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Executive summary

Traffic signs are one of the principal methods of conveying regulatory, warning and guidance information to road users. As such, any sign face must be conspicuous and clearly legible for it to be effective.

Retroreflective sheeting is used to improve the night time performance of signs. There are several types of retroreflective material, all of which are designed to reflect light predominantly back towards its source. The overall amount of light reflected can be reduced by a number of different factors and environmental conditions, which are likely to make the signs appear less bright and become more difficult to read. Thus, retroreflective signs at night are adversely affected by dew formation, reducing the luminance and readability of the sign.

This literature review considers previous research on the effect of dew on traffic signs, and identifies the factors which affect the likelihood and pattern of dew formation. From this recommendations are made for the planning of trials in Phase 2.

Phase 2 will consist of trials where a sample of Highways Agency and local authority traffic signs will be observed to determine the loss of conspicuity and legibility. An assessment of the scale of the problem, in relation to the factors identified in Phase 1, will be produced.
1 Introduction

Traffic signs are one of the principal methods of conveying regulatory, warning and guidance information to road users. As such, any sign face must be conspicuous and clearly legible for it to be effective.

Retroreflective sheeting is used to improve the night time performance of signs. There are several types of retroreflective material, all of which are designed to reflect light predominantly back towards its source. However, sign faces can be affected by a number of different factors, such as dirt, and environmental conditions, such as frost and dew, which are likely to make the signs appear less bright and become more difficult to read.

This literature review (Phase 1) identifies the factors which influence the loss of conspicuity and legibility of Highways Agency and local authority traffic signs, arising from dew formation. The areas of consideration include sign face materials, sign substrate, position of sign, e.g. height from the ground and whether the sign is sheltered or not. Weather and lighting conditions are also taken into account. Given these factors recommendations are made (see section 6) for the planning of the trials in Phase 2.

Phase 2 will consist of trials where a sample of Highways Agency and local authority traffic signs will be observed, to determine the loss of conspicuity and legibility, using a luminance camera. An assessment of the scale of the problem across Highways Agency traffic signs, in relation to the factors identified in Phase 1, will be produced.

The literature for this study has been collected via the TRL Information Centre, which contains bibliographic references and abstracts of English and foreign language articles from journals, books and research reports. It is the English language version of the world-wide ITRD database (International Transport Research Documentation) and therefore regularly receives material from the USA, Australia, Scandinavia, the Netherlands, Canada and other countries in addition to the UK input. The internet has also been used to find articles containing key phrases relating to the field. The amount of literature found on issues relating to dew formation on road signs has been somewhat disappointing, and much of the research is American based. However, some research has been undertaken in the last four years and, although no solution to the problem has been proposed, many factors which affect the conspicuity and luminance of signs are highlighted, and these are discussed in this review.

2 Retroreflectivity and luminance

Retroreflective materials predominantly reflect light back towards its source, thus making the object appear brighter and more conspicuous than non-reflective materials, (Hildebrand and Bergin, 2004). These materials either contain minute beads of glass or, more recently, microprismatic retroreflective elements. Retroreflectivity is measured in candelas per lux per square metre (cd/lux/m²) and depends on the angle at which light strikes the sign and the position from which it is viewed. In general, the higher the retroreflective coefficient for a given arrangement of light source and observer, the greater will be its luminance, (Carlson, 2003). Retroreflectivity, however, is a property of the material and is only one element that defines the luminance of a sign.

The luminance of a sign, measured in candelas per square metre (cd/m²), depends upon the amount of light reaching the sign, the retroreflectivity of the sign and the viewing geometry (the relative position of the headlight, sign and driver). The theoretical luminance will be reduced by attenuation of light due to poor weather conditions and by dirt, dew etc on the sign face. The luminance seen from a vehicle will be reduced by the presence of the windscreen.

A study at TRL compared the performance of different retroreflective materials, (Cooper and Smith, 1997). This concluded that, in general, from an initial distance of 300 metres the luminance of a retroreflective sign will increase as the observer approaches the sign. At a certain point, dependant on
the viewing geometry and the sign material, a maximum luminance value will be reached. After this the luminance of the sign will rapidly decrease as the sign is approached.

The viewing geometry is defined by the angles between the headlight, sign and driver. (There is a different viewing geometry for each headlight. The total sign luminance is the sum of the luminances for each headlight calculated separately.) Figure 1, (Hawkins et al., 2003), illustrates, in two dimensions, the entrance and observation angles in relation to the driver and a headlight. In terms of retroreflectivity, the most significant of these angles is the observation angle. As the angles of entrance and observation change so does the reflectivity of the sign. Therefore, it is important to ensure that the viewing geometry is the same each time a given site is visited during the trials.

![Figure 1. Entrance and Observation Angles in Real-World Conditions, (Hawkins et al., 2003).](image)

### 3 Dew formation

#### 3.1 How dew forms

The temperature at which dew starts to form is known as the *dew point*. Dew forms when moist air cools as it comes into contact with a cooler surface and the ambient temperature falls below the dew point. Cool air cannot hold as much moisture as warm air and thus, when saturated, water droplets condense onto the coolest surface, forming dew.

Dew can form by one of two means. The first of these is *radiation cooling*. Dew forms on a sign when its temperature falls below the dew point of the surrounding air. This cooling is caused by heat radiation from the sign to the sign’s surroundings.

The second mechanism of dew formation is *advection cooling*. Usually wind restricts or even prevents dew from forming; a steady flow of air over a sign does not remain in contact with the sign long enough for it to cool below its dew point and thus for condensation to occur. However, in some circumstances condensation can take place. This happens when warm air from a different source passes over the cold surface of a sign. This often occurs when the weather changes and moist south-westernly winds return after a cold spell.
3.2 When dew forms

Ideal conditions for dew formation are a high level of humidity, a rapidly falling temperature, clear skies and little wind. Cloud cover may inhibit the formation of dew because heat released by the earth is radiated back. A strong wind will distribute the heat and moisture more evenly throughout a larger proportion of air, thus it is unlikely to cool sufficiently for the dew point to be reached. The formation and dissipation of dew can start off slowly then increase quite rapidly, or vice versa, (Kersloot and Cooper, 2000).

Dew can form at any time of the day but its effect on retroreflective signing is most evident at night when it appears as dark patches on the sign face. (Consequently only retroreflective signs, during night time hours, need be considered in Phase 2.) Dew formation can affect a sign’s luminance and hence affects both the conspicuity and legibility of the sign. The effect on conspicuity and legibility may be different depending on whether the sign is lit or not, and whether it is located in a lit or unlit area.

Figure 2 indicates that dew formation is most likely to occur from May to October. This is because of the relatively large drop in temperature experienced in the evenings. However, there are longer daylight hours in these months, and so the hours that dew affects road signs during darkness is proportionally low. The greatest prevalence of dew during night time hours occurs from the middle of September to the end of October.

4 How dew affects road signs

If dew forms evenly over the sign it is likely to result in a uniform reduction in luminance and consequently a lower conspicuity. The reduction in conspicuity may be greater for a sign in a lit area where the background is likely to have a much higher luminance than in unlit surroundings. Sign legibility will also be reduced due to lower contrast between the sign legend and background.

However, dew may not form evenly; it may form in small areas producing dark patches, as often seen on large motorway direction signs. In this case, the conspicuity may be maintained or even increased if the presence of light and dark areas leads to a great enough contrast across the sign face. The variation in luminance is likely to reduce the legibility of the legend. However, Hildebrand and Bergin (2004) suggest that a high variation of dew coverage across a sign face may conceivably serve to improve recognition or legibility of the sign.
Previous work carried out for the Highways Agency investigated the problem of dew formation on retroreflective signs, (Cooper and Smith, 1997). This focused only on the effect on unlit retroreflective signs used for temporary traffic management. During the course of the project a number of site visits were undertaken to observe these temporary signs. On a number of occasions dew was observed to be forming on the signs. In several cases this was noted to have a serious effect on luminance and hence conspicuity and legibility of the sign.

In the same work site engineers were asked to complete relating to the effectiveness of signs. Some comments concerning dew formation were received:

- ‘small amount of dew - signs remained bright and clear’
- ‘heavy dew made signs appear dirty’
- ‘dew on signs appeared to reduce reflectivity’

Due to the difference in structural support and quality of retroreflective sheeting (eg due to wear and tear), and because of the likelihood of temporary traffic signs being repositioned, it is not recommended that these be used in any study of retroreflectivity.

4.1 Hydrophobic and hydrophilic surfaces

When dew forms on a retroreflective sign it distorts the path light takes as it reaches the sign face and returns to the driver. As less light is returned along the correct path, the luminance of the sign is diminished.

Figure 3 illustrates the bending of light as it enters the sign face material and is refracted, (3M, 2004a).

The surface in Figure 3 is an example of a hydrophobic material. That is, one which repels the dew droplets forming rounded beads of water. On hydrophilic surfaces, (see Figure 4), dew drops coalesce to form a sheet of water over the signs surface. Light is virtually unaffected by the layer of water and is reflected back towards its source. The luminance of a hydrophilic sign remains essentially unchanged, (3M, 2004a). In their experiments on different sign substrates Kersloot and Cooper (2000) found that dew resistant sheeting had a significant effect on reducing the conspicuity problems caused by dew formation.
The effects of dew on normal (hydrophobic) and dew resistant (hydrophilic) signs have been studied by 3M, a major manufacturer of signing material. They developed a clear, colourless, dew resistant film to use as an overlay on a standard traffic sign. The film transforms the sign face to give it hydrophilic properties when dew forms, without significantly reducing the retroreflectivity at other times, (3M, 2004b). Details of the trials, (3M, 2004a), were not reported, but results showed that a sign with a dew resistant overlay retained its luminance, compared to around 40% retained reflection of a hydrophobic sign. However, although apparently effective, the film is easily damaged and, therefore, only appropriate for permanent traffic signs.

This dew resistant sheeting has been used for over 11 years, throughout Europe and the Far East. The overlaminate is guaranteed by 3M to remain hydrophilic for five years. Moreover, 3M showed that trial signs in the UK maintained dew resistance for at least eight years, (Newell-Hart, 2003). A later study, also conducted by 3M, showed signs to still have “significant hydrophilic character” after being on the roadside for 10 years, and these were the only signs in the area unaffected by dew, (3M, 2004a). Since 3M manufacture dew resistant sheeting, it is important to put these results into context. Ultimately the hydrophilic properties of the sheeting will fail. In this case, the sign will remain as effective as a standard, hydrophobic retroreflective sign of the same age.

Dew resistant sheeting has also been developed by Rennicks, and both this and the 3M version are now in use on permanent traffic signs.

5 Sign Factors

5.1 Siting of road signs

The siting of a road sign can have a significant affect on the quantity and prevalence of dew. In rural, sheltered areas the air is likely to cool more quickly than in urban areas where, although there may be less wind, the air temperature remains higher for longer because buildings cool slowly.

It is unlikely that dew will form on all signs in an area because of the considerable influence of siting: signs next to a road will be affected by the movement of air caused by passing vehicles. Those located further away from the edge of the road, or higher than the disturbed air (eg signs on gantries) are more likely to be prone to dew formation.

Different areas of the UK experience very different levels of dew during hours of darkness. The south east coast experiences the greatest quantity of dew with more than 600 night hours per year affected, (Newell-Hart, 2003).

5.2 Sign substrate

Another factor that has an influence on the quantity of dew, and the length of time for which it will persist for, is the material used in the sign construction. Research by Kersloot and Cooper (2000),
conducted under laboratory conditions on aluminium and polyplate substrates, firstly suggested that aluminium substrates were more prone to dew formation.\footnote{The climatic chamber control system proved incapable of simulating evening dew. Therefore, the experiments involved the simulation of morning dew. This was achieved by raising the temperature by approximately 14 degrees over an hour. A further test was later carried out in a smaller climatic chamber capable of replicating evening dew formation. Again dew formed on the aluminium substrate first.}

The experiments were repeated outdoors, on six nights at different times of year, using small plates, approximately 15cm square in size. Various retroreflective materials were mounted in a number of substrates. In this case the aluminium substrate appeared to be more effective in inhibiting dew formation than the composite materials. However, although the conditions of this outdoors trial were more realistic than the test carried out in the climatic chamber, the effect was small and it was concluded that any requirement to use aluminium, based on this evidence, was not justified.

For full size signs the thermal conductivity of any cross-bracing or mounting poles will have an effect on both the likelihood and pattern of dew formation. Areas of the sign in front of any support will take longer to warm up, in the mornings, and thus retain dew for a longer period. Similarly, the same areas will retain heat for longer and are less likely to have dew form on them in the evenings.

Hutchinson and Pullen (1978) considered, under test conditions, the formation of dew and frost on signs with various combinations of legend, background and mounting materials. They found that dew formed earlier on plywood-backed panels leading to greater total accumulation of dew, and that, under road conditions, the mounting post acted as a “heat sink”.

It was also reported by Hildebrand and Bergin (2004) that previous studies had shown that dew formed earlier on signs backed with plywood compared to those backed with aluminium.

5.3 Sign and Legend Colour

Research carried out by Hildebrand, (2003), showed that there was no correlation between the colour of sign-face material used and the degree to which the sign’s retroreflectivity was reduced, with the presence of dew. The study showed that, except for white, all American Type I (engineering grade) sign-sheeting colours provided substandard reflective properties when dew was present. The retroreflectivity of white coloured sign-sheeting, with dew, was marginally over the value recommended by the US Department for Transportation Federal Highway Administration (FHWA) research. All Type III (high intensity) sign-sheeting colours, except green, were shown to meet minimum retroreflectivity levels given dew conditions. (Red Type III sign-sheeting only just met the minimum value.) In most American jurisdictions blue coloured signs and symbols indicate tourist information. Therefore, it was not considered necessary, from a safety perspective, to include this colour in the study.

Although the colour of a retroreflective sign does not have a direct effect on the likelihood of dew formation, Liz Newell-Hart suggested, in a telephone conversation (October 2004), that darker colours (eg the dark green of primary route direction signs, which provides the greatest contrast between background and legend during the day) can become the least legible when dew forms on them.

Hildebrand and Bergin (2004) investigated the average reduction in retroreflectivity for signs with dew and frost formation. Twelve, 30.5cm x 61cm, samples of Engineering, High Intensity and Microprismatic (Type I, III and VII respectively) grade sheeting, of various colours, were mounted on a north facing test-deck in an exposed area. This ensured the samples experienced the same weather conditions and that data could be collected quickly. A retroreflectometer was used to record the retroreflectance of a point on the sign in both dew and frost conditions. Periodic readings of the samples, under normal conditions, and readings from like-new in-service signs, were also made to
provide a benchmark for the calculations. Temporal and spatial variations in retroreflectance were also measured.

Thirteen recordings were made, in the autumn and winter of 2003/04, when dew was present. The retroreflectivity of the materials, under dew conditions, were reduced by 41% to 88%, (average of 69%). The largest reduction occurred in the higher grade signs which experienced a disproportionate drop in the retroreflectivity levels. However, these higher grade signs still retained a greater level of retroreflectivity than the lower grade materials, but did not always meet the proposed FHWA minimum levels. (Details of the FHWA minimum retroreflectivity levels, for Type III and VII grade sheeting, and the results from these trials can be found in Appendix A.)

The average spatial variation, the measure of the difference in dew coverage across a sign face, was 5.3%. The average temporal variation, the level by which the dew coverage changed from day to day, was 39%. These results are greatly influenced by several factors: formation of dirt on the sign face; the deterioration of the sign face material; the difficulty in measuring exactly the same spot on the sign face and the natural variations in the dew formation over the sign face.

6 Summary and Recommendations

6.1 Summary

The problem of dew formation affecting traffic signs has been recognised for a number of years.

There are many different factors which affect dew formation, and the mechanism may be different at dusk and at dawn. Certainly the siting and the microclimate around the sign are known to be an important influence.

Hutchinson and Pullen (1978) found that plywood backed signs accumulated a greater amount of dew than those backed with a metallic substrate. Also, any mounting posts or bracing acted as a heat sink.

The final report of the project N216, Cooper and Smith (1997), carried out by TRL on behalf of the Highways Agency considered the use of unlit retroreflective signs for temporary traffic management. This identified the problem of dew formation, remarking that the appearance of dark areas on fixed retroreflective signs after dark is a common sight. The whole face of a smaller sign could be darkened. They recommended that further research should be carried out to investigate possible solutions to the problem.

Experiments carried out in a climatic chamber suggested that aluminium signs were more prone to dew formation, (Kersloot and Cooper, 2000). However, a further experiment in more realistic outdoor conditions appeared to show the opposite, ie that composite materials led to earlier dew formation and later clearing. In this instance aluminium appeared to be the most suitable substrate for inhibiting dew formation, although the effect was relatively small. It was concluded that any requirement to use aluminium was not justified.

Hildebrand (2003) showed that there was no correlation between the sign-face material colour and the degree of reduction in retroreflectivity of a sign with dew.

Hildebrand and Bergin (2004) investigated the reduction in retroreflectivity of various materials under the presence of dew. They discovered that High Intensity and Microprismatic materials experienced a larger reduction in retroreflectance than the Engineering grade. (The average reductions in retroreflectivity were 61.5% for Type I, 72.5% for Type III and 87% for Type VII sheeting.) Although they still out-performed lower grade material, not all of the higher grade materials met the FWHA minimum retroreflective levels.

The problem of dew formation has been investigated by 3M, a major manufacturer of signing material. They developed a dew resistant film which, although apparently effective for permanent signs, is easily damaged by manual handling and so was considered unsuitable for temporary signs.
6.2 Recommendations

The conflicting results from previous research show that it is important to base any trial looking into the effects of dew formation on signs of the same substrate located by the road side rather than off-road. Therefore, when planning the trials in Phase 2 the following recommendations should be considered. (Only unlit, permanent traffic signs are to be considered in Phase 2.)

- Trials should be carried out when the weather conditions for dew formation are favourable. Local weather reports should be consulted to determine the likelihood of dew formation.

- Signs in various sitings and positions should be viewed to assess any influence these factors may have on the sign’s microclimate, and thus the likelihood of dew formation. Passing traffic can also have an effect on this.

- Signs of differing size, substrate and structure (e.g., any mounting posts etc) should be viewed to assess any influence these factors have the likelihood and the pattern of dew formation.

- Both primary route (dark green background) and non-primary route (white background) direction signs should be viewed as differences in size, shape and background colour will affect the dew formation and the conspicuity and legibility of a sign.

- The signs viewed should include those with legends or panels of various colours (of yellow, blue, white, black and red) in order to assess the conspicuity and legibility these signs. This is likely to be affected by the contrast between the background and legend colours.

- Care should be taken to ensure that the observation and entrance angles of a particular sign remain constant for each viewing. Each sign will be in a different position relative to either the edge of the carriageway or the viewing position, and therefore there will be differences in the observation angle (and entrance angle) for the different signs.

- Recordings should be made when no other vehicles are nearby, as additional light sources from vehicle headlights are likely to affect the image taken.
## Appendix A.

Table 1: Compliance with Proposed FHWA Minimum Retroreflectivity Levels - 2002 Revisions, (Hildebrand and Bergin, 2004).

<table>
<thead>
<tr>
<th>Sign Type</th>
<th>Application (Legend / Background)</th>
<th>Proposed Minimum Value (cd/lx/m²)</th>
<th>Normal (cd/lx/m²)</th>
<th>Dew (cd/lx/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type III – White</td>
<td>White / Red</td>
<td>35</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Black / White</td>
<td>50</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>White / Green (shoulder sign)</td>
<td>120</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Type III – Red</td>
<td>White / Red</td>
<td>7</td>
<td>✓</td>
<td>19</td>
</tr>
<tr>
<td>Type III - Yellow</td>
<td>Black / Yellow (bold symbols or text signs ≥ 48 inches)</td>
<td>50</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Black / Yellow (fine symbols or text signs &lt; 48 inches)</td>
<td>75</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Type III – Green</td>
<td>White / Green (overhead sign)</td>
<td>25</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>White / Green (shoulder sign)</td>
<td>15</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Type VII- White</td>
<td>White / Red</td>
<td>35</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Black / White</td>
<td>50</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>White / Green (overhead sign)</td>
<td>250</td>
<td>✓</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>White / Green (shoulder sign)</td>
<td>120</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Type VII - Yellow</td>
<td>Black / Yellow (bold symbols or text signs ≥ 48 inches)</td>
<td>50</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Black / Yellow (fine symbols or text signs &lt; 48 inches)</td>
<td>75</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ - meets proposed FHWA minimum retroreflectivity levels

X – does not meet proposed FHWA minimum retroreflectivity levels
Acknowledgements
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References


Newell-Hart L (2003). Dew formation and its effects on traffic signs. 3M
3M (2004a). Traffic signs: dew resistance & self cleaning. 3M.