,517,014	
Year 2	-8,789,269	6,544,510	-2,244,759	-£7,761,773
Year 3	-8,789,269	9,816,765	1,027,496	-£6,734,277
Year 4	-8,789,269	13,089,020	4,299,751	-£2,434,526
Year 5	-8,789,269	16,361,275	7,572,006	£5,137,480
Year 6	-8,789,269	19,633,530	10,844,261	£15,981,741
Year 7	-8,789,269	22,905,785	14,116,516	£30,098,257
Year 8	-8,789,269	26,178,040	17,388,771	£47,487,028
				BENEFIT (Although at this point will need to deduct costs to start replacing tape on year 1 vehicles= -£18,329,121

Table 42. Contour marking – Minibus cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Cumulative total	Cumulative overall monetary cost or benefit
Year 1	-239,309	23,036	-216,273	
Year 2	-239,309	46,072	-193,237	-£409,510
Year 3	-239,309	69,108	-170,201	-£579,711
Year 4	-239,309	92,144	-147,165	-£726,876
Year 5	-239,309	115,180	-124,129	-£851,005
Year 6	-239,309	138,216	-101,093	-£952,098
Year 7	-239,309	161,252	-78,057	-£1,030,155
Year 8	-239,309	184,288	-55,021	-£1,085,176
				(+costs to start replacing tape on year 1 vehicles = -£415,824)

Table 43. Contour marking– Coaches/buses cost benefits of fitting tape to newly registered vehicles over 8 year period

Vehicle type	Cost	Benefits	Cumulative total	Cumulative overall monetary cost or benefit
Year 1	-1,542,599	325,865	-1,216,734	
Year 2	-1,542,599	651,730	-890,869	-£2,107,603
Year 3	-1,542,599	977,595	-565,004	-£2,672,607
Year 4	-1,542,599	1,303,460	-239,139	-£2,911,746
Year 5	-1,542,599	1,629,325	86,726	-£2,825,020
Year 6	-1,542,599	1,955,190	412,591	-£2,412,429
Year 7	-1,542,599	2,281,055	738,456	-£1,673,973
Year 8	-1,542,599	2,606,920	1,064,321	-£609,652
				(+costs to start replacing tape on year 1 vehicles = -£2,749,144)

6 Discussion

Due to limitations regarding relevant accident and tape performance data it is anticipated that over and underestimates regarding the calculation of benefits have occurred.

The following over and under estimations may have been made for calculating the benefits and these should be noted.

6.1 Potential over estimate of benefits

Accident reduction factors for tape effectiveness were based on studies using American data.

Accident reduction figures arising from studies analysing American data involved comparison of the accident involvement of vehicles with contour marking (red and white tape) and those with no retro reflective markings. Whereas in the UK reflectors and lighting on the rear and sides of HGV and rear retro reflective marking as prescribed in ECE 70 are already required for some classes of vehicles to improve their conspicuity. Therefore the effect of the addition of retro reflective tape markings may not result in similar reduction rates as those observed in America and the estimate is likely to be optimistic in this respect.

Lack of data regarding the performance of line markings

Research has shown that line and full contour markings differ in their degree of effectiveness, with full contour markings having a higher performance. However there is currently insufficient data to provide an estimate on how this difference will affect the number of accidents prevented by line markings compared to contour markings. Due to the lack of data, savings from the use of line markings have been calculated with the assumption that the line markings perform as well as contour markings i.e. preventing the same estimated number of accidents. The estimated savings presented for line markings therefore might present a slight over estimate.

Urban buses

Buses used solely in towns for scheduled services over short distances will be travelling predominantly with internal lighting illuminated and thus the accident reduction for this subset of buses and coaches will be optimistic.

6.2 Potential underestimate in the cost per accident.

Compared to other vehicle type accidents the consequences of crashes involving HGVs are typically greater in terms of the number and severity of casualties, vehicles involved, the duration of the incident and impact on delays. However, the current analysis uses 'average' accident cost figures and the average cost of HGV accidents are likely to be slightly greater than this value. The estimation is likely to be a conservative estimate in this respect.

6.3 Comparing results from ICE 1998 cost benefit analysis to 2003 cost benefits analysis

The findings from this report differ to those presented in the ICE 1998 cost benefit analysis, with ICE 1998 reporting an estimated cost of £6 million for fitting tape to HGVs. The current report considers applying tape to new and current vehicles (retro fitting tape) separately. This report shows a cost for retrofitting tape to the total current vehicle parc and a benefit for fitting retro reflective tape in line marking format to new HGVs >7.5t, minibuses and coaches/buses. Differences between the 1998 and current report in estimated cost/benefit are likely to result from differences in calculation procedures in determining the number of relevant vehicle accident cases and changes in accident cost values.

Aspects of interest of the two calculation procedures are summarised below;

- The ICE 1998 report based its cost benefit analysis on fitting contours to the rear and line markings to the side, where as this report provides separate estimates for

    1. fitting line markings to the side and rear

    2. fitting full contour markings to the side and rear.

- In the 1998 report the number of vehicles do not differ significantly from those used in this report. The 1998 report uses vehicle figures for 1995, this report uses figures for 2003 (Table 44).

Table 44. HGV parc figures for 1995 and 2003.

	1995 (unspecified weight)	2003 (total HGVs >3.5t)
Newly registered HGVs	52,261	55,590
Vehicle parc figures for HGVs	548,674	558,301

- ICE 1998 used an estimate that 13% of all HGV accidents are conspicuity related. This is based on findings from a study conducted by MIRA in 1980 which looked at 200 accidents. This percentage value was applied to all levels of accident severity. In contrast this report analyses actual accident data from STATS 19, 2003 incorporating 8,282 (HGV) accident cases. These cases were analysed in relation to the circumstances in which the accidents occurred. Therefore enabling accident cases to be filtered to identify accidents which occurred in conditions where conspicuity was likely to be a causal factor. From this the actual number of accidents within each severity level were gained. It is felt that the method used in this report is more reliable in that it uses actual accident data to calculate the impact area and the number and severity of accidents.

- ICE 1998 used an estimate that retro reflective tape will be effective in preventing 75% of all conspicuity related accidents (ICE estimate). Whereas this report uses estimates that retro reflective tape will be effective in reducing accidents by 8.15% and 25.1% (Vector 1985 and NHTSA 2001 accident data studies). The percentage values take account of the conditions in which accidents occurred and where retro reflective would be effective. These percentage values are the result of large accident data studies. Vector 1985 study results are based on a study comprising 4000 trucks and NHTSA results are from a study that looked at 10,959 accident cases.

- In the 1998 report it was estimated that 4 fatalities would be prevented from the use of retro reflective tape on HGVs, whereas in this report it is estimated that fitting tape to all vehicles would prevent approximately 15 fatalities.

- Since 1995 there has been a significant increase in estimates used to calculate accident costs, refer to Table 45.

Table 45. Accident costs for 1995 and 2003

	1995 Accident costs	2003 accident costs
Fatal	£947,370	£1,492,910
Serious	£111,970	£174,520
Slight	£11,020	£17,520

7 Conclusions

- Calculating the cost benefit ratios is a difficult task, due to the limited data available. This study used data which, for various reasons, may have resulted in an over estimate of the reduction in the number of accidents due to fitment of tape (leading to a reduction in potential benefits) and an underestimate of the costs of the accidents saved by fitting tape (leading to an increase in potential benefits). It is not possible to ascertain whether these will act to cancel each other out or not.

- It would be reasonable to expect that fitting contour markings would offer benefits over fitting line markings only. Unfortunately no real world accident data is available to verify this hypothesis. Therefore in this study the same accident reduction figures have been credited to both line and contour marking.

- Retro reflective tape is likely only to be of benefit in conditions of reduced visibility. To maintain performance of the tape it must be kept clear of dirt.

- Retro fitting tape to the total existing vehicle parc in line or contour marking formats incurs a cost for all vehicle types. Table 46 shows the ratio of the estimated benefits to the estimated costs for 2003.

Table 46. Ratios of costs to benefits for each type of vehicle

	Vehicle type	**3.5 – 7.5 t**	**>7.5 t**	**Minibus**	**Coach / bus**
Line markings	Ratio of benefits to costs	1 : 10 COST	1: 3.5 COST	1 : 7 COST	1 : 4 COST
Contour markings	Ratio of benefits to costs	1: 19 COST	1: 5.5 COST	1: 16.5 COST	1 : 8 COST

- The costs of fitting tape to new vehicles is considerably lower than the costs incurred when retro fitting tape to vehicles. This is due to the reduced time taken to fit the tape and that no off road costs are incurred. It should also be noted that as the years progress the proportion of the total vehicle parc fitted with retro reflective tape will also increase and therefore this will increase the number of accidents prevented. However it should be noted that after 7 years the costs will also increase due to the need to start replacing tape on the earlier marked vehicles and this will incur the higher costs associated with of retro fitting.

- There is a cost benefit for fitting line markings to newly registered HGVs greater than 7.5t, minibuses and coaches/buses.

- A benefit for fitting line markings to new HGVs >7.5t and to coaches/buses occurs after the 3rd and 4th years respectively. Fitting line markings to newly registered vehicles over an 8 year period shows that a benefit arises for HGVs >7.5t, minibuses and coaches/buses.Table 47 shows the ratio of the benefits to the costs after 8 years (please note that this does not take account of the additional costs that will start to be incurred through the need to replace the tape of previously marked vehicles).

Table 47. Ratios of costs to benefits for line markings for each type of vehicle

	Vehicle type	**3.5 – 7.5 t**	**>7.5 t**	**Minibus**	**Coach / bus**
Line markings	Ratio of cost to benefits	1:1.1 COST	2.5: 1 BENEFIT	1.07:1 BENEFIT	2.2 : 1 BENEFIT

- A benefit for fitting contour markings to HGV >7.5t occurs in the 5th year. Table 48 shows the ratio of the benefits to the costs after 8 years (please note that this does not take account of the additional costs that will start to be incurred through the need to replace tape of previously marked vehicles).

Table 48. Ratios of costs to benefits for contour markings for each type of vehicle

	Vehicle type	**3.5 – 7.5 t**	**>7.5 t**	**Minibus**	**Coach / bus**
Contour marking where possible and line marking to remaining	Ratio of cost to benefits	1: 2.1 COST	1.7 : 1 BENEFIT	1:2.3 COST	1: 1.05 COST

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