Motor vehicle and pedal cycle conspicuity: part 1- vehicle mounted warning beacons. Summary report.

Final Report: 9/33/13

Motor Vehicle

and Pedal Cycle Conspicuity

Part 1: Vehicle mounted warning beacons

Summary report

Undertaken on behalf of

The Department of the Environment,
Transport and the Regions

Prepared by

Sharon Cook
Claire Quigley
Laurence Clift

March 2000

Checked by:………………

1.0 Summary

Accident studies suggest that the early detection and identification of other types of road users is likely to be a safety benefit to drivers, and one means for achieving this is through the use of vehicle-mounted warning beacons. A review of previous research, current technology, standards and regulations, and the views of relevant parties confirms the contribution of warning beacons in this respect. It also indicates that the warning beacons available in the market are largely governed by the restrictions imposed by the relevant regulations. However contact with various warning beacon user groups suggests that these designs are not as effective as they would wish and may in certain instances be giving rise to disbenefits to other road users.

A rigorous scientific test programme identified those factors which make warning beacons more conspicuous and specific consideration was given to those vehicles, fitted with amber warning beacons, which work within environments of flashing amber road beacons. Disbenefits of warning beacon design, in terms of disability glare, discomfort glare, distraction and eleptogenesis, were also investigated.

It is recommended that the users of warning beacons be prioritised with the highest priority group being allocated the top values of those features which make warning beacons conspicuous (subject to consideration of the disbenefits likely to be generated). Road trials should be undertaken to further refine the recommendations.

2.0 Introduction

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

Warning beacons are used on a variety of vehicles to alert other road users to their presence or warn of potential danger.

The objectives of the study are to:

1. Determine the optimum performance characteristics and installation conditions for warning lights and produce recommendations for the following parameters:
   - number and positioning,
   - intensity for daytime and night-time use,
   - flash rate,
   - flash characteristics,
   - colour.

2. To determine whether vehicles fitted with amber warning beacons 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.

3.0 Information review

3.1 Research

There is little published research concerning the design, use or effects of flashing warning beacons so the information reviewed was broadened to consider the conspicuity of a variety of types of vehicle lighting.

3.1.1 The need for vehicle lighting conspicuity

Langwieder and Danner (1987), in their study of 1,200 truck accidents, noted that rear-end truck to truck accidents appear to be caused by the driver not appreciating the speed of the vehicle ahead. This supports the earlier work of Solomen, as reported by Mortimer (1969), which indicated that drivers are poor at judging relative velocities and that where the disparity in speed between vehicles travelling in the same direction exceeded 20mph there is a sharp rise in the probability of rear end collisions. Later work by Mortimer (1977) further validates this opinion since he concludes that in 80% of rear end collisions, the struck vehicle was travelling at 20mph or less. Obviously the slower the speed of the lead vehicle, the greater the disparity in speed with the following vehicle and, according to Solomen, the greater the opportunity for collision. Noble (1969) states that vehicles travelling at these slower speeds ought to indicate this fact to other road users through a unique form of lighting system. MIRA (1982) also suggest that such vehicles should be extra conspicuous and cite rotating lights as one such solution.

The central issue to this study is determining those parameters, which increase the conspicuity of warning beacons. Conspicuity refers to the ability of a warning beacon to draw attention to its presence even when road users are not actively looking for it.

3.1.2 Flash rate

There is some evidence to suggest that flashing lights are effective in attracting attention particularly when they are located in the periphery of vision. Work by Donne and Fulton (1988) showed that a flashing daytime running lamp in addition to a 40W headlamp increases mean peripheral detection of a motorcycle by 20% over a headlamp alone. 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 1-3 Hz, with 2-3 Hz found to improve the effectiveness of turn and hazard warning signals.

3.1.3 Flash intensity

In terms of intensity, Donne and Fulton (1988) found that for small motorcycles, a 50% increase in headlight power increased conspicuity distance by 350%; dependent upon beam pattern. Finch (1968) found that to secure a marginal improvement in the performance of rear marker lights in fog, intensities up to 100 times those normally used might be required.

There is concern that by increasing the intensity and/or flash characteristics of vehicle lighting to increase conspicuity, there may be an increasing spiral of lighting which is successively more attention-getting as different user groups strive to be more conspicuous than each other. In the long term the conspicuity of such lighting systems may be effectively diminished and potential hazards to other road users such as disability glare, discomfort glare and distraction may be induced. Refer to section 5.3.

3.1.4 Colour

In terms of colour, Arakawa (1953) used Motokawa's direct current method to determine the visual field for different lights. Four lights of equal energy were studied – red, yellow, green and blue. Values taken at the centre of vision and in the mid-periphery were found to be higher for yellow and green lights. Values for all lights decreased towards the periphery but less so for blue. This suggests that blue may aid detection of lights in the visual periphery whereas amber and green would offer a greater benefit to conspicuity in the forward field of view.

3.2 Technology

3.2.1 Light sources

Developments within the field of warning beacon design appear to be governed by market forces and legislative requirements, and seem to be limited to certain restricted technologies. Three light sources are used; tungsten which is the cheapest and uses filament technology, halogen which uses gas filled filament bulbs and xenon.

3.2.2 Flash type

The flashing effect is achieved through one of three systems; pulsing of the supply to the filament bulbs, discharge of the xenon lamps or intermittent shielding of the light by rotating or other mechanical devices.

3.2.3 Flash rate

In general flash rates of 2 ½-3 Hz are common for the filament systems, although some may go as low as ° Hz. Flash rates can be increased through the use of mirrors. Xenon beacons offer multiple flash modes, the most general being 'single hit' where one flash is discharged per cycle and 'double hit' where two flashes are discharged per cycle but in such rapid succession as to appear as one event. Typical flash rates for xenon beacons are 1-2 Hz.

3.2.4 Flash intensity

Flash intensity varies according to the technology with extremely high values quoted for xenon beacons. However because the xenon is discharged at such a rapid peak, its' effective intensity (the apparent brightness which it appears to have) is often considerably less. Many systems are selectable for high/low intensity to reflect daytime or night-time use.

3.2.5 Colour

The colours offered on the market reflect the restrictions imposed by The Road Vehicle Lighting Regulations 1989. However in addition to the amber, blue, green and red which are generally available, clear is also offered as an option.

3.2.6 Multiple systems

The characteristics described above can be used within one product or in combination in ‘lightbars’. As well as multiple flashing lights, light bars may include dot matrix displays, static lamps, illuminated signs and alley lights (spotlights located on the ends of the light bar).

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

3.3 Standards and legislation

Current regulations identified as most relevant to this work are detailed below.

3.3.1 ECE Regulation 65: Requirements for warning beacons

Table 2: Summary of ECE Regulation 65

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

3.3.2 The Road Vehicle Lighting Regulations

Table 3: 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.

Table 4: Prohibitions for the use of 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;
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;
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 emitting yellow light.	Must not be used on the road.

Table 5: 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, yellow
Wattage	None
Intensity	None
Electrical connections	None
Tell-tale	None

3.4 Views of relevant parties

3.4.1 Parties contacted

Relevant parties contacted for their opinions, observations and concerns regarding the design and use of warning beacons included:

- the emergency services (Association of Chief Police Officers, Chief and Assistant Chief Fire Officers Association, Ambulance Services Association),
- Recovery operators (Association of Vehicle Recovery Operators and Road Rescue Recovery Association),
- Breakdown services (AA and RAC),
- Other (British Medical Association, Road Haulage Association, Society of Motor Manufacturers and Traders, warning beacon manufacturers).

3.4.2 Reported problems of warning 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 due to the proliferation of its use for other purposes 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.

3.4.3 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.

3.5 Conclusions

Accident analysis suggests that improving the conspicuity of vehicles and providing messages as to those vehicles characteristics is likely to be of benefit. The warning beacon designs available in the market are largely governed by the restrictions imposed by the relevant regulations. However contact with the various warning beacon user groups suggests that current warning beacons are not as effective as they would wish and may in certain instances be giving rise to disbenefits to other road users. This confirms that there is a need for:

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

4.0 Design of the testwork

4.1 Description of the test programme

A programme of testwork was developed to investigate all the issues previously identified:

- the conspicuity of warning beacons according to: flash type, flash rate, flash intensity, colour, number and positioning,
- the conspicuity of vehicle-mounted amber warning beacons amongst amber roadside beacons,
- disbenefits resulting from the use of warning beacons: disability glare, discomfort glare and distraction.

To maximise the efficiency and scientific integrity of the test programme, a total of ten experimental trials were undertaken. Seven were conducted under ‘laboratory’ conditions where all the variables could be systematically controlled and combined using a model road; the remainder were undertaken as ‘field’ trials using real vehicle warning beacons in a real road environment. The laboratory trials were designed to maximise the amount and quality of data collected; the field trials were designed to investigate the validity of the laboratory trials.

4.2 Experimental measures

The following measures were used to investigate the issues described above.

- **Conspicuity** of the warning beacon features were measured by: beacon detection rate, beacon detection time and subjective opinions of perceived conspicuity.
- **Disability glare** was measured by: pedestrian detection rate and time.
- **Discomfort glare** was measured by subjective opinions (deBoer rating scale).
- **Distraction** was measured by the time taken to detect the onset of vehicles’ brake lights.
- **Annoyance** was measured by subjective opinions using a rating scale.
- **Urgency** was measured by subjective opinions using a rating scale.
- **Colour association** was measured by subjective opinions.
- **Eleptogensis** was derived from expert consultation.

4.3 Experimental equipment

4.3.1 The laboratory trials

The laboratory trials were undertaken using a model road which was a light-proof box, 8m long by 1.25m wide with a 1:20 scale road modelled inside. Representative levels of day and night-time illumination could be reproduced with the option for the night-time variants to include high pressure sodium street-lighting. 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, the background was removed to create a bland environment. The warning beacons were simulated using LEDs which allowed the effects of flash type, rate, intensity and colour to be assessed individually and in combination.

4.3.2 The field trials

Warning beacons, representative of those currently used on the road, were obtained from a reputable manufacturer for use in the field trials. The trials were run under both daytime and night-time conditions using an established test site. The test site was favoured for use over a busy, public road since it allowed greater control over 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 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.

4.4 Participants

Participants are members of the public who assist in the test work by giving their opinions and/or allowing measurements of their behaviour to be made eg the time it takes them to detect a warning beacon. For each of the trials undertaken in the test programme, the following participant requirements were met:

- All participants were UK driver licence holders,
- The gender ratio was in the order of 50:50,

- The young to old age ratio was in the order of 50:50 with the mid-40s broadly considered as the divide.

For ethical reasons, those individuals susceptible to epilepsy, sensitive to bright and/or flashing lights or having medical side effects which may have heightened their reaction to such lighting, were screened out of the test work.

5.0 Results of the testwork

5.1 General warning beacon design

5.1.1 Colour

When colour is the only variable under consideration i.e. intensity is held constant, the following results were found:

Amber: has the poorest warning beacon detection time (day and night).

Blue: minimises the effects of disability glare i.e. enables more pedestrians to be detected (night) and gives rise to the least discomfort glare (day).

Green: has the quickest warning beacon detection time (day), but is poorest for disability glare i.e. pedestrian detection, (night) and discomfort glare (day and night).

Red: has the quickest warning beacon detection times (night) and gives rise to the least discomfort glare (day and night).

In the real world, the coloured domes used in the construction of the warning beacons have the effect of filtering their intensity to varying extents. Clear warning beacons have the highest light transmission, followed by amber, red then blue or green, dependent upon the manufacturing process. Under these real world conditions, the following results were obtained:

Amber: has the quickest warning beacons detection times (day and night) but gives rise to greatest disability glare (night).

Blue: gives rise to the least discomfort glare (day and night).

Green: gives rise to the least discomfort glare (night) but has the poorest warning beacon detection times (night).

Red: minimises the effects of disability glare i.e. enables more pedestrians to be detected (night).

Magenta: was amongst the slowest to detect (day and night).

5.1.2 Flash type

Strobe warning beacons were subjectively considered to convey greater urgency (day) whilst rotating warning beacons were considered to be less annoying (day) and minimised the effects of disability glare (night).

5.1.3 Flash rate

The experimental work and expert consultation suggests that high flash rates (4 Hz) improve warning beacon detection time and are more effective in conveying an impression of urgency (day and night). Low flash rates (1 Hz) minimise - discomfort glare (day and night), disability glare (night) and perceived annoyance (day and night).

5.1.4 Flash intensity

High flash intensities minimise warning beacon detection times (day and night).

5.1.5 Flash pattern

When more than one warning beacon was present on a vehicle, beacons which flashed simultaneously were detected significantly more quickly than those which flashed alternately. Simultaneously flashing beacons were also subjectively rated as more attention-getting (day and night), whilst those which flashed alternately minimised discomfort glare (day and night).

5.1.6 Beacon number

Subjective ratings indicate that the greater the number of warning beacons present, the greater the perceived attention-getting quality (day and night). Four warning beacons were rated significantly more attention-getting than 1, but significantly less than 8 (day and night). Eight warning beacons were rated as having more discomfort (day) although no relationship between beacon number and discomfort glare was found at night.

5.2 Amber vehicle-mounted warning beacons

The following results were found with respect to the detection of a vehicle, displaying amber warning beacons, located amongst amber roadside beacons.

5.2.1 Effect of the presence and flash status of roadside warning beacons

A vehicle with flashing amber warning beacons (2 Hz) was detected quickest when:

- the roadside beacons were static (day),
- there were no roadside beacons (night – no street-lighting).

(For night-time conditions with street-lighting, the presence/absence of warning beacons or their flashing/static status had no effect on the speed of vehicle detection).

5.2.2 Effect of vehicle warning beacon flash rate

Increasing the flash rate of the vehicle warning beacon to 4 Hz, when located amongst flashing roadside beacons, did not assist its detection.

5.2.3 Effect of using static and flashing amber vehicle warning beacons

A static amber warning beacon was used in conjunction with the flashing amber warning beacon on the vehicle to provide a source of constant light output. Whilst it was theorised that this would differentiate the vehicle from its flashing environment, this was not proven by the testwork.

5.2.4 Effect of using an additional colour with an amber warning beacon on the vehicle

Using an additional flashing colour in conjunction with amber improves detection times over flashing amber only (red, white and blue tested).

A red light (equated in intensity to amber) and used in a flashing mode alongside a flashing amber beacon is likely to offer the best compromise in terms of detection, disability glare and discomfort glare.

5.3 Hazard analysis

As well as identifying what makes a warning beacon conspicuous, it is important to know if any of its features pose disbenefits to other road users.

5.3.1 Eleptogenic response

Approximately 0.5% of the UK population suffers from epilepsy (around 350,000 people). Of these only a few percent may have seizures induced by flashing lights and such sensitivity declines with age being very uncommon from the mid-twenties onwards. However whilst eleptogenic seizures caused by flashing lights are relatively rare, effects such as discomfort, headache and eyestrain may be induced. This appears to be borne out by one police officers comment: ‘It can be distracting 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’.

Features of flashing lights which are relevant to eleptogenic response include:

Frequency: Research by Jeavons and Harding (1975), Hopkinson and Collins (1970) and Orne (1986) is in broad agreement that flashing lights operating at frequencies between 10-20 Hz are most likely to evoke an eleptogenic response with lights operating closer to 50 Hz appearing constant. To minimise the onset of an eleptogenic response, frequencies above 5 Hz should be avoided.

Colour: Jeavons and Harding (1975) report that all colours are almost equally eleptogenic.

Luminance: Luminance, averaged over time, as low as 20 cd/m² can trigger an eleptogenic response. This exceeds the luminance required to make a warning beacon conspicuous.

Field of view: Lights flashing in the centre of the visual field are more effective in stimulating eleptogenic responses than those in the periphery.

Flash type: Rumar (1975) reported that drivers of emergency vehicles reported strobe beacons to cause more visual discomfort than rotating beacons.

5.3.2 Disability glare

Disability glare occurs when 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 scatter light superimposes itself on the object under view as a veiling luminance and reduces its contrast such that it appears ‘washed out’. In the context of this study, the effect of disability glare caused by warning beacons was assessed by the ability to detect a pedestrian in their vicinity. This was especially pertinent to recovery operators and other roadside workers. Our experimental work showed that disability glare was found to be worsened by amber beacons, strobe beacons and maximum intensities.

5.3.3 Discomfort glare

Discomfort glare is that which is annoying or painful, but does not cause disability in the visual field. In the road environment discomfort glare may arise from the reflection of the headlights of following vehicles in the rear view mirror 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. In the context of this study, the effect of discomfort glare caused by warning beacons was assessed by the opinions of the participants given using the conventional deBoer rating scale. Our experimental work showed that discomfort glare was found to be worsened by amber and green beacons, strobe beacons, maximum flash rates and simultaneous flash rates.

5.3.4 Distraction

The function of a warning beacon is to draw attention to an area of the road where drivers may not be looking. A balance needs to be made between the warning beacon being attention-getting and it being distracting. In this study the amount of distraction a warning beacon provided was measured by the number of times participants 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 indicated that a warning beacon present in the driving environment is significantly more distracting than no warning beacon at all, but the extent of the distraction was not related to flash type, rate or intensity.

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

In the 'moth-to-flame' effect was mentioned by interested parties several times in this study. Concern was expressed that warning beacons may actually be contributing to the hazard at the scene by drawing drivers into it. This appears to of greater interest in America where a recovery operator was held liable, because of his use of flashing amber beacons, for another vehicle driving into the recovery area and seriously injuring the owner of the broken down vehicle. No scientific documentation for this effect has been found to date.

5.3.6 Conclusion

Warning beacons by their nature have to contain an element of distraction, however since the experimental work has shown that warning beacons increase distraction significantly in the driving environment, their use should be kept to a minimum. The disbenefits caused by warning beacons of: eleptogenic response, disability glare, discomfort glare and distraction can be minimised by: restricting their use, ensuring that the minimum number are used at an emergency scene and incorporating a cut off into the beam pattern which would limit the light falling in the vicinity of the vehicle.

6.0 Recommendations

The test programme confirmed that, in general, those factors which make a warning beacon more conspicuous also give rise to disability glare, discomfort glare and distraction. Therefore the recommendations given below seek not to maximise conspicuity but to optimise it in relation to the disbenefits it generates. The recommendations have been made giving full consideration to the unique requirements of the different groups of warning beacon users.

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.***

Level one warning beacons (highest level of conspicuity)

<table>
<tr><th></th><th>Amber</th><th colspan="2">Blue</th><th>Green</th><th>Red</th></tr>
<tr><td>Permitted users</td><td></td><td colspan="2">Police
Fire
Ambulance
Other emergency vehicles</td><td></td><td>Police
Fire
Ambulance
Other emergency vehicles</td></tr>
<tr><td>Conditions of use</td><td></td><td colspan="2">Going to incident
At incident (vehicle closest to approaching traffic only)
Escort duties</td><td></td><td>At incident when personnel are on the carriageway (vehicle closest to approaching traffic only)</td></tr>
<tr><td>Flash intensity cd (with beam cut-off)</td><td></td><td colspan="2">Day: 1100 to 1680
Night: 400 to 670</td><td></td><td>Day: 1200 to 1680
Night: 500 to 670</td></tr>
<tr><td>Flash intensity cd (without beam cut-off)</td><td></td><td colspan="2">Day: 800 to 1000
Night: 300 to 350</td><td></td><td>Day: 900 to 1100
Night: 350 to 450</td></tr>
<tr><td>Flash rate</td><td></td><td colspan="2">200 to 240 fpm (3.3-4.0 Hz)</td><td></td><td>200 to 240 fpm (3.3-4.0 Hz)</td></tr>
<tr><td>Flash configuration</td><td></td><td colspan="2">Simultaneous if more than one in use</td><td></td><td>Simultaneous if more than one in use</td></tr>
<tr><td>Flash type</td><td></td><td colspan="2">Strobe</td><td></td><td>Strobe</td></tr>
<tr><td>Number</td><td></td><td>Min. of one to be visible 360°</td><td>Further beacons as required</td><td></td><td>Minimum of one to be visible to rear and side</td></tr>
<tr><td>Positioning</td><td></td><td>Roof or other high area on vehicle</td><td>As required (grille level for visibility in car mirrors)</td><td></td><td>Roof or other high area on vehicle</td></tr>
</table>

Level two warning beacons (intermediate level of conspicuity)

<table>
<tr><th></th><th colspan="2">Amber</th><th>Blue</th><th>Green</th><th>Red</th></tr>
<tr><td>Permitted users</td><td>Break-down vehicles</td><td>Slow moving or stationary vehicle</td><td></td><td>Medical practitioners</td><td>Breakdown vehicles</td></tr>
<tr><td>Conditions of use</td><td>At incident (vehicle closest to approaching traffic only)</td><td>All times except when appropriately parked</td><td></td><td>Going to incident</td><td>At incident when personnel are on the carriageway (vehicle closest to approaching traffic only)</td></tr>
<tr><td>Flash intensity cd (with beam cut-off)</td><td colspan="2">Day: 800 to 1000
Night: 325 to 425</td><td></td><td>Day: 500 to 700
Night: 175 to 275</td><td>Day: 800 to 1000
Night: 325 to 425</td></tr>
</table>

Flash intensity cd (without beam cut-off)	Day: 500 to 700 Night: 150 to 200		Day: 300 to 450 Night: 100 to 150	Day: 600 to 800 Night: 200 to 300
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

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			

7.0 Cost-benefit analysis

7.1 Costs

	Strobe beacons
Current beacon sales	
Number of units on the road	60,522.00
Incremental unit cost	
Re-wiring for dual intensity/unit	Included
Photo-electric cell	20.00
Tool up costs of new lens	4.00
Total incremental costs	24.00
Total costs/annum	1,452,528.00
Additional beacon sales	
Number of additional beacons	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)	50.00
Total cost	1,513,050.00
Maintenance	
Incremental costs (Cost of maintaining an additional beacon)	75.00
Total cost	2,269,575.00
Total cost	8,684,907.00

Since our primary recommendation has been to use strobes, only these have been included in the cost-benefit analysis. All figures are estimates which have been calculated over the guaranteed five year life of a strobe beacon.

7.2 Benefits

	Injury severity		
	Fatal	Serious	Slight
Mean casualties 1990-97	4037	48224	265569
Estimated casualties resulting from accidents with vehicles with warning beacons	65	772	4249
Estimated casualties resulting from accidents with vehicles with warning beacons where beacon design may have been a factor	13	154	850
Estimated reduction in accident casualties due to improved beacon design	6	74	386
Estimated financial benefits accruing from casualty reduction (Fatal=£902,500 Serious=£102,880 Slight=£7,970)	5,829,428	7,605,836	3,079,061
Total benefits (annum)	16,514,325.00		
Total benefits over five years	82,571,625.00		

7.3 Conclusion

Within the constraints and assumptions made in obtaining and manipulating the data, the preceding analysis would indicate a net benefit to society of £14,777,344.00 per annum of improved warning beacon design.

About ICE Ergonomics . . .

- ICE is the largest ergonomics research and consultancy in the UK.
- ICE is the leader in this field and has provided a high quality and cost-effective service to its clients for nearly thirty years.
- ICE offers specialist services in research, consultancy, hazard and risk assessment, product evaluation, expert appraisal and training courses.
- ICE has a confidential test laboratory with full technical support and facilities.
- ICE has scientifically reliable and valid assessment methods which are used in combination with its 400 person database for public testing.
- ICE has been repeatedly invited to work closely with the following clients: the Home Office, the Department of the Environment, Transport and the Regions, Ford Motor Company and the Police Scientific Development Branch amongst others.
- ICE has a thirty plus team of qualified personnel from a variety of scientific and engineering disciplines including ergonomists, designers, psychologists, mechanical engineers and occupational safety and health professionals.
- ICE is wholly owned by Loughborough University and so has access to its specialist resources and skills base.

Consumer products
ensuring products are safe and easy to use

Transport
ensuring people travel in safety and comfort

Occupational ergonomics & safety
Protecting the workforce and improving productivity

Vehicle safety
Improving the crashworthiness of vehicles and the safety of occupants

ICE Ergonomics · Holywell Building · Holywell Way · Loughborough · Leicestershire · LE11 3UZ
Tel: +44 (0)1509 283300 · Fax: +44 (0)1509 283360 · e-mail: enquire.ice.co.uk