MONASH University ACCIDENT RESEARCH CENTRE

GUIDELINES FOR VEHICLE SAFETY MARKINGS FOR FLEET VEHICLES

Report commissioned by
Transurban Group

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November 2016

1 BACKGROUND

Transurban has identified a need for vehicle safety markings guidelines for road operators and infrastructure builders in the transport sector. It is anticipated that these guidelines would apply primarily to: (1) incident response, (2) project site vehicles and (3) sweepers, tow trucks, etc.

The main criteria for vehicle safety markings on incident response vehicles should be to ensure the safety of both vehicle operators and the general public. This should be achieved through being highly visible during daytime and at night and, to a lesser extent, as a vehicle owned or operated by a particular company or organisation. For vehicles not specifically operating as emergency response vehicles, the listed criteria are most important when stationary at the roadside rather than with the goal of warning road users while in motion.

2 LITERATURE REVIEW

2.1 Introduction

The vast majority of the published literature centres on emergency response vehicles, primarily police, ambulance and fire. Clearly, with these vehicle categories, vehicle markings must be visible while the vehicles are in motion in addition to when stationary at roadside scenes. The interpretation of the literature for response vehicles was undertaken with stationary roadside conspicuity the main priority. It was also kept in mind that these types of vehicles operate in a range of road environments, including motorways.

The issue of vehicle conspicuity is a complex one, depending on physical size of the target, colour and reflectivity, patterns and lighting conditions. All of these physical properties are then subject to interpretation by approaching road users, significantly complicating the issue by introducing human perception and cognitive processing factors. In summary, conspicuity comprises the following elements (Killeen, 2011a):

- Physical conspicuity: ability of an observer to detect a target in a brief presentation (Engel, 1977). Relates to body colour, shape and markings;
- Cognitive conspicuity: the ability to recognise and process what is seen;
- Visibility: ease of discrimination of an object with a known location (Langham *et al*, 2002). An object may be able to be discerned, but the colours and markings effectively camouflage it, making it less visible.
- Recognition: the ability to interpret the particular shapes and colours of the object. Some visibility markings actually make recognition less effective, with haphazard or complex marking designs inducing camouflage effects in complex environments or low lighting conditions.

Killeen (2011a) also highlights some 'awareness factors' leading to optimal contrast between subject vehicles and the background environment, including:

- Vehicle speed;
- Apparent visual size: maximised through appropriate vehicle markings;
- Shape: communicating vehicle type and orientation;
- Colour: some colours are able to be seen more quickly than others in an urban environment, with fluorescence enhancing this effect further;

- Brightness: effect is maximised at dawn and dusk, during adverse weather conditions and under low light conditions.

2.2 Regulations

No jurisdictions were found to have vehicle marking regulations relating to non-emergency response vehicles. In Victoria, the Road Safety (Vehicles) Regulations 2009 - Schedule 2, Division 19, Clause 118 specifies that 'exempt vehicles', "may be fitted with any light or reflector." It is not clear what, if any, requirements or restrictions apply to 'special use' vehicles.

Australian Standard AS 1742.3:2009, 'Manual of uniform traffic control devices; Part 3: Traffic control for works on roads', Section 3.12, primarily specifies vehicle-mounted flashing signs and arrows. Section 3.12.4 requires only that, "vehicles should be painted a distinctive bright colour. The colour should contrast with the colour of high visibility clothing used by personnel."

2.3 Colour

The colour of vehicle markings is important primarily in daylight, since the colour receptors in the eye lose sensitivity in the dark. Human vision sensitivity peaks at between 555 nm (day) and 507 nm (night), corresponding to a colour range between green and yellow-green (Killeen, 2011a). A suitable colour representing the midpoint of this range is international standard colour RAL 1016 (RGB 241-221-56)[1]

Killeen (2011a) recommends RAL 1016 as a base vehicle colour, but alternatively, white was shown to be the statistically safest colour by 10% for real world crash involvement (Newstead and D'Elia, 2007). Every other colour apart from white was found less safe, with little distinction between any of the non-white hues. Solomon and King (1995) in the USA studied visibility-related crashes of fire engines in Dallas, Texas, where the fleet of formerly red or red/white fire units was replaced by yellow-green/white vehicles. They found that crash rates of all severity levels were 3.5 times higher among red vehicles, with injury crashes higher by a statistically significant factor of 6.5.

According to Killeen (2010), dark colours adjacent to one another (such as red and blue) cause visibility problems with the eye not able to easily lock focus with such combinations. Killeen recommended the following body colours and combinations as suitable for emergency vehicle use:

- Yellow-green
- Chrome or Euro Yellow
- White and fluorescent yellow-green
- White and fluorescent red
- Fluorescent red

He also suggested that where more neutral body colours are used, coloured infill panels should comprise a minimum of 10% of total surface area. Chapter 8 of the UK Traffic Signs Manual (TSO, 2009) concurs in general, specifying that vehicles used for roadside service or incident response be a "conspicuous colour" and, "where the main body of the vehicle being used is not a recognised conspicuous colour (yellow or white) then [...] should be supplemented by a high visibility fluorescent yellow retroreflective strip, of not less than 50 mm wide, along the side of vehicle as a minimum."

[1] Also Pantone Solid Coated 603 C, Pantone Solid Uncoated 395 U or Pantone Pastels Neons Coated 809 C. See http://rgb.to/ral/1016

De Lorenzo and Eilers (1991) suggested that multi-coloured ambulances, while distinctive in isolation, may be less conspicuous in urban environments in particular because of camouflage effects. As with much of the research in this field, it was noted that adequate field studies to assess this issue have yet to be conducted.

Fluorescence is also very important for visibility, since colours not found in nature are more readily discernible against non-fluorescent backgrounds. The US Fire Administration carried out a comprehensive study into emergency vehicle visibility and conspicuity (USFA, 2009), in which it was found that fluorescent colours, especially fluorescent yellow-green and orange, were particularly visible during daylight hours.

The USFA also observed that the increased use of retroreflective materials, "holds great promise for enhancing the conspicuity of emergency vehicles," and the use of contrasting colours can assist drivers with locating a hazard amid the visual clutter of the roadway. It was noted, however, that it is theoretically possible to overdo the use of retroreflective materials and thus interfere with the ability of drivers to recognise other hazards.

The study summarised a number of recommendations for their organisation, including:

- The concentration of retroreflective material lower on emergency vehicles will optimise interaction with the headlights of approaching vehicles (USFA, 2014);
- Fluorescent retroreflective materials should be considered in applications where a high degree of day/night time visibility is desired;
- The use of high-efficiency retroreflective materials can improve conspicuity while reducing the amount of vehicle surface area requiring treatment.

2.4 Pattern

The nature and extent of patterns designed for maximum visibility, conspicuity and recognition is the most controversial topic in the literature on vehicle safety markings. The efficacy of the two most popular treatments, chevron markings and checkerboard patterns, has been doubted in recent research, with Killeen (2011b) finding no scientific basis demonstrating the effectiveness of chevrons beyond there being a presumed analogy with roadside barriers (USFA, 2014). So-called Sillitoe patterns, comprising multiple rows of small checks, have become particularly popular with police forces in Australia, but it is suggested that while they have high recognition levels among road users, they cause difficulties in discerning vehicle outlines against urban backgrounds.

Figure 1. Full Battenburg scheme.

In the United Kingdom, the Battenburg scheme was devised from basic behavioural testing and attitudinal research with the UK Police (Harrison, 2004). The full Battenburg was designed for the motorway environment and was designed to make police sedans visible at 500 m. The half Battenburg was a later adaptation for urban environments and has about half the visible range of the full scheme. The large squares used were found to be easily recognisable, particularly when created in fluorescent hues. Some of the advantages of the Battenburg were listed as:

- It overlays and covers full side of vehicles of any base colour;
- The large block pattern is visually superior and quite conspicuous;
- It includes fluorescent retroreflective yellow/green;
- The blue blocks are the last colour to be visualised as light fades;
- It includes rear chevron pattern to reduce collisions;
- It is effective under different types of street lighting.

Countering these, Killeen (2010) notes a number of disadvantages:

- The pattern is difficult to apply to small, curved or odd shaped vehicles;
- The pattern has to be die-cut for most vehicle shapes, leading to high materials and labour costs;
- It is not possible to sign-write over the pattern;
- It can be confusing when several vehicles visually overlap;
- The rear chevron pattern has never been individually tested;
- Different colour combinations from the standard blue/yellow are not as effective;
- In the UK the standard Battenburg is reserved exclusively for police vehicles and its effectiveness is likely to be reduced in a different colour combination.

Chevrons have been widely applied to the rear of the full range of emergency vehicles, but appear to have a number of pitfalls. Usually applied as an inverted-'V' to the vehicle rear only, the intention of the effect is to direct approaching vehicles around each side. However, they can blur body edge discrimination (Killeen, 2011a) and disrupt distance perception (Killeen, 2010). Killeen (2010) also suggested that the horizontal scan pattern characterising the human eye leads to slower recognition of vertical or diagonal patterns, but fails to reference his source for this assertion. Tijerina *et al* (2003) separately agreed that multi-colour rear end chevron markings may actually reduce conspicuity by camouflaging the rear of the vehicle.

Accepting that chevrons were going to continue to be used, Killeen (2010) recommended that they should not attempt to blanket the entire rear end, but be limited to 25-50% coverage and be an inverted-'V' with wide stripes (at least 150 mm) centred on the vehicle rear. Recommended colours are reflective red and yellow or their fluorescent equivalents (Killeen 2011b). Furthermore, he recommended that they should never be used on the side of a vehicle, nor on the inside of doors or hatches and should be avoided altogether on complex rear ends. To compensate for the camouflage effect chevrons cause, yellow or white retroreflective stripes should be applied along the vehicle contour (see next section). The UK Traffic Signs Manual (TSO, 2009) agrees with the spirit of the above recommendations, adding a recommended orientation of 45-60 degrees from the horizontal. This reference also suggests an alternative to chevrons in the form of, "a solid block of fluorescent orange-red retroreflective material."

2.5 Contour markings

Contour markings appear to have a critical role in restoring the outline of a heavily marked vehicle, particularly by night. The European Commission has a specific standard — UNECE R104 — establishing guidelines for their application to heavy vehicles, but it is apparent from the literature that they are of value for smaller vehicles also. Tested in New Brunswick, Canada (Hildebrand and Fullarton, 1997) among a sample of observers stratified to represent the profile of licensed drivers in the province, a continuous white stripe of reflective tape around the perimeter of a semi-trailer was found to be the most effective of a selection of nine different marking schemes. ECE R104 specifies stripes of 50-60 mm width (perhaps able to be reduced for smaller vehicles) covering not less than 80% of the vehicle length in retroreflective white, yellow or red. The US Fire Administration (USFA, 2014) recommends that they be matched to body colour in order to be visible only at night and prevent further visual confusion during daylight.

2.6 Vehicle fronts

The literature places little emphasis on signage on the front of vehicles. This is potentially a consequence of the minimal area available for markings outside of the windscreen, headlights, grille and other hardware important to vehicle operation located on this side of most vehicles. In general, the consensus seems to be to avoid front-mounted chevrons or checker patterns to aid rapid vehicle recognition and to use only one or two broad solid yellow fluorescent stripes. Body colour reflective contour markings could be applied to join up with those recommended for the sides.

3 GUIDELINES AND CAVEATS

Guidelines:

- A base vehicle colour of white is desirable (Newstead and D'Elia, 2007) for maximum visibility, paired with fluorescent markings.
- Wide reflective or fluorescent stripes or panels of colour improve visibility, as well as the ability to discern vehicle size and outline. Cut-outs around wheel arches assist in providing visual cues to drivers.
- Use reflective contour markings to outline the vehicle. Should be 25-50 mm wide, in the vehicle base colour.
- Balance reflective and fluorescent elements to ensure effective layouts in all lighting conditions. Avoid red and blue reflective colours in close proximity. With fluorescent colours, stick with one primary colour and minimal areas of secondary colours to avoid glare.
- Use visual cues to enhance perception. Complex patterns can disguise the profile of the vehicle.
- Text should be in sentence case rather than block capitals.

Caveats:

- Inverted-V chevrons can blur body edge discrimination;
- Angled stripes or repeating patterns can break the vehicle into disjointed segments;
- A fluorescent red/orange baseline stripe can improve long distance recognition;

- Body-colour reflective door frame contour markings show open doors effectively;
- Avoid oversized text or excessively complex marking layouts that might camouflage the vehicle or personnel around it. Hybrid layouts with a mix of Battenburg, Sillitoe and chevrons should be avoided;
- Do not use complex graphics, designs or patterns;
- Minimise text, logos and badges.

Finally, overall visibility needs to be assessed in a real-world environment, not in a framed photograph of the vehicle on a neutral background.

Figure 2. Effective fluorescent and multi-level layout on a white base (from Killeen, 2011)

Note the absence of any chevron markings, bold, simple panels of colour including cutouts around the wheel arches and the yellow stripes along the roofline to provide contour delineation.

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