FLASHING WARNING LIGHTS FOR SCHOOL BUSES

Michael P. Paine
Vehicle Design and Research
Alec J. Fisher
E-Consultancy
Australia

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ABSTRACT

Motorists who are approaching a bus which is picking up or dropping off school children should be alert to the possibility of children crossing the road. In country areas of New South Wales the motorists may be travelling at speeds around 100km/h. At this speed the warning signal should be readily seen at 250 metres in order for the motorist to be able to detect and react to the signal and to slow down without heavy braking. In bright daylight conventional vehicle signalling systems, such as direction indicator lamps, do not provide this required signal range. Traffic signals practice suggests that much brighter lights are required.

A dilemma is that bright warning lights might cause discomfort and glare at dusk or at night. The authors examined the geometry of a typical scenario for a car encountering a bus at the side of the road. It was found that a warning light system could be specified which achieved the required signal range but which, due to its high mounting position on the bus and sharp vertical cut-off of the light distribution downwards, enabled motorists to move into a lower intensity portion of the beam as they approached the bus.

INTRODUCTION

School children who are hurrying to catch a bus in the morning or who have just disembarked from a bus in the afternoon might not cross the road with care (RTA 1992, Staysafe 1994). Motorists in the vicinity of the bus should be alert to the possibility of children on the road. These motorists should be travelling at a speed which gives them a reasonable chance to stop in time if a hazardous situation arises.

In New South Wales (NSW) current practice is to have "wig wag" yellow flashing lights and signs at the front and rear of the bus. The authors were engaged by the NSW Department of Transport to investigate the suitability of several proposed signalling systems, together with the current system. This paper describes the outcome of an analysis of the technical and visual ergonomic requirements of signalling systems fitted to school buses.

FUNCTIONAL REQUIREMENTS

The function of a school bus signalling system is to alert motorists who are approaching from either direction to the possibility of children on the road in the immediate vicinity of a bus which is stationary or has just departed. This must occur at a sufficient distance to enable the motorist to take action to avoid an accident.

To be effective the system must satisfy each of three requirements (after Lay, 1981):

i. It must be *readily seen* by approaching motorists and it must *command their attention*. It must be conspicuous from other signals and signs and the general visual clutter at the front and the rear of buses. It must stand out in adverse lighting conditions such as bright daylight.

ii. It must be *recognised* as indicating the possibility of school children in the immediate vicinity of the bus, in a clear, credible and unambiguous manner.

iii. It must elicit an *appropriate response* from the motorists, such as slowing down and preparing to stop to avoid an accident.

What is a sufficient distance?

It is assumed that a motorist is to be travelling at no more than 40km/h when passing a bus with its flashing lamps operating. Research into pedestrian-vehicle collisions has shown that the proportion of these accidents which are fatal increases sharply as the speed of collision rises. This increase occurs at about 40km/h (Fisher and Hall 1972). Roads adjacent to many NSW schools now have a 40km/h speed limit which applies during school travel hours.

The motorist will require a distance away to see the signal (the signal range) which takes into account the distance travelled during the response time to the signal, the distance travelled during slowing down to 40km/h and the distance over which to stop from 40km/h, if necessary (the buffer zone). These three stages are illustrated in Figure 1.

The response time (driver's reaction time to the signal plus time before vehicle starts to decelerate) is typically taken to be 2.5 seconds in Australian traffic engineering practice (Lay, 1981). This, and a shorter, more optimistic time of 1.5s, will be used in the analysis.

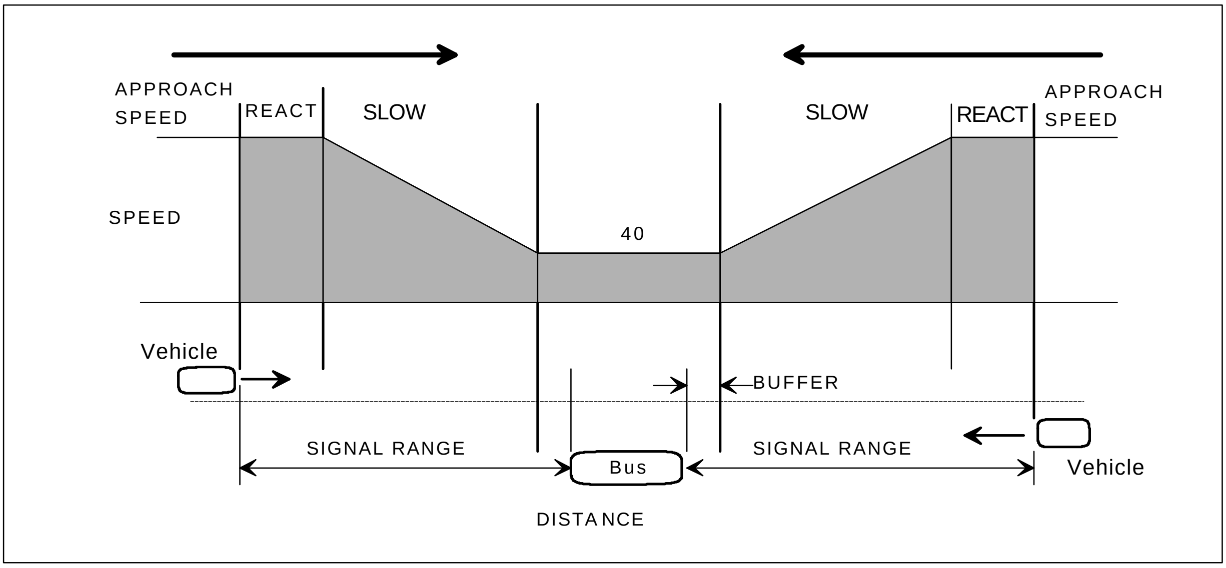

Figure 1. Derivation of signal range for vehicles approaching the bus from either direction.

It is preferable that the motorist does not brake heavily because this may be a hazard to following traffic and it could also lead to reluctance to slow down if school buses with lights flashing are repeatedly encountered on the road. On a level road at 100km/h a typical vehicle will decelerate at between 0.5 and 1 metres per second per second (m/s/s) without the use of brakes. Under gentle braking a deceleration of 2m/s/s is regarded as comfortable. Heavy braking involves decelerations of around 5m/s/s (all decelerations described in this paper are average, not peak).

From these values the distance at which a signalling system on the bus has to be first seen by an approaching motorist can be calculated. The formula is:

$$s = ((V^2 - v^2)/2a) + Vt + d \qquad (1.)$$

Where
s = distance from motorist to bus, signal range (m)
V = initial speed (m/s)
v = final speed (m/s, 11.1m/s = 40km/h)
a = average deceleration (m/s/s)
t = motorist response time (s)
d = buffer zone; distance before bus at which the final speed is to be achieved to enable the motorist to stop if necessary (m)

The buffer zone distance can be derived from equation (1) by substituting a final speed of zero and is about 30m for an initial speed of 40km/h and an alert response time with heavy braking.

Table 1 shows the application of Equation 1 to several scenarios.

Table 1
Signal Range Required to Slow from 100km/h to 40km/h, Including a 30m Buffer Zone

Type of braking	Deceleration m/s/s	Distance for typical reaction time (2.5s)	Distance for alert reaction time (1.5s)
None (engine braking)	1.0	424	396
Gentle	2.0	261	234
Heavy	5.0	164	136

The distances involved are often not appreciated by motorists who might not realise that, at 100km/h, they have typically travelled some 70m after a hazard/signal first became visible before their foot even hits the brake pedal. To enable a motorist to see and respond to a signal and slow down under engine-braking from 100km/h to 40km/h the signal range must be about 400m. If the signal range is 250m then gentle braking will usually be required in order to slow to 40km/h. A signal range less than about 150m will usually require heavy braking.

On the basis of this analysis, the signal on a school bus should be visible and recognisable at no less than 250m for buses operating in 100km/h areas (this assumes some gentle braking will be required and it includes a 30m buffer). A minimum of 100m is required for buses operating in 60km/h areas but a common signal range of 250m for all buses is preferable for uniformity.

SIGNAL LIGHTS FOR DAYTIME USE

There is a sound knowledge of signal light requirements derived from research and practical experience on which to base requirements of signal lights.

The human eye is more sensitive to a light source the closer that source is to the line of sight. This means that the further a signal is from the line of sight the brighter it will need to be to elicit a response. The necessary luminous intensity of a signal will also increase as the square of the distance away. The relationship is:

$$I = 2Kd^2L_Bx10^{-6} \qquad (2.)$$

where

I = Optimum luminous intensity of a steady red signal for a required signal range (cd)

K = $(a/3)^{1.33}$

a = angle of the signal from line of sight (degrees, minimum 1^0)

d = required signal range (m)

L_B= background brightness (cd/m^2)

The formula is the outcome of considerable research (Cole & Brown, 1968, Fisher & Cole, 1974). The optimum intensity is that which invokes, essentially, 100% probability of seeing, coupled with a near minimum reaction time. This and other data form the basis of Australian Standard AS2144 (AS 1989) and international recommendations (CIE 1988) on the photometric specification for traffic signals.

It should be noted that the intensity is directly proportional to the brightness of the background to the signal. Typical values of background luminance range from 10,000 cd/m2 on a bright day to 100 cd/m2 or less around dusk. Therefore the range of a signal of given intensity can vary by a factor of more than 10 depending on background lighting conditions (intensity is proportional to the square of range). This is why signals of relatively low intensity can appear quite adequate for long distances under favourable (dull) lighting conditions while being unsuitable for bright conditions.

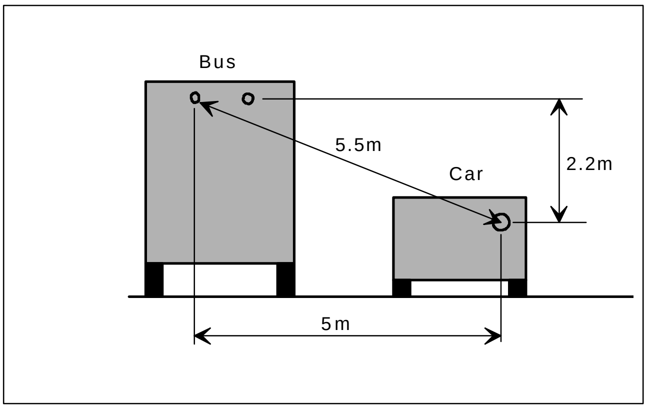

Figure 2. Derivation of offset distance for a typical car/bus geometry. Looking from rear with right-hand drive vehicles.

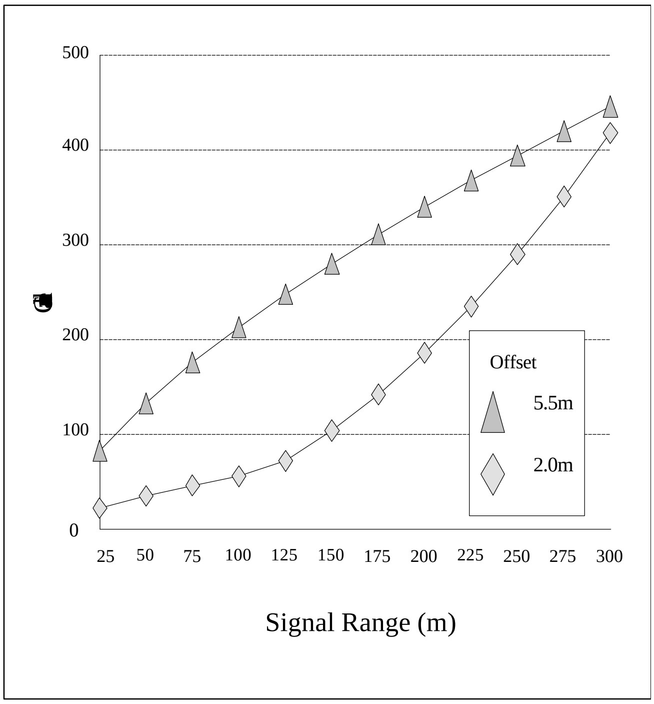

Figure 3. Relationship between signal intensity & signal range for a steady red light, based on constant offset and a background brightness of 10,000cd/m^2.

For a given signal offset (Figure 2.), the angle of the signal will be proportionally closer to the line of sight as the distance increases. Applying this effect to Equation 1, the luminous intensity requirements for a *steady red signal light* for various signal ranges are given in Figure 3. These are shown for an offset of 5.5m, which is typical for a car approaching a school bus which is pulled off to the side of the road (see Figure 2), and an offset of 2m, which is more typical of a car following another car. The bus-car geometry assumes that the lights are mounted as high as practicable on the bus. This has advantages in reduced discomfort and glare for motorists approaching the bus under dull background lighting conditions (described later) and it also provides maximum range when the bus stops beyond a crest in the road.

The intensity values for yellow signals need to be three times that for red for equal visual performance (Fisher & Cole, 1974). This will not normally be a problem in practice since a yellow lens can transmit about 3 times the light from an incandescent lamp over that for a red lens and therefore the wattage of the lamps needed will be the same.

Using Equation 2, the following signal intensity requirements can be deduced, as shown in Table 2.

Table 2.
Signal Intensities for Two Signal Ranges with *Steady* Signals Viewed Against a Sky Background of 10,000cd/m^2 and an Offset of 5.5m

Signal Range (m)	Signal Intensity (cd)	
	Steady Red Signal	Steady Yellow Signal
100	210	630
250	390	1170

These intensities relate to in-service equipment; some addition on these values is needed to take into account dirt, deterioration and flashing of the signals. On the other hand, these intensities are for a high, but not uncommon, brightness of sky background (Fisher & Cole, 1974), without any black backboard. They also allow for the observers gaze to be not directly towards the signal.

Road Traffic Control Signals

In Australian Standard AS2144 (AS 1989) the minimum luminous intensity of traffic signals are specified, as shown in Table 3:

Table 3.
AS2144 Minimum Traffic Signal Intensity (cd)

Type of signal	Range (m)	Red	Yellow
General Purpose	100	200	600
Extended range	240	600	1800

These values apply to new equipment, are on-axis values and provide the range when viewed against a sky background of 10,000cd/m^2, the signals being fitted with black backboards.

The values at 100m signal range match those of Table 2. The values for extended range traffic signals exceed those of Table 2 since traffic signals have a greater offset (Hulscher 1975).

Vehicle Signals

The large majority of vehicles in Australia are fitted with single intensity lamps which are used day and night. These are a compromise between the necessity of a relatively high intensity by day and limiting the intensity at night so lamps are not excessively bright.

In the case of yellow aftermarket lamps intended for use as either front or rear vehicle turn signals, a manufacturer would logically aim for an intensity around 200cd which is the maximum permitted for single-intensity rear mounted turn signals. In bright daylight these would provide a signal range of about 100m when used on a car or small trailer but they become ineffective when high-mounted on a large vehicle such as a bus. Referring to Figure 3, a 200cd yellow signal is equivalent to a 67cd red signal which has a range of about 100m when used on a car but less than 25m when high-mounted on a bus.

SAE Standard J887

Many school buses in the USA are fitted with bright red and yellow flashing warning lamps. SAE Standard J887 "School Bus Warning Lamps" (SAE 1987) which sets out requirements for these signal lights, including photometric performance. The signal units are tested at operational voltage (e.g 12.8V or 25.6V). Requirements are for total luminous intensity in prescribed zones. The Standard also includes guidelines for meeting the zonal requirements. These guidelines are summarised in Table 4.

Table 4.
SAE J887 Guidelines for Yellow Signal Units

Degrees Up & Down (-ve)	Degrees Left (Right is mirror image)				
	30	20	10	5	0
10				50	125
5		375	750	750	750
0	75	450	1000	1250	1500
-5	75	500	750	1125	1125
-10				100	100

The intensity at the reference axis (0,0) in Table 4 is similar to the required values for yellow signals at 250m signal range given in Table 2. The values are even closer if the reduced effective intensity of flashing signals is taken into account in evaluating the requirements of the SAE standard. The values in the SAE standard are minima, no maximum values are given. There appears to be no guard against the signals being excessively bright at night.

Intensity Requirements for School Bus Signals

The requirements set out in Table 2 are for steady lights against a bright background sky, without target or backboard. Several factors would need to be taken into account when applying these requirements to the school bus scenario.

Flashing Signals - Lights may be made to flash. Contrary to popular belief, a flashing light is more difficult to detect initially than a steady one of the same intensity. However, once detected a flashing light is more likely to demand inquiry or be taken notice of than a steady light. In order to maintain the same signal range, the intensity of a flashing light will need to be increased over that of a steady light (Cole 1972, Holmes 1971).

Assuming a signal to flash at 60 cycles per minute (typical for flashing turn signals), with the off time equal to the on time, then the intensity will need to be increased by a factor of about 1.4 times to that derived from Equation 2. Even greater intensity would be required for a faster rate of flashing but, in any case, there are technical limits to the rate at which automotive lamps can be flashed (e.g. losses due to incomplete heating up of the filament and decreased service life).

Cycle Time -A property related to flashing rate is cycle time. The message should become unambiguous when a complete cycle of the signal system has elapsed and the next cycle begins. In the case of single colour wig-wag signals this will be after three light operations (e.g. left, right then left) and the total time will be about 1.5 seconds. This duration is similar to the response time used in Equation 1. In effect the cycle time is part of the process of recognition of the signal.

Dirt & Deterioration - The signal may become dirty and the hardware deteriorate over time. Taking these factors into account a nominal factor of 1.1 is used to cover the in-service deterioration of signal intensity.

Backboards - In the case of buses it is not practical to fit a black backboard of sufficient size to improve the signal range. This is because the angle between the edge of the signal and the outer edge of the backboard needs to be about 1° in order to effectively isolate the signal from the background (Fisher & Cole 1974). This translates to a backboard diameter of about 4m when viewed from 250m. No allowance is therefore made for backboards.

Derived signal intensities - Applying these factors to the values in Table 2, and rounding the results, leads the values in Table 5.

Table 5.
Necessary Signal Intensities for *Flashing* Signals on School Buses

Signal Range (m)	Signal Intensity (cd)	
	Red	Yellow
250	600	1800
100	300	900
50	200	600

DUSK & NIGHT-TIME CONDITIONS

The intensity requirements for the school bus signals are those for a bright day background. For low ambient brightness, particularly at night, care needs to be taken to guard against the possibility that high intensity signals might be overbright. This has the potential to produce glare, manifested by making the view of the signal discomforting to the approaching motorist and possibly degrading visibility.

The limitation of these adverse effects is generally given much attention in the provision of lighting and signalling at night. Light directly towards the eyes of motorists is kept to the minimum practicable.

The specified maximum intensity limit for red traffic signals is 1000cd (AS 1989), there being no limit to the yellow signal "in view of the relatively short intervals for which such signals are normally displayed". The standard suggests that the 1000cd should normally satisfactorily limit glare, at night, from signals used on roads where traffic route lighting is installed. However where roads have local road lighting or are unlit authorities are advised to consider installing signals with intensities not greater than 350cd.

Essentially similar values of intensity are embodied in road lighting standards (AS 1973) viz, 1000cd and 500cd maximum intensities for the light emitted at the horizontal from luminaires used for traffic route and local road lighting respectively.

In Australia the maximum values for vehicle yellow turn signals are 700cd and 200cd for front and rear signals respectively. The maximum intensity from the white low beam headlight in the direction of oncoming motorists is 437.5cd.

There is evidence that the intensity of a yellow light can be higher than that of a white light before being deemed unsatisfactory; the results of some investigations suggest that it can be 40% greater (van Bommel & de Boer 1980).

Practice leads to the conclusion that, in order for a light not to be glaring when viewed at night, it should have a maximum intensity of about 1000cd in the direction of view, preferably less if the road is poorly lit or unlit. Reference to Table 5 shows that the required peak intensity of the light beam of a yellow bus signal (1800cd) needs to be greater than this in order to fulfil its alerting role.

A SCHOOL BUS SIGNAL SPECIFICATION

There arises the common problem in road traffic signalling of reconciling the need for high intensity by day and low intensity by night. This problem has been tackled in a number of ways. One is by the use of a dual day-night system, with dimming of the signal at night;

although this is the best solution it has not found favour in application in Australia. Another is to have a compromise day-night system. This has been generally applied to vehicle lighting in Australia.

A third way is to give careful attention to the light beam shape. This is done for the vehicle headlight low beam in which the high intensity portion for forward seeing and the low intensity portion for limiting glare are sharply separated. The authors therefore examined whether this approach could be applied to the school bus signal.

Only at 250m away is it necessary for the motorist to experience the elevated intensity (1800cd), whilst closer to the bus (100m) the required signal intensity decreases substantially (900cd), even though still producing a clear signal. When very close to the bus (50m and less) the motorist should only be subjected to the same intensity as would be experienced with conventional turn signals, i.e 200cd to 700cd.

In order to set out a specification for the complete angular light intensity distribution for a signal light it is necessary to analyse the angular position of the signal in the field of view as the motorist approaches the bus. A desirable outcome is that motorists are in the high-intensity part of the beam some distance from the bus in order to be alerted and then move into a lower intensity portion of the beam when they get closer to the bus, to alleviate any potential over brightness of the signal.

Using the offsets of the motorist to the bus shown in figure 2. (viz eyes to far signal light; 2.2m vertical and 5.0m horizontal), the angular offsets during approach to a bus are obtained as shown in Table 6.

Table 6.
Angular Offsets for Various Distances from the Bus and the Required Signal Intensity for a Yellow Flashing Signal

Distance Away d (m)	Angular Offset (degrees)		Required Signal Intensity (cd)
	Horizontal a_H	Vertical a_V	
250	1.2	0.5	1800 min
100	2.8	1.3	900 min
50	5.7	2.5	600 min
25	11.3	5.0	(600 max)
12.5	21.8	10.0	200 max

Also shown are the required signal intensities on approach to a yellow signal, taken from Table 5. The value at 12.5m is the maximum allowed for a night/day rear turn signals on vehicles in Australia.

To cope with some vertical misalignment of the signal the maximum intensity requirements at d=25m. ($\mathbf{a}_v$=5°) should be 600cd; this value will provide the required signal intensity but will also restrict potential over-brightness.

The values of the required intensities for 50m and beyond are minimum values. These need to be associated with maximum values to avoid the potential for excessive brightness of the signal. Taking into account available technology a maximum intensity not more than 1.5 times the minimum intensity was applied. The minimum values in Table 6 have therefore been reduced by half this tolerance (i.e. by 25%). Thus the maximum values will be only 25% above the values in Table 6. The adjusted minimum values will result in only a 10% reduction in signal range, whilst providing a tolerance in design and manufacture. In practice manufacturers are likely to design signal lights well within the tolerance range and the resulting intensities are likely to be close to those given in Table 5. A model specification based on these considerations can be constructed and is given in Table 7.

Table 7
Recommended Intensities for a Flashing Yellow Signal Light (cd)

Degrees from Reference Axis		Degrees from Reference Axis				
		Left (Right is mirror image)				
		30	15	10	2.5	0
Up	5					500
	3					700
	1.5					1400
	0		500	700	1400	1400
Down	1.5					1400
	3					700
	5					500
	10	*200*	*200*	*200*	*200*	*200*

Notes:

i. The intensities shown are minimum values except those at 10° down which are maximum (*italicised).*

ii. The minimum intensities shall not be exceeded by more than 50%.

iii. The intensity between test points shall change in a smooth manner.

iv. The intensity shall be measured for a steady light run at the signal operating voltage (12.8V or 25.6V).

v. The intensities include provision for a manufacturing tolerance.

vi. Colour of signals should be in accordance with international standards (CIE 1975).

vii. Flashing red signals should be one third of the intensities shown in table 7 (rounded to nearest 50cd).

By reference to Table 4 it can be seen that there are similarities between this specification and the SAE standard for school bus signals. The axial (0,0) values and the horizontal spread of the light distribution are very similar. However the fall off in intensity vertically downwards is much less in the SAE standard, the intensity at 5° being more than twice that required. In addition there are no maximum limits to the intensities given in the SAE standard.

Available Technology

In order to obtain the relatively high intensities necessary a signal unit needs to consist of a light source of modest wattage, a reflector to efficiently collect and project the light and a front refractor (to spread the light into the required beam shape to provide angular coverage and to colour the light). Lighting technology is readily available to produce the required light distribution and was confirmed by photometric tests.

CONCLUSIONS

In order to been seen and command attention school bus signal lights must fulfil the following requirements:

i. They must have a signal range of at least 250m; this value will cover the various speed limits of roads over which school buses operate and it will provide sufficient warning to enable motorists to slow down without heavy braking.

ii. A yellow flashing signal must have an on-axis intensity of 1800 candela.

iii. In order not to be potentially glaring to approaching motorists the signal light beam must be carefully controlled.

These requirements are met by a signal complying with the specifications set out in Table 7 and mounted as high as practicable on the bus.

Field trials confirmed that signals of this intensity were clearly seen at 250m by a group of motorists. Whether the purpose of the signal will be recognised and whether it elicits the appropriate response from approaching motorists will depend on the uniqueness of the signal system and driver education. But that is another story.

ACKNOWLEDGMENTS

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