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Trials of Road Marking Monitor to determine performance levels for network surveys

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Executive Summary

For reasons of road safety Highways England requires that the condition of road markings and reflective road studs be monitored on a ‘frequent’ basis on the strategic road network. The current standard, TD 26, states that road markings shall be routinely inspected in order to identify when the deterioration is such that a reduction in the delivery of safety benefits could result. To avoid the need for lane closures it is desirable for assessments of road marking condition to be carried out at traffic-speed. Therefore the measurement of the retro-reflectivity (or night-time visibility) of longitudinal markings, was introduced to Highways England’s TRACS2 (TRAffic-speed Condition Survey 2) network survey of road surface condition in 2008. The TRACS2 survey experienced problems with the network level measurement of the retro-reflectivity of road markings when attempting to utilise the standard equipment available at the time (Ecodyn). Therefore a research programme was commissioned by Highways England to identify and develop an improved approach to the measurement of retro-reflectivity of road markings. The programme had the longer term aim of demonstrating a practical method to deliver improved measurements of road marking retro-reflectivity, so that Highways England could re-introduce this measurement into the TRACS survey with confidence that the survey would be capable of delivering accurate and consistent information on the condition of road markings.

The research programme has shown that high-speed imaging equipment, mounted in a novel configuration, and illuminated by a high intensity LED light source, can provide an improved method of measuring the retro-reflectivity of road markings. The research programme delivered a prototype device incorporating this approach, carried out initial tests on its performance, and demonstrated a fully working prototype (called the Road Marking Monitor (RMM)) to Highways England in the autumn of 2014. Initial trials of the RMM were carried out on the road network to assess the device in comparison with the existing equipment (Ecodyen). The trials confirmed the improved capability of the RMM in comparison with the previous technology, and the results were used to propose the level of performance that Highways England should be able to confidently specify for the measurement of road marking retro-reflectivity in a future TRACS contract. However, at the conclusion of the initial trials it was recommended that a further comparison of the RMM be carried out against other, more recently developed devices, to provide a greater understanding of the capabilities of both the RMM and these other devices.

Three survey devices were selected for comparison with the RMM: the Zehntner ZDR6020, the DELTA LTL-M and the Vectra Ecodyn. Road Vista’s Laserlux was available in the UK but was unfortunately temporarily out of commission so unable to be included in the tests. Comparisons have been carried out between these devices and the RMM at the laboratory and network level. The laboratory tests incorporated a hand held reference device (Stripemaster) which was used to measure test lines constructed in the laboratory. The devices then surveyed the reference lines and the results compared with the Stripemaster. The network tests comprised a survey route of approximately 65km on the local and strategic road network. The route was chosen due to the diversity of markings present, including dashed and solid lines, different pavement types, and various stud types. During the tests, data was collected with each of the four retroreflectometers using a back to back (convoy) survey method. The three standard geometry retroreflectometers drove as they normally would for surveying (using an off-centre driving line) and the RMM used a standard driving line (centrally in the lane). The
measurements provided by each of the devices were compared with each other and assessed for repeatability and agreement between devices.

It is apparent from the results of the network test that traffic speed retroreflectometers have come a long way since the first generation Ecodyne used in the previous TRACS survey. Although the two newer generation retroreflectometers (Zehntner and DELTA) still employed a dedicated non-central driving line, the data provided from these systems was to a higher level of quality than experienced with the older Ecodyne device (note: a second generation Ecodyne is now available that has not been tested in this work), in particular after initial “cleaning” of the raw 10m values provided by these devices. The RMM agreed well with these two devices on the network routes, and showed a level of repeatability on a par with the best of the devices. When compared, all the devices disagree over the road marking condition at one place or another, even when carrying out back to back (convoy) surveys. This demonstrates the challenge involved in measuring road marking retroreflectivity in typical network conditions. However, two of the devices are definitely more consistent with each other and with themselves – the LTL-M and the RMM. The promising results suggest that the RMM is suitable for surveys at a network level. Nevertheless, it is suggested that there would be benefit in continuing the development of its algorithms, including the exploration of a method proposed to reduce the influence of the anomalous line types identified in the static tests.

The performance observed in the measurement of retroreflectivity by both the RMM and the LTL-M have enabled this work to confirm the requirements for TRACS that were proposed in the previous work, and also to include a coverage requirement:

<table>
<thead>
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<th>Parameter</th>
<th>Performance as difference from reference</th>
<th>Target (% of differences in range)</th>
<th>Coverage requirement (all)</th>
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</thead>
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<tr>
<td>Retro-reflectivity</td>
<td>±13mcd/m^2/lux</td>
<td>65%</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>±25mcd/m^2/lux</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>±50mcd/m^2/lux</td>
<td>100%</td>
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</table>

It is recommended that the devices be required to deliver their data as retroreflectivity profile. This method of raw data delivery would enable Highways England to specify the processing method, and hence overcome the issues identified with noise in the 10m values (e.g. as provided by the Zehntner and LTL-M devices). It is suggested that the algorithms used for the processing of the previous TRACS retroreflectivity profile data could form a good starting point as an adaptation of these has been used successfully in this work to process the RMM data.

The experience gained in this project has shown that it is difficult to run controlled laboratory based tests for the assessment of these devices, as retroreflectivity of road markings is inherently a very variable property and a significant sample size is needed. A network level test is useful in these circumstances, but the relatively short lifespan of a road markings and susceptibility to the weather makes it very hard to establish a reliable and practical reference (e.g. collection of reference data using a hand held device). A possible solution for this may lie in a correlation trial using the fleet mean as reference, as used for many other road condition parameters.
1 Introduction

For reasons of road safety Highways England requires that the condition of road markings and reflective road studs be monitored on a ‘frequent’ basis on the strategic road network. Current advice (TD26, Highways Agency, 2007), states that road markings shall be routinely inspected in order to identify when the deterioration is such that a reduction in the delivery of safety benefits could result. Therefore the measurement of the retro-reflectivity (or night-time visibility) of longitudinal markings, was introduced to the Highways England’s TRACS2 (TRAffic-speed Condition Survey 2) network survey of road surface condition in 2008. Unfortunately, the TRACS2 survey experienced several problems with the network level measurement of the retro-reflectivity of road markings when attempting to utilise the standard equipment available at the time (Ecodyne). These problems included:

- The impractical equipment mounting which was low and to the side of the survey vehicle, exposing the equipment to hazards, presenting a potential safety risk for other road users and exposing the equipment to dirt/detritus.
- Inconsistencies in the measurements resulting from poor calibration and the effect of changes in the measuring equipment angle relative to the road markings.
- A limited measurement width resulting in the need for an impractical driving line and the inability to measure both the nearside and offside road markings in the same survey run – which also increases survey costs.
- Susceptibility to changes in ambient light, which cause higher levels of noise in the data and prevents the system from providing good quality data regardless of the lighting conditions.

As a result of these issues a research programme was commissioned to improve the ability to measure road marking condition. The programme had the longer term aim of demonstrating a practical method to deliver improved measurements of road marking retro-reflectivity, so that Highways England could re-introduce this measurement into the TRACS survey with confidence that the survey would be capable of delivering accurate and consistent information on the condition of road markings. The research proposed that newer technologies should be able provide a more effective method of measuring the retro-reflectivity of road markings than current methods. A programme of work was undertaken to identify suitable sensors, develop and construct equipment and test this equipment in the laboratory and on the network.

The research programme ultimately demonstrated a fully working prototype (called the Road Marking Monitor (RMM)) to Highways England in the autumn of 2014, after which initial trials of the device were carried out on the road network to assess the device in comparison with the existing (Ecodyne) equipment (Gleeson et al., 2015). The trials confirmed the improved capability of the RMM in comparison with the previous technology, and the results were used to propose the level of performance that Highways England should be able to confidently specify for the measurement of road marking retro-reflectivity in a future TRACS contract. However, at the conclusion of the initial trials it was recommended that a further comparison of the RMM be carried out against other devices to provide a greater understanding of the capabilities of both the device and these other devices. This report presents the results of further trials carried out to assess the prototype on the network.
2 The Road Marking Monitor

2.1 The equipment

The prototype Road Marking Monitor (RMM) (Figure 1) described by Gleeson et al. (2014a, 2014b, 2015) consists of a measurement head that can be mounted on a survey vehicle which utilises a multiple LED light system coupled to a line-scanning camera mounted in a configuration to give a near linear retro-reflectivity response. It has a waterproof enclosure and can be easily installed and removed from the vehicle.

The device uses 24 high power LEDs which can be strobed at a frequency of greater than 2kHz. The high intensity from the LED light source means that the system can cope in even the brightest conditions and hence the strobing system should allow the retroreflectivity measurements to be lighting condition independent. The system is linked to the distance measurements provided by the survey vehicle such that an image line is triggered every 15mm longitudinally down the road whilst taking 512 measurements transversely over the 1.5m measurement width. This translates to approximately 33,000 measurements being taken every metre.

![Figure 1: Prototype device mounted onto the TRL TRAMS survey vehicle](image)

2.2 The data and processing

The system provides bitmap images of the road markings. An image consists of rows of data reported approximately every 0.015 metres longitudinally, covering a length of approximate 3.75 metres. The system operates such that image rows are collected alternately with the LEDs on and off. Hence the rows in the image alternate between a line of data captured in ambient lighting conditions, and another line of data captured under the LED lighting; as a result the resultant image (Figure 2) has a striped effect as shown in the enlarged image on the left hand side of Figure 2. Each image is around 0.5MB in size and is referenced to the distance travelled in the survey. When the device is installed on a survey vehicle which records geographical position via GPS in addition to the distance travelled (such as the TRL TRAMS vehicle) the retroreflectivity data can be linked to the location via section, chainage and geographical position.
Processing of the images is carried out to obtain the road marking retroreflectivity. In the first stage of processing the lines of data reported in the images with the “lights off” (ambient light) are subtracted from the lines of data reported in the images with the lights on (LED illuminated) profiles, to give a ‘retroreflectivity profile’. The road markings are then identified using these retroreflectivity profiles, and extracted from the image.

However, before extracting the markings the image pixels obtained over highly reflecting items such as retro-reflecting road studs are removed. This is relatively straightforward and can be achieved using a fixed thresholding technique. However, extraction of the road markings is not so simple, as the retroreflective response of a road marking has a large variability depending on the condition of the marking. Therefore more sophisticated methods have been developed to isolate road markings using dynamic thresholding, combined with the application of morphological dilation and erosion algorithms. The output of this first stage is therefore a set of transverse retroreflectivity profiles each containing 100 transverse points, averaged over 0.1m longitudinal lengths, which are centred on the road marking (e.g. Figure 3, which shows the transverse retroreflectivity profile data after colour coding with white representing the values with the highest level of retroreflectivity). The retroreflectivity profiles can be delivered with calibration applied that scales the image intensity values into retroreflectivity values expressed in mcd/lux/m², the calibration factors being obtained from a combination of lab data and network test data.

Having obtained the retroreflectivity profile, the simplest way to report the retroreflectivity of lengths of markings would be to simply average the data extracted in
the first stage of processing that is above a minimum threshold. However, the transverse retroreflectivity profile provides the potential to calculate more sophisticated parameters. Algorithms have been developed to estimate the length, width and spacing of markings. These are used to generate a “mask” which is placed over the data, and all the values within the mask can then be averaged. Where the markings are highly eroded this provides an assessment of the average retro-reflectivity of the whole area that “should” have contained a marking, which is felt to be more representative of the true condition in comparison with a simple average of the reported values above a threshold. The potential difference between this approach and simple averaging is shown schematically in Figure 4. Here the left hand side shows the concept of a mask being applied over a road marking to assess the overall condition in relation to the area of the pavement that would have been originally covered by a new marking. To calculate the reported value we would sum up all the values in the rectangular mask and report the average. The right hand example shows the values that would be considered without using the mask. In this case we would average only over values exceeding a certain threshold, which is represented by the values enclosed by the irregular red lines. The latter case is likely to give a higher average value of retro-reflectivity. As it is assumed that devices currently on the market are more likely to apply this latter case, in this work the road marking monitor data was processed in this fashion so that a fair comparison could be made.

Figure 4 Example retroreflectivity profile region averaged, masked (left) and unmasked (right)
2.3 Performance

In an earlier study (Reference) the prototype RMM was been tested statically and on the network against a commercial survey device (Ecodyn 1) which was used in the previous network surveys of road marking condition (carried out under the TRACS2 survey contract). The tests have shown that the device is repeatable and, via suitable calibration, gives values that can be correlated to standard methods. The tests showed it to be generally comparable with the test device (Ecodyn 1), and to be significantly more repeatable. Based on the performance of the prototype the previous work proposed an outline end result performance requirement for delivery of routine retroreflectivity data in TRACS surveys.

It was hence specified that a proposed TRACS retroreflectivity system must have the ability to deliver retroreflectivity profiles from which the average retro-reflectivity could be determined. To cater for variation in lane width and driving line it was recommended that these would cover a minimum width of 1m (the RMM covers 1.5m). It was recommended that the transverse resolution be a minimum of 0.01m per value (which would provide around 20 transverse points across a longitudinal marking). It was also recommended that the profiles be delivered at a longitudinal spacing of around 0.1m.

The performance assessment leads to a recommendation for the levels of accuracy shown in Table 1. Table 1 specifies the percentage of average retroreflectivity readings delivered by the road marking measurement device that should fall within the indicated difference from the reference, or true, retroreflectivity. However, it is noted that establishing a true reference is difficult for retroreflectivity, therefor the true reference may include a data collected from a HA approved device or an average from a larger fleet. Table 1 also shows the actual levels achieved in the tests of the prototype carried out in the previous work (Gleeson et al., 2015). Note that in the previous work these were only able to be assessed as the repeatability achieved, because the low level of performance of the then available Ecodyn 1 prevented a practical comparison of the devices.

For the traffic speed tests used in the remainder of this report, these thresholds are used for the assessment of both the reproducibility and repeatability of the measurement devices. It is acknowledged however that a distinction may be made between the criteria in the future.

<table>
<thead>
<tr>
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<th>Target (% of differences in range)</th>
<th>Performance Achieved (repeatability)</th>
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<td>±25mcd/m²/lux</td>
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<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 1: Proposed performance requirements for TRACS in terms of difference from reference and repeatability performance achieved in the previous tests
3 Measurement devices

As the previous research only undertook a comparison with Ecodyn 1 it was suggested that there would be benefit in obtaining a deeper understanding of the performance of the RMM via further tests against road marking assessment equipment (in addition to Ecodyn). The project team contacted operators of systems in the UK and Ireland to determine the availability of equipment and the willingness to undertake trial surveys. The following devices were secured for the trials and are shown in Figure 5:

- Zehntner ZDR6020
- DELTA LTL-M
- Vectra Ecodyn\(^1\)

Road Vista’s Laserlux was also available in the UK but was unfortunately temporarily out of commission so was unable to be included in the trials.

![Figure 5: left: Zehntner ZDR 6020, Middle: Delta LTL-M, Right: Vectra Ecody](image)

All of the devices measure retroreflectivity in accordance with the measurement geometry set out in BS EN 1436 (BS EN, 2007), that is simulating the geometry of a driver and headlamp at a viewing distance of 30m (often referred to as \(R_L\)). As a result of this geometry the devices must be mounted onto the side of the vehicle and require that the survey vehicle take an off-centre driving line in order to ensure that the survey covers the road marking. By mounting a head on the opposite side of the vehicle they are all capable of surveying both nearside and offside markings, but this would require two separate surveys as a result of the offset driving line. The data from the devices are locationally referenced using both a wheel encoder to determine distance and a GPS receiver for absolute location allowing the resulting measurements to be aligned for the trial.

Table 2 below shows gives a comparison of the different devices and although not used in the trial, Road Vista’s Laserlux is included for completeness.

\[^1\] The device used here was the Ecodyn 1. Since then an Ecodyn 2 and Ecodyn 3 have been released with better capabilities.
### Table 2: Comparison of different devices

As well as the measurement of retroreflectivity some of these devices offer other capabilities such as the automatic detection of road studs, separation of several lines, wet condition retroreflectivity, line geometry (width and length), and temperature and humidity adjustment. However these were not investigated or verified for the study.

#### 3.1 Emerging technology and development

The project team also identified other commercial devices capable of traffic speed measurement of retroreflectivity, which were not included in the study. Details of each are as follows:

- **Retrotek’s Retrotek-M**: Traffic speed measurement of retroreflectivity with the benefit of full lane width measurement with the device mounted on the front of the vehicle. This device was not expected to be available until Q3 2015 and so could not be tested. However, this device is restricted to night time surveying and therefore would not have been suitable for use in the daytime “convoy” style tests applied in this work.

- **AMAC (Advanced Mobile Data Collection)**: Another traffic speed measurement of retroreflectivity with the benefit of full lane width measurement. The measurement of the road markings is part of a larger package which also measures the retroreflectivity of road signs. The AMAC was not currently available for UK road surveying at the time of the trials. However, as for the above device this is restricted to night time surveying.

- **Ecodyn**: There is also continual development with existing of equipment, for example Vectra’s Ecodyn 2 and Ecodyn 3, which are likely to have improved performance over the Ecodyn 1, but were not available for tests within the resource and time constraints of this study.

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2 Measurement angle from the sample to the sensor is 2.29°, and that angle from the illumination to the sensor is 1.24°
4 Testing

To undertake a robust assessment of the devices, it was deemed that the tests should include both a fundamental assessment against a known reference in a controlled laboratory environment, and a network level test in a survey setting that is representative of the conditions likely to be experienced on the network. The first test would allow an understanding of the relationship between the different devices, and the second would give insight into the expected data quality from network level surveys.

4.1 Laboratory test

Controlled conditions were required to assess the different devices against a reference measurement. To achieve these conditions, it was decided that samples would be measured on a test floor at the TRL premises. This floor is very flat, indoors and can be safely surveyed at slow speeds. These conditions would rule out possible effects caused by road geometry, vibration, and challenging lighting levels. Twelve 1m long road marking samples were manufactured. The samples were constructed to provide a range of retroreflectivity values using a range of bead types and densities (pictured in Figure 6 (left)).

Figure 6: (left) Sample road markings created for the tests and (right) the handheld retroreflectometer (Stripemaster)

To determine the reference retroreflectivity values of these samples, a handheld retroreflectometer (the Stripemaster, Figure 6 (right)) was used. The Stripemaster undertakes measurements according to the standard set in BSEN 1436 and is widely used for routine investigations in the UK. Each sample had ten measurements taken along its length with the Stripemaster. The average and standard deviation value for each sample is displayed below in Table 3. For the trial, six of the twelve lines were chosen, based on the requirement for a wide overall range of values for the tests, with the individual values having a sufficiently low standard deviation to indicate a consistent road marking sample. The samples chosen are highlighted in Table 3.
Table 3 Stripemaster readings on sample lines

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<th>Sample number</th>
<th>Average Retroreflectivity (mcd/m²/lux)</th>
<th>Standard Deviation</th>
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<td>12</td>
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</tbody>
</table>

To test the retroreflectometer survey devices, the samples were placed on the test floor and measured one at a time by driving over them at slow speeds using each retroreflectometer. Five runs were carried out for each sample and the average was taken and compared to the reference retroreflectivity. Measurements taken by the Ecodyn were not used due to the difficulty in extracting measurements for such a short length of data. Below in Figure 7, the three remaining traffic speed retroreflectometers are plotted against the Stripemaster values and a linear regression is used to determine their gradient, offset and coefficient of correlation (labelled $R^2$ on the graphs). In theory if the calibrations are correct for these test samples we would expect the reference and the test machine output to have a one to one relationship – that is, a gradient of one, which we will henceforth refer to as parity. However this does not appear to be the case and in fact the gradient appears to be different between each device. Interestingly, all of the lines of best fit also have a non-zero offset.
Two notes of concern are apparent from Figure 7:

1. None of the devices measure parity with the reference
2. The correlation between the Stripemaster and RMM is weakest of the three devices

Given the variability in the results, and as we will see later the consistency of the network trial, we are forced to question the effectiveness of this test. The standard deviations of the Stripemaster values shown in Table 3 indicate the fairly wide range of values measured by the Stripemaster on these lines. The brightest line had a measured range of 260-397 mcd/lx/m². This variability is not due to the measurement equipment but rather the actual variation along the sample line. Clearly this variation would also be measured by the test Retroreflectometers, and this may be emphasized by higher resolution devices such as the RMM, which should be able to measure the actual variability in the line to an even high level of capability than the Stripemaster. The observed differences could then possibly be explained by the different retroreflectometers covering different parts of the sample line.

An explanation for the RMM’s lower correlation than the other two devices can be attributed to two anomalous points (highlighted in Figure 7), that when removed gives a much better correlation (increasing the R² value to 0.997), and interestingly a very similar gradient to the Zehntner (see Figure 8).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_8.png}
\caption{Traffic speed retroreflectometers plotted against Stripemaster (anomalous point removed)}
\end{figure}

However the reason for the two anomalous points measured by the RMM is not clear. The differences could be caused by an error in the experiment or they could be due to a more fundamental measurement principle, i.e. is this a result of the different measurement geometry? Further investigation was carried out to address this specific point.
4.1.1 Further investigation into anomalous points of the RMM

A further test was carried out to investigate the cause of the two anomalous points observed when comparing the RMM to the reference. For this test, reference values were obtained again using the Stripemaster but this time only a single measurement was taken on each sample - it should be noted that if the Stripemaster’s position is not changed, then the results are very consistent. The exact location of each of the Stripemaster measurements on the sample was noted and marked out on the sample. The RMM data was then collected, and data was extracted from the 12 available and averaged from this exact region. This was done for nine sample lines, where the sample areas were chosen to give a broad range of values. Plotting the RMM against the reference yields Figure 9.

Figure 9: Correlation between RMM and Stripemaster before corrections

We can again see good agreement between the RMM and the Stripemaster apart from two outliers which are highlighted on Figure 9. A visual inspection was made of these samples and it was observed that the line which was over-read had an extremely high bead density, whereas the line that was under-read had a very low bead density, but with very large beads – a photograph of these lines are shown in detail Figure 10. These differently constructed samples do not appear to have affected the other two test devices. The different behaviour may be a result of the different geometries used by the devices, as shown in Table 2 the RMM measures at 12.5° whereas the other devices measure at the much lower angles specified in BSEN 1436, around XX degrees.

Figure 10 Different constructions in outlying samples, higher bead density (top) and lower bead density (bottom)
The different geometry used by the RMM is designed specifically to overcome some of the practical limitations of standard geometry devices (mounting position, sensitivity to detritus etc.). It is possible that measurements on road markings with certain specific constructions could behave differently when measured using this geometry. For example on a marking with a lower bead density a larger proportion of light rays from a higher measurement geometry would hit the non-beaded surface and may report a lower level of retroreflectivity. Figure 11 illustrates this with exaggerated angles, where the orange lines illustrate the light beams coming from the traditional geometry measurement, and the green lines show those coming from the higher geometry.

![Figure 11: Measurement angle effect on retroreflectivity measurement](image)

As will be noted below, this behaviour does not seem to have been observed in the network tests. However, it may be possible to correct for the effect based on an assumption that raw transverse retroreflectivity profile measurements from lines with a lower bead density line would contain greater variability than measurements on lines with a higher bead density. Equation 1 attempts this correction by assessing the ratio between the sum of the absolute adjacent differences across a transverse retroreflectivity profile and the average retroreflectivity.

\[
R_{\text{new}} = K \left[ \frac{\sum_{i=1}^{N-1} |R_i - R_{i+1}|}{N - 1} \right] \frac{R_{\text{original}}}{R_{\text{original}}}
\]

Where \( K \) is a normalising co-efficient\(^3\), \( N \) is the number of points transversely across a marking, and \( R \) is the retroreflectivity of a single point.

**Equation 1: Compensation formula**

A value for \( K \) was determined by analysing the raw data from the test samples and using this to “correct” the RMM data for this effect. The equation was then applied to the data set collected for this testing and the results are shown above in Figure 12, the figure shows the correlation both before (blue) and after correction (red). As can be seen, the correction has a small effect on a number of the values, bringing them closer to the

\(^3\) This normalisation coefficient is calculated so that all the correction term within the square brackets for the dataset has an average value of 1.
linear fit line, but the effect on the larger outliers is much more significant and the overall correlation is greatly improved. This method shows promising results however, this was not the focus of the work for this study and this methodology represents a first attempt at using statistical analysis to correct for marking constructions and was not used in the analysis for the road trial.

Figure 12: Correlation between RMM and Stripemaster, both before corrections (blue) and after (red)

4.1.2 Static tests - summary

Although we have seen some evidence of disagreement between the Stripemaster and the RMM on two of the test lines, and a non-unitary relationship between the Stripemaster and all of the devices across the set of test lines, we will later show (section 4.2) that the different relationships observed between the devices and the Stripemaster are not apparent when assessing the data from the network trial. We have not been able to explain why the differences observed in the laboratory tests do not extend to the network tests. It may be a result of a non-representative nature of some of the test lines, or be a result of edge effects that occur when measuring short sample line (previous work on Ecodyn identified this as a potential issue, see Iaquinta, 2009). Therefore, we have not attempted to apply any adjustment (such as that proposed above for the RMM measurements) on the network level tests discussed in the next section.

4.2 Network tests

The network tests comprised a survey route of approximately 65km on the local and strategic road network, consisting of parts of the A329M, M4, A404(M) and A404. The route was chosen due to the diversity of markings present, including dashed and solid
lines, different pavement types (including concrete), and various stud types⁴, the route is shown below in Figure 13. During the tests, data was collected with each of the four retoreflectometers, as well as high definition forward facing imaging. For the tests the three standard geometry retroreflectometers drove as they normally would for surveying, using an off-centre driving line, whereas the RMM used a standard driving line (centrally in the lane). Location referencing data was collected using distance and inertially corrected GPS. This allowed the data from each retroreflectometer to be aligned to investigate points of interest. In order to obtain a dataset that was not affected by outside factors, all four retroreflectometers carried out their survey at the same time and day, in convoy. The order of the vehicles within the convoy was also varied from run to run. The route was completed by all survey vehicles three times so that their repeatability could be assessed. Along the route were areas that were not assessed, such as roundabouts, slip roads and road works; these sections were removed from the dataset. The results herein are shown after the removal of these lengths of road.

![Figure 13: Network route site](image)

### 4.2.1 Data alignment

The data was delivered by all four survey vehicles in 10m averages, and aligned to the network route using section definition data either defined by the survey team (for the local authority roads) or extracted from the Highways England HAPMS database.

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⁴ Although stud detection was not investigated for the trial, it is important to see how retroreflectometers perform in their presence.
Although manual push buttons were used to mark section points along the survey these are not accurate for location referencing. Therefore the GPS co-ordinates were used to align the data. In addition further visual checks were carried out to ensure the data was aligned, as the trials aimed to determine the performance without poor location referencing complicating the analysis. As a result, where poor GPS data was found to significantly affect the locational accuracy, these lengths were removed from the analysis.

4.2.2 Data cleaning

The 10m values of RMM and Ecodyn data were obtained using algorithms previously described by Gleeson (2014b) and Iaquinta (2009). These algorithms were designed to deliver as “clean” a dataset as possible, with spikes removed. Such spikes can arise from the presence of road studs or noise in the data. However, the Zehntner ZDR6020 and LTL-M 10m data was found to contain many spikes that had not been filtered out by the processing algorithms prior to delivery to TRL (in particular the Zehntner ZDR6020). It was not practical to undertake a robust assessment of this data and therefore the spikes were removed using a simple threshold that removed values reported over 400 mcd/lx/m². The data for a single run from each retroreflectometer before and after this threshold has been applied is shown in Figure 14. It should be noted that whilst these spikes are not desirable, in practice one would expect a contractor carrying out such work to similarly apply some kind of cleaning to the data before delivery. Once the data had been cleaned and aligned, it was then averaged to 100m sub-section lengths.

![Figure 14: Raw and cleaned data sets of the Zehntner (top) and the LTL-M (bottom)](image-url)
4.2.3 Data coverage

In previous survey work carried out for Highways England (which used the Ecodym 1 system), it was found that significant lengths of the network were not covered due to poor or missing data, and this emphasised a need to increase data coverage – that is the percentage of valid data collected from a run. An investigation into the data coverage of each of the retroreflectometers was carried out, using the data obtained from the network trial. The percentage of valid data reported for each vehicle averaged over the three runs from the network level trials is shown in Figure 15:

![Figure 15: Percentage of valid data](image)

As previous experience has shown, a large amount of data was missing from the Ecodym dataset (~24%). This is likely to be due to the small transverse measurement area of the device resulting in missed markings. The other three devices all report on over 96% of the survey length, which is a satisfactory result. The missing measurements in the RMM dataset (2.5%) is more likely to be caused by areas where road markings are not picked up by the algorithm, or where perhaps no markings are present. The coverage achieved in these newer devices would give very representative values and would indicate that a requirement for such devices to report over 95% of the marking would be achievable in a future TRACS survey.

4.2.4 Assessment criteria

The

4.2.5 Assessment of repeatability

For each of the four devices used on the network route, the data was processed as described in section 4.2.2. The three runs from each device are plotted against each other from Figure 16 through to Figure 19. On the LTL-M runs, some of the data from two of the runs has been omitted due to poor quality of GPS (see 4.2.1).
Figure 16: Repeatability of the Ecodyn

Figure 17: Repeatability of the ZDR6020
Figure 18: Repeatability of the LTL-M

Figure 19: Repeatability of the RMM
An objective measure of the repeatability was obtained by comparing the differences between each run carried out by each vehicle, over the entire length of the survey. The differences were calculated between runs 1 & 2, 2 & 3, and 1 & 3, and then averaged. These are plotted as a cumulative frequency graph in Figure 20. Section 2.3 above stated that the previous work on the RMM (Gleeson, 2015) proposed repeatability criteria for future TRACS surveys of retroreflectivity. The three dashed lines in Figure 20 show these thresholds, at 13, 25 and 50 mcd/lx/m². The repeatability performance reflects the behaviour than can be seen in Figure 16 through Figure 19, in that the LTL-M and RMM were much more repeatable than the ZDR6020 and Ecodyn on the network route, with the Ecodyn 1 performing particularly poorly. Both the LTL-M and RMM meet the criteria in Table 1 for 65% of values falling within ±13 mcd/lx/m² (they achieve 81% and 78% respectively). However the criteria for 25 and 50 mcd/lx/m² are just missed by both reflectometers, by ~2 to 3% in both circumstances.

Note that as a result of the extremely poor repeatability of the Ecodyn 1, this device was not considered when comparing reproducibility across the different retroreflectometers, as inclusion of this data would be more likely to cloud the issues than add insight.
4.2.6  Reproducibility between vehicles

To assess the reproducibility between the vehicles, the average value across the three runs was taken for each 100m section. Figure 21 shows this plot for the LTL-M, the ZDR6020 and the RMM, the Ecodyne having been excluded as discussed above. As can be seen from the figure, there is good general agreement between the three retroreflectometers, and particularly the RMM and LTL-M.

![Figure 21: Reproducibility between vehicles (Ecodyne excluded)](image)

As there is no reference data collected for this section, we cannot present a statistical assessment which assesses how each retroreflectometer reproduces the true retroreflectivity. However, we can quantify the devices relative to each other. Figure 22 shows a cumulative frequency plot of the absolute differences between the LTL-M and the RMM. The vertical lines indicate the thresholds proposed for TRACS (also shown in section 4.2.4). The reproducibility of the LTL-M by the RMM does not give as good results as the repeatability of each device, as may be expected (Figure 20). However, it is interesting that the LTL-M and RMM are in closer agreement with each other than the repeat runs of either the Zehntner or the Ecodyne devices. The percentages achieved at each performance level (13, 25 and 50 mcd/lx/m²) do not quite meet the proposed TRACS requirements but, at approximately 45, 75 and 95% respectively, are significantly closer than achieved by the Ecodyne in the previous TRACS survey. This reasonably high level of general agreement between the devices suggests that, where local agreement occurs, the reported values are likely to be a good estimation of the true retroreflectivity for the length, but this cannot be confirmed without true laboratory measurements of the entire site. However, it can be seen from Figure 21 there are also
some areas along the test site where these two devices are not in full agreement, and hence where the true level of retroreflectivity is uncertain.

**Figure 22: Reproducibility between the LTL-M and the RMM**

We have examined several of these areas of disagreement, and for each area manual inspection of both the forward facing images from the survey and the retroreflectivity profile data from the RMM were carried out. The results from ZDR6020 were used as a further source of information, where this was deemed applicable, but this data was used with caution considering its more limited repeatability performance. Table 4 summarises the observations of this review.
<table>
<thead>
<tr>
<th>Chainage</th>
<th>Issue</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0km</td>
<td>RMM &lt; LTL-M</td>
<td><strong>Forward Images:</strong> Road markings not unusual, no particular characteristics of note&lt;br&gt;<strong>RMM Profile:</strong> Processing appears successful&lt;br&gt;<strong>ZDR6020:</strong> Closer agreement with the RMM in this case&lt;br&gt;RM and ZDR6020 agree, and the LTL is the outlier - there is no evidence to suggest which device is incorrect on this length</td>
</tr>
<tr>
<td>20.5km</td>
<td>RMM &gt; LTL-M</td>
<td><strong>Forward Images:</strong> Road markings not unusual, no particular characteristics of note&lt;br&gt;<strong>RMM Profile:</strong> Processing appears successful&lt;br&gt;<strong>ZDR6020:</strong> Closer agreement with the RMM in this case.&lt;br&gt;RM and ZDR6020 agree, and the LTL is the outlier - there is no evidence to suggest which device is incorrect on this length</td>
</tr>
<tr>
<td>22.0km</td>
<td>RMM &gt; LTL-M</td>
<td><strong>Forward Images:</strong> Road markings not unusual, no particular characteristics of note&lt;br&gt;<strong>RMM Profile:</strong> Processing appears successful&lt;br&gt;<strong>ZDR6020:</strong> Closer agreement with the LTL-M in this case&lt;br&gt;LTL-M and ZDR6020, and the RM is the outlier - there is no evidence to suggest which device is incorrect on this length</td>
</tr>
<tr>
<td>28.0km</td>
<td>RMM &gt; LTL-M</td>
<td><strong>Forward Images:</strong> Road markings not unusual, no particular characteristics of note&lt;br&gt;<strong>RMM Profile:</strong> Processing appears successful&lt;br&gt;<strong>ZDR6020:</strong> Closer agreement with the LTL-M in this case&lt;br&gt;LTL-M and ZDR6020, and the RM is the outlier - there is no evidence to suggest which device is incorrect on this length</td>
</tr>
<tr>
<td>36.0km</td>
<td>RMM &lt; LTL-M</td>
<td><strong>Forward Images:</strong> Lane 2 survey, appears to be a large amount of grass very close to the markings&lt;br&gt;<strong>RMM Profile:</strong> The areas extracted from the retroreflectivity profile seem odd and erratic.&lt;br&gt;<strong>ZDR6020:</strong> closely agrees with the LTL-M&lt;br&gt;The failure of the algorithm to correctly identify the road markings on the RMM data indicates that the LTL-M is likely to be correct here. The evidence and reasons for the RMM's failure here are explained below (Point of interest A)</td>
</tr>
<tr>
<td>44.0km</td>
<td>RMM &gt; LTL-M</td>
<td><strong>Forward Images:</strong> Road markings not unusual, no particular characteristics of note&lt;br&gt;<strong>RMM Profile:</strong> Processing appears successful&lt;br&gt;<strong>ZDR6020:</strong> Reads higher than both the LTL-M and RM&lt;br&gt;No reasonable conclusion can be made from this. Three different readings from three devices.</td>
</tr>
<tr>
<td>55.5km</td>
<td>RMM &lt; LTL-M</td>
<td><strong>Forward Images:</strong> Visual inspection of forward facing images shows a large amount of erosion&lt;br&gt;<strong>RMM Profile:</strong> Appears to correctly extract outward edge of eroded lines.&lt;br&gt;Large amounts of erosion suggest that the differences here are caused by differences in the algorithms. The RMM is averaged on the eroded markings whereas the LTL-M here will be only averaging values above a threshold. This is discussed below (Point of interest B)</td>
</tr>
</tbody>
</table>

**Table 4: Investigated points of interest**
Out of the seven points of difference investigated above, two are immediately explainable by the difference in collection and processing methods between the devices as discussed below:

**Point of interest A**

In the case at chainage 36.0km, we can see that the marking surveyed was very close to a grassy verge with the RMM capturing large amounts of this verge. Both the forward facing imaging and raw retroreflective profile (before calibration are shown in Figure 23. From the transverse profile shown we can see why the algorithm may struggle to extract the correct area. This makes the difference in the dataset explainable by processing, as opposed to a measurement issue.

![Figure 23: Forward facing imaging (top) and RMM raw profile (bottom) of challenging area for algorithm in lane 2 on grassy verge](image)

**Point of interest B**

At chainage 55.0 km we see the differences are caused by the different processing methods between the RMM and LTL-M when faced with an eroded road marking. As discussed in section 2.2 the RMM processing extracts a mask which envelopes the whole of an eroded marking and averages the retroreflectivity across the whole area, whereas other devices remove values below the detection threshold, in the case of the LTL-M, we believe that a threshold of 30 mcd/lx/m² was used (however, the details of exactly how this threshold is applied is not available). This difference in processing methods results in the RMM reporting a lower reading on eroded lines.

Of the other five differences we see in the dataset between the LTL-M and the RMM, in one case (44.0 km), there are differences across all three devices, in the other four cases we see an agreement between two of the devices with a 50% split between the RMM being in the minority and the LTL-M being in the minority. Whether or not these differences are a result of measurement geometry (discussed in 4.1) or how the algorithms are applied is not clear. But there is no clear indication of incorrect measurements from any of the devices based on this evidence alone.
4.2.7 Network tests - discussion

The results from the Ecody 1 equipment were, as expected, relatively unrepeatable and showed little agreement with the other devices. Ecody 1 also delivered poor levels of coverage. The performance reflects Ecody's design age and its lack of suitability for carrying out robust data collection on the network. However, its performance should not be used to base any decisions regarding the newer generation Ecodyns 2 and 3, which were not included in these tests.

Work was required to remove noise from both the LTL-M and Zehntner ZDR6020 raw (10m value) datasets before analysis could be completed. This suggests a need for pre-processing of the data from these devices before it can be confidently applied for network level assessment. However, subsequent to this data cleaning, both devices delivered reasonably stable and repeatable data. The RMM also provided stable and repeatable data from the network sites (without the need to pre-process) and all three devices delivered a high level of coverage.

In the repeatability assessment the Zehntner device performed notably worse than both the LTL-M and the RMM. There is a lot of noise in the Zehntner data and in places the data disagrees strongly from run to run. Interestingly, when the average of three runs of Zehntner data is obtained these average results compare well with the LTL-M and the RMM data. This suggests that the device is broadly capable of providing an indication of road marking condition, but there is more likelihood that any one survey run could contain outlying or erroneous data. Given that in some locations these differences amounted to over 50 mcd/lx/m², which exceeds the difference currently specified for the separation between sound and poor lines (Highways Agency, 2007), this raises concern over the use of the system for routine assessment, unless multiple runs are undertaken.

It is interesting that all the devices disagree over the road marking condition at one place or another, even when carrying out back to back (convoy) surveys. This demonstrates the challenge involved in measuring road marking retroreflectivity in typical network conditions and shows that assessment tests which are restricted to controlled, short lengths, are not appropriate for the assessment of these devices. The investigation of where there are differences between the devices shows that, often, two devices will agree whilst the third disagrees, but this is not consistent. Hence it is difficult to conclude whether either of the devices could be said to be more or less correct than the other device at these locations. However, two of the devices are definitely more consistent with each other and with themselves – the LTL and the RMM. From their performance both seem well suited to carry out network level tests. Both devices give comparable performance and both have their advantages/disadvantages. The LTL-M exhibits good performance and measures to the standard geometry set in BSEN 1436, but like most retroreflectometers, requires an off-centre driving line for surveys. The RMM measures at a different geometry but is capable of dual head operation and integration with other survey equipment, greatly increasing survey practicality.

In terms of the requirements for TRACS proposed in the previous work (Gleeson et al., 2015) and presented in Table 1 of Section 2.3, the observations herein suggest that these requirements would be achievable on the network. The results also suggest that a coverage requirement could be included for the measurement of retroreflectivity. The current TRACS3 contract requires a coverage of 99% for most parameters. Although the observations herein suggest this would not be achievable with these devices, a coverage of 95% would be achievable and is suggested as a suitable requirement for TRACS4.
5 Conclusions and Recommendations

The work described in this report was carried out with the objective of developing a better understanding of the capability of the enhanced Road Marking Monitor. This device has been developed to overcome some of the limitations observed in the previous equipment employed in the TRACS survey to measure the retroreflectivity of road markings. In particular the device aims to deliver more accurate, repeatable data using a configuration that can be incorporated into a survey vehicle without the need for "special" survey requirements such as driving off-center and close to the road marking.

The first observation that we can make from the tests carried out in this work is that traffic speed retroreflectometers have come a long way since the first generation Ecodyne used in the previous TRACS survey. Although the other retroreflectometers still employed a dedicated off-centre driving line, the data provided from these systems was to a higher level of quality than experienced with the older device. We note that there are other traffic speed retroreflectometers on the market (including a second generation Ecodyne) that have not yet been tested in this work.

The static trials identified some anomalies with the RMM data, which seem to be associated with particular types of lines. However, there was no evidence that these anomalies occurred in the network tests. The RMM agreed well with the other devices on the network routes, and demonstrated repeatability on a par with the best of the current devices. The network route was large but probably did not account for all that is possible on the network. However, the results suggest that the RMM is suitable for surveys at a network level. Nevertheless, there would be benefit in continuing the development of its algorithms and outputs, including the exploration of the statistical method suggested herein, to reduce the influence of certain types of line on the measurements.

The performance observed in the measurement of retroreflectivity by both the RMM and the LTL-M enables us to confirm the requirements for TRACS that were proposed in the previous work (Gleeson et al., 2015) and also to propose that a demanding coverage requirement (95%) be included, as these devices do now seem capable of delivering a high level of coverage in comparison with that achieved previously. To complete the specification for TRACS surveys there will be a need to decide on the method of data delivery. The previous work recommended that the devices be required to deliver a measure of retroreflectivity profile. This method of raw data delivery provides the advantage that Highways England can specify the processing method, which could overcome the issues identified in this work with noise in the 10m values provided by the Zehtner and LTL-M devices. The definition of the processing algorithms will need to be the subject of future work. However, the algorithms used for the processing of the previous TRACS retroreflectivity profile data could form a good starting point. An adaptation of these has been used successfully in this work to process the RMM data.

The experience gained in this project has shown that it is very difficult to run a controlled laboratory based test procedure for the assessment of these devices, as retroreflectivity of road markings is inherently a very variable property and a significant sample size is needed. A network level test is useful in these circumstances, but the relatively short lifespan of road markings and susceptibility to the weather makes it hard to establish a reliable and practical reference (e.g. collection of reference data using a hand held device). A possible solution for this may lie in a correlation trial, using the mean of the fleet as reference, but the details of this have not been explored in this project.
6 References

Gleeson A, Dhillon N, Lodge R and A Wright (2015): Development of Retroreflectivity prototype and proposals for TRACS requirements, (RPN3042), Transport Research Laboratory (TRL), Crowthorne, Berkshire (UK).


BSEN 1436 (2007): “Road marking materials – Road marking performance for road users”