Motor vehicle and pedal cycle conspicuity - part 3: vehicle mounted warning beacons. Final report.

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Motor Vehicle and Pedal Cycle Conspicuity

Part 3: Vehicle mounted warning beacons

Undertaken on behalf of

The Department of the Environment, Transport and the Regions

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1.0 Purpose of the study

1.1 Introduction

Vehicle mounted warning beacons have developed from flashing tungsten filament bulbs through constant luminance bulbs with rotating reflectors to multiple, high intensity, strobe lamps with various phase options. Warning beacons are used on a number of types of vehicles, each undertaking its own range of tasks, to either alert other road users of their presence or warn of potential danger. With the wider use of flashing beacons, not just on vehicles but also for road works, it is necessary to review the current safety requirements and the regulations covering their use.

Whilst this study has a broad ranging remit, of particular concern is the conspicuity of vehicles fitted with amber warning beacons (e.g. recovery vehicles) when they are in environments where other flashing amber lights are present.

1.2 Objectives of the study

This study had three primary objectives:

1.2.1 To determine the optimum performance characteristics and installation conditions for warning lights and produce recommendations for the following parameters:-

i) Number and positioning

ii) Intensity for daytime and night-time use

iii) Flash rate

iv) Flash characteristics

v) Colour

1.2.2 To determine whether vehicles fitted with amber warning are sufficiently conspicuous when they are in environments where other flashing amber lights are present. If not, to identify alternative arrangements and determine their relative effectiveness.

1.2.3 To determine whether existing legislation is adequate and propose improvements where necessary.

2.0 Literature review

Although of topical interest, a review of published literature reveals remarkably few published documents with regard to the design, use or effects of flashing beacons. Some specific work does exist, though it may have wider implications than just beacon illumination. The issues of conspicuity, visibility and general lighting are dealt with in more depth and provide some useful information when evaluating the performance of beacons.

2.1 Conspicuity and Visibility

There is much ambiguity over the terms visibility and conspicuity. A typical illustration is found in Cole and Hughes (1984) where they describe two types of conspicuity. *Attention conspicuity*, they say refers to the capacity of a stimulus to be noticed when the observer is not actually looking for it. *Search conspicuity* refers to the capacity of a stimulus to be noticed when the observer is specifically searching for it. In fact, the observation of an object not actively being searched for is determined by its *conspicuity*, whilst *visibility* is the ease with which an object can be detected when the observer is looking for it, which may depend on the experience of the viewer. Hence the conspicuity of an object remains a constant property, whilst its visibility may change with different observers. The primary concern of this study is the *conspicuity* of objects, and various devices which may affect that property.

2.2 Legal Limitations

There are legal restrictions to the use of flashing beacons, and more specifically their colour. Red, blue and green beacons have prescribed uses and it is an offence to fit or use beacons of these colours unless authorised to do so. However, the use of amber beacons is less well controlled, and it is the profusion of different functions being identified by such use which may account for the uncertainty of the message delivered by these lights.

An example would be a flat-bed recovery truck, which whilst loading a broken down car indicates its presence with a flashing yellow beacon. Once completed it then joins the main carriageway with the beacons still illuminated.

In truth, however, it offers no hazard, since the recovered vehicle is contained wholly within the confines of the flat-bed. The legality of this is questionable since the wording of the legislation allows some subjective interpretation.

In the United Kingdom, the only vehicles legally required to display an amber flashing beacon are those which are: at the scene of an accident, involved in breakdown recovery or are only capable of less than 25 mph whilst on 70mph dual carriageway or motorway. The importance of these scenarios is underlined by work identifying the number of collisions involving slow moving vehicles, and the difficulty drivers experience in determining relative velocities.

2.3 The Use of Beacons to Convey Messages

Mortimer (1969) reports that data by Solomen showed a sharp rise in probability of rear end collisions when the disparity in speed exceeded 20 mph for vehicles travelling in same direction. The work also shows drivers poor at judging relative velocities. This is clearly the type of speed differential to be found between construction or recovery vehicles, which currently utilise flashing beacons, and the majority of traffic.

More detailed research by Mortimer (1977) revealed that for 80% of rear end collisions the struck vehicle was travelling at 20 mph or less. This underlines the importance if giving a clear message of the vehicle's speed as well as providing other cues as to the nature of the hazard, for example its size. Clearly, the message associated with such conspicuity devices should be unambiguous and undiluted by their use in a variety of scenarios. This may go some way to explain the success of flashing beacons on emergency vehicles, in that their message cannot be confused with any other visual stimulus on the road.

The range of coloured lamps used on the road was examined by Mortimer (1977). He identified that 25% of all highway crashes are rear impacts, and this impact style accounts for around 40-50% of all two vehicle accidents. Of these impacts, approximately 35% are injurious with 0.2% resulting in a fatality. He concludes that this does not indicate a very serious problem. However, as traffic densities increase it is likely that these figures will become more severe. Additionally, whilst this impact configuration may not be highly injurious, it is still very costly.

The work examines the role of presence, stop and turn lights. He proposes optimised values of 4-15 cd for presence lights of green or blue coloration. The values for stop lights are given as 80-190 cd at night and 300 cd during the day. Turn signals are given recommended values of 80-320 cd at night and 425 cd during the day.

Mortimer (1977) concludes that functional separation is a useful concept, worthy of further exploration. The various roles of different flashing beacons can be seen to be a very clear application of functional separation. This work extends from earlier studies by Mortimer (1970) where he also recommends different light intensities for day and night time applications, and goes on to define values for different colours. This proposition may be one avenue worthy of exploration in order to overcome the increasing intensity of rival lighting systems.

2.4 Colour

In 1953, Arakawa used Motokawa's direct current method to determine the visual field for different lights. Four lights of equal energy were studied (red 650λ, yellow 585λ, green 530λ and blue 470λ). Within these samples, the at-centre and mid-periphery values were higher for yellow and green lights than for red and blue. The value for green decreased abruptly towards the periphery whilst blue showed the slowest decrease. This would suggest that, for objects in the periphery, the use of a blue light would be an aid to conspicuity. This would support the choice of a blue light for emergency vehicles where other road users need to readily detect them within the periphery of their vision.

However, for objects located in the forward field of view, yellow and green would offer greater benefit to conspicuity.

The use of yellow flashing light at high intensities was investigated in a study by Van Bommel and de Boer (1980). They state that the maximum intensity of a white low beam vehicle headlight in the direction of the oncoming motorist is 437.5 cd. In comparison, a yellow light can be up to 40% more intense than a white light before being deemed to generate unsatisfactory levels of glare.

Early work by Mortimer (1967) showed that red and yellow flashing lights can be very easily confused. He sights values of 24% of normally sighted individuals and 46% of individuals with colour deficiency confusing the two light sources.

This would indicate that a significant proportion of the population would be unable to determine the function of a vehicle, as represented by a flashing light, if the only difference were one being yellow and one being red. This could lead to potential confusion and as a consequence additional risk on the road, though it may be more likely that both situations would be viewed as potentially the worst case, especially if one light was normally associated with a law enforcement vehicle.

Clearly, the colour of any illumination will have a profound affect upon the observer. This can be quantified in an entirely empirical fashion, to identify for example the most readily observed light. Alternatively, allowance can be made for the experience of the observer, who may, quite naturally, pay more attention to a flashing blue light, even in a laboratory environment.

2.5 Flash characteristics

The primary difference between beacons and other lights is the periodic nature of the flash. Traditionally, this has been achieved by rotating a mirror around a filament lamp. This resulted in relatively slow flash rates and low intensities. More recently, technology has progressed and allows for stroboscopic lighting. This permits much faster flash rates with a higher intensity. It may still be linked to a rotating reflector, or other device, and may involve multiple flashes in the same phase. Little work appears to have studied the effectiveness of different flash rates either as a single variable, or linked to colour and intensity.

However, Voevodsky undertook a progressive piece of work in 1974. In this instance, high mounted brake lights of high intensity (1200 cd compared with a normal value of 300 cd) were used in an accident study. The lights were flashed between 1Hz and 7.6 Hz depending on the rate of deceleration of the vehicle. This resulted in a 60% reduction in rear end accidents for the vehicle fitted with these lighting systems.

The values Voevodsky (1974) chose for the flash rates appear to be typical for highway applications, with 1 or 2 Hz the most predominant flash rates for vehicle lighting systems. The origins of the these values is unclear, but they appear in many different applications. The Highway Safety Research Institute (1976) examined warning signal flasher performance and concluded with the recommendation that the flash rate should be increased from 1-2 Hz to 1-3Hz, with 2-3Hz found to improve the effectiveness of turn and hazard warning signals.

2.6 Flashing vs Steady Lights

Paine et al (1996) argue that flashing lights are more difficult to detect initially than a steady light of same intensity, but once detected will command more attention. Given a flash rate of 1Hz and equal on/off times, the intensity must be increased by a factor of 1.4 over a steady light. Faster rates of flashing would require even greater intensities, since they reduce the apparent brightness. They go on to consider the practical application of this and suggest that the values are increased by a factor of 1.1 to allow for deterioration due to dirt and ageing.

In conclusion, they recommend that in practical applications a steady light should have a maximum intensity of 1000 cd, less if the road is poorly lit. The work shows that a flashing light intensity of 1800 cd needs to be used if the alerting role is to be fulfilled. The final recommendations for yellow flashing lights are given as 1800 cd (at 0,0 reference) to 200 cd (10 degree vertical deflection). These values could be used for priority situations, with reduced values being applied to other users of lights of similar colour.

2.7 The effect of intensity on conspicuity

It is the potential for increased conspicuity which offers the main attraction for flashing beacons, and this can be shown to be quite significant. Donne and Fulton (1988) showed that flashing a daytime running light on a motorcycle in addition to a 40W headlamp increases mean peripheral detection by 20% over a headlight alone, compared with a steady daytime light where the increase was only 10%. They also found that for small motorcycles, a 50% increase in headlight power on its own increased conspicuity distance by up to 350%; however, this was dependent on beam pattern. A further finding was that combination lighting was worse than a single headlamp in the identification of motorcycles. Since motorcycles are known to be difficult to identify, this could be analogous with other rarely observed hazards. This implies that combination lighting may actually reduce the ability of a driver to correctly identify a vehicle displaying combination lighting (especially if flashing), thus delaying the implementation of the correct response.

A later consideration of this work was that striplights aided the identification of motorcyclists. This may also offer benefits for the identification of other vehicle types and may be a viable alternative to flashing beacons in disseminating valuable information about the form and function of a vehicle. However the studies that have been conducted appear to be relatively specific, and often offer little reasoning for the selection of the particular parameters tested.

Recommended values for lighting systems must be modified to account for environmental conditions and there may be substantial differences in the optima for each condition. Finch (1968) determined that to secure a marginal improvement in the performance of rear marking lights in fog may require intensities up to 100 times that normally used. Hazard lights are likely to require similar values.

It would appear, however, that increased intensities and flash rates are often adopted to attempt to raise the profile of the bearer above background distraction. As more users adopt higher specification products, key users wish to be identified more readily and so extend the intensity or flash rate even further. There seems little opportunity to end this spiral without the legislative curtailment of use. However, it may be demonstrable that the increased specification of the lights may result in a reduced performance, even against a more confused background as found in urban environments. Increased intensity may not guarantee increased conspicuity.

2.8 Lighting in the surrounding environment

The other lighting systems found in the road environment also contribute to the performance of hazard warning systems. In 1974 Mortimer and Olson described how discomfort glare was only ‘just acceptable’ with properly adjusted headlamps. They recommended that any new lighting systems should, therefore, not exceed the levels produced by such a system. However, this does not address the need to raise hazard systems above the visual stimulation of normal lighting, though it is envisaged that the use of colours and flash rates may achieve this objective.

It has been shown by Mortimer and Jorgeson (1975) that drivers frequently look directly at oncoming vehicle lights and the frequency of such glances increases with decreasing inter-vehicle distance. This will result in glare and inability to determine vehicle detail. Therefore as the hazard becomes increasingly imminent, the driver is progressively less able to determine the detail and hence devise an appropriate response.

2.9 Older drivers

Consideration needs to be given to older drivers as they are a growing proportion of the driving population. Mortimer (1989) demonstrated that a 70 year old may require 30 times as much light on an object than a 15 year old just to see it. This is due to physiological changes (e.g. a reduction in the light transmission of substances in eye, yellowing of the lens and reduction in pupil size), and an increase in the scattering of light rays inside the eye which increases the disabling effect of glare sources and the discomfort. This may result in the driver either being unable to determine the source of the illumination or having to avert their eyes to avoid discomfort, and so being less aware of the hazard. Hence, the continual increase of intensity of the light source may not be the solution to increasing its effectiveness.

2.10 Detection Distances

Paine et al (1996) undertook an extensive study covering a range of aspects of vehicle lighting and illustrated some key issues. They determined that motorists who may be travelling at 100 km/h may need to slow for school buses (or indeed, other similar vehicles) and will require a distance of 250 metres in order to do this safely. They showed that in bright daylight, conventional vehicle signalling cannot be detected at this range. As a solution they proposed a high mounted light with high intensity, but with a sharp cut off, so as the drivers approach the vehicle they move into a low intensity beam, reducing glare.

The background for this proposition was that the human eye is more sensitive to a light source the closer the source is to the line of sight. Paine et al went on to provide a formula for calculating the optimum luminous intensity of a steady red beam for a given distance. They defined the optimum as 100 % probability of detection coupled with a near minimum reaction time. This would appear to imply a completely conspicuous light source. The argument continued that the light source should be selected according to the range needed for its application, as opposed to the current ‘bigger is better’ thinking. This can be readily determined since the intensity is proportional to the square of the distance.

Fischer and Cole (1974) found that yellow signals require three times the intensity of red for equal apparent brightness. However, a yellow lens will transmit approximately three times the light of a red lens and so the wattage remains the same. Hence a steady red signal requires 390 cd for 250 m, whereas a yellow signal would require 1170 cd to be equally detectable. The maximum permitted vehicle value for their study is 200 cd for a yellow signal. This can then be shown to be inappropriate, since it only gives a range of about 100m, which is insufficient to allow a safe stopping distance for other vehicles.

3.0 Technologies

Developments within the field of flashing beacons and lighting appear to be governed by market forces and legislative requirements, and seem to be limited to certain restricted technologies. However, manipulation of those technologies introduces new products into the market and constantly improves the claimed performance.

All manufacturers seem to offer a basic format of lighting system, which is then augmented by increased power, altering flash rates or modes and projection devices. The integration of the product into combined ‘light bars’ with additional similar or complementary products adds a further dimension.

Three light sources are used. Tungsten is the cheapest and uses simple filament technology; halogen, which uses gas filled filament bulbs and Xenon. All styles of light appear to be available with a choice of coloured lenses which is restricted to blue, red, amber, green or clear.

The flashing effect for beacons is achieved through one of three systems:

- Pulsing of the supply to filament bulbs;
- Flashing of xenon lamps through discharge;
- Rotating or other mechanical devices which intermittently shield the light to give a flashing effect.

Sometimes these features may be combined to produce special types of lighting. However, since the requirement is usually to provide 360° lighting, it is normal for one system to be used exclusively.

Some special applications require lights to be viewed from unusual angles, such as by pilots of aeroplanes, and hence feature modifications to provide novel beam patterns. The beam pattern tends to be controlled by the lens of the light, with Fresnel lenses often offered as accessories.

Simple light systems consist of a light source with a rotating mirror, encapsulated in a coloured lens unit and powered from a vehicle's electrical supply. The intensity of the light depends on the type of light source chosen.

Tungsten lights are commonly rated at 48 W for 12 volt systems and 60 W for 24 volt systems. Halogen light sources are rated at 55 W for 12 volts and 70 W for 24 volts. Xenon systems are usually quantified by other variables but are typically rated at less than 20W.

Most systems feature automatic voltage detection and switching, and many claim extensive service lives, up to 3000 hours for Xenon lights though filament systems are more normally around 150 hours. Many systems are selectable for high/low intensity to reflect daytime or night time use.

Pulse rates vary considerably. Filament light systems are typically around 150 to 180 flashes per minute (fpm) though may go as low as 40 fpm. Mirrors can be added to the system to increase the flashing effect, with some systems claimed to offer up to 800 fpm.

Xenon lights offer multiple flash modes, though typically are offered as 'single-hit' (SH) or 'double hit' (DH) units. These normally function at between 60 and 125 fpm on SH and somewhat less on DH, though the frequency takes the double flash as one event. These do not appear to be limited by technology since some lights offers substantially different levels of performance, such as 120 DH per minute on the Premier motorcycle strobe system.

Individual systems may be highly developed, with sophisticated control units. Premier directional lighting heads offer single, double, four or five flash programs with a 'Superflash' mode which they claim to be the 'ultimate warning pattern' at 700 fpm. Additional controls allow the user to select from 32 different flash patterns.

Lightbars are constructed to the operator's requirements with combinations of lighting systems. This may be multiple flashing lights, but may also include dot matrix displays, static lamps, illuminated signs, public address systems, chaser effects and spotlights (often referred to as 'alley lights' and located on the ends of the light bar).

Output is measured in a variety of ways with figures for Xenon systems quoted as between 25 and 960 cd with short peaks claimed to be up to 330,000 cd. Full brilliance viewing appears to be restricted, and may typically be seen to be between +/-3 and +/-8 degrees.

New developments appear to include the use of high intensity LED systems and multi mode chaser systems to raise the profile above background lighting. Electronic control of other vehicle lighting systems (such as headlights or spotlights) is also seen, with interlocks being applied to prevent inadvertent or inopportune use.

Table 1 shows a summary of the current warning beacon technologies. There are more advanced features, such as flash choreography, flash pattern and combination lighting systems such as roof bars. However, the majority of the devices use essentially the same technology. This technology appears to feature fixed limits to the performance of lamps. For instance, Tungsten lamps have a maximum intensity that can only be improved by changing to a better light source. Similarly, Xenon strobes lights have a practical maximum flash rate, which can be overcome by the use of additional mirrors or reflectors to give a much higher apparent flash rate. There do not appear to be any new technologies which are likely to significantly change these performance limitations in the near future.

Table 1 - Summary of the characteristics of warning beacon technologies

Technology	Colours	Wattage	Flash Rate			Intensity
			Single Hit	Double Hit	Multiple Flash	
Tungsten	Blue, Red, Amber, Green, Clear	48W at 12V 60W at 24V	40 75	N/A	N/A	N/K
Halogen	Blue, Red, Amber, Green, Clear	55W at 12V 70W at 24V	130 180	N/A	N/A	256-486 cd
Xenon	Blue, Red, Amber, Green, Clear	10-18W	60-140	80-120	<700	25-440cd 960 cd quoted max

To indicate the application of these technologies across the market place, the following Table 2 summarises the products offered by the main suppliers of warning beacons. As can be seen, the main features appear largely similar, with significant differences largely accounted for by methods of measurement or differing units.

Table 2 - Key features of the principle supplier's products

Supplier	Features
Lucas	Colours: Blue, red , amber, green Light sources:Tungsten, Halogen, Xenon Flash rates (75 tungsten 180 halogen, 140 Xenon (double flash available)) Tungsten - long peak intensity 12 or 24 V Halogen 55 W at 12 V or 70 W at 24 V Rotating or static models Light bars - combinations of flashing and static lights
Delta Design	Colours: Amber, blue, red, green and clear Light sources: Tungsten, Halogen, Xenon Automatic 12/24V detection and switching Guaranteed 3000 hour use for strobes (20 x that for rotating beacon) Xenon tubes at 15 - 18 W and 125 flash rate Double flash also quoted at 125 fpm Multi voltage beacons flash at 75 fpm, with 2 or 5 W 12-100V
DG Controls	Colours: Amber, red, green, blue and clear Light sources: Tungsten, Halogen, Xenon Vehicle lights go from 40 to 180 fpm, with Xenon flashing, pulsed filament and pulsed halogen versions 12 - 230 V DC Filament lights 48 W at 12V or 60 W at 24V Halogens 55 W at 12 V or 70 W at 24 V Halogen flash rates 180 fpm Halogen intensity 256cd to 750 cd Full brilliance view angle between +/-3° and +/-8° Small xenon lights flash at 60 fpm and 25-440cd Fresnel lenses available Some models go up to 960 cd (330,000 cd short peak quoted) Pulsed beacons offer LED model with multi mode chaser Unidirectional projector gives 3000 cd at 40 fpm
Dorman	Colours: Amber, blue, red, green, clear

	Light sources: Tungsten, Halogen, Xenon Halogen 55/70W 150 rpm 486/16,000cd Xenon DH 10W 60 fpm 148,700(1st)35,199(2nd)/40,600cd/sec Light intensity multiplication factors for lenses are: Clear(1), Amber (0.5), Blue(0.24), Green(0.28), Red (0.21) Xenon beacon 12/24V 14W, 10J output at 60 fpm (120 on DH) peak intensity 208,000(1st), 41,434(2nd) effective light output 56,784 (1st)
Ring	Colours: Blue or amber Light source: Halogen 12 or 24V 55 or 70 W 150 or 130 flash rate
Premier	Colours: Red, blue, green, amber, clear, yellow Light sources: Halogen, Xenon Gyrolaser features Halogen light,55/70W 160rpm, additional mirror for up to 800fpm Strobe flashing beacons - 90 fpm SH, 80 fpm DH Optic beacons - no dazzle, recommended for airports, confined spaces, indoor use Motorcycle strobes 120 double flashes per minute *Products*: *Maxim 90* tow specials -huge array of lights to customer spec, mirrors can be used to triple light flashes to the rear. *Optimax Lightbars* constructed to user spec *Maxim lightbar*- alley lights to side, up to 100w rotating lights etc *Directional lighting heads* feature double, four, and five flash plus superflash at 700fpm (“ultimate warning pattern”) with up to 32 flash patterns available. Most offer hi/lo intensity with up to 225 w. Also headlamp flasher units

4.0 Views of relevant parties

4.1 Introduction

To fully appreciate the needs, concerns and working practices of warning beacon users, a range of interested parties were contacted directly for information. A wider audience was reached through the use of a Press Release sent to a selection of relevant publications. A summary of the key responses obtained is given below.

4.2 Emergency services - Police

The Association of Chief Police Officers, ACPO; the Police Research Group and the Central Motorway Police Group provided the following information.

4.2.1 The need for warning beacons

Police use warning beacons on vehicles for a wide range of activities including escorting loads, on the way to and at an RTA and vehicle pursuit. A critical issue for motorway police is work on the hard shoulder which is particularly hazardous (20% of all motorway accidents occur on the hard shoulder. AVRO). Reasons for being on the hard shoulder include: accidents, pulling drivers over, coning off, picking up debris and investigating breakdowns. Fast dual carriageways are also particularly hazardous.

4.2.2 Equipment used

The majority of police vehicles currently use roof bars consisting of blue flashing lights, white spot lights to the front and red flashing lights to the rear. Conventional vehicle lighting is also used for warning or signalling e.g. headlights which on some vehicles are being replaced by blue.

4.2.3 Working practices

In general, in an emergency situation (where other drivers need to take a specific course of action), the blue lights are used. Where the situation is cautionary (drivers need to be aware but do not need to take any specific action), the red lights are used. It is left to the officer's judgement to determine what is most appropriate but typical lighting scenarios include:

- Pulling someone over: blue flashing lights to front, flash headlights.
- Pursuit: blue flashing + 360° flash.
- Hard shoulder: Flashing reds to rear.
- Rolling road block: rotating blue + red flash to rear.

4.2.4 Problems of beacon use

The problems considered to be associated with beacon use include:

- masking of personnel at, and the layout of, the accident scene,
- distraction when working under flashing lights for a length of time appears to increase the mental workload.

4.2.5 Suggested improvements

Overall the police feel that the beacons available are adequate although there are some issues relevant to future use:

- the blue lights may be being overused and as such may diminish public response in genuine emergency situations,
- variants of police practice copied by other road users may also diminish public response,
- with regard to technology, pulsing strobes are brighter and are more effective over greater distances,
- optional high/low intensity rates for daytime and night-time use would be beneficial,
- directional shielding of beacons to oncoming traffic would be of value,
- with reference to recovery operators, the police appreciate the dangerous work which they undertake and the ambiguity associated with the amber beacon.

However they do not believe that the use of red flashing lights should be extended to them nor should they be granted a further colour since this, they believe, will confuse the public. The police solution for recovery operators is for them to continue to use amber but have their own unique characteristic such as intensity and/or flash rate.

4.3 Emergency services - Fire

The Chief and Assistant Chief Fire Officers Association CACFOA provided the following information.

4.3.1 The need for warning beacons

Fire crew experience indicates that fire appliances would benefit from being more conspicuous to drivers being approaching or being approached in traffic and at the scene of an incident.

4.3.2 Suggested improvements

Although research by CACFOA indicated that blue lights are not the most effective colour in terms of conspicuity, their universal association and acceptance was considered too entrenched to change. Their use therefore had to be improved by the following means:

- front roof mounted beacons - dual synchronised combination strobe and halogen beacons providing 360°warning,
- rear mounted beacons - blue strobe beacon set offside at the maximum appliance height,
- rear facing lamps - red strobe beacons to be located as far as possible in the upper and lower corners of the rear face of the vehicle. Operable only when the handbrake is on, the nearside and offside pairs are to flash alternately,
- front strobe grilles - blue strobe lamps to be fitted to the front grille so as to be seen in the rear view mirror of passenger cars. Operable only when the handbrake is off,
- flashing headlamps - wired to flash alternately on main beam except when headlamps are required for use,

- all strobe lamps to have a low intensity setting for night-time use.

4.4 Emergency services - Ambulance

Mersey regional, and Nottinghamshire, ambulance services responded on behalf of the ambulance Service Association as follows:

4.4.1 The need for warning beacons

As for all the emergency service vehicles, there is a need for ambulances to be quickly seen and recognised and given the priority on the road which they require.

4.4.2 Problems of beacon use

One services states that its halogen rotating roof mounted beacons cannot be seen in sunshine.

4.4.3 Suggested improvements

Improvements which the respondents feel could be made to their working practices include:

- alternating red lights to the rear,
- forward facing blue roof lights to include a ‘Pulsar’ which is a white light in the centre of the lamp,
- grille level lights for other drivers rear view mirrors,
- blue repeaters to the front to fill the blind spot in rear view mirrors between the roof beacons and the grille lights,
- blue strobes.

4.5 Recovery operators

Information was gathered from spokespersons from the Association of Vehicle Recovery Operators AVRO, the Road Rescue Recovery Association RRRA and the Association of Chief Police Officers: Traffic - Vehicle Recovery Group.

AVRO-EX 98, an industry trade show, was also attended to encourage contributions from individual operators, manufacturers and other interested parties.

4.5.1. The need for warning beacons

Recovery operators work in highly vulnerable road environments involving a combination of the following factors: high speed and high volume traffic, lane closures, poor weather resulting in poor visibility and the need for night-time recovery. Beacons are considered to be an important part of the job as the operators attention is focused on their recovery task, not the surrounding road environment. They therefore rely on drivers seeing them and so they need to be visible to them.

4.5.2 Equipment used

There is no consensus within the industry as to which format of warning beacon is best for use since each recovery operator has their own preferences and so purchases accordingly. Generally, operators use light bars, consisting of two pairs of rotators, rather than single beacons. (One operator consulted uses alternate flashing amber beacons to front (strobes) and random flash red beacons to rear (currently illegal)). The warning beacons, which are frequently hardwired into the vehicle's ignition, are used in conjunction with white working lights which illuminate the scene of the recovery. The AVRO Code of Conduct requires that:

' - all breakdown vehicles will display a minimum of two unobstructed revolving amber beacons or strobe lights when at the scene of a breakdown or accident

- vehicles to be equipped with suitable lighting equipment for the illumination of the recovery area and the possible inclusion of red alternating lights to be used while stationary'.

4.5.3. Problems of beacon use

The specific problems which recovery operators mentioned were that amber beacons do not provide them with the protection they believe that they require because they:

- no longer convey meaning since they are used in a wide variety of less life threatening circumstances,
- are difficult to distinguish in road works where there are other amber beacons,
- are frequently misused and abused.

Whilst there is no doubt that recovery operators do work in dangerous environments, there is very little in the way of near miss or accident data to assist in determining the adequacy of the protection offered by amber beacons.

4.5.4 Suggested improvements

Both AVRO and RRRA believe that a unique colour or colour combination of warning beacons on their vehicles will differentiate them from other beacon users and so provide the increased protection they consider that they need. However both organisations agree that blue and green beacons should remain the preserve of the emergency and medical services respectively.

Approximately five years ago AVRO, in conjunction with Surrey police, undertook their own study to investigate the effectiveness of different colour warning beacons. Motorists driving responses to each colour was observed and some driver interviews were conducted. It is claimed that the study found that magenta and amber on their own had little effect, green was associated with medical vehicles and red on its own implied ‘stop’. However it was noted that when amber was displayed in conjunction with a red flashing light, motorists tended to move away from the danger zone sooner in a more controlled manner i.e. not last minute avoidance. This option is therefore preferred although AVRO would not wish to use this all the time, only when stationary. (The study was recounted by AVRO members who were unfortunately unable to provide written documentation or video footage of this work until the final report was being written).

The RRRA suggest the following improvements to their working practices:

- roof bars containing a number of rotating beacons.

- alternate flashing amber beacons to front.
- random flash red beacons to rear (currently illegal).
- white lights to front (Important on single carriageways where on-coming traffic is a greater potential danger.)
- white working lights (would like to use to highlight load in exceptional circumstances).

In terms of beacon technology, neither AVRO and RRRA favour strobe lights because:

- they may not be visible in bright daylight,
- they may produce dazzle and after effects at night,
- the off period too great.

4.6 Breakdown services

4.6.1 The need for warning beacons

Similar need to that of recovery operators. Breakdown patrols work in vulnerable road environments, particularly those involving motorway, 'A-class' or urban roads, and need therefore need to be seen and recognised by other road users. This is a genuine concern and the AA cite two fatalities to their patrols in the last three years to support this.

4.6.2 Equipment used

Breakdown patrol vehicles predominantly use amber rotating beacons and some strobes.

4.6.3 Working practices

Beacon assemblies are generally located on the roof of the vehicle towards the rear to ensure good visibility to other road users. Their drivers are instructed to use the warning beacons: on approach to (when the broken down vehicle is visible), at and on immediate departure from the breakdown scene. The amber beacons are not to be used whilst towing unless a particular hazard is being presented to other road users. If a towed vehicle is being steered by its driver and so is not directly under the control of the breakdown operator, the AA consider this to be sufficient potential hazard to other road users to merit the use of the amber beacons.

4.6.4 Problems of beacon use

Problems identified regarding beacon use were:

- overuse of amber beacons has diluted the significance of the message they give thereby reducing the safety benefit to their drivers,
- beacons can be too bright and may cause dazzle, glare and annoyance,
- amber beacons can blend with street lighting at night,
- that some drivers actually drive into breakdown vehicles either because they have not perceived them to be stationary or because the beacons may attract drivers to them ('moth-to-flame').

4.6.5 Suggested improvements

Both the AA and the RAC believe that a further colour (their preference being red) in addition to amber may act as a distinctive, unique identifier for individuals working beside the. The AA suggest the use of red in a specific formation so as to distinguish them from the red flashing lights used by the police.

The RAC consider that further benefits could be achieved by reducing dazzle, employing day and night intensity settings and using directional shields.

The AA tend to favour rotating beacons due to their cost, reliability, good light output, good flash definition and high visibility in most conditions although they are less compact than strobe lights. They do not believe that more or brighter lights are the answer.

4.7 British Medical Association

The BMA support initiatives to reduce the number of accidents and casualties occurring because of inadequate lighting. They specifically believe that GPs should continue to be able to use green flashing beacons on their vehicles when responding to emergencies.

4.8 Road Haulage Association

The view of the Road Haulage Association is that amber flashing beacons are too frequently used at the present detracting from their primary function of drawing attention to stationary or slow moving vehicles. However they do believe that amber should be retained for use by recovery operators.

4.9 Society of Motor Manufacturers and Traders

SMMT are of the opinion that warning beacons are adequately specified in ECE Regulation 65 and their application regulated by the Road Vehicle Lighting Regulations. However one member noted that the effectiveness of the warning beacons is also dependent upon maintenance and correct and appropriate use.

4.10 Warning beacon manufacturer

Delta Design, the largest manufacturer of xenon beacons in Europe expressed an interest in the relative performance in terms of conspicuity of:

- synchronous versus alternating beacons,
- single versus double hit strobe pulses.

4.11 Summary

4.11.1 Problems of beacon use

All users of warning beacons mentioned that their beacons were not as effective in portraying their message as they would have wished. The emergency services consider that the blue beacon whilst well understood has a poor response time from other road users. Recovery operators and breakdown services consider that their use of amber beacons is poorly understood and, in certain instances, may not be seen at all.

Further complaints from both sets of users were that warning beacons had the potential to cause dazzle and be distracting both to the workers at the scene and other road users.

4.11.2 Suggested improvements

The emergency services are of the opinion that the colour association between themselves and a blue beacon is too strong to practically be changed. They are therefore addressing their problems in terms of the technology employed (rotating beacons or strobe lights) and the location of the beacons on their vehicles.

The recovery operators and breakdown services believe that the best means for increasing their presence on the road is to use another colour in conjunction with their amber lights. There is agreement that blue and green should remain the domain of the emergency services and medical practitioners respectively, but that red (as favoured by the breakdown services) or magenta (as favoured by the recovery operators) should be employed.

4.11.3 Conclusions

The views expressed above confirm that:

- general research is needed into warning beacons effectiveness and disbenefits,
- specific research is needed to determine if any benefits are to be derived from recovery operators and breakdown services employing an additional colour to amber.

5.0 Beacon conspicuity trials

To obtain an overall view of the optimum performance characteristics of warning beacons in terms of their colour, number and flash rate, type and intensity during the day and night, a test programme of ten trials was developed. To maximise the efficiency and scientific integrity of the programme, both laboratory and 'real world' test environments were used.

5.1 The laboratory trials

5.1.1 Rationale for laboratory trials

Due to the volume of the information to be obtained concerning the performance of warning beacons, a model road environment, where all the variables could be systematically controlled and combined, was the most practical and efficient method of investigation and data collection.

5.1.2 Experimental variables

The model road consisted of a light-proof box, 8m long by 1.25m wide with a 1:20 scale road modelled inside. This equated to a road 160m long. The top surface of the box had seven apertures cut into it. Streetlights placed over these apertures allowed representative streetlighting to fall onto the road surface. The model road was observed through a viewing aperture at one end of the road. The exposure time during which participants would view the road was controlled using a shutter. The participants' eyes were positioned at the equivalent of 1.5m above the road surface to give a drivers' eye view of the model road scene.

Night conditions were simulated on the model road by blackening out the sides of the box and using high pressure sodium lighting to illuminate the road. Day conditions were simulated using a variety of high intensity spotlights and lamps and by whitening the sides of the road. The light intensities achieved were equivalent to those typically encountered during rush traffic hour in summer (Pritchard, 1990).

To simulate a busy urban scene, the road had a visually complex background modelled on an actual parade of shops which could be illuminated to represent lighting levels at night. Further complexity was introduced, when required, through the addition of vehicle and street furniture lighting (Belisha beacons). For trials requiring less visual complexity, this background was removed to create a bland environment.

The beacons were simulated using a series of light emitting diodes (LEDs). It was possible to adjust the intensities of the LEDs via a control unit, thereby making it possible to simulate the maximum and minimum regulated intensities for day and night as outlined in ECE regulation 65, as well as intermediate intensity levels. (ECE regulation 65 outlined levels for amber and blue beacons only. Therefore, maximum intensities for red and green beacons were kept the same as amber and blue, while minimum intensities were estimated using comparative levels which were obtained from subjective comparisons of red and green with amber and blue).

5.1.3 Participants

For all of the laboratory trials, twenty UK driving licence holder participants were used. For each trial it was ensured that the ratio of male to female participants was approximately 50:50 and the ratio of young to old participants was also 50:50, the age range being between 24 and 71 years.

For ethical reasons the participants were screened for: any form of epilepsy, sensitivity to bright or flashing lights and medical side effects which may have heightened their reaction to flashing lights. In addition the participants undertook the Ishihara tests for colour blindness (Ishihara, 1978). Only one participant was found to have been so affected.

5.1.4 Summary of results

A summary of the main results of the laboratory trials programme is presented in table 3 and discussed below. The detailed findings are extensively reported in appendices 1 to 7.

Table 3: Rankings of warning beacon performance - laboratory trials (numbers in bold italics = not significant results)

	DAY	Test 1: Conspicuity			Test 2: Subjective		Test 5: Disability Glare		Test 6: Discomfort Glare			Test 7: Distraction	
		Time	Colour	Location	Attention	Urgency	Time	Y/N	Discomfort	Annoyance	Threshold	Time	Number
Colour	Amber	4	4	***1***	4	4			3	3	3		
	Blue	2	1	***1***	2	2			1	1	2		
	Green	1	1	***1***	1	1			4	4	4		
	Red	3	1	***4***	2	2			1	1	1		
Rotating beacon flash rate (fpm)	60	4	***4***	***4***	4	4			1	1	1		
	120	3	***1***	***4***	3	3			1	2	1		
	180	2	***3***	***1***	2	2			3	2	3		
	240	1	***2***	***1***	1	1			4	4	4		
Flash type	Rotate	2	***2***	***2***	2	2			***1***	1	1		
	Strobe	1	***1***	***1***	1	1			***2***	2	2		
Strobe pulse type	Single	2	***2***	***1***	2	2			1	1	1		
	Double	1	***1***	***1***	1	1			2	2	2		
Beacon location	Direct	1	***2***	***1***									
	Peripheral	2	***1***	***1***									
Intensity	Maximum	1	***1***	***1***	1	1			2	2			
	Minimum	2	***1***	***2***	2	2			1	1			

	NIGHT	Test 1: Conspicuity			Test 2: Subjective		Test 5: Disability Glare		Test 6: Discomfort Glare			Test 7: Distraction	
		Time	Colour	Location	Attention	Urgency	Time	Y/N	Discomfort	Annoyance	Threshold	Time	Number
Colour	Amber	4	3	***3***	4	4	***2***	3	2	2	3		
	Blue	4	4	***4***	2	2	***3***	1	2	2	2		
	Green	1	2	***1***	1	1	***4***	4	4	4	4		
	Red	1	1	***1***	3	3	***1***	2	1	1	1		
Rotating beacon flash rate (fpm)	60	4	***3***	***4***	4	4	***1***	1	1	1	1	***2***	***1***
	120	3	***4***	***1***	3	3	***1***	1	2	2	2		
	180	2	***1***	***1***	2	2			2	2	3		
	240	1	***2***	***1***	1	1	***4***	4	4	4	4	***1***	***2***
Flash type	Rotating	***1***	***1***	***1***	2	2	1	***1***	1	1	1	***2***	***2***
	Strobe	***1***	***2***	***2***	1	1	2	***2***	2	2	2	***1***	***1***
Strobe pulse type	Single	2	***2***	***1***	2	2	2	***2***	***1***	***1***	1		
	Double	1	***1***	***2***	1	1	1	***1***	***2***	***1***	2		
Beacon location	Direct	***1***	***1***	***2***									
	Peripheral	***1***	***2***	***1***									
Intensity	Maximum	1	***2***	***2***	1	1	2	2	2	2		***2***	***1***
	Minimum	2	***1***	***1***	2	2	1	1	1	1		***1***	***2***

Daytime conditions

Colour

In general, blue and red performed the best over all tests. They caused the least discomfort glare and annoyance and were ranked better than amber for conspicuity (objective and subjective measures).

Green performed the best in terms of conspicuity, but performed worse than all other colours in terms of discomfort glare and annoyance.

Overall, amber performed the worst over all tests. It performed the worst in terms of conspicuity and only green was worse than amber in terms of causing discomfort glare and annoyance.

Rotating beacon flash rate

Beacons with flash rates 120fpm and 180fpm performed the best as they were better than 60fpm in terms of being conspicuous and better than 240fpm in terms of causing less discomfort glare and annoyance.

Rotating vs strobe beacons

Strobe beacons performed the best in terms of being conspicuous and rotating beacons performed the best time terms of causing the least discomfort glare and annoyance.

Single vs Double pulse strobes

Double pulse strobe beacons performed better than single pulse in terms of conspicuity and single pulse strobe beacons performed better than double pulse in terms of causing the least discomfort glare and annoyance.

Peripheral view vs direct field of view

Beacons positioned in the participants' direct field of view were seen better than those in the peripheral field of view in terms of detection time.

Maximum vs minimum regulated intensity

Beacons at maximum intensity performed better than those at minimum intensity in terms of conspicuity. In terms of discomfort glare, all beacons were found to be unacceptable at maximum intensity by at least one participant. Table 4 shows the mean levels of intensity at which beacons became acceptable (i.e. discomfort threshold).

Table 4: Discomfort thresholds for each beacon colour at day

Beacon colour	Mean discomfort threshold (cd)	Range (dependent upon technical features of each beacon)
Amber	880	675 - 1100
Blue	1030	930 - 1135
Green	715	500 - 890
Red	1100	950 - 1190

Night-time conditions

Colour

In general, the colour red performed the best over all tests. It was ranked the best for conspicuity (reaction time and number of correct beacon detections), caused less disability glare than amber and green, and gave rise to the least discomfort glare and annoyance, even at maximum intensities. However, red did not perform as well in terms of subjective measures of conspicuity, with only amber being worse than red.

Overall blue and green performed similarly to each other, although green was better ranked in terms of the conspicuity aspects (e.g. beacon detection time, number of correct beacon detections, attention-getting qualities and level of urgency) and blue was better ranked in terms of causing less disability and discomfort glare and annoyance.

Amber performed the worst over all tests. It was rated one of the worst for conspicuity and only green was worse than amber in terms of causing disability and discomfort glare and annoyance.

Rotating beacon flash rate

Beacons with flash rates 120pm and 180fpm performed the best as they were better than 60fpm in terms of being conspicuous and better than 240fpm in terms of causing less disability and discomfort glare and annoyance.

Rotating vs strobe beacons

Rotating beacons caused the least disability and discomfort glare and annoyance. Strobe beacons performed the best in terms of being rated as being more attention-getting and having a greater level of urgency.

Single vs double pulse strobe

Double pulse strobe beacons performed better than single pulse in terms of conspicuity (objective and subjective measures) and in terms of causing less disability glare.

Peripheral view vs direct field of view

No significant differences were found in the conspicuity of beacons positioned in the participants' direct field of view and those in the peripheral field of view.

Maximum vs minimum regulated intensity

Beacons at maximum intensity performed better than those at minimum intensity in terms of conspicuity and beacons at minimum intensity performed better than those at maximum intensity in terms of causing the least disability glare. In terms of discomfort glare, all beacons were found to be unacceptable at maximum intensity by at least one participant. Table 5 shows the mean levels of intensity at which beacons became acceptable (i.e. discomfort threshold).

Table 5: Discomfort thresholds for each beacon colour at night

Beacon colour	Mean discomfort threshold (cd)	Range (dependent upon technical features of each beacon)
Amber	292	249 - 397
Blue	373	290 - 520
Green	217	134 - 308
Red	430	533 - 375

5.2 The validation trials

5.2.1 Rationale for validation trials

In order to validate the data from the laboratory trials, real vehicle beacons were assessed in a real road environment in terms of their objective and subjective conspicuity, disability and discomfort glare, levels of urgency and annoyance.

The aim of these trials was to investigate the certainty to which the results of the laboratory trials could predict real world performance.

5.2.2 Variables

The trials were undertaken during both daytime and night-time using an established test site. The test site was favoured for use over a busy public road since it allowed greater control of the experimental variables and was less hazardous to other road users who may have been unduly distracted by the test work. The test site was mocked-up to simulate a busy road scene by using vehicle headlights, 1 metre high road cones and BS3143 approved roadside lights. Vehicle lights from a road passing the end of the test site added visual noise to the test scene similar to that encountered on a public road.
A rotating dual reflector beacon and a four flash sequence strobe were assessed with four colour dome formats, these being amber, blue, green and red. In addition, to investigate the effects of the colour magenta, another dual reflector beacon was set up to emit magenta light. The dual reflector beacons could rotate at one of two speeds, these being 60fpm and 120fpm and both the rotating and strobe beacons could be viewed at their normal intensity and half their original intensity using a filter placed in front of the beacon and its dome.

The beacons were shielded so that the light emitted from the beacons could only be seen from ahead and not from the sides, above or behind, thereby minimising disruption to other road users. The shield was painted matt black so that participants were only able to see the light emitted from the beacon and not reflected light.

When taking objective measures of conspicuity, the shielded beacons were placed at a 30^{o} angle, 57m from the participants' viewing position. This represented a worse case scenario, as the participants would need to use their peripheral vision rather than their direct line of sight to detect the beacons. When subjectively assessing conspicuity and taking measures of disability glare, discomfort glare and levels of urgency and annoyance, the shielded beacons were placed in the

participants' direct line of sight (0^o), 93m away from the participants' viewing position. To assess the disability glare of each beacon, a target detection task was undertaken. The target used was a 20cm diameter illuminated wooden disc with a reflectance factor of 20%, which is a standard target used in vision testing.
To ensure that the participants' looked straight ahead during the trial, their view of the "road" site was controlled through the use of viewing apertures.

5.2.3 Participants

The same participant requirements employed for the laboratory trials were used in the validation trials. Refer to section 5.1.3.

5.2.4 Summary of results

A summary of the main results of the validation trials programme is presented in table 6 and discussed below. The detailed findings are extensively reported in appendices 8 to10.

Table 6: Rankings of warning beacon performance - validation trials (numbers in bold italics = not significant results)

DAY		Test 1: Conspicuity		Test 3: Subjective Rankings				Test 3: Paired Comparisons			
		Time	Colour	Attention	Urgency	Discomfort	Annoyance	Attention	Urgency	Discomfort	Annoyance
Colour	Amber	1	1	4	4	***2***	2	3	2	5	5
	Blue	***2***	1	5	4	1	1	6	6	1	1
	Green	***2***	***3***	3	1	***2***	3	3	3	4	4
	Red	***2***	5	2	3	4	3	2	3	3	3
	Magenta	5	***3***	1	1	4	3	5	5	2	2
	White							1	1	6	6
Rotating beacon flash rate (fpm)	60	***1***	***1***	***1***	1	***2***	2				
	120	***2***	***2***	***2***	2	***1***	1				
Flash type	Rotate	***1***	***1***	***2***	2 (120)	***1***	1 (120)				
	Strobe	***2***	***2***	***1***	1	***2***	2				
Intensity	Low	2	***2***	***1***	***1***	***1***	***2***				
	High	1	***1***	***2***	***2***	***1***	***1***				

NIGHT		Test 1: Conspicuity		Test 2: Disability Glare		Test 3: Subjective Rankings				Test 3: Paired Comparisons			
		Time	Colour	Time	Y/N	Attention	Urgency	Discomfort	Annoyance	Attention	Urgency	Discomfort	Annoyance
Colour	Amber	1	***2***	5	***4***	1	3	3	3	2	6	4	4
	Blue	3	***2***	***2***	***3***	4	4	1	1	3	2	3	1
	Green	5	***5***	***2***	***5***	4	4	1	2	3	4	5	5
	Red	2	***4***	1	***1***	1	1	3	5	5	2	1	1
	Magenta	4	***1***	***2***	***2***	1	1	3	3	6	5	2	3
	White									1	1	6	6
Rotating beacon flash rate (fpm)	60	***1***	***1***	***2***	***2***	***2***	***1***	***1***	***1***				
	120	***2***	***1***	***1***	***1***	***1***	***2***	***2***	***2***				
Flash type	Rotate	***2***	***1***	1	***1***	1 (120)	***1***	***1***	***1***				
	Strobe	***1***	***2***	2	***2***	2	***1***	***1***	***1***				
Intensity	Low	2	***2***	***1***	***1***	***2***	***1***	***1***	***2***				
	High	1	***1***	***2***	***2***	***1***	***2***	***1***	***1***				

Daytime conditions

Colour

In general, there was found to be no particular colour that performed the best over all tests.

Amber was ranked the best for conspicuity i.e. quickest beacon detection time, but was poor for the subjective ratings of conspicuity.

Blue was rated best for reducing discomfort glare and annoyance but rated worst for its subjective attention-getting ability.

Both green and red had middle rankings for beacon detection time, annoyance and discomfort glare. However, green was rated as the most urgent, being more urgent than red.

Magenta beacons were rated by the participants as being the most attention-getting but this was not borne out by the finding that they took longest to detect.

Rotating beacon flash rate

There was no difference in the beacon detection times or discomfort ratings for beacons of 60 fpm and those of 120 fpm. Beacons with flash rate 60fpm were rated as more urgent, whilst beacons of 120 fpm were rated as less annoying.

Rotating vs strobe beacons

There was no difference in the beacon detection times, attention-getting or discomfort ratings for all rotating beacons and strobe beacons. Strobe beacons were rated as conveying more urgency and more annoyance than rotating beacons of flash rate 120fpm.

High vs low intensity

High intensity beacons were detected quicker than lower intensity beacons. In terms of ratings for attention-getting, urgency, discomfort glare and annoyance there were no significant differences in their performance.

Night-time conditions

Colour

Amber beacons were detected the quickest and were rated as being one of the most attention-getting, however it took significantly longer to detect a person in the vicinity of an amber beacon.

Blue and green beacons were rated the best for reducing discomfort glare and annoyance but rated poorest for being attention-getting and conveying urgency. In addition green beacons took the longest to detect.

Red beacons gave rise to the quickest times to detect the presence of a person in their vicinity and they were rated as one of the most attention-getting. However they were also rated as being the most annoying.

Magenta beacons were rated as one of the most attention-getting and were second only to red for the speed with which a person could be detected in their vicinity. However, after green, they were the longest to detect in a road environment.

Rotating beacon flash rate

There were no significant differences between flash rates of 60 fpm and 120 fpm in terms of: time to detect the beacon, time to detect a person in the vicinity of the beacon, and ratings for attention-getting, urgency, annoyance and discomfort glare.

Rotating vs strobe beacons

Flashing beacons were rated as more attention-getting than strobe beacons and enabled a person to be detected more quickly in their presence.

High vs low intensity

High intensity beacons were quicker to detect than low intensity beacons.

5.3 Comparison of the laboratory and validation trials

5.3.1 Colour

Comparison of tables 1 and 2 indicates inconsistencies in the results of the laboratory and validation trials with respect to the effect of colour. The main inconsistencies are given in Table 8. However discrepancies of this nature are to be expected and can be accounted for by the fact that the laboratory trials assessed the effect of colour *only* whilst the validation trials could only consider colour *compounded by intensity*. For the laboratory trials, the legislative minimum and maximum intensity requirements were assessed and these were held constant for each colour. However in the validation trials, which were designed to be representative of the real world, 'off-the-shelf' beacons were used which consist of a standard flasher unit with interchangeable coloured domes. Whilst the intensity produced by the flasher unit is constant, the intensity viewed by onlookers varies according to the extent to which each coloured dome acts as a filter. The effects of filtering of the domes used in the validation trials are given in the table below.

Table 7: Effects of dome colour on beacon intensity

Colour	Strobe beacons		Rotating Beacons	
	% Transmission	Rank	% Transmission	Rank
Clear	100	1	100	1
Amber	56	2	83	2
Blue	33	4	26	5
Green	14	5	29	4
Red	36	3	62	3

The table above indicates that for a given constant intensity, amber beacons will appear brighter than other beacon colours, whilst green and blue will appear duller. Since, as shown by this study, higher intensities are more conspicuous (as measured by beacon detection time and ratings of attention-getting and urgency) and result in more discomfort glare and ratings of annoyance, it can be assumed that colour will be directly related to these attributes due to its filtering effect on intensity. Therefore it would be expected that amber and blue beacons would appear to be more conspicuous, more annoying and cause greater discomfort glare in the real world than in the laboratory; the reverse being true for red and green. If this rationale is applied to table 8 it would appear to account for the discrepancies noted and therefore the validation trials support the findings of the laboratory trials.

Table 8: Comparison of laboratory and field trial results for colour

Day

Laboratory performance	Unvalidated measure
HIGH performance of BLUE not validated for	Attention-getting rating Urgency rating
HIGH performance of GREEN not validated for	Beacon detection time Beacon colour identification Attention-getting rating
HIGH performance of RED not validated for	Beacon colour identification Discomfort glare Annoyance
POOR performance of AMBER not validated for	Beacon detection time Beacon colour identification
POOR performance of GREEN not validated for	*Discomfort glare*

NB For the items in italics the differences between the laboratory and validation results were less significant than those items not in italics.

Night

Laboratory performance	Unvalidated measure
HIGH performance of AMBER not validated for	*Person detection time*
HIGH performance of BLUE not validated for	*Person identification* Attention-getting rating Urgency rating
HIGH performance of GREEN not validated for	*Beacon colour identification* Beacon detection time Attention-getting rating Urgency rating
HIGH performance of RED not validated for	*Beacon colour identification* Discomfort glare Annoyance rating
POOR performance of AMBER not validated for	Beacon detection time Attention-getting rating
POOR performance of BLUE not validated for	*Beacon colour identification*
POOR performance of GREEN not validated for	*Person identification* Discomfort glare Annoyance rating
POOR performance of RED not validated for	Attention-getting rating Urgency rating

NB For the items in italics the differences between the laboratory and validation results were less significant than those items not in italics.

5.3.2 Flash rate

A comparison of beacon performance according to flash rate for laboratory and field trials is shown in table 9.

Table 9: Comparison of laboratory and field trial results for flash rate

Day

	High flash rate best for …	**Low flash rate best for …**
Lab (Rates tested: 60,120,180, 240)	Beacon detection time Attention-getting Urgency	Discomfort glare Annoyance
Valid (Rates tested: 60, 120)	Annoyance	Urgency

Night

	High flash rate best for …	**Low flash rate best for …**
Lab (Rates tested: 60,120,180, 240)	Beacon detection time Attention-getting Urgency	Disability glare Discomfort glare Annoyance
Valid (Rates tested: 60, 120)	No difference	

It is not possible to undertake a direct comparison of the laboratory and validation trial flash rates since the higher flasher rates of 180 fpm and 240 fpm could not be replicated in the field trials and therefore differences in the extremes of the flash rates could not be observed.

However the basic principles of human vision would suggest that the laboratory results are likely to be an accurate depiction of real world behaviour. Higher flash rates have a greater total on time and therefore are likely to be more conspicuous because there is greater opportunity for them to be observed. Also higher flash rates can have up to four times as many changes in state between on and off (an attribute which is known to be attention-getting) and so will be perceived as more conspicuous. Consultation with a lighting expert at Loughborough University also supports the laboratory findings. At low frequencies the increased length of the on-off cycle implies that the it will take longer to detect the beacon and so in this respect its conspicuity will be poor. At high frequencies the flicker becomes less until it appears as a constant output which similarly results in poor conspicuity. The frequencies at which flicker is perceived to be at its strongest is 5-10 Hz. This would suggest that beacons operating at 4 Hz would be perceived as more conspicuous than those operating at 1 Hz which confirms the results of the laboratory trials.

5.3.3 Flash technology

A comparison of beacon performance according to flash technology for laboratory and field trials is shown in table 10.

Table 10: Comparison of laboratory and field trial results for flash technology

Day

	Rotating beacons best for …	Strobe beacons best for …
Lab	Discomfort glare Annoyance	Beacon detection time Attention-getting Urgency
Valid	Annoyance	Urgency

Night

	Rotating beacons best for …	Strobe beacons best for …
Lab	Person detection time Discomfort glare Annoyance	Attention-getting Urgency
Valid	Person detection time Attention-getting	

The tables above suggest that generally there were no major contradictions in the results of the laboratory and field trials; the exception being the ratings for attention-getting at night. The laboratory trials indicate that strobe beacons were considered more attention-getting, whilst the validation trials indicate that rotating beacons were considered more attention-getting. However it should be remembered that these are subjective rating measures and a more definitive measure of conspicuity is the objective measure of beacon detection time. Consultation with tables 3 and 6 indicate that there is no significant difference in the time taken to detect rotating or strobe beacons at night for both the laboratory and validation trials. This discrepancy therefore in the subjective ratings is not a cause for concern.

5.3.4 Flash intensity

A comparison of beacon performance according to flash intensity for laboratory and field trials is shown in table 11.

Table 11: Comparison of laboratory and field trial results for flash intensity

Day

	High intensity best for …	Low intensity best for …
Lab	Beacon detection time Attention-getting Urgency	
Valid	Beacon detection time	

Night

	High intensity best for …	Low intensity best for …
Lab	Beacon detection time Attention-getting Urgency	Person detection time
Valid	Beacon detection time	

The tables indicate that the results of the laboratory trials were fully validated by the field work.

5.4 Summary

The results of the validation trials fully support the findings of the laboratory trials. The results of the laboratory work can therefore be considered as valid and can be used as the foundations for the recommendations given in section 8.0 of this report.

6.0 Roadwork trials

6.1 The laboratory trial

6.1.1 Aim

The aim of this trial was to obtain objective and subjective measures of the conspicuity of vehicles fitted with amber warning beacons i.e. recovery vehicles, in an environment where other flashing amber lights are present. The measures used in this trial were reaction time, accuracy of detection and ease of identification.

6.1.2 Variables

The testwork was undertaken using the model road which is described in more detail at the start of section 5.0. The model road was set up to simulate a wet, busy road works scene, with road cones and roadside beacons under both day and night conditions (with and without street lighting). Figure 1 shows an example of this set-up.

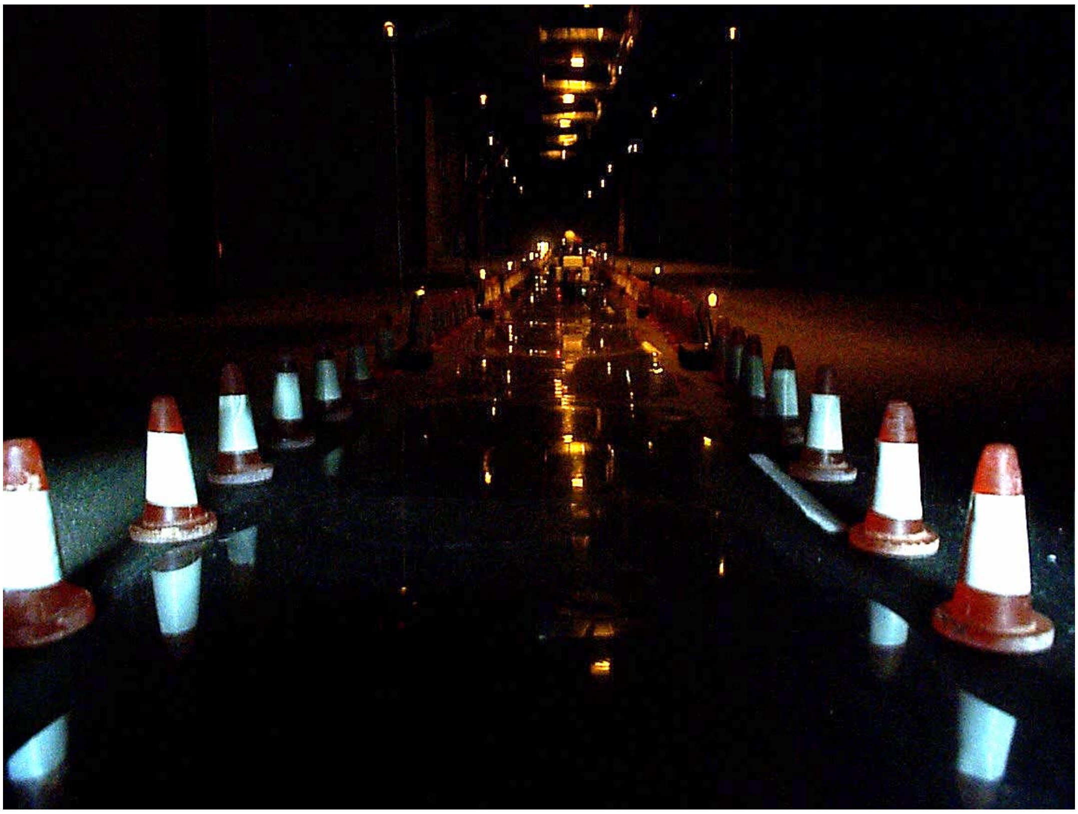

Figure 1: The road works scene (night conditions with street lighting)

The road works were set out in compliance with the Traffic Signs Manual Chapter 8 and BS3143: Road Danger Lamps (Parts 1, 2 and 4). The section of the road works which was simulated was the diversion from one lane to the adjacent lane, as this could potentially be the most hazardous section of the road works. The LED vehicle beacons were set up at a simulated distance of 100m from the viewing position and were located amongst the roadside beacons. In this instance, the LEDs were set up to simulate the various beacon combinations which are outlined in table 12.

Table 12: Roadside and vehicle beacon combinations assessed

	Vehicle lights	**Roadside beacons**
1	Flashing amber	None
2	Flashing amber	Static amber
3	Flashing amber	Flashing amber
4	Flashing amber (faster rate than cones)	Flashing amber

5	Flashing amber with steady amber	Flashing amber
6	Flashing amber with flashing red	Flashing amber
7	Flashing amber with static red	Flashing amber
8	Flashing amber with flashing white	Flashing amber
9	Flashing blue	Flashing amber

This combination of lighting variables allowed the following aspects to be addressed:

- the effects of combining red, white or amber with amber compared to amber on its own (3 v 5, 6, 8).
- the effects of flash pattern (3 v 4 v 5, 6 v 7)
- the effects of the characteristics of roadside beacons (1 v 2 v 3)
- how conspicuous recovery vehicles are compared to emergency service vehicles (3 v 9).

6.1.3 Procedure

The participant was seated at the end of the model road with the scene blocked from view. When the participant was ready, the shutter was dropped, revealing the scene and starting the timer. The participant was required to search the scene for vehicle beacons and then respond by saying “yes” or “no”, as appropriate, which would stop the timer. Both the nature of the response and the time taken to make it were recorded. The nine scenarios represented above were presented randomly along with nine instances of no vehicle beacons being present. This introduced an element of uncertainty into the task thus making it more representative of the driving situation.

On completion of this task, each scenario was displayed again to the participant who was required to rate the ease of identification of the presence of the vehicle beacons amongst the roadworks. This was accomplished by using scenario 3, in the table above, as the mid-point on a unmarked scale (see Figure A8 in Appendix 3) and comparing it with the other eight scenarios by placing a mark on the scale depending on whether the vehicle was more difficult or easier to identify.

6.1.4 Participants

Twenty UK driving licence holder participants were used. The ratio of male to female participants was approximately 50:50 and the ratio of young to old participants was also 50:50.

For ethical reasons the participants were screened for: any form of epilepsy, sensitivity to bright or flashing lights and medical side effects which may have heightened their reaction to flashing lights. In addition the participants undertook the Ishihara tests for colour blindness (Ishihara, 1978). No participants were found to have any form of colour blindness.

6.1.5 Results

A summary of the main results of the roadwork trials are presented in table 13 and discussed below. Tables A1 and Figures A1, A2 and A3 in Appendix 3 also show the mean results for each beacon combination and road working condition investigated, while the t-test results are shown in Tables A2 and A3.

Table 13: Rankings of warning beacon configurations - roadwork trials (laboratory) (numbers in bold italics = not significant results)

DAY		Test 1: Conspicuity	Test 3: Roadworks			Test 4: Number	
		Time	Y/N	Time	Ease of ID	Attention	D. Glare
Beacon configuration	Amber (None)		***1***	9	6		
	Amber (Static)		***1***	***3***	8		
	Amber (Flash)		***8***	7	8		
	Fast Amber (Flash)		***1***	8	5		
	Amber & S. amber (Flash)		***1***	2	6		
	Amber & F. red (Flash)		***1***	1	2		
	Amber & S. red (Flash)		***8***	5	2		
	Amber & F. white (Flash)		***1***	6	4		
	Blue (Flash)		***1***	***3***	1		
Roadside lighting	None		***1***	3	1		
	Static		***1***	1	2		
	Flashing		***3***	***2***	2		
Flash speed	120fpm		***2***	***1***	2		
	240fpm		***1***	***2***	1		
Number of simultaneous beacons	1	5				8	1
	2	***4***				7	7
	3					3	2
	4	***2***				3	***4***
	5					3	***4***
	6	***3***				3	***4***
	7					2	2
	8	1				1	7
Alternating beacons	2	***2***				2	***2***
	8	***1***				1	***1***
Alterntating vs simultaneous	Alternating	***2***				2	***2***
	simultaneous	***1***				1	***1***

NIGHT		NIGHT (WITH STREET LIGHTING)						NIGHT (NO STREET LIGHTING)		
		Test 1: Conspicuity	Test 3: Roadworks			Test 4: Number		Test 3: Roadworks		
		Time	Y/N	Time	Ease of ID	Attention	D. Glare	Y/N	Time	Ease of ID
Beacon configuration	Amber (None)		***1***	5	6			***4***	5	5
	Amber (Static)		***1***	6	6			***7***	7	6
	Amber (Flash)		***1***	8	8			***8***	7	8
	Fast Amber (Flash)		***8***	8	5			***8***	5	6
	Amber & S. amber (Flash)		***8***	4	8			***6***	9	8
	Amber & F. red (Flash)		***1***	2	3			***1***	2	3
	Amber & S. red (Flash)		***1***	6	3			***1***	4	3
	Amber & F. white (Flash)		***1***	2	2			***4***	2	2
	Blue (Flash)		***1***	1	1			***1***	1	1
Roadside lighting	None		***1***	***1***	***1***			***1***	1	1
	Static		***1***	***2***	***1***			***2***	***2***	2
	Flashing		***1***	***3***	***3***			***3***	3	2
Flash speed	120fpm		***1***	***1***	2			***2***	***2***	***2***
	240fpm		***2***	***1***	1			***1***	***1***	***1***
Number of simultaneous beacons	1	***2***				8	***3***			
	2	***1***				8	***4***			
	3					***5***	***7***			
	4	***3***				1	***8***			
	5					1	***4***			
	6	***5***				1	***1***			
	7					1	***2***			
	8	***4***				1	***4***			
Alternating beacons	2	1				2	***2***			
	8	2				1	***1***			
Alterntating vs simultaneous	Alternating	2				2	1			
	simultaneous	1				1	2			

Which combination of vehicle and roadside beacons gives rise to the most accurate and quickest identifications?

The worst case scenario for detecting vehicles' beacons amongst roadside beacons was on unlit roads at night. Not only were the detection times significantly slower than those during the day and at night with street lighting (mean time of 1.08 seconds compared to 0.80 and 0.96 seconds respectively), but the number of times the beacons were detected when present was significantly less.

When investigating the effects of roadside beacons on the visibility of vehicles with flashing amber beacons, it was found that the vehicle was seen quicker at night when no roadside beacons were present; however this was only significant when no street lighting was present. During the daytime, the vehicle was seen the quickest amongst static roadside beacons, this being significantly quicker than there being no roadside beacons.

In terms of detection rate, opposed to detection time discussed above, the highest detection rate of the vehicle, day and night, was when there were no roadside beacons. However, this result was not statistically significant.

By increasing the flash rate of the amber vehicle beacons from 120fpm to 240fpm, it was hoped that this would increase the visibility of the vehicle among roadside beacons set at a flash rate of 120fpm. However, the results revealed that this made very little difference to either the detection rate or the detection time.

A further means of potentially increasing the conspicuity of the vehicle amongst roadside beacons flashing at 120fpm was to use a static amber light in conjunction with the flashing amber light on the vehicle. This would provide a source of constant light output and so would differentiate the vehicle from its flashing surroundings. Under day and night conditions, the addition of a static amber light to the vehicle did not significantly improved detection rate or time.

The effect of using another colour in conjunction with the flashing amber beacons was also investigated.

- Flashing red: used with flashing amber made the vehicle significantly quicker to detect in all environments, but more noticeably at night.
- Static red: used with flashing amber did not significantly affect detection times.
- Flashing white: used with flashing amber made the vehicle significantly quicker to detect only at night.
- Flashing blue: was detected significantly quicker than the combinations discussed above at night (apart from amber and white when viewed under street lighting) and was not seen significantly slower than any other beacons during day conditions.

In terms of detection rates, flashing amber beacons (at 120 fpm and 240 fpm) were seen the least number of times by all participants, while the combination of flashing red and amber beacons and the flashing blue beacons were the only two beacon combinations to be seen by all participants on all occasions. These results suggest that introducing another colour, particularly red, to a vehicle which is using amber beacons in an environment saturated with amber lights (e.g. a road working site) improves the conspicuity of the vehicle.

Which combination of vehicle and roadside lighting was rated to be the easiest to identify?

Under day conditions and at night with no street lighting, the vehicle with flashing amber beacons was rated by participants as the easiest to identify when there were no roadside beacons. However, at night under street lighting, the vehicle was no easier to identify (see Table A3 and Figure A4 in Appendix 3).

The effect of increasing the flash rate of the amber beacons from 120fpm to 240fpm was that the vehicle became significantly easier to identify amongst flashing road works during day conditions and at night when viewed under street lighting, but was no easier to identify when viewed under no street lighting.

Introducing static amber to flashing amber did not make the vehicle any easier to identify.

In terms of the effect of colour:

- Flashing red: used with flashing amber was rated as improving vehicle identification. This combination was better for daytime viewing than flashing amber and white.
- Static red: used with flashing amber was rated as improving vehicle identification.
- Flashing white: used with flashing amber was rated as improving vehicle identification.
- Flashing blue: The vehicle could be identified the easiest amongst flashing roadside beacons when displaying blue beacons.

6.2 The validation trials

6.2.1 Aim

An additional set of trials were carried out, this time using real vehicle beacons on a full scale road length in an outdoor environment. The aim of these trials was to investigate whether similar results to the laboratory trials would be reached in a real world environment and also to undertake preliminary investigations into the use of a magenta beacon. The beacons were assessed in terms of subjective ratings of beacon conspicuity, urgency, discomfort glare and annoyance under day and night-time conditions.

6.2.2 Variables

The test environment was the same as that described for the validation trials in section 5.0. The combinations of beacon colour which were assessed amongst roadside beacons are given in the table below.

Table 14: Combinations of beacon colour assessed

Beacon combinations assessed
Amber with Blue
Amber with Green
Amber with Red
Amber with Magenta
Amber with White

The rating scales used were those used previously in the laboratory tests, these being the GP50 scale for attention-getting qualities and level of urgency, the nine-point deBoer rating scale for discomfort glare and a nine-point scale similar to the deBoer scale for annoyance (see Figures A11, A12 and A13 in Appendix 10).

6.2.3 Procedure

For these trials, groups of ten participants carried out the trial at one time. Participants were given a set of rating scales each and a response sheet to record their responses. Each of the six beacon colour combinations were viewed in a random order and rated for perceived attention-getting, discomfort glare, urgency and annoyance.

6.2.4 Participants

Twenty UK driving licence holder participants were used. The ratio of male to female participants was approximately 50:50 and the ratio of young to old participants was also 50:50. As with the laboratory trials, all participants were screened for any heightened sensitivity to flashing lights and any deficiencies in colour vision.

6.2.5 Results

A summary of the main results of assessing beacon combinations during the validation trials are presented in table 15 and discussed below.

Table 15: Rankings of warning beacon combinations - validation trials (numbers in bold italics = not significant results)

		Test 3: Subjective Rankings			
	Beacon combination	**Attention**	**Urgency**	**Discomfort**	**Annoyance**
Day conditions	**Amber + Blue**	***4***	***4***	1	2
	Amber + Green	5	5	1	2
	Amber + Red	***3***	***3***	1	2
	Amber + Magenta	***2***	***2***	1	1
	Amber + White	1	1	5	5
Night conditions	**Amber + Blue**	2	2	2	1
	Amber + Green	2	4	4	4
	Amber + Red	5	4	1	1
	Amber + Magenta	2	2	2	1
	Amber + White	1	1	5	5

How attention-getting is each beacon combination?

The mean ratings for extent to which each beacon colour combination was perceived to be attention-getting are given below in table 16 (see also Figures A5(a) and A6(a) in Appendix 10).

Table 16: Mean ratings for attention-getting for each colour combination

	Daytime					**Night-time**				
Amber with...	Blue	Green	Red	Magenta	White	Blue	Green	Red	Magenta	White
Mean rating	38	36	38	39	40	45	45	42	45	47

(Higher values imply more favourable ratings)

The mean ratings indicate that under day conditions, amber with white beacons were rated as the most attention-getting whilst amber with green beacons were rated as the least attention-getting, the difference being significant at a level of 5%. Under night-time conditions, amber with white was also rated as the most attention-getting, being significantly more so than amber with green, red or magenta beacons. Under the same conditions, amber with red beacons were found to be significantly less attention-getting than amber with blue or magenta beacons.

Further analysis indicated that amber beacons alone were rated as significantly less attention-getting than amber combined with other colours, an exception to this being red at night-time. (When comparing other single colour beacons to their combination with amber, the single colour was found to be significantly less attention-getting, the exceptions being magenta under daytime conditions and green under night-time conditions).

How urgent does each beacon combination appear?

The mean ratings for the urgency associated with each colour combination are given below in table 17 (see also Figures A5(b) and A6(b) in Appendix 10).

Table 17: Mean ratings for urgency for each colour combination

	Daytime					Night-time				
Amber with...	Blue	Green	Red	Magenta	White	Blue	Green	Red	Magenta	White
Mean rating	36	34	37	38	39	43	41	40	42	44

(Higher values imply more favourable ratings)

The daytime trials revealed that the amber and white beacon combination was rated as the most urgent whilst the amber with green beacon combination was rated the least urgent, the difference being significant. Under night conditions, the amber with white combination was again rated as the most urgent, being significantly more urgent than the amber with green or red combinations.

Further analysis indicated that amber beacons alone were rated as conveying significantly less urgency than amber combined with other colours. (When comparing other single colour beacons to their combination with amber, the single colour was found to be significantly less urgent, the exceptions to this being magenta and red under daytime conditions).

How much discomfort glare does each beacon combination appear to have?

The mean ratings for the perceived discomfort glare associated with each colour combination are given below in table 18 (see also Figures A5(c) and A6(c) in Appendix 10).

Table 18: Mean ratings for discomfort glare for each colour combination

	Daytime					Night-time				
Amber with...	Blue	Green	Red	Magenta	White	Blue	Green	Red	Magenta	White
Mean rating	5.1	4.9	5.0	4.9	3.8	3.5	3.1	4.1	3.5	2.4

(Ratings less than 5 imply unacceptable levels of discomfort glare)

The amber with white beacon combination was found to have significantly more discomfort glare than all other beacon combinations under day and night conditions. In addition, from the night-time testing, it was found that amber with red was rated as having significantly less discomfort glare than amber with magenta, green or white.

Further analysis indicated that amber beacons alone were considered to cause significantly less discomfort glare than amber combined with other colours, both day and night, the exception being the use of blue beacons at day. (When comparing other single colour beacons to their combination with amber, the single colour was found to have significantly less discomfort glare than the beacon combination on all occasions, the exception being magenta and green under daytime conditions).

How annoying is each beacon combination?

The mean ratings for the extent to which each beacon combination was considered to be annoying are given below in table 19 (see also Figure A5(d) and A6(d) in Appendix 10).

Table 19: Mean ratings for annoyance for each colour combination

	Daytime					Night-time				
Amber with...	Blue	Green	Red	Magenta	White	Blue	Green	Red	Magenta	White
Mean rating	4.6	4.8	4.6	4.9	3.7	3.6	3.2	3.8	3.7	2.8

(Ratings less than 5 imply unacceptable levels of discomfort glare)

The amber with white beacon combination was rated as being significantly more annoying than other combinations in the day trials. It was also the most annoying in the night trials, being significantly more so than the amber with blue, magenta and red combinations.

Further analysis indicated that amber beacons alone were rated as significantly less annoying than amber combined with other colours. (When comparing other single colour beacons to their combination with amber, the single colour was found to be significantly less annoying than the beacon combination on all occasions apart from when comparing single magenta with amber and magenta under day conditions.)

6.3 Comparison of the laboratory and validation trials

The laboratory trials indicated that there were significant advantages to vehicle conspicuity if amber beacons in combination with another colour are used when the vehicle is located in an environment of amber beacons. The results suggested that both red and white would improve conspicuity, although allowing for the filtering effects of the domes (as discussed in section 5.3) it would be expected that white would offer greater increases in conspicuity than red in the road environment. A comparison of the results for red and white in the validation trials confirms this.

6.4 Summary

At night, both with and without street lighting, the detection and ease of identification of the vehicle was most favourable when no roadside beacons were present. When roadside beacons were present, static was more favourable than flashing. During the day, detection times suggest that static roadside lighting may be of benefit.

Vehicle beacon flash rates of 240 fpm (used in conjunction with roadside beacon flash rates of 120 fpm) did not improve vehicle detection, although under certain conditions, it was subjectively considered easier to identify its presence.

A static amber beacon employed in conjunction with the flashing amber beacon on the vehicle did not improve the vehicle’s detection rate, time or ease of identification.

An additional colour to the flashing amber vehicle beacon improved the ease of identification of the vehicle during the day and night and resulted in quicker detection times when the additional colour was flashing red (day and night) or flashing white (night only) when located amongst other amber beacons.

The results of this study, and the analysis of the performance of coloured beacons undertaken in section 5, suggest that:

- a flashing white light used on the vehicle in conjunction with a flashing amber light is likely to assist in vehicle detection. However due to the lack of filtering of a clear dome, it is likely that it would increase discomfort glare and annoyance.
- a flashing red light used on the vehicle in conjunction with a flashing amber light is likely to assist in vehicle detection but also increase discomfort glare and annoyance, although to a lesser extent than white, green and magenta at

night. Red beacons are the most favourable to assist in detecting people in their vicinity.

- a flashing magenta light used on the vehicle in conjunction with a flashing amber light is unlikely to assist in vehicle detection, although subjectively it was considered to be attention-getting. Like red beacons, it is favourable for detecting people in its vicinity, but suffers the same levels of discomfort glare and annoyance.

7.0 Hazard analysis

7.1 Eleptogenic response

7.1.1 Description of the hazard

Approximately 0.5% of the UK population suffers epilepsy (around 350,000 people) but of these only a few per cent may have seizures induced by flashing lights. Such sensitivity is commoner in children and adolescents and becomes less frequent with age, being very uncommon from the mid twenties onwards. Thus only a very small proportion of people exposed to warning beacons are likely to suffer provoked seizures.

However is also recognised that the visual stimuli which provoke seizures are also implicated as triggers for migraines and can provoke feelings of discomfort, headaches or eyestrain in otherwise healthy individuals who suffer from neither epilepsy nor migraines.

Experimental studies indicate that when an observer looks at a flickering light, the electrical brain activity over the occiput at the back of the head shows a response at the same frequency as the light and sometimes this response is so large as to be visible against the other brain rhythms. It has been suggested that it is this response which underlies the feeling of discomfort as it may compromise the computational processes involved in processing underlying vision, such as those involved in the control of eye movements (Wilkins, 1995). Further experimental work has shown that when text is illuminated by light pulsating at 100Hz the number of eye movements necessary for reading is as much as doubled.

These studies may help to account for the effects of working under the light from beacons described by one police officer:

"It can be distracting when working under flashing lights for a length of time. This seems to be a mental workload issue, not a vision problem in that it feels that it takes longer to process what is going on and what needs to be done; more concentration is needed."

Thus consideration of the psychological/neural response to flashing lights have to be considered in the specification for the design and use of beacons because the effects may not be restricted to those who suffer from epileptic seizures.

7.1.2 The influence of lamp characteristics on eleptogenic responses

No research work specifically relating to beacons has been identified, however from the work that has been reported it is possible to discuss the main factors and their influences.

Frequency

Jeavons and Harding (1975) report that the probability of epileptiform EEG activity in grouped data rises sharply above 5 Hz and appears to peak at 20 Hz before tailing of steadily to 50 Hz and more abruptly from then on. This broadly concurs with Hopkinson & Collins (1970) and Orne (1986) who state that lights, especially high intensity lights, operating at a frequency of 10-15 Hz are associated with epileptic occurrences. (Lights operating at 30-50Hz will start to appear as a steady light). Whilst some individuals will be sensitive to lower frequencies, grouped data should be considered for devices intended to be exposed to the general public. Accordingly, frequencies above 5 Hz (300fpm) should be avoided in applications such as vehicle lighting.

Colour

Jeavons and Harding (1975) report that all colours of light are almost equally epileptogenic, although Takahashi and Tsukahara (1976) found that red light may be more epileptogenic than white. Whilst there are large individual differences in response to colour, the population as a whole must be considered and there seems little evidence that any specific colour, in particular red, should cause more problems than other colours for use in beacons.

Waveform

There is no association between the waveform of the light and its epileptogenic response. However wave forms which increase the frequency of the flash, such as synchronised double flash strobe lights, may have some effect. (See 'Frequency' above).

Luminance

The luminance averaged over time can be as low as 20 cd/m^{-2} in order to trigger epileptiform EEG activity. This, of course, exceeds the luminance required to make a warning beacon conspicuous.

Field of view

Activity in foveal vision (the centre of gaze) is far more effective in stimulating epileptiform EEG responses than activity in the periphery. Jeavons et al (1971) found that a strobe, operating at 7Hz, only envoked a response when viewed directly at 0° and was ineffective at 30°, 45° or 90° to the direction of gaze. Although drivers may not choose to view a beacon directly, there may be instances where this is unavoidable eg reflected light.

Duration of exposure

Short duration bursts of 2 seconds of intermittent light are used in routine EEG recording because they can provoke epileptiform EEG activity that does not progress to seizures. Longer stimulation increases the chances of a seizure although the effects of duration have not been studied. It would perhaps be safer to advise that beacons are used for the minimum time so as to expose the fewest number of people to their effects.

Technology

Following complaints of drivers of emergency vehicles concerning the perceived discomfort of beacons at the scene of accidents, it was found that flashing beacons (strobes) cause more discomfort than rotating beacons (Rumar 1975).

7.2 Disability glare

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

In the context of this study, disability glare caused by warning beacons may impair a driver's ability to detect a roadside worker. This scenario was modelled in our work and the results in the table below indicate the factors which significantly affect disability glare.

Table 20: Factors affecting disability glare

Disability glare	
minimised by…	**worsened by…**
Red beacons	Amber beacons
Rotating beacons	Strobe beacons
Minimum intensities	Maximum intensities

7.3 Discomfort glare

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

Discomfort glare resulting from warning beacons was assessed in this study by exposing participants to beacons at their maximum intensities and asking them to rate their visual discomfort. The results in the table below indicate the factors which significantly affect discomfort glare.

Table 21: Factors affecting discomfort glare

Discomfort glare	
minimised by…	**worsened by…**
Blue	Red and magenta
Minimum flash rates	Maximum flash rates
Alternating flashes	Simultaneous flashes
Rotating beacon (night only)	Strobe beacon (night only)
Strobe - single pulse (day only)	Strobe - double pulse (day only)

7.4 Distraction

7.4.1 'Eyes off the road'

The function of warning beacons is to draw attention to an area of the road where drivers may not be looking. A balance needs to be made between the beacon being attention-getting and being distracting. Part of this study investigated this aspect.

The amount of distraction a beacon provided was measured by the number of times a participant failed to detect the onset of a cars brake lights or, if they were seen, the time it took to respond to them. The results indicate that a beacon present in the driving environment is significantly more distracting than no beacon at all, but that the extent of the distraction was not related to flash rate, type or intensity.

7.4.2 'Moth-to-flame' effect (Phototaxis)

There is concern in America that the warning beacons used on recovery vehicles may actually be contributing to the hazard at the scene. The issue was raised in February 1998 in the recovery operators journal 'Tow Times' which recounted the case of a recovery operator being held liable for another vehicle driving into the recovery area and seriously injuring the owner of the broken down vehicle. The operator was judged to be negligent for using the amber warning beacons whilst at the scene as follows:

"Relying upon scientific evidence, the plaintiff concluded that rather than protecting the tow truck driver and his customer, the flashing lights actually created a hazard. His expert testimony demonstrated that, instead of diverting night-time drivers away from the scene of breakdowns, flashing tow truck lights actually attract tired, intoxicated or otherwise impaired night-time drivers 'like a moth to flame' ".

Investigation through Tow Times and various American attorneys has not revealed the scientific evidence mentioned above. Similarly consultation with the Sleep Research Laboratory at Loughborough University revealed that to date there has been no research undertaken concerning the interaction of the drivers' mental state and the affect on their driving performance of warning beacons.

7.5 Summary

The experimental work in this study has shown that warning beacons are significantly more distracting in a road environment than when no beacons are present. However by their nature warning beacons have to contain some element of distraction in order to gain attention. The current acknowledged misuse of warning beacons must therefore be viewed severely in light of this finding and efforts must be made to ensure that beacons are only used when there is a real hazard. This then becomes an issue for enforcement.

Distraction, to both the workers at the scene and passing drivers, can also be reduced by ensuring that the appropriate message is given to other road users with the minimum number of beacons. This is particularly important when more than one vehicle equipped with warning beacons is present at the scene.

Distraction can be further reduced by incorporating a cut off in the beam pattern which would limit the light falling within the vicinity of the vehicle. Work personnel would be able to carry out their duties without the disbenefits of working under flashing lights and drivers would be subject to reduced disability and discomfort glare whilst at the scene.

Another inherent hazard of warning beacons, aside from distraction, is that the luminance required to make them attention-getting is sufficient to trigger epileptiform EEG activity. Only a very small proportion of people exposed to warning beacons are likely to suffer a seizure but people who spend any time in the vicinity may suffer temporary psychological and perceptual effects. Thus only the minimum number of beacons should remain on at the scene of an incident eg the rearguard vehicle.

Consideration of disability and discomfort glare suggests that the disbenefits of warning beacons may be mitigated by:

- using minimum flash rates and ensuring that the combined flash rate of multiple beacons is less than 240 fpm,
- using minimum intensities,
- using rotating beacons (if use strobes, use single not double pulse),
- employing alternating flashing beacons instead of simultaneous flashing beacons,
- using blue in preference to amber beacons. Red could also be used since the benefits to be obtained from minimising disability glare are likely to outweigh the disbenefits of discomfort glare.

The growing concern of the ‘moth-to-flame’ phenomenon whereby warning beacons may cause drivers in an impaired mental state to drive towards them is an area requiring further investigation.

8.0 Recommendations

The findings of the test programme will be summarised here and general recommendations will be made based on them. These recommendations will then be applied to specific users giving full consideration to their unique requirements. It was noted in the analysis of the results data that the subjective measures of conspicuity (participant ratings) did not always coincide with the objective measures of conspicuity (detection rates and times). In these instances the more reliable, objective measure (ie what people actually do, rather than what they say they will do), has been used in determining the recommendations.

The test programme confirmed that, in general, those factors which make a warning beacon more conspicuous also give rise to increased disability glare, discomfort glare, distraction and annoyance. Therefore the recommendations given below seek not to maximise conspicuity but to **optimise** it in relation to the disbenefits which it generates.

8.1 Summary of recommendations

NB. The colour recommendations have accounted for current manufacturing methods whereby dome colour effects perceived intensity.

8.1.1 Flash colour

1. Retain the existing allocation of beacon colour by use.
2. Increase the conspicuity of the blue beacon by using the highest flash rates and intensities.
3. Increase the conspicuity of recovery operators by using amber in conjunction with red and at medium level intensities and flash rates.
4. Increase the conspicuity of slow moving vehicles by using amber at medium level intensities and flash rates.
5. Other users of amber beacons should employ intensities and flash rates at lower levels.

6. Increase the conspicuity of green beacons by using medium level intensities and flash rates.

8.1.2 Flash intensity

7. Use high intensities to maximise conspicuity but incorporate a beam cut-off so personnel at the scene are not masked and discomfort glare and annoyance is reduced. (For further description of the beam cut-off, refer to section 8.4).
8. Use different intensity settings for daytime and night-time.

8.1.3 Flash rate

9. Flash rates up to 240 fpm are acceptable.
10. The more safety critical the situation, the faster the flash rate which should be employed.
11. Use up to a maximum or four levels of flash rates.
12. Incorporate a beam cut-off to reduce annoyance and discomfort.

8.1.4 Flash technology

13. Use strobe beacons to improve daytime conspicuity but incorporate a beam cut-off so personnel at the scene are not masked.

8.1.5 Beacon number

14. The use of one beacon to be seen from any viewing angle is a sufficient minimum compromise between conspicuity and cost. (If two beacons are employed, there may be benefits, with regard to determining closing speed, if they are positioned at maximum possible separation, to rear and side orientations of vehicles).

8.1.6 Beacon positioning

15. Beacons should be positioned such that at least one is available for view from side and rear.

16. Beacons should be positioned high on the vehicle in order to be seen above traffic.
17. Additional beacons to the vehicle front should be positioned such that they easily viewable in the mirrors of preceding vehicles.

8.1.7 Flash configuration

18. To maximise conspicuity use beacons which flash simultaneously.

The rationale on which these recommendations are made is described below.

8.2 Rationale for recommendations

8.2.1 Flash colour - single

Table 22 shows the relative benefits and disbenefits of each colour. These factors need to be considered in conjunction with the specific requirements of the user groups so that the most appropriate colour is matched to the user needs.

Amber

The users of amber beacons as specified by the Road Vehicle Lighting Regulations can be divided into three categories:

a) Breakdown vehicles and other vehicles used at the scene of an emergency.
b) Vehicles with a maximum speed not exceeding 25 mph.
c) Where it is necessary or desirable to warn of the presence of the vehicle.

Amber should be retained for each of these uses since:

- amber is the most conspicuous colour ie it is detected the quickest,
- there are slight advantages of association which would be lost if the colour was changed,
- the alternative colour of blue has too great an association with the emergency services,

- the alternative colour of red has existing associations with danger which could be usefully employed across a variety of user groups rather than dedicated to just one group,
- the alternative colour of green offers no significant technical advantages over amber,
- the alternative colour of magenta is poorest for conspicuity ie it takes longer to detect a magenta beacon than any other colour.

Table 22: Factors in warning beacon optimisation - flash colour (single)

To maximise benefits use factors ranked 1.

Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Time to detect pedestrian)	Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
Amber	1	1	1	5	3	2.5	3		2	2	3.5	4	4.5	3	2.5	Roadworks, Recovery operator (Medium)
Blue	3	2	3	3	1	1	1		1	1	1	5	4.5	4.5	2.5	Emergency services (Strong)
Green	4	2	5	3	2	2.5	1		3	4	2	3	1.5	4.5	2.5	Medical (Weak)
Magenta	5	5	4	3	4.5	4.5	3		4	4	3.5	1	1.5	1.5	2.5	
Red	2	2	2	1	4.5	4.5	3		5	4	5	2	3	1.5	2.5	Danger (Weak)

Recovery operators: The concern of recovery operators is that amber beacons are not conspicuous enough and so do not offer them the protection on the road which they require. The strong performance of amber in terms of conspicuity can be improved for these users through the addition of a further colour (see section 8.2.2 below). In time, it is hoped that this additional colour may become associated with the meaning that there is an increased likelihood that personnel may be present on the carriageway. Flash rates and intensities should not be at the maximum since these levels, in conjunction with the use of amber itself (which is the most conspicuous colour), will compete with the performance of blue beacons which should have precedence. See 'Blue' below.

Slow moving vehicles: These should employ the same beacon characteristics as the recovery operators because they pose a particular threat to other roadusers. (This is described more fully in section 8.2.6). However they should not use the additional colour since the threat does not involve personnel being present on the carriageway. In time amber beacons used at these rates and intensities may become associated with slow or stationary vehicles.

Advising of the vehicle's presence: In situations where the threat to life is not so great as the two scenarios described above, the amber beacon should be employed at intensities and rates below those already recommended. The additional colour should not be used.

Blue

Blue should be retained for use by the emergency services since its association with them is so strong that the confusion resulting from a change in colour may negate any conspicuity advantages to be obtained. The disability glare and annoyance of blue beacons may be reduced through an improvement in beam pattern. Conspicuity ie the time taken to detect a blue beacon, may be improved by using it in conjunction with higher intensities and flash rates.

Green

Green should be retained for use by medical practitioners since, like amber, there are weak associations which would be lost if another colour was employed and there are no colours which are a suitable alternative. Disability glare can be reduced through a re-defined beam pattern and conspicuity can be increased by using medium to high intensities and flash rates. (However these must not be as high as those used by the emergency services).

Red

This is a desirable colour since it is conspicuous, conveys urgency and causes the least disability glare. It is not associated with any particular user group but is weakly associated with the concept of 'danger'. It would therefore be suitable to use in conjunction with other colours to imply the need for extra caution by other road users due to the increased likelihood of personnel on the road ahead.

- **Recommendation: Retain the existing allocation of beacon colour by use.**
- **Recommendation: Increase the conspicuity of the blue beacon by using the highest flash rates and intensities.**
- **Recommendation: Increase the conspicuity of recovery operators by using amber in conjunction with another colour (red) and at medium level intensities and flash rates.**
- **Recommendation: Increase the conspicuity of slow moving vehicles by using amber at medium level intensities and flash rates.**
- **Recommendation: Other users of amber should employ intensities and flash rates at lower levels.**
- **Recommendation: Increase the conspicuity of green beacons by using medium level intensities and flash rates.**

8.2.2 Flash colour - double

Table 23 shows the relative benefits and disbenefits of using a further colour in addition to amber. Although magenta offers the best compromise across the factors tested, it should be noted from table 6 that magenta beacons were the least

Table 23: Factors in warning beacon optimisation - flash colour (double)

To maximise benefits use factors ranked 1.

[shaded box] Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Time to detect pedestrian)	Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
Amber + …	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
… Blue					2.5	2.5	2.5		2.5	3	2	3	4	2.5	2.5	
… Green					4	2.5	4		4	3	4	5	5	4.5	2.5	
…Magenta					2.5	2.5	2.5		1	1	2	2	2	2.5	2.5	
…Red					1	2.5	1		2.5	3	2	4	3	4.5	2.5	
… White					5	5	5		5	5	5	1	1	1	2.5	

conspicuous (ie they had the slowest detection times). Red would therefore offer the best compromise and has the additional benefit that its association with danger would reinforce the cautionary behaviour required of other drivers.

- **Recommendation: Use red with amber to improve the conspicuity of vehicles fitted with amber lights when in the vicinity of other flashing amber lights .**

8.2.3 Flash intensity

For most of the factors tested there was no difference between beacons viewed at minimum and maximum intensities. However there was significant variation on two critical aspects; maximum intensities were more conspicuous ie were detected more quickly, whereas minimum intensities gave rise to less disability glare ie a pedestrian in their vicinity could be detected more quickly. One means for reconciling these factors is to design a cut-off into the beam pattern given by the beacon. In this way the beacon can be conspicuous at a distance thereby alerting drivers well in advance to the presence of the vehicle. Having become aware of the vehicle's presence, oncoming drivers then need information concerning the details of the scene such as personnel positioning and vehicle layouts for which less intensity is required. This ability to quickly assimilate the scene with minimal interference from beacon lights was specifically mentioned by the police and is also of crucial importance to the breakdown services and recovery operators.

- **Recommendation: Use high intensities to maximise conspicuity but incorporate a beam cut-off so personnel at the scene are not masked.**

  To maximise conspicuity, as measured by detection time, maximum intensities for both day and night should be used. The night-time maximum intensity of 670 cd is only about 1/3 of the luminance of the maximum daytime brightness and so would be insufficient for daytime use. With regard to discomfort glare, 500 cd was found to be the daytime threshold which was acceptable to 19 of the 20 participants. However at night-time 500 cd was found to be unacceptably bright by 18 of the 20 participants. It would seem therefore that in terms of disability and discomfort glare a single level of intensity cannot be applied both day and night. A lighting system which incorporates different intensity settings for daytime and night-time would therefore be of benefit. The best means for ensuring the appropriate use of such a system would be to incorporate a photo-electric cell for automatic adjustment between the two settings.

- **Recommendation: Use different intensity settings for daytime and night-time.**

Table 24: Factors in warning beacon optimisation - flash intensity

To maximise benefits use factors rated with 1.

Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Time to detect pedestrian)	Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
Minimum	2	2	2	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Maximum	1	1	1	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	

8.2.4 Flash rate

The data in table 25 indicates that the faster the flash rate, the more conspicuous a beacon is ie the quicker it is detected, but also the more annoyance and discomfort glare it offers as well as lower pedestrian detection rates. However these disbenefits are likely to be mitigated by a reduced beam pattern and so full advantage can be taken of the relative conspicuity benefits offered by different flash rates. Work by Cohen and Dinnerstein, reported in Holmes, 1971, "…investigated the number of flash rates that can be discriminated and suggest that three or four rates may be used as coding information. Reaction times for correctly identifying flash rates are less for higher rates, . . .". Therefore safety critical information to be conveyed by a warning beacon should use higher flash rates not just because they are more conspicuous but because they can be differentiated and identified quicker.

- **Recommendation: Flash rates up to 240 fpm are acceptable.**
- **Recommendation: The more safety critical the situation, the faster the flash rate which should be employed.**
- **Recommendation: Use up to a maximum of four levels of flash rates.**
- **Recommendation: Incorporate a beam cut-off to reduce annoyance and discomfort.**

8.2.5 Flash technology

Table 26 shows that the critical differences regarding the technology used were that strobes were more conspicuous by day ie they were detected more quickly, and rotating beacons gave rise to less disability glare ie pedestrians in the vicinity of a beacon could be detected more quickly, and less discomfort glare at night. This is a similar conflict to minimum and maximum intensities, discussed in section 8.2.3, to which a re-defined beam pattern is a possible solution. A double pulse strobe should be used in preference to a single pulse since it is more conspicuous and reduces the time taken to detect a pedestrian.

- **Recommendation: Use strobe beacons to improve conspicuity but incorporate a beam cut-off so personnel at the scene are not masked.**

Table 25: Factors in warning beacon optimisation - flash rate

To maximise benefits use factors rated with 1.

Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Pedestrian detection)			Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
	Overall	Day	Night	Overall	Time	Rate	Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
60 fpm	4	4	4	1.5	2.5	1.5	1	1.5	1	2.5	1	1	1	4	4	4	2.5	
120 fpm	3	3	3	1.5	2.5	1.5	2	1.5	2.5	2.5	2.5	2.5	2.5	3	3	3	2.5	
180 fpm	2	2	2				3	3	2.5	2.5	2.5	2.5	2.5	2	2	2	2.5	
240 fpm	1	1	1	4	2.5	4	4	4	4	2.5	4	4	4	1	1	1	2.5	

Table 26: Factors in warning beacon optimisation - flash technology

To maximise benefits use factors rated with 1.

[shaded] Not included in test programme. Data included from other sources.

Warning beacon characteristic	**Conspicuity** (Time to detect beacon)			**Disability glare** (Time to detect pedestrian)	**Discomfort glare** (Subjective rating)			**Distraction** (Time to detect brake light)	**Annoyance** (Subjective rating)			**Urgency** (Subjective rating)			**Eleptogenisis**	**Association** (Strength of association) (Subjective rating)
	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
Rotating	2	2	1.5	1	1	1.5	1	1.5	1	1	1	2	2	1.5	1.5	
Strobe	1	1	1.5	2	2	1.5	2	1.5	2	2	2	1	1	1.5	1.5	
Strobe - single pulse	2	2	2	2	1	1	1.5		1	1	1.5	2	2	2	1	
Strobe - double pulse	1	1	1	1	2	2	1.5		2	2	1.5	1	1	1	2 (if above 300 fpm)	

8.2.6 Beacon number

The test work reported in appendix 1 indicates that, in general, adding more beacons to a vehicle does not significantly increase its conspicuity. At night-time one beacon was as conspicuous ie detected as quickly, as eight and during the daytime one beacon was as conspicuous as six. Therefore to obtain any significant improvement in daytime conspicuity at least eight beacons would need to be viewed from any given angle. Since many vehicles currently only exhibit one, this would represent an extremely large investment on behalf of the vehicle owners and would gain just 0.27 seconds extra in beacon detection time.

- **Recommendation: The use of one beacon to be seen from any viewing angle is a sufficient minimum compromise between conspicuity and cost.**

The review of detailed accident data made as part of this study indicated that a high closing speed, where a following driver rapidly gains on a slow moving or stationary vehicle ahead, may be a factor in accident scenarios. This is supported by the research review undertaken for the related project concerning the conspicuity of vehicle markings which states that " . . . 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". (Cook et al 1997). Therefore not only is it important to see the vehicle but the following drivers closing speed to it must also be accurately judged. It can be observed that as a vehicle is approached its apparent size changes ie it appears to get larger. The rate of the change in apparent size is an indication of the velocity of the closing speed. At night a vehicle can only be seen at a distance by its lights. A warning beacon, which will be seen before the vehicle's presence lights, will be viewed as a point of light and changes in its apparent size as drivers approach are difficult to detect. Jannsen (1972) in Smith et al (1985) 'found that changes in size and brightness of taillights were ineffective cues in the detection of relative motion in depth. His results indicated that changes in the angular separation between taillights constituted the primary cues for such judgements'. It may be expected therefore that two beacons, at maximum separation on the sides and rear of the vehicle, would more usefully assist this process, although the addition of contour markings (retroreflective materials which outline the face of the vehicle) would be better still. (Factors concerned with speed estimation were beyond the remit of this study and so were not tested. Therefore these benefits are hypothesised but not validated by this work).

- **Recommendation: If two beacons are employed, there may be benefits, with regard to determining closing speed, if they are positioned at maximum possible separation, to rear and side orientations of vehicles.**

Table 27: Factors in warning beacon optimisation - beacon number

To maximise benefits use factors rated with 1.

Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Time to detect pedestrian)	Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
1	2.5	5	3		1	1	4.5									
2	2.5	2.5	3		7.5	7.5	4.5									
3					2.5	2.5	4.5									
4	2.5	2.5	3		5	5	4.5									
5					5	5	4.5									
6	2.5	2.5	3		5	5	4.5									
7					2.5	2.5	4.5									
8	1	2.5	3		7.5	7.5	4.5									

8.2.7 Flash configuration

Table 28 shows that beacons flashing simultaneously are more conspicuous, but cause more discomfort glare than those which flash alternately. However, the disbenefits of discomfort glare are likely to be reduced by a cut-off in the beam pattern.

- **Recommendation: To maximise conspicuity use beacons which flash simultaneously.**

Table 28: Factors in warning beacon optimisation - flash configuration

To maximise benefits use factors rated with 1.

Not included in test programme. Data included from other sources.

Warning beacon characteristic	Conspicuity (Time to detect beacon)			Disability glare (Time to detect pedestrian)	Discomfort glare (Subjective rating)			Distraction (Time to detect brake light)	Annoyance (Subjective rating)			Urgency (Subjective rating)			Eleptogenisis	Association (Strength of association) (Subjective rating)
	Overall	Day	Night		Overall	Day	Night		Overall	Day	Night	Overall	Day	Night	(Source Sec. 7.0)	
Alternating	2	2	2		1	1.5	1									
Simultaneous	1	1	1		2	1.5	2									

8.3 Specific user recommendations

(values for max/middle/min flash rates and intensities are given in tables 29 and 30)

8.3.1 Police

Currently permitted	**Vehicle used for Police purposes.**	
Front	Blue light from a warning beacon or special warning lamp (see restrictions 1,2) Headlamp may automatically flash	
Side	Not specified	
Rear	Blue light from a warning beacon, rear special warning lamp or any device fitted to a vehicle for Police purposes (see restrictions) Blue and white chequered dome lamp (see use restriction 3)	
Use restrictions	At the scene of an emergency; Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard.	
Performance requirements		
Going to incident	Emergency responses require highest level of all-round conspicuity	
At incident	To warn of obstruction/hazard in roadway (similar to any other highway obstruction) Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Going from incident	Unless going to other incident or escorting an ambulance no beacons required	
Escort duties	High speed, slow moving vehicles or where duty requires police vehicles to behave in unexpected manner then highest level required	
Recommendations		
Front	Minimum of one blue warning beacon	Use beam cut-off * Use max intensities day and night Use max flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one blue warning beacon Minimum of one red warning beacon	
Rear	Minimum of one blue warning beacon Minimum of one red warning beacon	

Use restrictions	As current Where more than one emergency vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.

* A beacon with a beam pattern designed to minimise glare closer to scene

8.3.2 Fire

Currently permitted	**Vehicle used for Fire purposes. Including Fire Service control vehicle**	
Front	Blue light from a warning beacon or special warning lamp (see restrictions). Headlamp may automatically flash. Red and white chequered dome lamp or segmented mast (see use restriction)	
Side	Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied	
Rear	Blue light from a warning beacon or rear special warning lamp (see restrictions 1,2). Red and white chequered dome lamp or segmented mast (see use restriction) (see use restriction 3)	
Use restrictions	At the scene of an emergency; Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard.	
Performance requirements		
Going to incident	Emergency responses require highest level of all-round conspicuity	
At incident	To warn of obstruction/hazard in roadway (similar to any other highway obstruction) Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Going from incident	No requirements	
Recommendations		
Front	Minimum of one blue warning beacon	Use beam cut-off * Use max intensities day and night Use max flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one blue warning beacon Minimum of one red warning beacon	
Rear	Minimum of one blue warning beacon Minimum of one red warning beacon	
Use restrictions	As current Where more than one emergency vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

8.3.3 Ambulance

Currently permitted	**An ambulance or a vehicle used for ambulance purposes.**	
Front	Blue light from a warning beacon or special warning lamp(see use restriction) Headlamp may automatically flash	
Side	Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied	
Rear	Blue light from a warning beacon or rear special warning lamp(see use restrictions 1,2). Green and white chequered dome lamp or segmented mast (see use restriction 3)	
Use restrictions	At the scene of an emergency; Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard.	
Performance requirements		
Going to incident	Emergency responses require highest level of all-round conspicuity	
At incident	To warn of obstruction/hazard in roadway (similar to any other highway obstruction) Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Going from incident	Highest level of all round conspicuity for conveying casualties to hospital.	
Recommendations		
Front	Minimum of one blue warning beacon	Use beam cut-off * Use max intensities day and night Use max flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one blue warning beacon Minimum of one red warning beacon	
Rear	Minimum of one blue warning beacon Minimum of one red warning beacon	
Use restrictions	As current Where more than one emergency vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

8.3.4 Other emergency vehicles

Currently permitted	**Other emergency vehicles (see definitions at foot of table)**	
Front	Blue light from a warning beacon or special warning lamp(see use restrictions 1,2) Headlamp may automatically flash	
Side	Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied	
Rear	Blue light from a warning beacon or rear special warning lamp(see use restrictions 1,2).	
Use restrictions	At the scene of an emergency; Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard.	
Performance requirements		
Going to incident	Emergency responses require highest level of all-round conspicuity	
At incident	To warn of obstruction/hazard in roadway (similar to any other highway obstruction) Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Going from incident	No requirements	
Recommendations		
Front	Minimum of one blue warning beacon	Use beam cut-off *
Side	Minimum of one blue warning beacon Minimum of one red warning beacon	Use max intensities day and night Use max flash rates
Rear	Minimum of one blue warning beacon Minimum of one red warning beacon	Use strobes Use simultaneous flash configuration
Use restrictions	As current Where more than one emergency vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

Definitions

An ambulance (a vehicle constructed and used for conveying sick or injured).
Forestry Commission fire fighters.
Bomb disposal, RAF nuclear emergency teams, RAF mountain rescue, RAF armament support
Vehicles primarily used for conveying human transplant tissue.

Vehicle owned and used for fire salvage.
Blood Transfusion Service vehicles.
HM Coastguard.
RNLI lifeboat launching vehicles.

British Coal Mines Rescue.

8.3.5 Breakdown vehicle

Currently permitted	**Breakdown vehicle (see definitions at foot of table)**	
Front	Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Side	Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Rear	Amber warning beacon	
Use restrictions	At the scene of an emergency. Whilst it is being used in connection with, and in the vicinity of, an accident or breakdown or whilst it is drawing a broken down vehicle. Necessary or desirable to warn of presence of vehicle.	
Performance requirements		
Going to incident	No requirement for beacons as vehicle largely behaves like any other and poses no risk. May occasionally act as emergency vehicle e.g. to lift vehicles off trapped occupants. So higher level conspicuity may be required	
At incident	To warn of obstruction/hazard in roadway (similar to any other highway obstruction) Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react Must be conspicuous amongst other amber beacons	
Going from incident	Need conspicuity/warning device if towing slowly.	
Recommendations		
Front	Minimum of one amber warning beacon	Use beam cut-off * Use middle level intensities day and night Use middle level flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one amber warning beacon Minimum of one red warning beacon	
Rear	Minimum of one amber warning beacon Minimum of one red warning beacon	
Use restrictions	As current Operators should comply with Code of Practice in BS 77121-12:1999 Where more than one emergency or breakdown vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

Definitions

Vehicle used to attend an incident or breakdown or to draw a broken down vehicle.

8.3.6 Vehicles with a maximum speed not exceeding 25mph

Currently permitted	**Vehicles with a maximum speed not exceeding 25 mph.**	
Front	Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Side	Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Rear	Amber warning beacon	
Use restrictions	Whilst it is being used in connection with, and in the vicinity of, an accident or breakdown or whilst it is drawing a broken down vehicle.	
Performance requirements	Warn of slow moving or stationary nature of vehicle Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Recommendations		
Front	Minimum of one amber warning beacon	Use beam cut-off * Use middle level intensities day and night Use middle level flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one amber warning beacon	
Rear	Minimum of one amber warning beacon	
Use restrictions	As current. Where more than one emergency or breakdown vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

8.3.7 Other users of amber beacons

<table>
<tr><td>Currently permitted</td><td colspan="2">Other permissions of use of amber beacons</td></tr>
<tr><td>Front</td><td colspan="2">Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)</td></tr>
<tr><td>Side</td><td colspan="2">Amber warning beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)</td></tr>
<tr><td>Rear</td><td colspan="2">Amber warning beacon</td></tr>
<tr><td>Use restrictions</td><td colspan="2">Necessary or desirable to warn of the presence of the vehicle</td></tr>
<tr><td>Performance requirements</td><td colspan="2">Advise of increased need for caution
Must not mask people in vicinity
Must not cause vision or other problems to people working in vicinity
Must not cause visual problems to other road users or cause them to over-react</td></tr>
<tr><td>Recommendations</td><td colspan="2"></td></tr>
<tr><td>Front</td><td>Minimum of one amber warning beacon</td><td rowspan="3">Use beam cut-off *
Use min level intensities day and night
Use min level flash rates
Use rotating beacons
Use alternating flash configuration</td></tr>
<tr><td>Side</td><td>Minimum of one amber warning beacon</td></tr>
<tr><td>Rear</td><td>Minimum of one amber warning beacon</td></tr>
<tr><td>Use restrictions</td><td colspan="2">As current.
Where more than one emergency or breakdown vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.</td></tr>
</table>

* A beacon with a beam pattern designed to minimise glare closer to scene

8.3.8 Medical practitioners

Currently permitted	**Medical practitioners vehicle**	
Front	Green beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Side	Green beacon (Not specified but warning beacon emits light through 360^{o} in horizontal plane – so implied)	
Rear	Green beacon	
Use restrictions	Vehicle occupied by a registered medical practitioner and used for an emergency	
Performance requirements		
Going to incident	Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard	
At scene	Must not mask people in vicinity Must not cause vision or other problems to people working in vicinity Must not cause visual problems to other road users or cause them to over-react	
Going from incident	Unless going to other incident no beacons required	
Recommendations		
Front	Minimum of one green warning beacon	Use bean cut-off * Use middle level intensities day and night Use middle level flash rates Use strobes Use simultaneous flash configuration
Side	Minimum of one green warning beacon	
Rear	Minimum of one green warning beacon	
Use restrictions	As current Where more than one emergency vehicle is present, all vehicles should switch off all beacons and warning devices except those closest to approaching vehicles.	

* A beacon with a beam pattern designed to minimise glare closer to scene

Table 29: Values of suggested flash rates

These values are based on the findings of the laboratory and field work and should be subjected to further refinement through road trials.

Flash rates (fpm)		
Min	**Middle**	**Max**
60-100	130-170	200-240

Table 30: Values for suggested intensities for use WITH a beam cut-off allowing for colour effect of dome filtering (rotating and strobe beacons)

These values are based on the findings of the laboratory and field work and should be subjected to further refinement through road trials.

	Day			**Night**		
	Min	**Mid**	**Max**	**Min**	**Mid**	**Max**
Amber	230 - 600	800 - 1000	1200 - 1680	100 - 250	325 - 425	500 - 670
Blue	105 - 200	250 - 350	400 - 1680	42 - 85	100 - 140	155 - 670
Green	40 - 200	250 - 350	400 - 1680	16 - 85	100 - 140	155 - 670
Red	270 - 450	600 - 750	900 - 1680	76 - 180	240 - 300	360 - 670

8.4 Definition of the beam cut-off

Warning beacons need to be sufficiently bright at a distance so that on-coming drivers see them in sufficient time to re-act accordingly. However once the beacon is seen, its intensity should be reduced such that the effects of disability glare are minimised when in the vicinity of the emergency/breakdown vehicle. A means to achieve both these objectives is to incorporate a beam cut-off into the beacon either by appropriate shielding or lens design. Guidelines on the beam design are given below

Table 31: Guidelines for beam cut-off design

	50mph	**80mph**
Intensity within beam	As per recommendations	As per recommendations
Intensity out of beam (within cut-off) Based on 95% pedestrian detection rate	60 cd	60cd
Effective distance of beam cut-off	500 feet 150 metres	1600 feet 488 metres

The table above indicates that one design of beam cut-off may not be sufficient to suit all situations. Variations arise from the height at which the beacon is mounted on the vehicle (consider the difference in roof height between a police car and a recovery truck) and the speed of traffic on the road which effects the distance at which the beacon must be visible.

If there is industry consensus that the provision of such a beacon is cost prohibitive, then disability glare will need to be controlled by some other means. An obvious method is to reduce intensity but this will have the disbenefit of reducing conspicuity (as measured by beacon detection time). However guidelines to intensity values which may offer a compromise between conspicuity and disability glare are given in the table below.

Table 32: Suggested intensities for use WITHOUT a beam cut-off allowing for colour effect of dome filtering (rotating and strobe beacons)

These values are based on the findings of the laboratory and field work and should be subjected to further refinement through road trials.

Rotating	**Day**			**Night**		
	Min	**Mid**	**Max**	**Min**	**Mid**	**Max**
Amber	230 - 500	650 - 750	900 - 1000	100 - 150	200 - 250	300 - 350
Blue	105 - 170	200 - 240	270 - 310	42 - 50	65 - 85	100 - 120
Green	40 - 170	200 - 240	270 - 310	16 - 50	65 - 85	100 - 120

Red	270 - 370	490 - 560	680 - 750	76 - 110	150 - 190	225 - 260

Strobe	**Day**			**Night**		
	Min	**Mid**	**Max**	**Min**	**Mid**	**Max**
Amber	230 - 400	550 - 650	800 - 900	100 - 120	150 - 200	250 - 300
Blue	105 - 300	350 - 450	500 - 600	42 - 70	90 - 130	150 - 190
Green	40 - 100	130 - 170	200 - 240	16 - 25	40 - 50	65 - 75
Red	270 - 300	350 - 450	500 - 600	76 - 80	95 - 135	150 - 190

8.5 Operational issues

Improving the benefits which warning beacons offer is not just related to their design. It is also dependent upon safe and responsible operation by their users.

- The intensity levels recommended for each user type should be strictly adhered to ie amber beacons should not be used at the intensities recommended for blue beacons.
- The conditions of use for each type of user should also be strictly adhered to ie beacons should only be used where it is important to convey a message to other road users.
- Where multiple vehicles are in attendance, only the rearmost should display its beacons. This will help to reduce masking at the scene and the discomfort experienced by those working under such lights.
- Personnel working by the roadside should ensure conformance to BSEN 471 for high visibility garments.

8.6 Further work

8.6.1 Road trials

The recommendations given in this section provide a good, initial brief for warning beacon design. ***However road trials using high quality prototype beacons should be undertaken prior to nation-wide introduction. Road trials are a valuable and necessary stage in the design process which allow fine-***

tuning of the final design by the end users thereby improving market acceptability of the final product.

Recent work of the Home Office on the development of conspicuity schemes for police motorway vehicles and police motorcyclists was conducted in this way ie initial designs were developed from laboratory and field testing and then verified with the users through six month road trials.

8.6.2 Related research

This study has addressed the issue of how to improve conspicuity and has provided realistic costings for this. However it has also been acknowledged that there is an unsubstantiated body of opinion that warning beacons may in fact cause accidents by drawing drivers into the accident scene. If this were true then there may be situations where the beacon which offers most safety on the road is the one that is switched off rather than the one which is conspicuous. This may be an issue worth re-visiting in the future.

9.0 Implications for legislation

The specific regulations relating to warning beacons are given below. Amendments to them are indicted in ***bold, italic font***.

9.1 ECE Regulation 65: Requirements for warning beacons

9.1.1 Current requirements

Table 33: ECE 65 requirements

			Colour	
			Blue	**Amber**
Flash rate, f (Hz)	Min		2	
	Max		4	
‘On’ time (sec)	Max		0.4/f	
Minimum value of effective luminosity within 360° angle (cd)	0°	day	105	230
		night	42	100
	± 4°	day	55	-
		night	22	-
	± 8°	day	-	168
		night	-	67
Max value of luminosity (cd)		day	1680	
		night	670	

9.1.2 Amended requirements

With reference to the table below, it should be noted that:

- Level 1 refers to warning beacons whose combined attributes display the highest level of conspicuity
- Level 3 refers to those displaying the lowest level of conspicuity
- Level 2 is intermediate

The various levels of warning beacons are allocated to users according to their need for conspicuity. For further explanation, refer to section10.

Table 34: ECE 65 amendments

WITH beam cut-off		***Level 1***		***Level 2***			***Level 3***
		Blue	***Red***	***Amber***	***Green***	***Red***	***Amber***
Flash rate (fpm)		***200-240***		***130-170***			***60-100***
Flash intensity at 0° (cd)	***Day***	*400 - 1680*	*900 - 1680*	*800 - 1000*	*250 - 350*	*600 - 750*	*230 - 600*
	Night	***155 - 670***	*360 - 670*	*325 - 425*	*100 - 140*	*240 - 300*	*100 - 250*
WITHOUT beam cut-off		***Level 1***		***Level 2***			***Level 3***
		Blue	***Red***	***Amber***	***Green***	***Red***	***Amber***
Flash rate (fpm)		***200-240***		***130-170***			***60-100***
Rotating flash intensity at 0° (cd)	***Day***	*270 - 310*	*680 - 750*	*650 - 750*	*200 - 240*	*490 - 560*	*230 - 500*
	Night	***100 - 120***	*225 - 260*	*200 - 250*	*65 - 85*	*150 - 190*	*100 - 150*
Strobe flash	***D***	*500 - 600*	*500 - 600*	*550 - 650*	*130 - 170*	*350 - 450*	*230 - 400*

	ay						
intensity at 0° (cd)	***Night***	*150 - 190*	*150 - 190*	*150 - 200*	*40 - 50*	*95 - 135*	*100 - 120*

9.2 The Road Vehicle Lighting Regulations

9.2.1 Regulations concerning the colour of warning beacons and permitted users.

Table 35: Regulations concerning the colour of warning beacons and permitted users.

Regulation	Exceptions
No vehicle to be fitted with a lamp capable of showing any light to the rear except a red light.	10. Blue light from a warning beacon or rear special warning lamp fitted to an emergency vehicle, or any device fitted to a vehicle for Police purposes. 11. Green light from a beacon fitted to a medical practitioner's vehicle. 12. Yellow light from a beacon fitted to airport vehicles. 13. Amber light from a warning beacon fitted to: Road clearance vehicle Refuse collection vehicle Breakdown vehicle Vehicle with maximum speed of 25 mph Vehicle with overall width exceeding 2.9 m Vehicle used for maintenance etc. of roads and road

	apparatus Vehicles under section 44 of the Act Escort vehicles travelling at speeds below 25 mph A Customs and Excise vehicle testing fuels A vehicle used for surveying A vehicle used for immobilisation or removal of vehicles as a statutory duty.

Vehicles permitted to show a red light from a warning beacon.	***1. Emergency and recovery vehicles***

9.2.2 Prohibitions for use for coloured beacons.

Table 36: Prohibitions for use for coloured beacons.

Type of lamp	**Manner of use prohibited**
Warning beacon emitting blue light.	Must not be lit unless: 1. At the scene of an emergency; 2. Necessary or desirable to indicate the urgency of purpose or to warn of presence of vehicle or hazard; 3. ***it is the closest to approaching vehicles.***
Warning beacon emitting amber light.	Must not be lit unless: 1. At the scene of an emergency; 2. Necessary or desirable to warn of the presence of the vehicle; 3. For breakdown vehicles, whilst it is being used in connection with, and in the vicinity of, an accident or breakdown or whilst it is drawing a broken down vehicle; 4. ***it is the closest to approaching vehicles.***
Warning beacon emitting green light.	Must not be lit unless: 1. Vehicle occupied by a registered medical practitioner and used for an emergency.
Warning beacon	***Must not be lit unless:***

emitting red light.	***1. In conjunction with amber or blue;*** ***2. At the scene of an emergency;*** ***3. Necessary or desirable to indicate the likely presence of personnel on the road;*** ***4. it is the closest to approaching vehicles.***
Warning beacon emitting yellow light.	Must not be used on the road.

9.2.3 Schedule 16 - specification of warning beacons

Table 37: Schedule 16 - specification of warning beacons.

Variable	**Specification**
Number	Sufficient to meet the requirements of 'Angles of visibility'.
Position	Mounted to the vehicle at a height not less than 1200 mm.
Angles of visibility	The light from at least one beacon (not necessarily the same one) to be visible from any point at a reasonable distance.
Markings	None
Size, illuminated area	None
Colour	Blue, amber, green, ***red,*** yellow
Wattage	None
Intensity	None
Electrical connections	None
Tell-tale	None
Other requirements	**Intervals between flashes to be constant.** ***As Table 34 for ECE65 requirements.*** ***Must not mask people in vicinity*** ***Must not cause vision or other problems to people working in vicinity*** ***Must not cause visual problems to other road users or cause them to over-react***

10.0 Draft specification and test procedure

10.1 Draft specification

The tables which follow summarise the recommendations made in section 8.0. Three levels of conspicuity have been recommended in order to prioritise the driving publics response to the different users of warning beacons. For each level of conspicuity the users, the conditions of use and the technical requirements needed to achieve the given level of conspicuity are detailed.

10.2 Draft test procedure

It is not envisaged that the performance requirements specified in tables 38 to 40 will need any additional test procedures to those currently used. However those currently in use may need to be amended to accommodate the different levels specified.

Table 38

Level one warning beacons (highest level of conspicuity)

	Amber	Blue	Green	Red
Permitted users		Police Fire Ambulance Other emergency vehicles		Police Fire Ambulance Other emergency vehicles
Conditions of use		Going to incident At incident (vehicle closest to approaching traffic only) Escort duties		At incident when personnel are on the carriageway (vehicle closest to approaching traffic only)
Flash intensity cd (with beam cut-off)		Day: 400 to 1680 Night: 155 to 670		Day: 900 to 1680 Night: 360 to 670
Flash intensity cd (without beam cut-off)		Day: 500 to 600 Night: 150 to 190		Day: 500 to 600 Night: 150 to 190
Flash rate		200 to 240 fpm (3.3-4.0 Hz)		200 to 240 fpm (3.3-4.0 Hz)
Flash configuration		Simultaneous if more than one		Simultaneous if more than

		in use			one in use
Flash type		Strobe			Strobe
Number		Minimum of one to be visible 360°	Further beacons as required		Minimum of one to be visible to rear and side
Positioning		Roof or other high area on vehicle	As required (grille level for visibility in car mirrors)		Roof or other high area on vehicle

Table 39

Level two warning beacons (intermediate level of conspicuity)

	Amber		Blue	Green	Red
Permitted users	Breakdown vehicles	Slow moving or stationary vehicle		Medical practitioners	Breakdown vehicles
Conditions of use	At incident (vehicle closest to approaching traffic only)	All times except when appropriately parked		Going to incident	At incident when personnel are on the carriageway (vehicle closest to approaching traffic only)
Flash intensity cd (with beam cut-off)	Day: 800 to 1000 Night: 325 to 425			Day: 250 to 350 Night: 100 to 140	Day: 600 to 750 Night: 240 to 300
Flash intensity cd (without beam cut-off)	Day: 550 to 650 Night: 150 to 200			Day: 130 to 170 Night: 40 to 50	Day: 350 to 450 Night: 95 to 135
Flash rate	130 to 170 fpm (2.2-2.8 Hz)			130 to 170 (2.2-2.8 Hz)	130 to 170
Flash configuration	Simultaneous if more than one in use			Simultaneous if more than one in use	Simultaneous if more than one in use

Flash type	Strobe		Strobe	Strobe
Number	Minimum of one to be visible 360°		Minimum of one to be visible 360°	Minimum of one to be visible to rear and side
Positioning	Roof or other high area on vehicle		Roof or other high area on vehicle	Roof or other high area on vehicle

Table 40

Level three warning beacons (minimum level of conspicuity)

	Amber	Blue	Green	Red
Permitted users	Those fulfilling conditions below			
Conditions of use	As currently regulated except for breakdown and slow or stationary vehicles			
Flash intensity cd (with beam cut-off)	Day: 230 to 600 Night: 100 to 250			
Flash intensity cd (without beam cut-off)	Day: 230 to 500 Night: 100 to 150			
Flash rate	60 to 100 fpm (1.0-1.6 Hz)			
Flash configuration	Alternating if more than one in use			
Flash type	Rotating			
Number	Minimum of one to be visible 360°			
Positioning	Roof or other high area on vehicle			

11.0 Cost-benefit analysis

11.1 Costs

11.1.1 Summary of technical recommendations

Recommendations made in Section 8.0 which have specific implications for the design of warning beacons are:

- a beam cut-off,
- daytime and night-time intensity settings,
- three levels of flash rate.

Any cost-benefit calculations must therefore include a realistic unit increase per beacon to account for these improvements.

11.1.2 Market size

In order to determine beacon costs there needs to be an understanding of the current market position with respect to the relative proportions of: different user types (police, recovery, etc.); beacon technology (rotating and strobe) and beacon application (single or multiple use ie roof bars).

Consultation with SMMT indicated that warning beacon usage by vehicle type is not a collected statistic and so cannot be obtained from one source. Due to the commercially sensitive nature of company output and market share, warning beacon purchases could not be estimated in this way. The remaining alternative was to contact the users directly for the information. However due to the fragmented nature of the warning beacon user market, this would necessitate contacting individual police forces, fire services, ambulance services, medical practitioners, recovery operators, breakdown organisations as well as dairies and individual farmers. Since this would be a time-consuming and costly approach to take, it was decided to base the costings on estimates of the number of vehicles using beacons and the number of beacons per vehicle.

11.1.3 Costings

The full costing calculation is given in table 41. The costings shown would be incurred at five yearly intervals based on the guaranteed life of the warning beacon. No costing is shown for flash rate since it was considered by an industry contact that this would be achievable within the current design.

Since our primary recommendation has been to use strobes, only these will be included in the cost-benefit analysis. These costs are calculated over the guaranteed five year life of a strobe beacon.

Table 41: Incremental cost of recommendations

	Strobe beacons
Current beacon sales	
Number of units on the road (a)	60,522.00
Incremental unit cost (b)	
Re-wiring for dual intensity/unit (c)	Included
Photo-electric cell (d)	20.00
Tool up costs of new lens (e)	4.00
Total incremental costs	24.00
Total costs/annum	1,452,528.00
Additional beacon sales	
Number of additional beacons (f)	30,261.00
Unit cost	90.00
Incremental cost (as per current beacons)	24.00
Total unit cost	114.00
Total cost/annum	3,449,754.00
Installation	
Incremental costs (Cost of installing additional beacon) (g)	50.00
Total cost	1,513,050.00
Maintenance	

Incremental costs (Cost of maintaining an additional beacon) (h)	75.00
Total cost	2,269,575.00
Total cost	8,684,907.00

(a) **Number of units in use**

This was estimated from the number of vehicles which use warning beacons which had to be estimated. This latter estimate was based on the search of the fatal accident data undertaken by TRL. If it is assumed that for each of the 500 accidents analysed two vehicles were involved, then this provides a sample number of 1000 vehicles. Of this sample only eight were vehicles with warning beacons. If this sample ratio of 8:1000 is applied to the total number of vehicles on the road of 30,261,000, then the number of vehicles with warning beacons can be estimated at 242,088.

To obtain a breakdown of beacon number by vehicle type and application, the following has been assumed:

Table 42: Calculation of number of strobe warning beacons in use

	Strobe beacons
% of vehicles with strobe warning beacons from all vehicles with warning beacons	25%
Number of vehicles with strobe warning beacons	60,522
Number of strobe warning beacons (assuming one per vehicle)	60,522

(b) **Incremental costs**

Only those costs incurred over and above what are currently covered in the purchase price of a beacon are relevant to the cost-benefit analysis.

(c) **Cost for re-wiring for dual intensity**

Current rotating beacon construction is such that adjustment of intensity necessitates adjustment of rotating speed. Independence of these functions can be achieved through additional wiring. Strobe beacons already incorporate this facility and so no additional costs are incurred.

(d) **Photoelectric cell**

Probably the most reliable means for ensuring that the correct beacon intensities are used in the correct conditions is to incorporate a photoelectric cell.

(e) **Tool up costs of a new lens**

One means for achieving the beam cut-off, which will allow conspicuity to be maximised and disability glare to be minimised, is to re-design the lens. The tool-up costs for this have been put in the region of £30,000 by a beacon manufacturer. Since there are about eight major manufacturers who will need to do this, the tooling costs for new strobe beacon lenses is £240,000 each. The unit cost of a strobe is just under £4.00.

(f) **Additional beacons**

The additional beacons required are for those users who need a red light to identify personnel on the roadway. Since this number cannot be accurately known, an arbitrary split of 50:50 between users and non-users has been used in the calculation.

(g) **Unit cost**

the unit cost of a new strobe beacon was given by a reputable manufacturer to be in the region of £90.00.

(h) **Cost of installing an additional beacon**

This is variable according to the degree of trim to be removed for installation. Based on advice from an industry representative, a cost of £50.00 is not unreasonable.

(h) **Cost of maintaining an additional beacon**

This has been based on the cost of an annual replacement of a flash tube.

11.2 Benefits

11.2.1 Difficulties in quantifying benefits

The benefits of the recommended improvements to warning beacons made in this report are difficult to accurately quantify because:

- the extent of the improvement is difficult to predict,
- some of the benefits are qualitative eg improved confidence amongst roadside workers,
- accident data on which to base estimates of lives and injuries saved is not available in an appropriate form.

However an attempt has been made to quantify the benefits and the assumptions made in doing so have been explicitly stated.

11.2.2 Casualty data

Casualty data was obtained Road Accidents Great Britain 1997 (Table 4C, page 60) from which the following table was constructed.

Table 43: Casualties by type for all roads (mean for)

Fatal	Serious	Slight
4037	48224	265569

11.2.3 Estimated casualties resulting from accidents with vehicles with warning beacons

The Fatal accident data held at TRL was sifted for accidents involving vehicles with warning beacons. Of the 500 accidents reviewed, only eight involved vehicles with warning beacons. If this proportion is applied to the accident totals given in table 43 (thereby assuming the same rate of involvement for serious and slight casualties as for fatals), then the estimated casualties resulting from accidents with vehicles with warning beacons is given in table 44.

Table 44: Estimated casualties resulting from accidents with vehicles with warning beacons

Fatal	Serious	Slight
65	772	4249

11.2.4 Estimated casualties resulting from accidents where beacon design may have been a factor

There are occasions however where the use of a beacon offers no benefit to its user or other drivers eg when the beacon is obscured from view or the accident is a result of mechanical failure. In these circumstances any improvement in the beacon characteristics would have no effect on the accident situation and so such cases should be discounted from this analysis. The proportion of such incidents has been estimated from two sources:

- TRL project report (Bartlett & Simmons, 1996): 117 injury accident reports covering the period 1989-94 which involved STGO (Special Types General Order) and heavy breakdown vehicles, ie vehicles with warning beacons, were analysed. Of these only 18 (15%) could have been attributed to the performance of warning beacons.
- TRL Fatal accident database: Details of eight accidents involving vehicles with warning beacons were provided by TRL. Of these only two (25%) could have been attributable to the performance of warning beacons.

Using this data, it will be assumed that accidents where beacon design was a possible factor account for 20% of all accidents involving vehicles with beacons. The adjusted casualty data is shown below:

Table 45: Estimated casualties resulting from accidents where beacon design may have been a factor

Fatal	Serious	Slight
13	154	850

11.2.5 Estimated reduction in accident casualties due to improved beacons

The table above shows casualty data for accidents where improved beacon performance may have prevented or reduced the severity of the accident. It is unrealistic to assume that improved beacons will prevent all future accidents, more likely they will reduce the numbers in each class of casualty severity. It is difficult at this time to predict what the extent of this improvement will be, however a nominal 50% has been chosen for use as follows:

- 25% reduction in all casualty classes due to *accidents being avoided* due to the improved beacons,
- 25% reduction in all casualty classes due *to accidents still occurring but being less severe* due to the improved beacons.

The adjusted data is as follows:

Table 46: Estimated reduction in accident casualties due to improved beacons

	Fatal	Serious	Slight
25% reduction in accident occurrence	3	39	212
25% reduction in accident severity	3	39	212
Increase in casualties from reduction in severity class above	0	-3	-39
Total casualty reduction*	6	74	386

* Errors due to rounding

11.2.6 Estimated financial benefits accruing from casualty reduction

Road Accidents Great Britain 1997 provides average values for the prevention of casualties and this is used in the table below.

Table 47: Estimated financial benefits accruing from casualty reduction

	Fatal	Serious	Slight	Total
Total casualty reduction	6	74	386	
Cost per casualty	902,500	102,880	7,970	
Total costs	5,829,428	7,605,836	3,079,061	16,514,325

The estimated total financial benefits which could potentially accrue from improved beacon design is £16,514,325 per annum. Over a five year period (on which the costings are based), this equates to £82,571,625.

11.3 Summary

Within the constraints and assumptions made in obtaining and manipulating the data, the preceding analysis indicates a cost to improve warning beacon design and use of £8,684,907 compared to a benefit of £82,571,625 over a five year period.

This equates to a net benefit to society, in terms of cost saving, of £14,777,344.

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