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PREMiUM

Identifying the key characteristics for road sign condition measurements

Deliverable D1b and D2b

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Executive summary

The objective of PREMiUM is to deliver improvements in the ability to manage road equipment by developing guidance that can be implemented by road administrations to improve the management of equipment assets. The types of road equipment that PREMiUM has considered are **road markings**, **road signs**, **vehicle restraint systems** and **noise barriers.**

This report provides guidance describing the key characteristics of condition that should be monitored and the potential condition monitoring regimes that could be implemented to obtain the data required to understand the condition of **road signs** to support maintenance and asset management decisions at the network level.

Key characteristics and measurement methods for the other three equipment asset types are discussed in separate documents.

PREMiUM wishes to ensure that the proposals for the key survey requirements are aligned with the experience and expectations of stakeholders. Therefore we are issuing this report to stakeholders to invite views on the recommendations that have been made. The project team welcomes comment and views from stakeholders, which will be taken into consideration when confirming the key condition requirements and the survey methodologies.

The PREMiUM project has been let under the CEDR "Call 2014: Asset Management and Maintenance" and funded by the following NRAs: Belgium-Flanders, Finland, Germany, Ireland, Norway, the Netherlands, Sweden, United Kingdom and Austria.

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1 Introduction and purpose of this document

The trans-national research programme "Call 2014: Asset Management and Maintenance" was launched by the Conference of European Directors of Roads (CEDR). CEDR is an organisation which brings together the road directors of 25 European countries. The aim of CEDR is to contribute to the development of road engineering as part of an integrated transport system under the social, economical and environmental aspects of sustainability and to promote co-operation between the National Road Administrations (NRA).

The participating NRAs in this Call are Belgium-Flanders, Finland, Germany, Ireland, Norway, the Netherlands, Sweden, United Kingdom and Austria. As in previous collaborative research programmes, the participating members have established a Programme Executive Board (PEB) made up of experts in the topics to be covered. The research budget is jointly provided by the NRAs who provide participants to the PEB as listed above.

Road operators draw on their knowledge of their assets to efficiently manage their road networks. This includes information on asset inventory, asset condition and information on the most appropriate maintenance approach to take for those assets. Although there has been significant growth in the use of objective tools to measure and interpret pavement condition at the network level, this has not been matched for the assessment of road equipment. Previous ERANet research on the assessment of equipment assets has found that the management of equipment such as road signs, lighting, markings, restraint systems, noise barriers and Variable Message Signs is often excluded from the integrated management process. There is a clear need to deliver improvements in the ability to manage these assets.

The objective of PREMiUM is to deliver improvements in the ability to manage road equipment by developing guidance that can be implemented by road administrations to improve the management of equipment assets. In summary the underlying objectives of PREMiUM are:

- To establish the condition characteristics a road administration should include in their asset management strategy for these road equipment assets in order to manage the risks of loss of performance of these assets;
- To help road owners to understand and balance network level and project level management of these assets so that they can establish a practical monitoring regime that enables the condition to be understood and the risks to be managed;
- To identify the existing and emerging measurement tools that could be applied by road owners to understand, monitor and manage these assets;
- To propose objective measures that could be applied to understand and quantify the performance of these assets, which are feasible for use at the network level;
- To hence enable road administrations to establish a maintenance regime that minimises risks and yet enables the road administration to focus maintenance expenditure on these assets in an efficient manner.

The types of road equipment that PREMiUM will consider are **road markings**, **road signs**, **vehicle restraint systems** and **noise barriers.**

PREMiUM aims to achieve its objectives through four technical work packages:

- **WP1 Understanding the Asset:** The development of better understanding of the equipment asset and the key characteristics of the asset which need to be monitored to manage the asset;

- **WP2 Monitoring the Asset:** How these key characteristics can be monitored across all equipment assets (i.e. on the network level);
- **WP3 Evaluating Condition:** How this data can be translated into the information required to determine the condition and hence evaluate the risk of failure;
- **WP4 Management of the Asset:** How the information can be used within a management strategy.

The approach taken for WP1 has been to combine technical expertise drawn from the project consortium with a direct stakeholder consultation, to establish current practice and existing and emerging standards. A review of these current practices and standards and consideration of what the objective of the monitoring is and how it will contribute to asset management has been used to propose the key characteristics of condition that need to be understood for each of the equipment asset types.

For WP2, the current measurement practice has been reviewed, along with emerging technologies, by liaising with survey consultants and equipment developers/providers. This has been used to determine how the key characteristics of condition could be monitored and measured at a network level, along with the feasibility of applying the monitoring.

This report provides summary guidance describing the key characteristics of condition that should be monitored to understand the condition of **road signs** and to support maintenance/asset management decisions. This summary guidance is presented in section 2, whilst more detailed technical background supporting the recommendations is given in section 4.

This report also provides summary guidance on potential condition monitoring regimes that could be implemented to provide the data required to understand the condition of road signs to support maintenance/asset management decisions at the network level. These are discussed in section 3, with more technical background given in section 5.

PREMiUM wishes to ensure that the proposals for the key survey requirements are aligned with the experience and expectations of stakeholders. Therefore we are issuing this report to stakeholders to invite views on the recommendations that have been made. The project team welcomes comment and views from stakeholders, which will be taken into consideration when confirming the key condition requirements summarised in section 2. Comments will also be welcomed on the survey methodologies summarised in section 3, which will be used to support recommendations for implementation trials of these methods.

As a guide to this document, it contains the following key sections:

1 Introduction and purpose of this document: This introduction section

2 Summary recommendations for the key characteristics of road sign condition that should be monitored: Here we present our summary recommendations for the key data requirements for road sign condition measurement.

3 Summary recommendations for potential methods to monitor road signs: Here we present our summary recommendations on the methods that are/could be used to obtain the key data. As noted above, sections 2 and 3 present the summary recommendations of this work. Detail on the technical background leading to these recommendations is then presented in the following sections, 4 and 5:

4 Technical background – Standards and Approach for Understanding Road Signs: This section presents a review of current standards employed in Europe and elsewhere, which we have drawn upon in developing our recommendations.

5 Technical Background – Methods for Measuring the Condition of Road Signs: This section presents a review of current and emerging measurement techniques and proposes potential condition monitoring regimes that could be implemented for road signs.

Finally Section 6 Definitions presents a summary of the definitions of technical terms used in this document.

2 Summary recommendations for the key characteristics of road sign condition that should be monitored

In this section we present summary guidance on the key characteristics of condition that should be monitored to understand the condition of road signs, and to support maintenance/asset management decisions at the network level.

2.1 Road Signs

Road signs communicate a variety of information to road users. They provide directions, convey regulations and warnings, and other information necessary to facilitate safe and efficient travel. In general they can be divided into four categories: regulatory signs, warnings & works signs, directional signs, and miscellaneous signs. This document only refers to unpowered permanent fixed road signs (i.e. variable message signs are excluded from this study).

2.2 Knowledge Gathering and Consultation

A review of standards and guidance documents for road signs was undertaken to identify the objective characteristics defined in the current standards that relate to the performance and condition of this asset (see Section 4.2).

A consultation was then undertaken with strategic road administrators/asset managers and asset inspection survey providers to seek information on their current practice in managing the condition of road signs. Two sets of questionnaires were designed to engage with these two groups of stakeholders. These questionnaires are provided in Appendices A & B:

- The questionnaire for asset managers aimed to understand their current approach to monitoring and managing their road signs (see Section 4.3). It also provided the list of characteristics that are required to be measured (as highlighted in the standards review) and asked participants to rank each one's importance for efficiently managing the asset.
- The questionnaire for asset inspection survey providers was developed and distributed to survey providers in order to understand their current method of inspection, what data they record and the technologies they employ to do so (section 5.1).

83 stakeholders received the questionnaire & information pack. Responses were received from 13 NRAs covering Austria, Sweden, the Netherlands, Ireland, Germany, Belgium, Norway and the UK. In total the 13 NRAs managed over 150,000km of motorways, dual and single carriageways, including over 2 million signs.

This knowledge gathering consultation with asset managers, and further consultation with experts (in the project team or colleagues), was then used to identify the key data requirements for road sign condition. These key data requirements are summarised in the following sections.

2.3 Key data - Inventory

Throughout the consultation it was found that the most important information to effectively manage the asset is that contained within the inventory. A robust and accurate inventory is an essential tool for providing engineers and decision makers with key information about the assets on their road network. However, only five NRAs believed they had a clear view of all their sign assets, while eight NRAs stated that they did not have a clear view of the status of their signs.

Up-to-date inventories are a prerequisite, for all types of assets, for ensuring that continual gains in network quality are made in an efficient way. A vigorous and effective asset management strategy cannot be designed or implemented if a road authority does not have knowledge of the most basic features and records of their assets (i.e. you cannot manage an asset if you don't know where it is).

If maintenance, renewal or modernisation of an asset is required, decision makers must be able to efficiently evaluate the specific needs of each part of the asset. To achieve this, a complete inventory is the starting point.

2.3.1 *What should an Inventory for road signs contain?*

For any particular asset, such as road signs, a well-structured inventory should contain a number of key characteristics, such as:

- Location Reference
- Identification Code
- Date of Installation
- Maintenance Records
- Cleaning Interval
- Manufacturer Declared Performance Characteristics.

The definitions for these terms are given in Section 6.

The stakeholder consultation highlighted that, even though this information is critical for understanding the performance of the asset, inventories remain out-of-date and incomplete. If inventory records are incomplete or out-of-date there are a number of ways to gather the relevant data to populate them.

Whether an inventory needs to be created or updated and developed, there will be a need to obtain the information required for population.

A **location reference** refers to the physical location of the asset, using geographical co-ordinates (e.g. longitude and latitude). The inventory should also contain other useful descriptions of the assets location, such as: unique network identification code (i.e. area and section marker), road name and number, chainage, marker posts, and general geographic references (county/province). The consultation identified a number of high/low speed, office based/on-site techniques available to determine the precise location reference and the type of system and components used, as discussed in section 3. If on-site methods are adopted, these can be combined with detailed inspections to make efficient use of time.

The **identification code** is a unique reference (numerical, alphabetical or a combination of both) which is assigned to the asset. A record of this should be maintained in the inventory. It also allows inspectors to confirm the asset they are inspecting. It is standard practice to locate a weatherproof sticker on the rear face of a sign to hold this information. If this information cannot be extracted from historical records it may be necessary to carry out a site visit, noting down the code on the rear face of the sign.

The **date a system was installed** should be held in a standard format (yyyy/mm/dd). If unknown it can be obtained through a review of historical records such as contract document and scheme bids/awards. It is also possible for an expert to estimate the age of the asset based on a site visit. An inventory should also hold a date log of **previous maintenance**

intervention (and provide references to the appropriate documents). Further to this it should also briefly describe the nature of each intervention. Similarly the same data should be kept for previous inspections, accompanied by a brief summary of the reported findings. The inventory should also hold details of the contract/scheme ID. The above information can only be compiled, if not already done so, through a review of historical records and documentation.

Maintenance records should summarise previous maintenance activities that have been applied to a particular asset. It should make clear what treatments have been applied and when the date this was carried out. It could include information such as: the dates fixings were replaced/repairs/tightened, dates of previous cleaning and vegetation cutting activities; support stabilisation dates etc. The inventory should also hold dates for past and future **cleaning activities**.

The information held against **manufacturer declared performance characteristics** should contain everything that is included in the products CE marking, such as: design standard; type of sign; daylight chromaticity and luminance factors; coefficient of retro-reflectivity class; durability conformity (impact resistance, resistance to weather), resistance to loads, and performance under vehicle impact).

2.4 Key data - Condition

The consultation found that 8 of the 13 NRAs that responded did carry out sign inspections and had a monitoring regime in place. However, these monitoring regimes did not cover all of the key condition aspects that might be associated with road sign performance, and only four participants had established an asset management system to use data for planning maintenance works and forecasting budgets. The majority of the NRAs stated that they did not use any form of measured condition threshold, as stated in the relevant standards to determine maintenance need, but instead relied upon the experience and professional judgement of inspectors.

It is therefore clear that there is a wide range of practice applied to understand the condition of signs across Europe, and that this practice is still relatively rudimentary in terms of technology, objective condition assessment and formal asset management practice. However, the consultation was able to obtain the views of the stakeholders on the key condition characteristics that they considered important, even though there are not necessarily many formal regimes in place to measure these. The results from the questionnaires hence highlighted a number of key condition characteristics of road signs. These are presented in Table 1, in order of importance, as assigned by NRAs.

The following sections discuss each of these characteristics; identifying their corresponding standards/guidance, and the typical measurement frequency. The sections also summarise the current standard measurement techniques that were identified in the standards review and consultation. However, these are provided as an indication of *current* approaches used by some NRAs and survey providers. Further detail, and a discussion of measurement methods, is given in section 3.

Table 1: Key condition characteristics of Road Signs

Rank	Property	Characteristic
1st	Visibility	Damage/Loss
2nd	Visibility	Obstruction/Obscuration
		Panel Alignment
3rd	Visibility	Night-time Visibility
4th	Visibility	Orientation
5th	Visibility	Colour Fade

2.5 Key Characteristic 1: Visibility – Damage/Loss

Definition: This characteristic considers any damage or loss which might impair the daytime and night-time visibility of the sign, hence affecting its visual performance. Such damage may be incurred from a vehicle collision, graffiti etc.

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: Slow speed detailed manual visual inspections are typically used to assess the presence or extent of damage to a road sign.

Measurement Frequency: For road safety routine patrols (at traffic speed) should be conducted every 2 months. A detailed manual inspection (slow speed) should be carried out every 2 years.

2.6 Key Characteristic 2: Visibility – Obstruction/Obscuration

Definition: This characteristic considers if the visual performance of the asset is impaired because of growing flora surrounding the asset, or if the sign is obscured by any other assets (e.g. other signs which have been placed within close proximity along the driver's line of sight.

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: Identifying assets which are obscured by plant growth or obstructed by other assets is achieved using a routine traffic speed visual inspection.

Measurement Frequency: These characteristics should be surveyed at least once per year, ideally in the spring and summer months when plant growth is at its peak.

2.7 Key Characteristic 3: Visibility – Orientation

Definition: This is an assessment of the position of the sign face relative to the carriageway and road users' line of sight. Incorrect orientation, caused by a number of factors, can impair legibility and night-time visibility.

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: A slow speed manual visual inspection.

Measurement Frequency: It is recommended that orientation is measured every 2 years.

2.8 Key Characteristic 4: Visibility – Panel Alignment

Definition: Panel alignment considers the relative vertical and horizontal positions of the panels that make up the sign face. This is only applicable for signs made from multiple panels. Panels should all align so that the information they display is not compromised and that road users can understand what is being communicated. It is more common for the vertical alignment to fall out of line; in this case the higher panels can overlap the lower panels, obscuring the information on the sign.

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: Slow speed visual inspection.

Measurement Frequency: It is recommended that this characteristic is inspected every 2 years

2.9 Key Characteristic 5: Visibility – Night-time Visibility

Definition: The night-time visibility considers the sign face material's current coefficient of retro-reflectivity ($cd.lx^{-1}.m^{-2}$). A sign's retro-reflective properties will degrade over the course of its lifetime, primarily caused by environmental factors (moisture, pollutants, and sunlight).

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: Slow speed manual surveys using a hand-held retro-reflectometer.

Measurement Frequency: This depends on the sign classification and varies between 7 years and 10 years after installation. However, if a sign is suspected of degrading faster than assumed, or if an overlay/dew resistant coating has been applied, initial inspections may be required at an earlier date. After the 7/10 year period, inspections should occur on a more frequent basis; every 2 years (DMRB, 2015).

2.10 Key Characteristic 6: Visibility – Extent of Colour Fade

Definition: The extent of colour fade refers to the damage that has been caused by ultraviolet radiation from the sun and adverse weather conditions. If colour fade is extensive the contrast between the elements (letters and numbers) can be reduced, hence reducing the legibility of the sign.

Standard/Guidance Document: TD 25/15 (DMRB, 2015)

Measurement Technique: Colour fade is assessed through a slow speed manual visual survey.

Measurement Frequency: This characteristic should be inspected every 2 years.

2.11 Summary

The key characteristics that PREMIUM proposes should be measured to describe the condition of road signs at the network level, are summarised in Table 2, along with the measurements that can be used to determine the characteristics, the measurement units and also any thresholds that are applied to the measurements.

Note that for many of the key characteristics the current standard method provides a quite subjective assessment (e.g. damage/loss condition). One of the purposes of PREMiUM is to assist in development of objective, network level assessment methods. Therefore we have further examined these subjective assessments and proposed, in Table 2, a quantitative, or more objective, way of reporting. For example, the damage could be reported as a percentage measure.

Table 2: Key condition characteristics for road signs

Characteristic	Current Measurement	Units	Standard Thresholds
Damage/Loss	General overall assessment by visual inspection. Potential quantitative assessment: % of sign area affected % of "important"* part of sign affected	Unit-less % %	None specified
Obstruction/ Obscuration	General overall assessment by visual inspection. Potential quantitative assessment: % of sign area affected % of "important"* part of sign affected	Unit-less % %	None specified – only requirement is that the visibility of the sign must not be impaired by obstructions or obscuration.
Orientation	Angle of orientation relative to carriageway by visual assessment.	Degrees	Although standards set out the orientation that a new sign should be relative to the road but there is little guidance on the level of deviation that would lead to a need for maintenance.
Panel Alignment (for signs that are constructed using more than a single panel)	General overall assessment by visual inspection. Potential quantitative assessment: Horizontal shift relative to font size Vertical shift	Unit-less mm(?) mm	None specified – only requirement is that the alignment is good enough to ensure legibility.
Night-time Visibility	Coefficient of retro-reflectivity (R_A). (Hand-held retro-reflectometer)	cd/ m^2/lx.	The coefficient of all printed colours, except white, shall be not less than 70% of the values in Table 7. In the UK, all locations where high – performance materials must be used, Class R3B (Table 7) is required. For other locations, Class RA2 is required. The intervention levels for retroreflectivity are given in Table 3.
Colour Fade	Chromaticity coordinates by slow speed assessment device.	factor	Classes defined for daylight chromaticity are given in Table 6.

* The important area is the area of the sign that contains the essential information i.e. the area that, if it were to be obscured, would reduce the road users' ability to interpret the information correctly

Table 3: Coefficient of retroreflection intervention levels used in the UK (TD25/15)

Class of sign	Coefficient of Retroreflection Intervention Level by Colour (cd/lx/m^2)								
	White	Yellow	Red	Green	Dark Green	Blue	Brown	Orange	Grey
RA2	144	96	20	16.8	11.2	11.2	6.4	52	72
R3B	240	156	48	24	19.2	15.2	7.2	120	120
Geometry of measurements: Observation angle of 20’, Entrance angle +5°, in accordance with BS EN 12899-1: 2007									

3 Summary recommendations for potential methods to monitor road signs

3.1 Measuring road sign condition

Measuring the condition of road signs at the network level is challenging because they are point items (i.e. are not a continuous feature along the length of a road) which have many different shapes, sizes and colours. This makes it difficult to perform in-situ condition surveys using high speed automated techniques. PREMIUM has investigated current and emerging methods that could be used to assess condition. This section discusses the measurement techniques that have been identified that have potential to provide information to NRAs on the key condition characteristics identified in Section 2. These include existing technologies that have been applied on the network and emerging equipment with which there may be less experience at the network level, but which have strong potential. Figure 1 presents a summary of these measurement methods, and further discussion is presented in the following sections.

3.2 Knowledge gathering and consultation

A knowledge gathering exercise was carried out to seek information on the methods available for the measurement of road signs. This included a review of available literature on equipment, consultation with providers of data and a questionnaire for asset inspection survey providers. The questionnaire was developed and distributed to survey providers in order to understand their current method of inspection, what data they record and the technologies they employ to do so.

Additional consultations with different survey providers were used to provide more details about the mobile measurement systems and the technical specifications against which the measurements were recorded. We also identified the projects ASCAM and TRIMM as resources for different measurement techniques for monitoring of road signs.

The following sections summarise the main observations and recommendations derived from the knowledge gathering and consultation exercise. The recommendations are broken down by the key data requirements defined above in section 2.

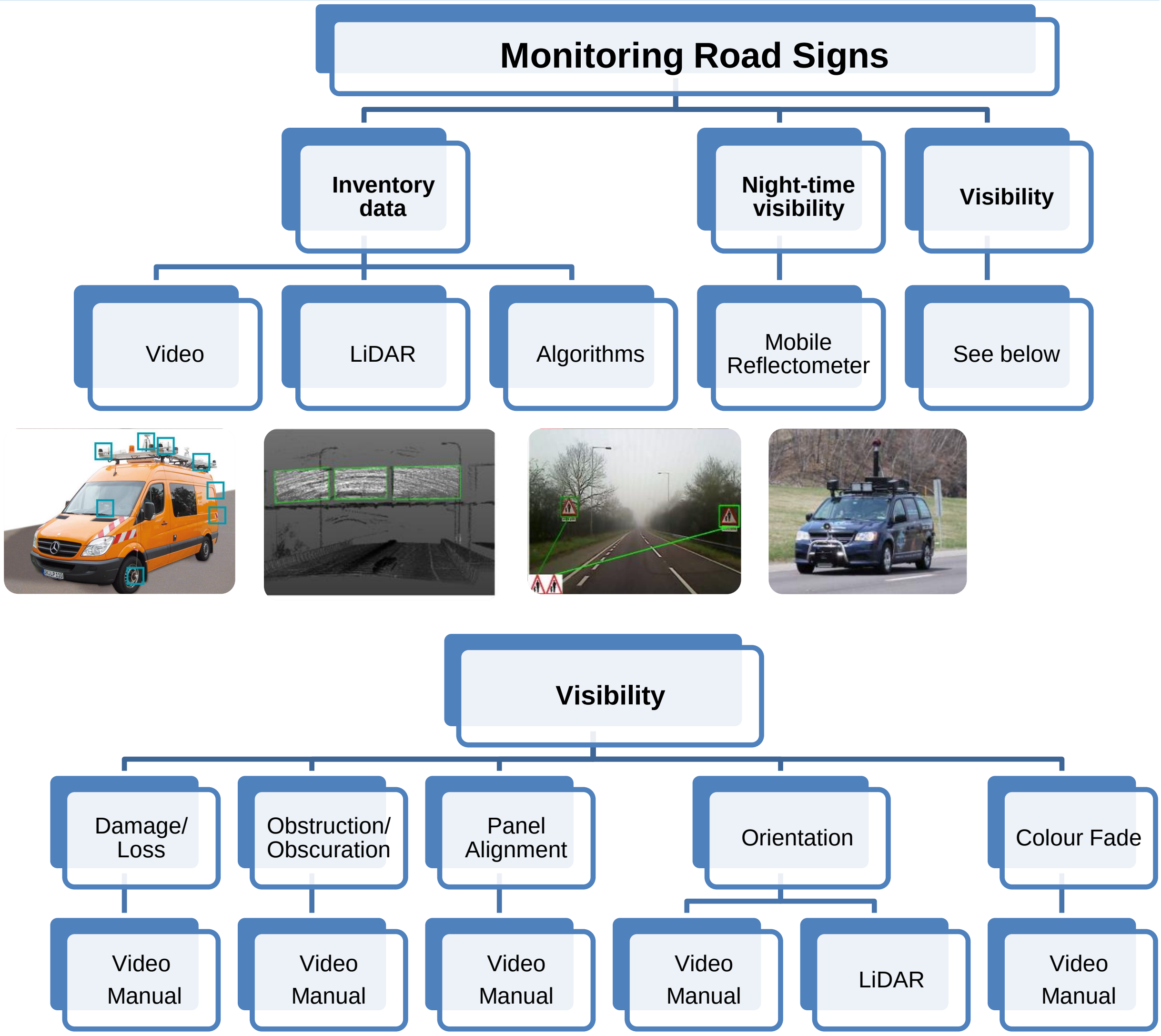


Figure 1: Measurement methods to monitor road signs

3.3 Key Data - Inventory

The following methods were identified as being used currently to measure the inventory of road signs. These methods collect information about the inventory characteristics, including type, height etc.:

- Historical Record Review: Reference to existing records such as construction drawings, documentation and contracts.
- Slow Speed Visual Survey: Field Inventory can be collected using a slow speed manual survey utilising a hand-held GPS data logging device, notepad, measurement equipment, tablet pc/laptop with suitable software (macros). However, this method requires traffic management (TM) for road closures (usually at night). Depending on the extent of the closure, TM time constraints, weather, general health and safety conditions, and the number of signs present, a single inspection (carried out by an experienced inspector) could survey the signs contained on a 6-10km stretch of road per night.

- Traffic Speed Visual Survey and manual feature extraction: This employs vehicles with GPS/GNSS recording devices, forward facing imaging capabilities, and an odometer. The image data is collected a manual assessment carried out to identify all the signs and hence record their location, type, etc. This method does not require traffic management, and is performed during the day-time, at traffic speed. Weather conditions should be dry and clear. The accuracy of GPS devices can vary depending on their quality and signal strength at time of measurement. Considering the point nature of road signs it is appropriate that any location co-ordinates have an accuracy of ±20cm.
- Traffic Speed Visual Survey and automatic feature extraction: Again this employs vehicles with GPS/GNSS recording devices, forward facing imaging capabilities, and an odometer, and also may employ a LIDAR system. The image and LIDAR analysis is performed using automated methods to identify the sign. The review has identified this approach as a powerful emerging method, with specific examples identified in a number of countries. However, there are varying levels of performance in the extraction process. Also, methods are in development that attempt to automatically identify the type of sign present using, for example, a reference library of known sign shapes (triangle, circle etc.).
- A desktop survey utilising up-to-date satellite and street-view maps/imagery (e.g. Google Earth Pro/StreetView, Ordnance Survey) could also be undertaken to determine the exact geographical location of assets.

The results of the review show that it is practical to obtain inventory data on road signs using traffic-speed techniques, including new/emerging technology employing traffic speed video and LiDAR. For Inventory data PREMIUM therefore recommends that:

- NRAs continue to make use of their ongoing maintenance programmes to maximise the accuracy of their databases.
- Video and LIDAR based methods should be more widely adopted by NRAs to update and maintain the population of their inventory databases on road signs.

In order to implement a reliable and accurate high-speed, network level survey for inventory of road signs, it is suggested that:

- Any system being used for the collection of inventory is tested against a suitable reference to provide information and understanding on the capability of the high speed systems (video/LiDAR). This would confirm that the inventory items are accurately located and reported.
- Most methods for extraction of asset types are manual. Thus just collecting video and LiDAR data will not provide a practical network level survey. However, as noted above the review identified a number of case studies in which algorithms are employed to detect and recognize road signs from video or images. There would be benefit in the further development of automated extraction processes for the identification and classification of road signs within the LiDAR and image survey data.

3.4 Key characteristic 1: Visibility – Damage/Loss

3.4.1 Measurement techniques

The surveys identified for assessing the presence or extent of damage include:

- Detailed Manual Inspections – a manual assessor walks the network and records damage using a data recorder (tablet, pen and paper etc.). Photographs may be taken for reference purposes.
- A coarse traffic speed survey - undertaken from a vehicle to identify obvious defects (such as damage resulting from vehicle impact or graffiti) and recorded manually using a data recorder;
- A traffic speed video survey – undertaken to capture image data, with manual analysis of the collected footage carried out after the survey collection is completed.
- In situ - It is theoretically possible to measure some forms of damage using in-situ monitoring using sensors that, for example, detect impact or movement.

However, although PREMIUM identified case studies employing Detailed Manual Inspections, we did not identify examples of routine application of the traffic speed methods that have a potential to provide information on damage, or of in situ methods.

3.4.2 Recommendations for measurement of Damage/Loss

PREMIUM was not able to identify a routine method or survey at a ready for market level which could be practically applied at the network level for measurement of the damage/loss to road signs. However, existing image collection and analysis methods could be easily implemented, if the analysis system is given information on where signs should be and what they should look like. We recommend that:

- The potential of the video and images from the traffic-speed systems used to collect road sign inventory should be investigated to determine whether manual analysis of these images could be used to monitor and quantify the extent of damage to signs.
- The automatic analysis of video and images combined with good quality inventory data (location, type of sign, expected size and shape etc.) should be investigated to determine the potential for this approach.
- Practical trials with different devices would provide more information and obtain a better understanding of the capability of current systems and would enable a specification for the minimum technical requirements (image resolution, image quality, positioning system accuracy) for video surveys to be derived.
- It is possible that in-situ monitoring could be achieved, but this would require focussed development and extensive testing using practical trials. This would be a longer term objective.

3.5 Key characteristic 2: Visibility - Obstruction/Obscuration

3.5.1 Measurement techniques

In contrast with the assessment of damage, PREMIUM found that traffic speed methods are used for the detection of obstructed road signs. For these inspections a video survey is used in which the images are accurately geographically referenced. Manual assessment of the images is used to identify obscured signs. It is possible that the use of traffic speed methods for this application reflects the relatively more straightforward analysis required to identify an obscured sign than a damaged sign. Detection of obscured signs also probably places less demand on resolution and quality than detecting damaged signs. However, it would seem that there is clear potential to achieve both measurements using the image data.

3.5.2 *Recommendations for measurement of Obstruction/Obscuration*

As there is already some evidence that video surveys can be used to identify obscured signs, we recommend that work continues on the development of measurement systems to convert the emerging methods into routine application. This should be developed alongside use to detect damage. The requirements of this work would be similar to those described in section 3.4.2.

3.6 Key characteristic 3: Visibility – Orientation

3.6.1 *Measurement techniques*

Manual visual inspections are currently employed to assess orientation. A walked survey assesses the signs and reports on the condition. However, the measurement is not impossible to carry out using high speed systems. A basic assessment to identify leaning signs could be achieved using manual inspection of video data. PREMIUM has also identified work in which static LiDAR has been used to quantify orientation. There is potential to mount this on a mobile device and thus offer the potential to provide measurements whilst the vehicle is moving.

It should also be possible to measure orientation via in-situ monitoring using sensors that, for example, detect the angle and report this to a central hub. However, the review did not identify a method being applied in this way.

3.6.2 *Recommendations for measurement of Orientation*

As there is already some evidence that video surveys can be used to identify poorly orientated signs, we recommend that work continues on the development of measurement systems to convert the emerging methods into routine application. This should be developed alongside use to detect damage. The requirements of this work would be similar to those described in section 3.4.2.

It would also be recommended that additional investigation into use of LiDAR measurements to determine orientation be carried out. This would confirm the viability of the static approach and then expand this to a mobile platform, including practical trials, assessment of the capability to survey on a network level and assessment of the performance of the method (accuracy).

3.7 Key characteristic 4: Visibility – Panel Alignment

3.7.1 *Measurement techniques*

As with other condition characteristics of road signs, the main established method for panel alignment is a low speed visual inspection. We did not identify any case studies in which NRAs were applying high-speed techniques to detect this problem. However, it is considered that this defect would be detectable, similarly to damage or other deterioration, using manual assessment of video survey data collected at traffic-speed. It may be possible to develop automatic analysis methods but research would be needed to confirm this.

3.7.2 *Recommendations for measurement of Panel Alignment*

We have not identified practical application of video surveys to identify poorly aligned panels. However, we feel this is achievable and recommend that work is undertaken on the development of measurement systems to achieve this. This should be developed alongside use to detect damage. The requirements of this work would be similar to those described in section 3.4.2.

3.8 Key characteristic 5: Visibility – Night-time Visibility

3.8.1 *Measurement techniques*

The main established technique for measuring the night-time visibility of road signs is a slow speed survey carried out using a hand-held device, which is not practical for measurement at the network level. However, the review has identified emerging traffic speed methods to measure the night-time visibility of road signs using equipment mounted onto vehicles that measures the luminance of the sign in response to a light source. However, we did not identify any routine use of this equipment, which appear to be in the advanced testing phase.

The accuracy of these mobile systems has been called into question, because of the difference in the measurements in comparison with the hand-held devices. These differences could be because of the effect of the sign orientation on the high speed measurements. In a slow speed (hand held device) survey it is possible to be control the orientation between the device and the sign. However, from a vehicle a sign that is angled away from the road will be less visible to the driver (and also the mobile measurement device). It therefore will appear less reflective than one that is positioned correctly. There is an ongoing discussion over whether the mobile survey therefore delivers data that is more representative of the driver's actual experience than the hand held device.

3.8.2 *Recommendations for measurement of Night-time Visibility*

Although PREMiUM has identified traffic speed methods that could provide a measure of night-time visibility at traffic speed, these methods are not widely implemented. It is recommended that work is undertaken to assist the development and implementation of mobile reflectometers, as this could rapidly allow the introduction of routine nigh-time visibility surveys on road networks. The work would include:

- Organisation of a large-scale experiment with different mobile devices
    - Practical trials which assess the performance of individual devices;
    - Practical trials which compare and harmonise the measurements collected by handheld reflectometer with those from mobile reflectometers;
- Provision of guidance to NRAs on the application of high speed systems e.g. defining standards for measurements with mobile reflectometers.
- Investigate the technical capability of determining night-time visibility from LiDAR data through practical trials and testing.

3.9 Key characteristic 6: Visibility – Extent of Colour Fade

3.9.1 Measurement techniques

Colour fade is currently assessed using slow speed manual visual surveys undertaken during the day. They are limited in terms of practicality for strategic roads due to the additional health and safety issues, and the difficulties in securing road closures to conduct the test.

We have not identified any application of traffic speed methods. In theory a video-based method could potentially be used for measurement of the colour fade of road signs. However, this may be difficult to implement, as the colours contained in the image will be dependent on the ambient light.

3.9.2 Recommendations for measurement of Extent of Colour Fade

PREMIUM was not able to identify a method or survey, at a ready for market level, which could be practically applied at the network level for measurement of colour of road signs. As video systems offer significant potential for the assessment of damage, orientation and panel alignment there is a need to examine whether it is practically possible to measure fade using the same approach. The achievement of this would be strongly influenced by the nature of the image collection system. Research work into this could include:

- Theoretical assessment of the requirements for the image collection system;
- Development of a method to overcome effects of ambient light on the measurements;
- Specification of image requirements;
- Practical trials that assess the use of video to measure colour fade;
- Guidance for NRAs.

3.10 Recommendations for measurements

The measurement methods are summarised in Table 4. As mentioned in the previous section, potential methods were identified for measurement of characteristics that could be used to determine the condition of road signs. The PREMiUM recommendations for any work required to achieve the recommended method are also described in the table.

Note:

- In the “characteristic” column we have highlighted in bold the characteristics for which we believe, if suitable investment is made, network level monitoring could be implemented within 3-5 years. We have in this timescale assumed that the data collection would be at traffic-speed, but there would still be a requirement for manual intervention in the analysis of condition.
- In the “PREMIUM recommendations for work required..” column we have also highlighted in bold the key work that needs to be completed to deliver the above 3-5 year implementation.

Table 4: Current and proposed measurement methods for monitoring road signs

Property	Characteristic	Recommended measurement method to achieve network level requirement	PREMIUM recommendations for work required to achieve recommended method
Inventory	**Location - e.g. road name, number, area, chainage, section label, GPS, etc.**	Extraction from Video images or LiDAR – manual and automatic.	**Obtain better understanding of capability of current systems.** **Develop minimum technical specification of requirements for surveys e.g. image resolution, resolution of LIDAR point cloud, accuracy and repeatability of image, LIDAR and positioning system** Develop extraction processes for LiDAR and image surveys to automatically identify signs. Undertake testing of performance by collecting video data, automatically analysing and comparing this with reference data i.e. obtained on site or manually from images. Test and validate the extraction algorithms and implementation at a network level.
	Cleaning Interval (years) Material Performance Class Date of installation Dates and details of maintenance	Historical records	No further development needed.
Visibility	**Damage/Loss**	Visual inspection from Video	**Develop minimum technical specification for video surveys e.g. image resolution, positioning system.** **Develop formal manual assessment regime to use images/LIDAR to quantify condition – including a reporting method (e.g. % damage)** **Provide NRAs with guidance on the application of high speed systems e.g. define Standards for measurements with image systems** Investigate and develop automatic assessment algorithms to replicate the manual assessment (long term development).
	Obstruction/ Obscuration		
	Panel Alignment		

Property	Characteristic	Recommended measurement method to achieve network level requirement	PREMIUM recommendations for work required to achieve recommended method
Visibility	**Night-time Visibility**	Mobile reflectometer LiDAR	**Perform practical trials to compare and harmonise results of handheld reflectometer to results from mobile reflectometers, to provide evidence to support transition to these methods.** **Provide NRAs with guidance on the application of high speed systems e.g. define Standards for measurements with mobile reflectometers**. Investigate the technical capability to determine night-time visibility from LiDAR data through practical trials
Visibility	**Orientation**	Video or LiDAR	**Develop minimum technical specification for video surveys e.g. image resolution, positioning system, LIDAR cloud.** **Develop formal manual assessment regime to use images/LIDAR to quantify condition – including a reporting method (e.g. "poor orientation")** **Provide NRAs with guidance on the application of high speed systems e.g. define Standards for measurements undertaken with image systems** Develop automated extraction processes for LiDAR and image surveys. Test and validate the extraction algorithms and implementation at a network level.
Visibility	**Colour Fade**	Visual inspection from Video	**Determine if this measure is achievable with video systems and/or what customisation is required** **Develop minimum technical specification for video surveys e.g. image resolution, positioning system,** **Provide NRAs with guidance on the application of high speed systems**

4 Technical background – Standards and Approach for Understanding Road Sign Condition

4.1 Information sources

As highlighted in Section 2, a stakeholder engagement exercise was carried out to understand current industry practice and to find out what authorities believe to be the most important characteristic (data on which could plausibly be collected during an inspection/condition survey) for determining the condition of the asset and its current level of performance. Prior to the stakeholder engagement a review of current standards and guidance documents was carried out to summarise the characteristics of road signs which are assessed. To support the review, additional information was also sourced from the HeRoad report into equipment condition assessment (Casse & Van Geem, 2012).

Table 5 identifies the different property groups, and their characteristics, for road signs. Project consortium members were also asked to review their national standards and guidance documents to see which characteristics were referenced. The characteristics listed in Table 5 were the findings from the standards review.

Table 5: Standard Requirements

Property	Characteristic	UK	Ireland	Germany	France	Austria	Bulgaria	Belgium	Australia
Inventory	Location Reference	✓	✓	✓	✓	✓	✓	✓	✓
	Identification Code	✓	✓	✘	✘	✘	✘	✓	✓
	Date of Installation	✓	✓	✘	✓	✓	✓	✓	✓
	Maintenance Records	✓	✓	✘	✘	✘	✘	✓	✓
	Manufacturer Declared Performance Characteristics	✓	✓	✓	✓	✓	✓	✓	✓
	Cleaning Interval	✓	✓	✘	✘	✘	✘	✘	✘
Durability	Resistance to Weathering	✓	✓	✓	✓	✓	✓	✓	✘
	Impact Resistance	✓	✓	✓	✓	✓	✓	✓	✓
	Vehicle Impact	✓	✓	✓	✓	✓	✓	✓	✓
Structural	Foundation Conditions	✓	✓	✘	✘	✘	✘	✘	✘
	Wind Load Deflections	✓	✓	✓	✓	✓	✓	✓	✓
	Snow Loading	✓	✓	✓	✓	✓	✓	✓	✘

Table 5: Standard Requirements (continued)

Property	Characteristic	UK	Ireland	Germany	France	Austria	Bulgaria	Belgium	Australia
Visibility	Night-Time Visibility	✓	✓	✓	✓	✓	✓	✓	✓
	Material Performance Class	✓	✓	✘	✘	✘	✘	✘	✓
	Age of Material	✓	✓	✘	✘	✘	✘	✘	✘
	Luminance/Illuminance	✓	✓	✓	✓	✓	✓	✓	✓
	Colour	✓	✓	✓	✓	✓	✓	✓	✘
	Minimum Clear Visibility Distance	✓	✓	✘	✘	✘	✘	✘	✘
	Obstruction/Obscuration	✓	✓	✘	✘	✘	✘	✘	✘
	Damage/Loss	✓	✓	✓	✓	✓	✓	✓	✓
	Panel Alignment	✓	✓	✘	✘	✘	✘	✘	✘
Legibility	Extent of Colour Fade	✓	✓	✘	✘	✘	✘	✓	✓
	Contrast between Elements	✓	✓	✘	✘	✘	✘	✘	✓
	Damage/Loss of Legend	✓	✓	✘	✘	✘	✘	✘	✓
	Orientation	✓	✓	✘	✘	✘	✘	✘	✓

4.2 Review of Standards defining the performance of road signs

Figure 2 provides an illustration of the key standards and guidance documents that relate to road sign performance. This section will now discuss each of these standards.

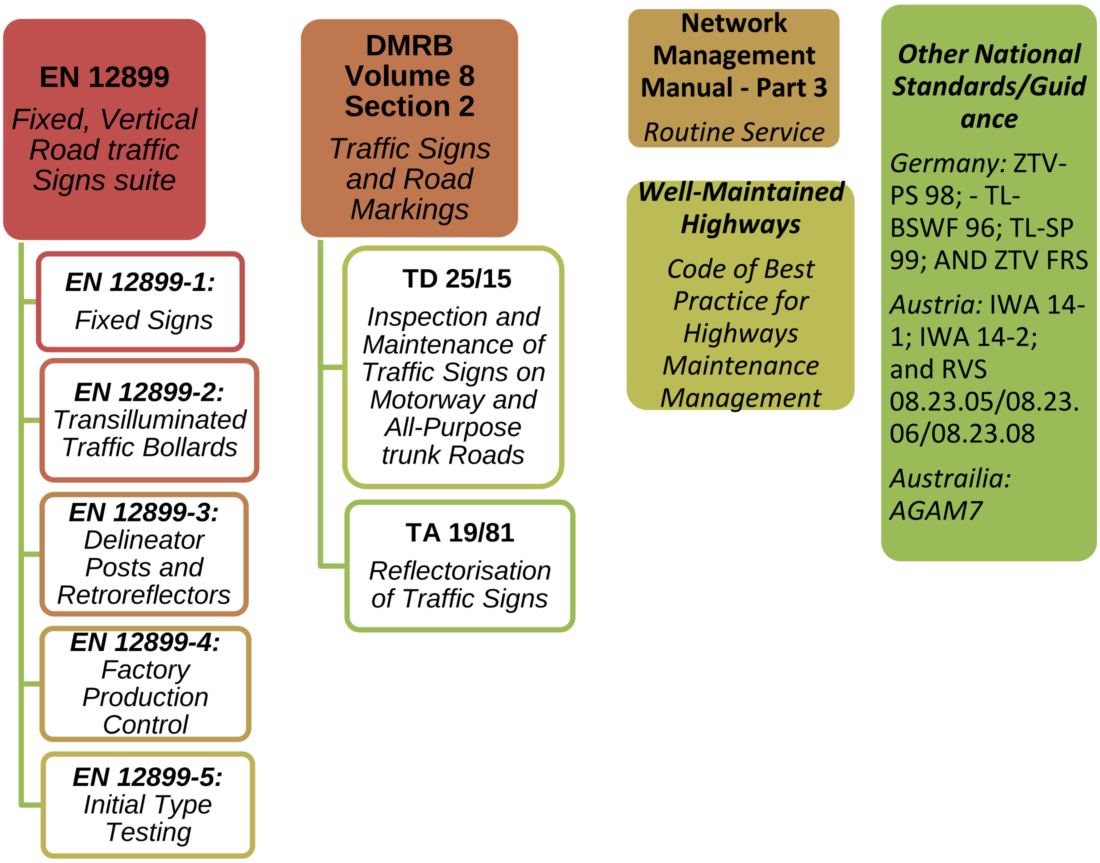


Figure 2: National Standards & Guidance

4.2.1 *EN 12899*

EN 12899-1 states the performance specifications for non-retro-reflective signs, trans-illuminated and glass bead retro-reflective signs. Within the standard, each country has a corresponding national annex, highlighting the recommended performance values specific to that state. While this standard is used for design purposes and classification it is useful to explore the standard to examine whether any of the performance requirements could be assessed in-situ or be used to benchmark and monitor the condition of the asset. It is the most commonly adopted standards for road signs.

The classes defined in this standard for daylight chromaticity are given in Table 6, whilst those for the coefficient of retroreflection are given in Table 7. The coefficient of retroreflection (R_A) of all printed colours, except white, shall be not less than 70 % of the values in Table 7. The recommended classes or values for visual performance most suitable for UK Practice are given in Table 8.

Table 6: Daylight chromaticity factors

Colour	Class	1		2		3		4	
		x	y	x	y	x	y	x	y
White	CR1	0,355	0,355	0,305	0,305	0,285	0,325	0,335	0,375
	CR2	0,305	0,315	0,335	0,345	0,325	0,355	0,295	0,325
	NR1	0,350	0,360	0,300	0,310	0,290	0,320	0,340	0,370
	NR2	0,305	0,315	0,335	0,345	0,325	0,355	0,295	0,325
Yellow	CR1[1]	0,522	0,477	0,470	0,440	0,427	0,483	0,465	0,534
	CR2[1]	0,494	0,505	0,470	0,480	0,493	0,457	0,522	0,477
	CR1[2]	0,545	0,454	0,487	0,423	0,427	0,483	0,465	0,534
	CR2[2]	0,494	0,505	0,470	0,480	0,513	0,437	0,545	0,454
	NR1	0,522	0,477	0,470	0,440	0,427	0,483	0,465	0,534
	NR2	0,494	0,505	0,470	0,480	0,493	0,457	0,522	0,477
Orange	CR1	0,610	0,390	0,535	0,375	0,506	0,404	0,570	0,429
	CR2	-	-	-	-	-	-	-	-
	NR1	0,610	0,390	0,535	0,375	0,506	0,404	0,570	0,429
	NR2	-	-	-	-	-	-	-	-
Red	CR1	0,735	0,265	0,674	0,236	0,569	0,341	0,655	0,345
	CR2	0,735	0,265	0,700	0,250	0,610	0,340	0,660	0,340
	NR1	0,735	0,265	0,674	0,236	0,569	0,341	0,655	0,345
	NR2	0,735	0,265	0,700	0,250	0,610	0,340	0,660	0,340
Blue	CR1	0,078	0,171	0,150	0,220	0,210	0,160	0,137	0,038
	CR2[3]	0,130	0,086	0,160	0,086	0,160	0,120	0,130	0,120
	CR2[4]	0,130	0,090	0,160	0,090	0,160	0,140	0,130	0,140
	NR1	0,078	0,171	0,196	0,250	0,225	0,184	0,137	0,038
	NR2	0,140	0,140	0,160	0,140	0,160	0,160	0,140	0,160
Green	CR1	0,007	0,703	0,248	0,409	0,177	0,362	0,026	0,399
	CR2[5]	0,110	0,415	0,150	0,415	0,150	0,455	0,110	0,455
	CR2[6]	0,110	0,415	0,170	0,415	0,170	0,500	0,110	0,500
	NR1	0,313	0,682	0,313	0,453	0,177	0,362	0,026	0,399
	NR2	0,230	0,440	0,260	0,440	0,260	0,470	0,230	0,470
Dark green	CR1	0,313	0,682	0,313	0,453	0,248	0,409	0,127	0,557
	CR2	0,190	0,580	0,190	0,520	0,230	0,580	0,230	0,520
Brown	CR1	0,455	0,397	0,523	0,429	0,479	0,373	0,558	0,394
	CR2	0,455	0,397	0,523	0,429	0,479	0,373	0,558	0,394
	NR1	0,510	0,370	0,427	0,353	0,407	0,373	0,475	0,405
	NR2	0,467	0,386	0,447	0,386	0,447	0,366	0,467	0,366
Grey	CR1	0,350	0,360	0,300	0,310	0,285	0,325	0,335	0,375
	CR2	0,305	0,315	0,335	0,345	0,325	0,355	0,295	0,325
	NR1	0,350	0,360	0,300	0,310	0,290	0,320	0,340	0,370
	NR2	0,305	0,315	0,335	0,345	0,325	0,355	0,295	0,325
Black	NR1	0,385	0,355	0,300	0,270	0,260	0,310	0,345	0,395
	NR2	-	-	-	-	-	-	-	-

Notes: Class CR1 and CR2 apply to retroreflective signs, NR1 and NR2 apply to non-retroreflective signs.
1 if luminance factor ≥0,27 and class RA1 coefficient of retroreflection
2 if luminance factor ≥0,16 and class RA2 coefficient of retroreflection
3 If class RA1 coefficient of retroreflection
4 If class RA2 coefficient of retroreflection
5 If luminance factor ≥0,04 and class RA1 coefficient of retroreflection
6 If luminance factor ≥0,05 and class RA2 coefficient of retroreflection

Table 7: Coefficient of retro-reflection R_A

Class	Geometry of measurements		Colour								
	α	β1 (β2=0)	Whit e	Yellow	Red	Green	Dark Green	Blue	Brown	Orange	Grey
RA1	12'	+5°	70	50	14,5	9	N/A	4	1	25	42
		+30°	30	22	6	3,5	N/A	1,7	0,3	10	18
		+40°	10	7	2	1,5	N/A	0,5	#	2,2	6
	20'	+5°	50	35	10	7	N/A	2	0,6	20	30
		+30°	24	16	4	3	N/A	1	0,2	8	14,4
		+40°	9	6	1,8	1,2	N/A	#	#	2,2	5,4
	2°	+5°	5	3	1	0,5	N/A	#	#	1,2	3
		+30°	2,5	1,5	0,5	0,3	N/A	#	#	0,5	1,5
		+40°	1,5	1,0	0,5	0,2	N/A	#	#	#	0,9
RA2	12'	+5°	250	170	45	45	20	20	12	100	125
		+30°	150	100	25	25	15	11	8,5	60	75
		+40°	110	70	15	12	6	8	5,0	29	55
	20'	+5°	180	120	25	21	14	14	8	65	90
		+30°	100	70	14	12	11	8	5	40	50
		+40°	95	60	13	11	5	7	3	20	47
	2°	+5°	5	3	1	0,5	0,5	0,2	0,2	1,5	2,5
		+30°	2,5	1,5	0,4	0,3	0,3	#	#	1	1,2
		+40°	1,5	1,0	0,3	0,2	0,2	#	#	#	0,7
R3B*	20'	+5°	300	195	60	30	24	19	9	150	150
		+20°	240	155	48	24	19	16	7.2	120	120
		+30°	165	110	33	17	13	11	5	83	82
		+40°	30	20	6	3	2.4	2	#	15	15
	1°	+5°	35	23	7	3.5	2.8	2.5	1.1	18	17
		+20°	30	20	6	3	2.4	2	#	15	15
		+30°	20	13	4	2	1.6	1.5	#	10	10
		+40°	3.5	2	1	#	#	#	#	2	1.8
	1.5°	+5°	15	10	3	1.5	1.2	1	#	7.5	7.5
		+20°	13	8	2.5	1	1	#	#	6.5	6.5
		+30°	9	6	2	#	#	#	#	4.5	4.5
		+40°	1.5	1	#	#	#	#	#	1	#

# Indicates value greater than zero but not significant or applicable.

* Dark green, Brown and Grey are additional colours added to CUAP for UK legislation

Table 8: Recommended classes or values for visual performance most suitable for UK Practice

Characteristic	Product	Location	Recommended performance classes or values in BS EN 12899-1:2007 unless otherwise stated.
1. Chromaticity	Retroreflective sign face material	All locations	Class CR1 or CR2 (Table 6). See NOTE 1
	Non-retroreflective sign face material	All locations	Class NR1 or NR2 (Table 6).
2. Coefficient of retroreflection (cd·lx-1·m-2)	Retroreflective sign face material	All locations other than those where high-performance materials are required	Class RA2 (Table 7) or Class R2, CUAP Table 7 See NOTE 2
		Locations where high-performance materials are required	Class R3B (Table 7) See NOTES 3 and 4

NOTE 1 A material which has a valid ETA that attests conformity to CUAP Table 4 can be treated as conforming to Class CR1 in BS EN 12899-1:2007.

NOTE 2 A material which has a valid ETA that attests conformity to CUAP Table 7, Class R2, can be treated as conforming to Class RA2 in BS EN 12899-1:2007.

NOTE 3 Direct lighting of many traffic signs is optional. Examples of these are certain warning signs and most informatory and directional signs other than motorway gantry signs. In the case of warning signs in particular, it is recommended that when these are not directly lit, high-performance microprismatic retroreflective materials are used.

NOTE 4 Specifiers should note that dark green (used on Primary Route signs), brown and grey are not currently included in Table 10 of the CUAP. This matter is being addressed and in due course the CUAP will be amended. In the meantime, specifiers can require conformity to Table NA.1B in EN12899-1, which replicates Table 10 with the addition of values for dark green, brown and grey.

4.2.2 *TD 25/15: Inspection and Maintenance of Traffic Signs on Motorway and All-Purpose Trunk Roads*

TD 25/15 describes the requirements and recommendations for the safety inspection and maintenance of permanent road signs on the strategic network in England (DMRB, 2015). The guidance covers regulatory, warning, informatory and directional signs, alongside related equipment. The document places emphasis on the importance of the sign's visual performance, structural integrity and electrical safety. The guidance does not cover lighting columns, variable message signs nor regulatory signs associated with light signals (such as traffic lights).

The guidance opens by setting out six key principles of road signs, each of which are then later developed into inspection criteria and considerations. The key principles as stated in the manual are as follows:

i. Performance failures of signs may affect their legal status.
ii. Excessive provision of signs, known as "sign clutter", can result in negative environmental impacts (such as visual and aesthetic impacts), and reduce the comprehension of road users in scenarios of information overload.

iii. Signs' visual performance declines over time, resulting in a decreased conspicuity and legibility during the day and night.
iv. Obstructions leading to impairments in visibility and legibility can negatively impact road safety by distracting and/or hampering drivers' intake of critical information.
v. Damaged and deteriorating supporting structures and electrical fittings can become potential hazards to road users.
vi. Pro-actively addressing and repairing defects through corrective maintenance measures are vital for sign installations achieving its design life.

Inspections should be carried out routinely under both day and night-time conditions. The key elements of a safety inspection are highlighted in Figure 3.

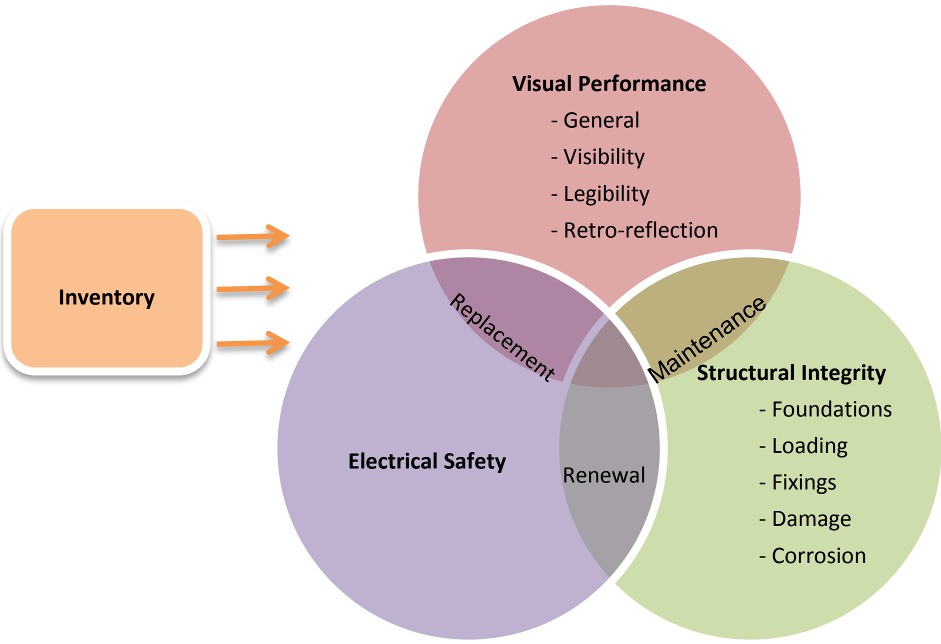


Figure 3: Key Elements of Safety Inspection

In general, a loss in visual performance can be attributed to a number of factors which need reviewing during each inspection. Factors contributing to losses in visual performance are highlighted in Figure 4. Obstruction and obscuration can be caused by excessive build-up of dirt, vegetation, posters, and graffiti or, in cases of over provision, other signs. Signs can experience damage, lose elements/legend or fade due to weathering and sunlight. When signs are constructed using more than a single panel, the horizontal and vertical alignment must be checked, otherwise this could affect the road users' understanding of what information is being presented. Alignment may also indicate some form of structural failure, i.e. failing fixings. A failed illumination system, caused by faulty/damaged electrics could negatively impact road safety, thus internal and external lighting systems must be checked to ensure they are in a serviceable condition. The retro-reflective performance of sign face materials can degrade over time, or variances may be present where part of a sign has been replaced. Finally the orientation of a sign, relative to road users, must be in the correct position. If not it could pose a number of negative impacts, such as misdirecting the road user or causing the road user to miss the information presented, which in some cases could be critical warnings.

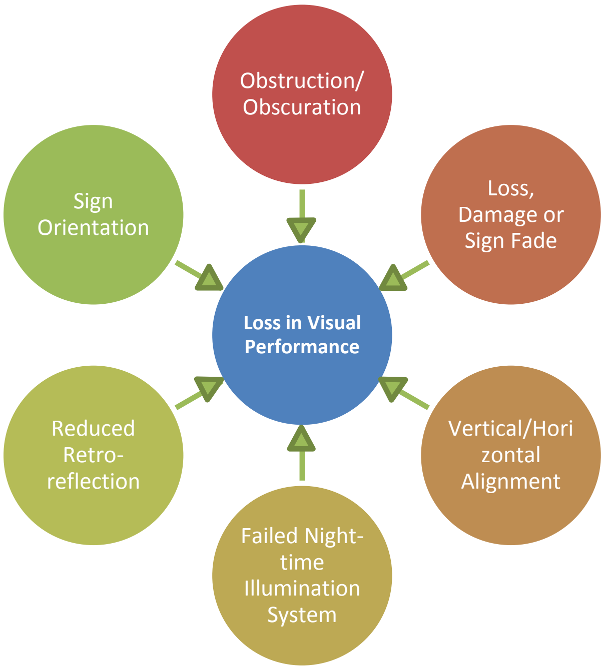


Figure 4: Factors Contributing to a Loss in Visual Performance

Considering the above, road signs must meet a number of outcomes to ensure failure modes highlighted are mitigated and do not impact road safety. The general visual performance outcomes a sign must demonstrate are as follows:

1. The minimum clear visibility distance (in metres) under both day and night-time conditions is met.
2. All elements are legible under both day and night-time conditions.
3. Where required, under the Traffic Signs Regulations, the sign is illuminated.
4. Where provided, illumination systems must be fully functional during night-time conditions and correctly orientated so as aligned with the sign face.

The minimum clear visibility distance is evaluated from a vehicle travelling at traffic speed using dipped headlights. If it is not possible to estimate the in-situ clear visibility distance from a moving vehicle, static measurements must be made during a site visit. As discussed above, visibility must be assessed against the criteria/considerations set out in Figure 4. With respect to obstruction and obscuration, additional assessments may have to be undertaken during spring and summer seasons – growing vegetation may obscure signs.

The method for assessing legibility is by means of travelling towards the target sign, in a vehicle operating at the prevailing traffic speed, and attempting to read and note down the information from the sign from the start of the minimum clear visibility distance. The survey continues until it is no longer practical for a driver to continue reading the sign. Again, reference should be made to the factors listed in Figure 4, in case they impair legibility. An assessment should also be carried out relative to the extent of colour fade, losses or damages that may have occurred. These will have greater impacts on road safety during night-time conditions. However the standard does not set out objective levels of fade or provide photographic examples and a scoring system.

The coefficient of retro-reflection is a measure of brightness during the hours of darkness. Retro-reflection is when the light emitted from a vehicles headlamps strikes a surface (e.g. a sign face) and then a large proportion of that light is reflected directly back to the original source. Retro-reflective properties degrade over the lifespan of the sign, relative to their exposure to environmental conditions such as sunlight, moisture and pollutants. The standard provides intervention threshold values for retro-reflection (measured in $cd.lx^{-1}.m^{-2}$) based on the retro-reflective material class and the colour of the sign. This is complemented by a brief guide, making use of photographic examples to classify the material type. Retro-reflectivity surveys are required to be carried out using a hand-held retro-reflectometer, carrying out spot measurements for each sign under investigation. The guidance also notes that these measurements only need to be made for class RA1 materials 7 years after their installation. Performance classes RA2, R2 and R3B only need a retro-reflectivity survey 10 years after installation. If the sign does not meet the corresponding threshold value the sign should be considered defective.

The structural integrity of a sign considers the worthiness of the supporting structure (e.g. post and foundation condition) and the fixings connecting the sign face to the support. If a structure fails it may pose a hazard to all road users and impact the visual performance of the sign. The guidance notes state that it is critical that the supporting structure does not present a safety hazard to road users. This may be obvious but it is common for signs to be installed in front of vehicle restraint systems or behind the system, but still within the restraint's working width. In such a case, the installation is directly attributable to reductions in road user safety. If a vehicle were to impact a restraint it is possible that it would first hit an outlying sign or the sign support would prevent the restraint from achieving its design deflection. All components must be managed so that the service life is maximised. When assessing the structure, factors contributing to compromising integrity should be evaluated, these are illustrated in Figure 5. Each of these factors must be assessed based on the inspector's professional judgement, and as it stands there are no objective measures to assess structural factors against. However the standard does provide photographic examples of each of the structural failure modes. In this respect inspections are slow-speed and manual.

The condition of the support's foundations is critical. However, as it lies beneath ground level it can be difficult to assess this directly. The easiest way to identify foundation issues is to assess the vertical position of the support. If the structure is leaning, or the surrounding ground exhibits movement (visible heave), or if a small force is applied to the structure and it begins to move, foundations can be considered defective. Corrosion can reduce the strength of the structure; if corrosion is present it is only a matter of time before the structure will fail. Similarly, if the structure exhibits cracking and buckling then this is a good indicator that the structural integrity is/or will be compromised in the near future. Fixings, bolts, washers and nuts should be inspected, firstly to ensure they are all present, and secondly to ensure they are secured tightly. However overtightening of fixings can cause damage to the channels. If butting clamps and plates are missing or insecure this could lead to alignment issues. If post caps are not fitted it will lead to moisture infiltration. In this case the build-up of moisture will lead to corrosion.

Figure 5: Factors Compromising Support Structural Integrity

The frequency of the above inspections, with the exception of retro-reflectivity surveys, is determined by undertaking a risk assessment. Such a risk assessment should consider:

- Whether the sign is critical for road safety (warning signs) or essential for the application of a legal provision (speed camera signs).
- Whether the sign must be lit during the hours of darkness in order to meet the requirements set out in the Traffic Signs Regulations.
- The amount of time that has passed since the previous safety inspection.
- The condition of the asset, and its individual components determined from the previous safety inspection.
- The location of the sign, with respect to adverse weather conditions (such as strong winds)
- If vegetation is present within close proximity to the sign, and its growth is likely to obscure the sign.
- The distance the sign is from the carriageway – if a sign is closer to the carriageway it is likely to have increased rates of dirt/pollution build-up.

With the above in mind however, the standard does state that the maximum time period between inspections should not be more than every two years. It also makes clear that it might not be practical to assess all of the factors discussed above in a single survey. In this respect it is allowable that surveys are split between site safety inspections, routine patrols and mobile safety inspections using automated asset data collection technologies.

The standard also provides guidance on maintenance techniques, however there are not many possible treatments that can applied to signs; with this in mind particular weight is given to cleaning the sign face (every 3 years for normal signs and every 6 years for signs mounted at height). Furthermore it sets out the conditions for the removal and/or replacement of signs.

TD25/15 also includes intervention levels for the coefficient of retroreflection (in Annex C) and these are reproduced in Table 9.

Table 9: Coefficient of retroreflection intervention levels

Class of sign	Coefficient of Retroreflection Intervention Level by Colour (cd/lx/m^2)								
	White	Yellow	Red	Green	Dark Green	Blue	Brown	Orange	Grey
RA1	40	28	8	5.6	N/A	1.6	0.5	16	24
RA2	144	96	20	16.8	11.2	11.2	6.4	52	72
R2	144	96	20	16.8	11.2	11.2	6.4	52	72
R3B	240	156	48	24	19.2	15.2	7.2	120	120
Geometry of measurements: Observation angle of 20', Entrance angle +5°, in accordance with BS EN 12899-1: 2007									

4.2.3 *TA 19/81: Reflectorisation of Traffic Signs*

This technical advice note prescribes the functions and performance requirements of retro-reflective traffic (road) signs (DMRB, 1981). It provides a commentary on regulatory requirements, sign functions, performance requirements for various retro-reflective sign materials, financial considerations and a number of recommendations. However this document does not set out any additional retro-reflective performance levels to those set out in TD 25/15, nor does it highlight any alternative measurement techniques for assessing the night-time visibility of signs.

4.2.4 *Network Management Manual Part 3 – Routine Service*

The Network Management Manual provides a list of consideration that affect the condition of road sign, thus affecting their performance (HE, 2009). These are:

- Visual Performance
- Electrical Safety
- Structural Integrity
- Sign Cleaning
- Improper Installation (parts damaged or missing)
- Loss of Legend
- Reduced Retro-reflectivity Properties
- Sign Face Material Degradation
- Illumination Failure (Lamps not working, lamps on during daylight, electricity failure)
- Wiring Wear/Wiring in Hazardous Condition
- Corrosion on Post/Support/Frame, Fittings and Plates
- Incomplete Inventory.

4.2.5 *Well-Maintained Highways*

This guidance document details the importance of regularly monitoring road signs to ensure legibility, visibility and effectiveness are not compromised (UKRLG, 2005). It reiterates many of the aspects covered in TD 25/15, calling for inspections to monitor the condition of numerous characteristics such as:

- Daylight Visibility (Surface Luminance)

- Degradation of Colour
- Night-time Visibility (Retro-reflectivity)
- Fixings Condition
- Legibility Distance (Minimum Clear Visibility Distance).

All of the above characteristics should be inspected after the sign face has been cleaned. Again it calls for inspections and data to be collected on an annual basis as a default option. More frequent inspection will be determined by their need and the associated risks to the inspector. Inspections should also examine whether a sign is still suitable for purpose, inappropriate or a distraction to road users (sign clutter). Any signs that are deemed unnecessary should be noted for removal.

4.2.6 *Other National Standards*

A number of additional standards, regarding sign performance, inspection and maintenance, were reviewed by consortium members. In Australia, the Austroads Guide to Asset Management (Part 7: Road-Related Assets Performance) provides advice for NRAs (in Australia and New Zealand) on the management and monitoring of road signs. This guidance reiterates the majority of the information presented in the UK standards and guidance. Similarly for the standards used in Ireland.

In Germany a number of standards and guidance documents are available including: RWBA (Guidelines for Signposting on Highways); HAV (Notes for Installing Traffic Signs); TLZ VZ (Technical Delivery and Test Conditions for Vertical Signs); and ZTV VZ (Specification and Guidelines for Vertical Traffic Signs). In Austria national standards and guidance include: RVS 08.23.01 (Road Safety Measures – Traffic Signs); RVS 05.02.12 (Delineators – Signs and Signposts on the Network); and RVS 05.02.13 (Signage and Signposting on Motorways). An examination of these national standards has shown that, in general, they cover the same criteria as laid out in UK standards and guidance.

4.3 Review of practice in the assessment of the performance of road signs

A stakeholder engagement exercise was carried out to investigate current industry practice in evaluating the performance and condition of road signs. Two questionnaires, one for NRAs and one for survey/equipment providers, were developed on the basis of the standards review findings and consultations with the consortium partners (these questionnaires can be found in Appendices A and B). This section will discuss the results from the NRA questionnaire, whilst those for the survey provider questionnaire are discussed in section 5.

The questionnaire developed for NRAs comprised of two sections: The first section contained 10 questions regarding the NRA’s current level of understanding of the asset, and their current approach to managing them. The second section contained a list of the characteristics, identified from the standards review. For each characteristic stakeholder were asked:

- If that characteristic was measured or recorded? (yes/no)
- How is the characteristic measured? (method and/or instrument used)
- What level of importance would you assign to this characteristic for the assessment of its condition? (high, medium, low, neither).

This allowed us to determine what NRAs judged to be the most and least important characteristics in order to effectively manage the asset. Across the consortium, 83 National

Road Authorities (NRAs) (including regional authorities) were identified and approached. An information pack and the questionnaire were then distributed to all 83 potential stakeholders.

4.3.1 *Summary of NRA Questionnaire responses to section 1 (understanding the asset)*

Q1. What is the approximate length of your road network?

Q2. *Roughly how many road signs do you have on your network?*

Of the 83 stakeholders who received the questionnaire & information pack, timely responses were received from 13 NRAs, a 14% response rate. These included responses from Austria, Sweden, the Netherlands, Ireland, Germany, Belgium, Norway and the UK. In total the 13 NRAs managed over 150,000km of motorways, dual and single carriageways. Across this figure NRAs held over 2 million signs.

Q3. *What is your general approach to managing and understanding the condition of road signs? For example:*
a. *Do you have a clear view of the status of all assets i.e. a regular monitoring regime?*
b. *Do you perform ad hoc repairs if something goes wrong (is there a reporting system - details?)?*
c. *Is the approach based on age of the asset?*

Only five NRAs believed they had a clear view of all their sign assets, while eight NRAs stated that they did not have a clear view of the status of their signs. Despite a relatively low understanding of the assets' status eight NRAs did carry out regular inspections and had a monitoring regime in place. This demonstrates that whilst a regular monitoring regime may be in place, it may not result in the NRA having a clear understanding of the current performance levels of their assets. In some cases this may relate to monitoring regimes which are only just being introduced, or still in their infancy, in which case the NRA does not hold enough data on all their assets to make such a judgement. Five NRAs did not have a regular monitoring regime in place. The majority of road authorities (12) said they carried out ad hoc repairs; with only one of these basing their management approach on the age of the asset.

Q4. *Where you have a monitoring regime, what does this measure and what methodology do you use? E.g. Measurement of retro-reflectivity using retro-reflectometer (hand held or attached to a vehicle travelling at traffic speed); Measurement of wear or corrosion; Measurement of structural integrity*

Of the eight authorities that had a regular monitoring regime in place, only 6 made objective retro-reflectivity measurements, all using hand-held devices. In most cases retro-reflectivity measurements would not be made across all assets on the network, instead a representative or random sample (e.g. 5% of the total network) would be chosen and surveyed. Seven of the eight authorities inspected their assets for signs of corrosion and subjectively assessed the overall structural integrity through visual inspections.

Q5. *Where you do not have a regime, do you feel there is a need for condition monitoring to map the state of these assets? If not, please tell us why not (e.g. the condition cannot be measured, regular replacement removes the need for monitoring).*

The five NRAs that did not currently have a monitoring regime in place all believed that there was a need to implement some form of condition monitoring. Even those that already had a regime in place also remarked upon its importance, and the need for continually updating inventory records and improving their current level of understanding and the survey techniques they adopt. One respondent that regularly monitored their assets (based on retro-reflectivity demands and visual inspection criteria) believed that they could not add anything, in terms of measurements, to their current approach, reporting that they had experienced few issues and rarely encounter structural problems.

Q6. *Do you use an asset management system for managing road signs?*

Surprisingly only four participants had established an asset management system for planning maintenance works and forecasting budgets. The other eight NRAs stated that they did not use any formal asset management tools; although two did state that they were currently in the process of initiating systems in the near future to help manage their sign assets.

Q7. *What methods of maintenance are applied to road signs?*

All respondents stated that they undertake a range of maintenance treatments, such as replacement/renewal; cleaning; post stabilisation; clearing vegetation; tightening fixings and other minor treatments. Replacement and cleaning (including graffiti treatments) were by far the most popular maintenance techniques used. Second to these was vegetation cutting. Only a couple of NRAs carried out foundation stabilisation works; tightening fixings, re-orientating sign faces and replacing missing pole caps. None undertook specific works to target corrosion; instead they would default to replacing the asset as a whole.

Q8. *How do you decide if a road sign requires each type of maintenance? I.e. on what criteria are maintenance / repair decisions made: Is the decision based on e.g. the asset's age, its measured condition etc.? Please give details.*

Participants highlighted that there were a number of considerations to take into account depending on the need of the asset when determining maintenance need. The majority stated that maintenance was carried out based on the inspector's findings and professional judgement. In many cases NRAs would automatically replace the asset if it was damaged during a vehicle collision. Further to this if signs displayed poor retro-reflectivity properties, exhibited signs of wear and deterioration, which could not be rectified through cleaning, the sign would be replaced. Only one NRA based their approach on the age of the asset, as highlighted in question 3: if a sign exceeds its service life it would be replaced. Routine maintenance, such as cleaning and vegetation clearing, were carried out as a matter of best practice. In most cases cleaning would be undertaken 2-4 times per year for all assets and vegetation clearing would be carried out 1-2 times per year during the spring and summer.

Q9. *If the maintenance is based on measured condition, are thresholds applied to the measurements? If so are these thresholds defined in a standard or just within your organisation?*

Five NRAs (and the contractors they employ to carry out inspections) used some form of measured threshold to justify maintenance; four of these used intervention levels stated in national and international standards; whilst one NRA had developed their own in-house thresholds. The other 7 participants stated that they (and their contracted inspectors) did not use any form of measured threshold, as stated in the relevant standards, and instead relied upon the experience and professional judgement of inspectors. Some of these respondents commented that they would not apply established intervention thresholds because of budgetary constraints; adopting threshold values would often interfere with the best use of available funding.

Q10. *Do you combine different types of measurements, to make a decision on maintenance e.g. combine measurements of structural integrity and corrosion?*

Eight NRAs stated that they did not combine measurements in order to decide upon the maintenance approach, instead if the asset failed to perform on any single measure, or if the inspector recommended so, it would simply be replaced. Four NRAs however stated that they did combine different measurements and made best use of any available data to target maintenance.

4.3.2 *Summary of NRA responses to section 2 (monitoring road signs at the network level)*

The second part of the questionnaire considered each condition property identified in the standards review and asked stakeholders if these characteristics were currently monitored, and how. Stakeholders were asked to assign an importance rating to each characteristic, allowing the determination of which characteristics were most important relative to their condition. Low importance levels indicated that information on the characteristic in question would be good to have but was not essential. Medium importance indicated that this information on this characteristic could be quite useful. Assigning a high importance rating meant that this information was essential. Table 10 summarises the overall importance ranking of each characteristic according the NRA stakeholders. In addition to the characteristics listed in Table 10, the NRAs felt that asset inventory was also very important. Asset inventory and the key characteristics of condition are discussed in more detail in the following sections.

Table 10: Key Requirements of Road Signs

Rank	Property	Characteristic
1st	Visibility	Damage/Loss
2nd	Visibility	Obstruction/Obscuration
	Legibility	Orientation
3rd	Visibility	Panel Alignment
4th	Visibility	Night-time Visibility
5th	Legibility	Colour

4.3.2.1 Property: Inventory

Figure 6 illustrates the results of whether or not each characteristic, within the *Inventory* property group, was measured or recorded by the respondents. It can be seen that ten NRAs reported that they had some form of network level location referencing system in place and recorded the locations of their assets. Location references include: area reference and section label; road name and number; chainage; and GPS co-ordinates. Current techniques for locating assets vary. Location data can be compiled from: contractors' hand-over documents; a review of historical records (such as construction drawings and contracts); desktop surveys utilising satellite and street-view images; high-speed video surveys enabled with GPS; and slow-speed manual survey using a hand-held GPS device. This characteristic received the highest importance rating of all characteristics across all property groups. An asset cannot be managed if you do not know where it is located.

Second to a location reference in importance was that assets had a unique ID code. Nine NRAs stated that they used ID codes, recording these codes in their inventories and placing a weatherproof sticker on the signs backing board. This allows inspectors to account for the assets with ease during manual visual inspections. Only three NRAs said they recorded, either as a function of the inventory records or by means of a database, and actively monitored the time period between cleaning maintenance. This characteristic received a very low importance rating, despite it being one of the principle maintenance activities.

Similarly to monitoring the cleaning interval, only three NRAs held records of the manufacturer declared performance criteria as found on the products CE marking. It can be seen that most participating NRAs recorded the assets date of installation, which would be stored in the inventory records or within a similar database. This characteristic received a relatively high importance rating, despite most NRAs stating that they did not base their management approach on the age of the asset. Surprisingly, and contrary to the positive responses discussed earlier, nine NRAs did not record the dates and details of previous maintenance efforts.

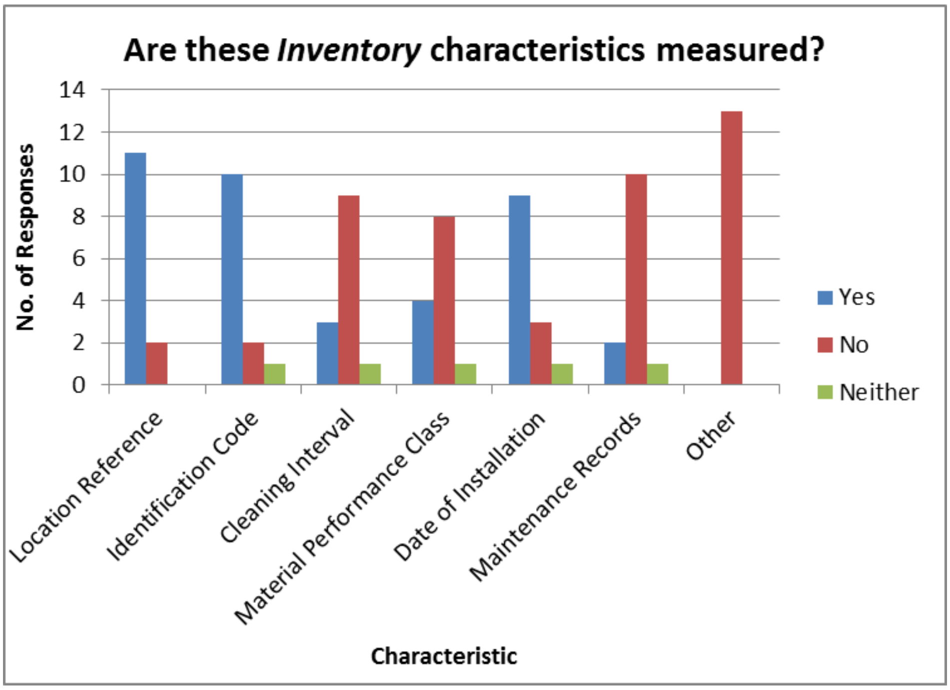


Figure 6: Inventory Characteristics Results

4.3.2.2 Property: Visibility

Figure 7 illustrates the results for the visibility characteristics. Despite being ranked as the fourth most important characteristic, for determining the asset's overall performance, night-time visibility (coefficient of retro-reflection) was only objectively measured by four NRAs. This may be due to the practical limitations for making such measurements: The current technique is to use a hand-held retro-reflectometer, a slow speed manual approach. For any single network there can be tens of thousands of signs, so conducting spot measurements for each sign would take an inordinate amount of time. Further to this it would require extensive use of traffic management to ensure the inspectors safety whilst onsite, which would be a costly exercise if all assets were to be inspected.

The lack of measurement of night-time visibility is also in contrast to the national and international standard requirements discussed above, where night-time visibility is seen as one of the most important factors relating to performance.

Further, daytime visibility was only measured by one NRA, with the other eleven not making any daytime visibility measurements. This at least agreed with the rating of daytime visibility not being seen as an important performance characteristic.

Four NRAs undertook colour measurements; however this was not by means of daytime luminance and chromaticity co-ordinates but instead by visual assessments (high-speed and low-speed methods). The low uptake of colour measurements was reflected in its importance rating which was very low.

Eight NRAs did not measure the minimum clear visibility distance. Again, this is reflected in a very low importance rating. Obstruction and obscuration, mostly caused by vegetation growth and the build-up of dirt, was seen as one of the most important characteristic relative to performance; if you cannot see the asset it is obviously not performing as intended. Whilst there is no practical measure to assess flora and dirt build-up, the negative effects can be minimised through routine cleaning and seasonal cutting.

Damage/Loss was rated as the second most important characteristic for determining performance. Seven NRAs currently measure this by means of visual inspections which can either be detailed manual inspections or by coarse traffic speed inspections.

The last characteristic is this group was panel alignment; this was rated as one of the most important characteristics overall. Despite its importance, only six NRAs make these measurements by means of visual assessment.

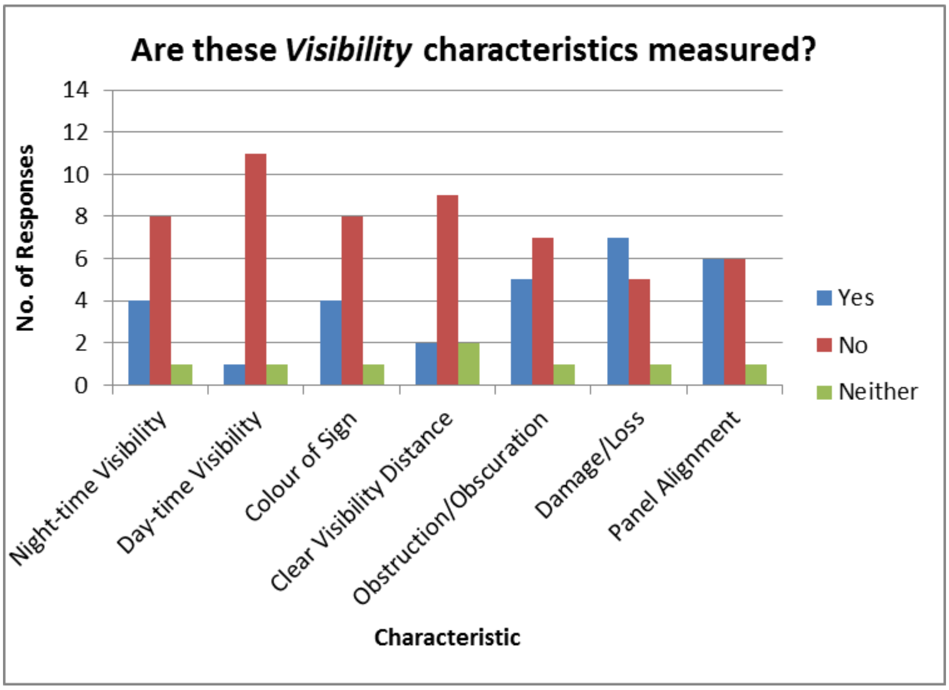


Figure 7: Visibility Characteristics Results

4.3.2.3 Property: Durability

As can be seen from Figure 8, resistance to weathering and impact resistance (both laboratory measurements) were not measured by the majority of participants. This is mirrored in their importance ratings which again were very low: they did not place in the top 15 characteristics.

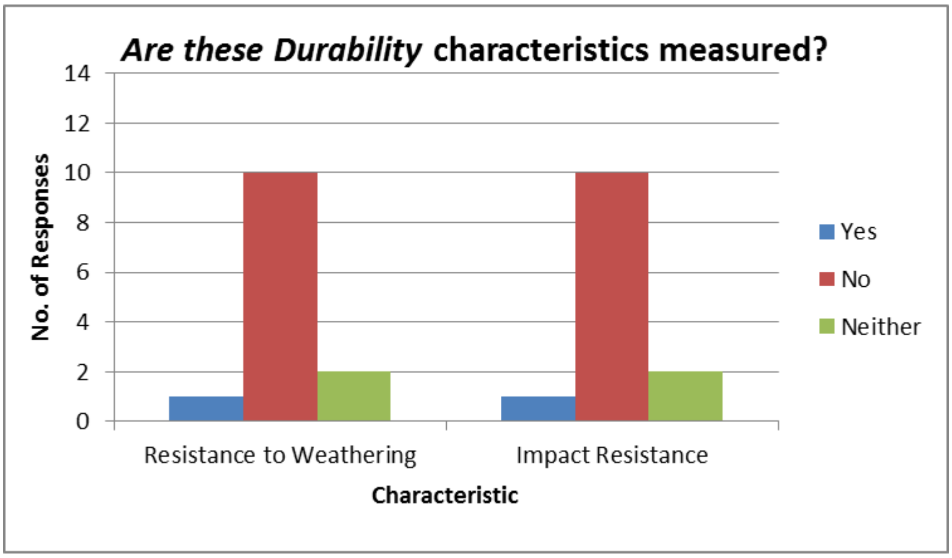


Figure 8: Durability Characteristics Results

4.3.2.4 Property: Legibility

The legibility characteristics, which in many respects are closely tied to the visibility characteristics included extent of colour; contrast between elements; damage/loss of legend; and orientation. All of these characteristics were measured or assessed from a visual inspection. The most highly rated of these was orientation, which was also voted as the fifth most important characteristic for understanding the performance level of the asset. As can be seen from Figure 9, nine NRAs recorded this characteristic during their visual inspections. The other three characteristics received low importance ratings, despite many NRAs considering these characteristics in their visual inspections.

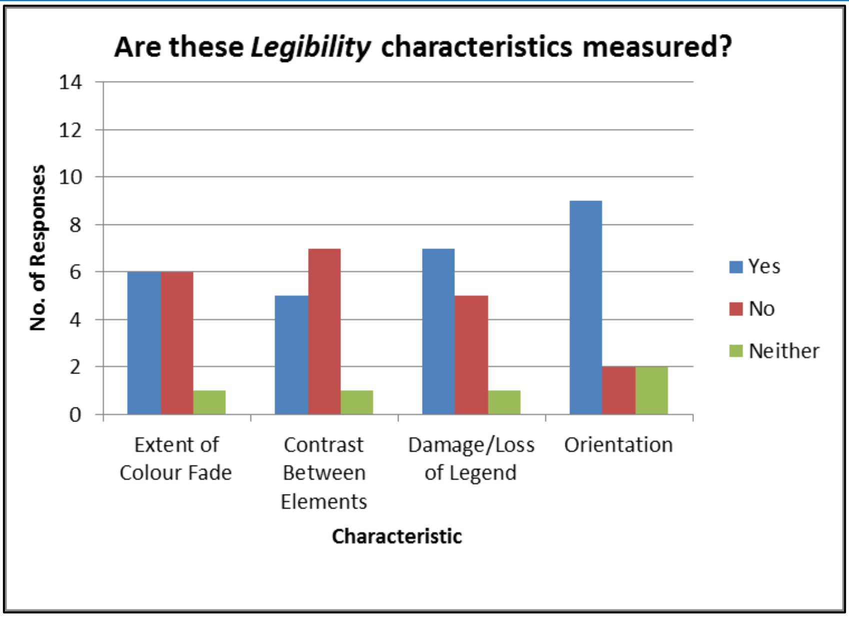


Figure 9: Legibility Characteristic Results

4.3.2.5 Property: Structural

Five NRAs measured the foundation condition during their visual inspections (Figure 10). While this cannot be measured directly there are a number of indicators that relate to the foundations condition and stability, such as leaning and swaying supports, and obvious signs of ground movement around the structure. Six NRAs however did not monitor or measure this characteristic. Similarly, five NRAs also said that inspecting the structure for missing or damaged fixings was also a consideration during the visual inspection. Wind load deflections were not regularly measured by NRAs as this is considered during the design of the asset, and further to this there are few ways to assess this characteristic in-situ. All structural characteristics received low importance ratings.

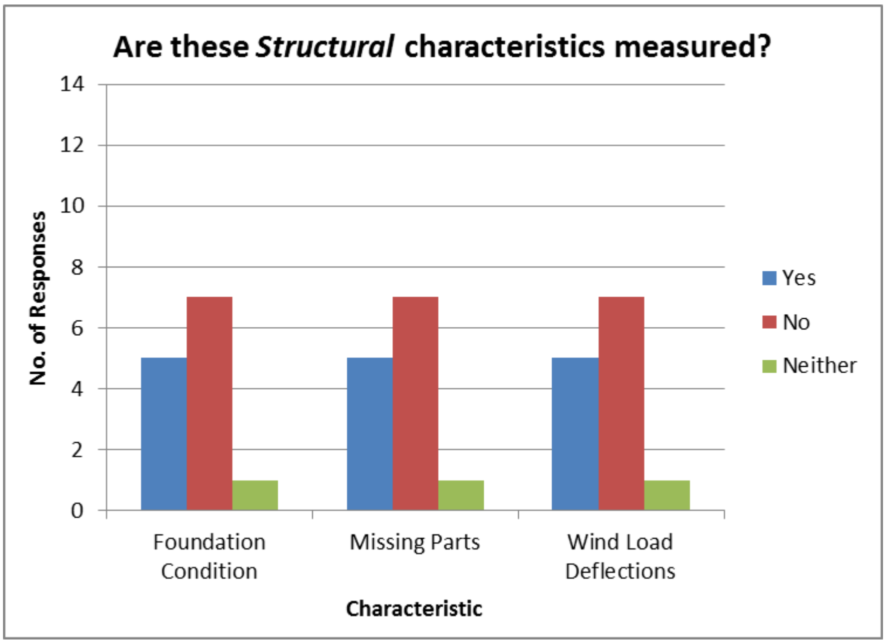


Figure 10: Structural Characteristics Results

4.4 Summary and Recommendations

The results from the NRA questionnaire suggested that NRAs felt that Inventory was the most important information to collect for road signs - without this collecting condition data is redundant. The inventory should contain information such as location, identification code, date of installation, maintenance records, manufacturer declared performance characteristics, cleaning interval etc.

Damage and loss, a measure of visibility, was the condition characteristic considered to be most important by the NRAs and was the second most measured condition characteristic (6 respondents measured this). Thus this was considered to be the first and most important key characteristic for road signs.

Obstruction or obscuration of the sign and also the orientation of the sign were ranked as equal second in importance by the NRAs. Whilst Orientation was the most measured of the characteristics (9 of the 12 respondents), it was thought that this was due to the relative ease of measurement of this characteristic. Also, if the orientation of a sign is not correct, this does not necessarily mean that it is not visible/illegible but obstruction or obscuration of a perfectly oriented sign does result in a reduction in the visibility of the sign. Therefore it is proposed that Obstruction/Obscuration should be the second key condition characteristic, with Orientation as the third key condition characteristic.

The third most important characteristic identified by the NRAs was Panel Alignment. This was measured by half of the respondents and therefore is suggested as the fourth key condition characteristic.

Retroreflectivity of unlit signs – the night-time visibility – was the fourth most important characteristic to the NRAs. This was measured by only 4 (a third) of the respondents and is a irrelevant is the sign is damaged/missing, obscured, or has its visibility or legibility reduced by one of the condition characteristics mentioned above. Thus retroreflectivity is proposed as the fifth key condition characteristic.

The last characteristic considered important by the NRAs was the colour of the signs – particularly colour fade, affecting the legibility. This was measured by half of the respondents and thus is proposed to be the sixth key condition characteristic.

All other characteristics received a low importance rating and were not often measured. Thus these have not been considered to be key condition characteristics.

In summary, the key characteristics of road signs that indicate their condition and are considered important by road owners are therefore:

- Damage or loss
- Obstruction/Obscuration
- Orientation
- Panel Alignment
- Night-time Visibility
- Colour fade.

5 Technical Background – Methods for Measuring the Condition of Road Signs

5.1 Information gathering

5.1.1 *Survey Provider Questionnaire*

A questionnaire, consisting of 8 questions relating to road signs (Appendix B) aimed to understand the current inspection techniques used by survey providers; i.e. what equipment is used for monitoring, what characteristics they measure, what data is delivered, and how this data is then used to assess the asset's condition. In total 24 survey/equipment providers were identified and contacted. Despite repeated efforts to engage with this stakeholder group, only four survey providers submitted completed questionnaires in the allocated time frame. The following summarises the responses received for current surveys.

Q1. *For which road network(s) have you had or do you have a contract to provide asset surveys for?*
All survey providers that responded to the questionnaire stated that they primarily undertook surveys for national motorways and highways, with two stating that they also carried out surveys on smaller roads for local council authorities.

Q2. *What survey methods/techniques do you currently use to monitor the condition of road signs? What measurements are recorded?*
As highlighted through the NRA questionnaire results, survey providers use a number of methods to assess sign assets:

- **Traffic Speed Survey**: These inspections use a vehicle fitted with a GPS tracker, high resolution forward/backward facing imagery, and an odometer. This allows the survey inspector to capture large amounts of data within a short space of time. From the installed equipment the following measurements can be made/inferred: inertial data; sign type; defect images; location co-ordinates; dimensions; mounting height, distance from carriageway; legibility of text at known distance increments; orientation; alignment; and support type and condition. From this data a trained inspector makes an overall judgement of whether or not the asset is fit-for-use.
- **LiDAR Survey**: These surveys use a vehicle fitted with a LiDAR system, HD imagery and a GPS tracker and can be carried out at traffic speed. All results are automatically processed and analysed using purpose built software with auto-recognition capabilities. This approach can distinguish location, sign type and retro-reflectivity properties.
- **Manual Inspection**: These are slow-speed manual surveys relying on the professional judgement of the inspector. Although it is a slow-speed approach, it has the advantage of being able to collect detailed datasets on each sign. The type of measurements that could be made varied and was dependent on the requirements of the NRA.
- **Traffic Speed Routine Survey**: This survey is the simplest and least technical. It is simply a vehicle operating at traffic speed with the inspector sitting in the passenger seat taking notes. In this case the inspector is simply observing if any obvious defects are present which may pose hazards to road user safety, such as signs damaged from collisions, graffiti, and obstruction caused by vegetation.

Q3. *Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.*
The only slow-speed technique inspectors used was manual visual inspections. These surveys could be undertaken from a moving vehicle but the quality of data per asset would be reduced. In cases where retro-reflectivity measurements are taken using a hand-held retro-reflectometer these could be performed at traffic speed, utilising traffic speed retro-reflectivity equipment developed by two European companies Euroconsult and Cidaut.

Q4. *How is the inspection performed? Please describe how the condition of road signs is determined? (For example: Scale 1-5; Yes/No; good condition – bad condition)*
Two survey providers stated that they used a general scale/rating based on professional judgement. One provider stated that they did not use a scale, instead signs would either pass or fail based on the individual inspector's judgement. The last provider said the inspections were performed in accordance with their clients' needs. When retro-reflectivity measurements were undertaken surveyors would compare results against some form of retro-reflectivity index.

Q5. *Does the inspection take place according to a standard?*
None of the survey providers carried out inspections in accordance with any standard.

Q6. *How often does inspection take place?*
Providers stated that inspections would be undertaken depending on their clients' needs and budget. This could be from 1-4 times per year, to rarely.

Q7. *What are the yearly costs per km for these measures?*
Costs can vary depending on the level of detail the client requires. For high-yield data acquisition techniques and detailed visual inspections prices range from 30-100 €/km. Routine traffic speed surveys cost approximately 3.5€/km.

Q8. *Are you aware of any novel or emerging technology that could be used to provide high speed measurements of road sign condition? If so, please provide details of this?*
All survey providers were aware of some form of novel traffic speed technologies for sign inspections, these are listed below:

- Driveby Mobile Mapping
- Korec Asset Survey System
- LiDAR Surveys
- Automatic Recognition Systems
- Traffic Speed Retro-reflectometer (EuroConsult & Cidaut).

5.2 Information gathering – further consultation and review

In addition to the stakeholder (survey provider) questionnaire discussed above, a further knowledge gathering exercise was carried out to seek information on the methods available for the measurement of road signs. This built on the responses provided by the survey providers, combined with a review of available literature on equipment, to identify existing and emerging technologies. PREMIUM also identified previous research projects, including ASCAM and TRIMM, as information resources for different measurement techniques for collection inventory data of road signs and reflectivity measurements. The literature review showed that several tests have reported measurement of road signs at traffic speed. This was followed up with a number of consultations with different survey providers to obtain more details about particular mobile measurement technologies.

The results of the further information gathering are discussed in the following sections, in which we break down the technologies identified in terms of the key characteristics listed in Section 2:

- Inventory
- Damage/Loss
- Obstruction/Obscuration
- Orientation
- Panel Alignment
- Night-time Visibility
- Colour Fade

These measurement technologies are shown in Figure 11. The techniques include visual inspections, hand-held and mobile devices, image analysis using algorithms and novel systems.

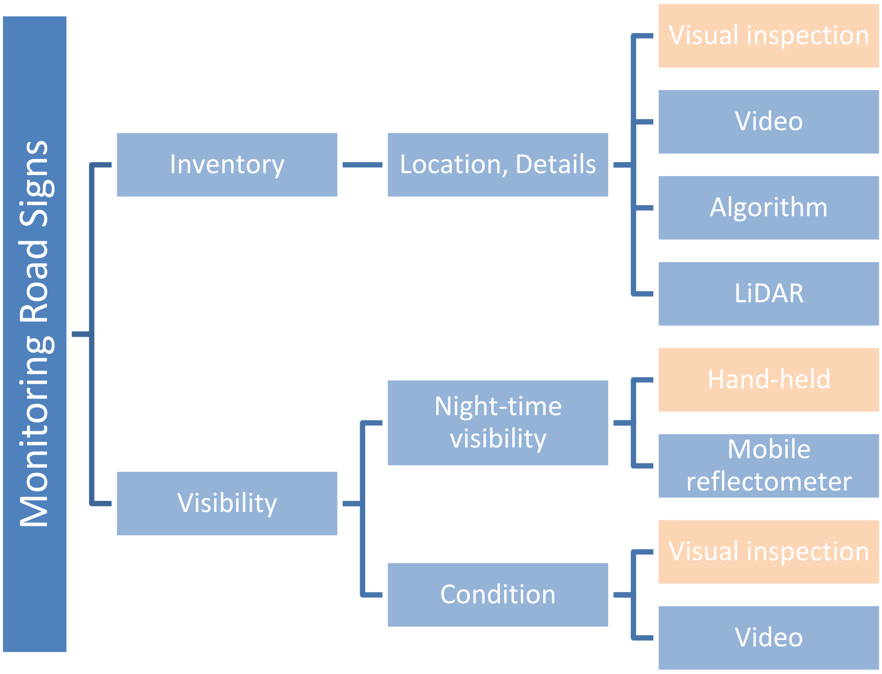


Figure 11: Measurement technologies for monitoring of road signs

5.3 Key data - Measuring the inventory of road signs

As noted in Sections 2 and 4, it has been generally recognised that information on the asset inventory is important for effective management of the road sign asset. The collection of inventory data forms the basis of road inventory management as it enables the road authority to understand the extent and value of the inventory stock present on their network and can be linked with ongoing condition monitoring. Ideally the inventory should be continuously updated.

As observed in the TRIMM project (Spielhofer, 2014) road authorities commonly record inventory using pen and paper and optionally a GPS transmitter. This requires that an inspector walks the network to record the location of assets. As a result TRIMM concluded that the approach to the collection of inventory data in some of the leading industrial countries of the European Union is resulting in limited knowledge about the type, location and condition of road inventory.

However, there are a number of new/emerging recording methods which can be used for inventory data collection:

- Photogrammetric, one camera (2D location)
- Photogrammetric, panorama (2D location, 360° view)
- Photogrammetric, two cameras (stereovision, 3D location)
- Photogrammetric, multiple cameras (3D location)
- Laser scanning (LIDAR), static (3D Point cloud with intensity/colour information)
- Laser scanning (LIDAR), moving (3D Point corridor point cloud with intensity/colour information).

The photogrammetric recording methods deliver video-sequences or photos using one or several cameras, with each image accurately geographically referenced using inertially aided GPS so that inventory items can be identified in the images and their position extracted using either manual or automated methods. The creation of point clouds, which include intensity and/or colour information, is the main outcome of laser scanning methods. High level systems claim to provide absolute position accuracy of up to ~10 cm, although this depends heavily on GPS reception. To improve accuracy, control points with known locations can be used. This leads to accuracies of better than 5 cm.

The implementation of video and LIDAR based systems for the collection in inventory data has grown significantly in recent years. A review of these systems (in TRIMM and in PREMIUM) identified several including:

- The German (Lehmann+Partner) I.R.I.S – using single cameras (Figure 12)
- The Dutch Cyclomedia Measurement System, using 360° rotating camera (Figure 13)
- The Austrian AIT Stereo photogrammetric systems (Example 1)
- Fugro/VDOT asset data collection (Example 2)
- The Belgian KLM Aerocarto, using up to 14 cameras
- The UK Yotta Video Survey Van – using multiple cameras.

Figure 12: Integrated Road Information Scanner I.R.I.S (LEHMANN & PARTNER)

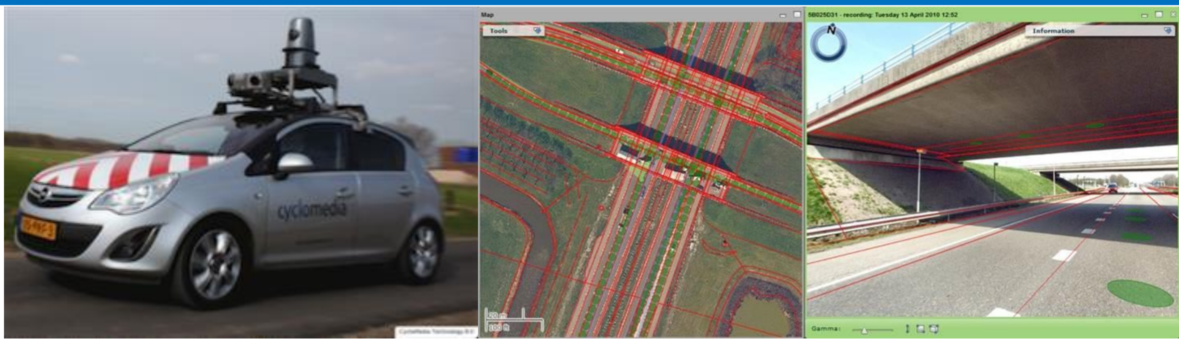


Figure 13: Cyclomedia Measurement System

Example 1: Video survey - AIT

AIT operates two image acquisition systems for road asset inventory analysis. Both the truck and the passenger car are equipped with up to five cameras that record street level image from different angles. The two front facing cameras are calibrated and allow stereoscopic positioning of road assets (e.g. road signs and road markings). In combination with the integrated positioning system (Applanix POS LV420), geographic coordinates can be determined for all visible objects. The camera resolution is 2 Megapixel and images are triggered every 2 m. The truck is used for inventory on motorways and highways (together with other road surface property measurements like skid resistance and evenness) while the passenger car is used for asset collection in urban environments. The absolute location accuracy is – depending on the effort for post-processing – up to 10 cm which has been evaluated using static GPS measurements.

In the last 5 years, more than 2.500 km of roads have been surveyed and ~27.000 road signs have been inventoried together with 15.000 road markings and 10.000 driver location signs.

The process starts with identification and positioning of road sign poles. After that, the (up to three) road signs on the post are identified and grouped according to viewing angle. Text of the signs and additional plates is captured and the condition of the sign plates is evaluated according to a catalogue. Finally, an algorithm checks for legal conformity of the signs (e.g. if every “No stopping” has a beginning and an end) and a report is produced.

Figure 14: The two survey vehicles (truck and passenger car)

TRIMM undertook a practical trial of the use of video equipment to collect inventory, as discussed in Case Study 1 below. It can be seen that this approach is becoming proficient for application in the identification of road signs and hence population of inventory databases. However, it should be noted that the extraction of the inventory (road signs) data is manual, requiring that an assessor views each image and “clicks” on the signs.

Several recent studies have also investigated the use of LIDAR for road signs detection and extraction, and are showing reliable results. These surveys can combine imaging and LIDAR techniques to identify signs, and offer the potential for automated extraction of the road signs, as discussed in Case Study 2.

Case Study 1: Inventory of roadside objects – TRIMM

In the FP7 research project TRIMM (“Tomorrow's Road Infrastructure Monitoring and Management”), an equipment evaluation of a survey vehicle for inventorying roadside objects has been carried out. The evaluation was done in three areas in Vienna with different characteristics, ranging from densely built-up urban areas to rural areas. A reference data set provided by the municipality of Vienna from terrestrial survey containing locations of masts and poles, hydrants manholes and gullies was prepared. A second reference dataset containing road signs was prepared using geodetic GNSS survey equipment. The equipment to be evaluated represented state-of-the-art mobile mapping technology with calibrated cameras and a GNNS-IMU coupled positioning device that uses RTK corrections (correction data from fixed reference stations or networks) in post-processing.

Two tasks were evaluated:

- What is the location accuracy of objects detected by the mobile mapping vehicle? and
- How complete is the survey meaning how many objects could be detected in comparison to the reference data sets.

The trials have shown that it is possible to undertake surveys at traffic-speed to identify and locate inventory assets such as signs, manholes etc. With the combined GNSS-IMU measurement devices and RTK corrections that are available in most countries, a position accuracy of locating these items of better than 1 m should be possible for most locations on the network. Due to IMU coupling, passages through forests and alleys do not reduce the accuracy significantly. Of course this is possible only to a certain extent. Densely built up areas (city centres) with high buildings still remain a challenge. However, manual GNSS surveys with RTK rely on the same base technology and therefore face the same problems in these areas. In area 1, getting a highly accurate RTK fix with the handheld GNSS receiver was a rare occasion and the calculated accuracies obtained were in the range of 4-5 m. For the more rural areas, the accuracy of ~1 m could be reached for most items. If the satellite outtake is short (e.g. only a few seconds when driving through a tunnel) the traffic speed survey has the edge over a manual survey as the static measurement would not get a position at all.

If the demands are higher, in the decimetre-range or even centimetre-range, additional control points are absolutely necessary.

The trial showed differences in terms of completeness for different asset types. Road inventory that can be seen from the survey vehicle and is unique in shape, colour etc. perspective will have a higher percentage of completeness than more challenging items. Categories that are similar in look and appearance (like gullies and manholes in the equipment evaluation) may be difficult to distinguish. Objects like manholes, that are often hidden under or behind parked cars are more difficult to locate and will lead to a lower completeness level. On the other hand, manual surveying from a moving vehicle faces similar problems for inventory objects hidden under parked cars.

Figure 15: The Yotta survey vehicle

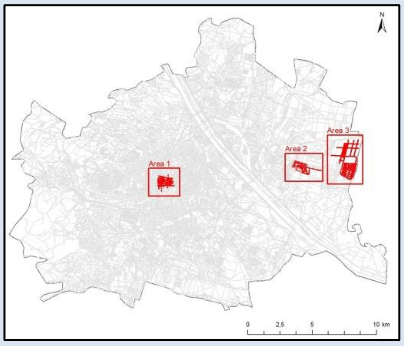


Figure 16: Location of areas for equipment evaluation in Vienna

Figure 17: Road sign example

	AREA 1 (%)		AREA 2 (%)		AREA 3 (%)	
	< 1m	< 5m	< 1m	< 2m	< 1m	< 2m
Gullies	19.5%	76.5%	97.1%	99.7%	93.0%	98.2%
Hydrants	29.9%	93.1%	94.9%	98.3%	96.9%	100.0%
Manholes	25.2%	88.2%	90.8%	99.6%	96.7%	99.8%
Masts and Poles	35.4%	96.9%	92.0%	99.7%	95.2%	99.3%
Signs	No data	No data	92.6%	98.9%	No data	No data

Table 11: Correctness of position for the asset types

	AREA 1 (%)	AREA 2 (%)	AREA 3 (%)	Comments
Gullies	60.5%	85.5%	69.8%	
Hydrants	77.8%	95.2%	91.5%	
Manholes	87.6%	64.%	97.3%	
Masts and Poles	95.5%	99.5%	100%	
Signs	No data	90.5%	No data	Reference Data only available in area 2

Table 12: Results of completeness for the asset types

Example 2: Asset data collection for Virginia Department of Transportation (VDOT)

Fugro Roadware has been providing pavement and asset data collection for Virginia Department of Transportation (VDOT) since 2008. VDOT's road network includes approximately 51,000 miles of Interstate, Primary and Secondary routes. Fugro Roadware's Automatic Road Analyzer (ARAN) collects information for the road condition (longitudinal profile, rutting, surface defects etc.) and Digital Right of Way (ROW) video using a single Sony (1920 x 1080 pixel) high-definition forward-facing camera (3CCD broadcast quality) for 90º field of view. The digital ROW images are displayed using Fugro's iVision web-based software. The software was used for asset inventory and extraction for over 1.2 million VDOT assets including; signs, highway lighting, drop inlets, curb and gutter, guardrails, ditches, pavement messages, rumble strips, sidewalks, barriers, signalized intersections and logo panels. The asset types and attributes are summarized in Table 13.

Linear Assets	Typical Add-on Attributes	Point Assets	Typical Add-on Attributes
Bridges		**MUTCD Signs**	MUTCD Name, Category, Code, Sign Text, Side of Road, Field Inspection Required?, Support Info
Concrete Barriers	Type, Side of Road, Field Inspection Required?	**Sign Supports**	Type, Material, Side of Road, # of Signs Present, Field Inspection Required?
Sound Barriers	Type, Side of Road, Field Inspection Required?	**Speed Limit Signs**	Speed @ Location
Curbs	Type, Material, Side of Road, Field Inspection Required?	**Drop Inlets / Catch Basins**	
Guard Walls	Type, Side of Road, Field Inspection Required?	**Highway Lighting**	Type, Side of Road, Field Inspection Required?
Guardrails	Rail Type, Post Type, Start/End Treatment Type, Side of Road, Field Inspection Required?	**Intersections**	Controlled? Intersecting Street Name, Pedestrian Signals Present?
HOV Lanes	Specific Hours	**ITS Devices**	Type, Side of Road, Field Inspection Required?
Linear Pavement Markings	Type, Colour, Lane Location, Field Inspection Required?	**Manholes**	
Raised Pavement Markings	Markers Missing? Lane Location	**Median Openings**	
Medians	Width, Curbed?, Protected (Guardrail Present)?, Field Inspection Required?	**Mile Markers**	Side of Road, Field Inspection Required?
Number of Lanes		**Overpasses**	
Retaining Walls	Type, Side of Road, Field Inspection Required?	**Point Pavement Markings**	Type, Lane Location, Field Inspection Required?
Rumble Strips	Side of Road, Field Inspection Required?	**Railroad Crossings**	
Shoulders		**Sidewalk Ramps (ADA)**	
Sidewalks	Material Type, Side of Road, Ramp Present?, Obstructions Present?, Field Inspection Required?	**Traffic Lights**	Lamp Formation, # Present, Pole Type, Field Inspection Required?
Tunnels		**Turn Lanes**	Type, Lane Location, Field Inspection Required?
		Utility Poles	Type, Side of Road, Field Inspection Required?

Table 13: Typical Add-on Attributes for linear and point assets

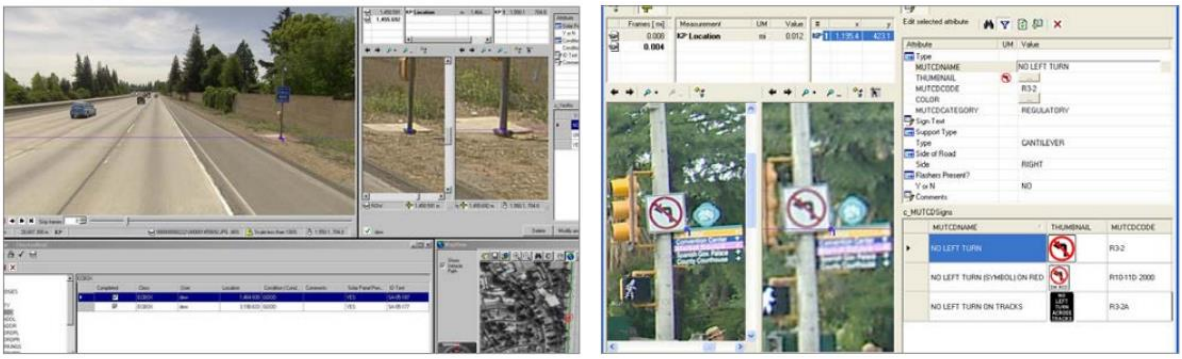


Figure 18: Fugro's software for road signs extraction

Case Study 2: Automatic Retro-Reflective Road Feature Extraction using LiDAR [1]

Data is collected by NAVTEQ using the equipment shown in Figure 21. The data collection apparatus features a 360 degree LIDAR sensor (Velodyne HDL-64E), panoramic camera (Ladybug 3), high definition cameras, GPS, Inertial Measurement Unit (IMU) and Distance Measurement Instrument (DMI). The LIDAR sensor operates on 64 lasers mounted on upper and lower blocks of 32 lasers each and the entire unit spins.

The point cloud has the following data attributes per point: 3-D coordinates, intensity, distance to sensor, sensor angle and time stamp. The detection of the retro-reflective surfaces consists of the following steps:

- Data filtering
- Data clustering
- Geometry fitting

Out of 104 road signs of interest the program detected 102 (≈ 98% recognition) on 7 miles of highway. The two missed signs have significant paint degradation, so the corresponding points have low intensity values. Typical false positives are billboards, passing cars, and signs that are not traffic related.

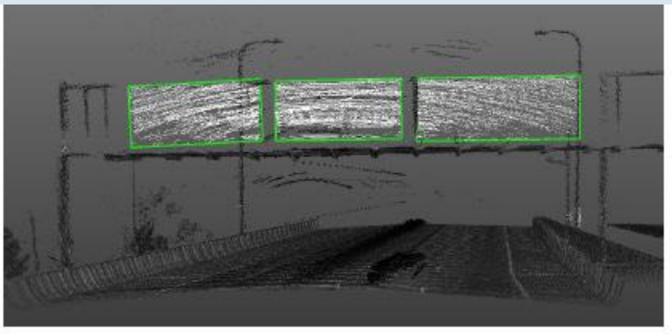


Figure 19: Lidar point clouds and detected retroreflective surfaces

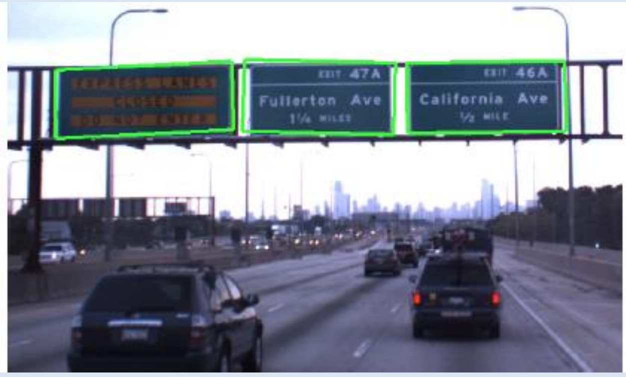


Figure 20: Rendering of the bounding boxes of the detected retroreflective surfaces using the registration of the images with the point clouds

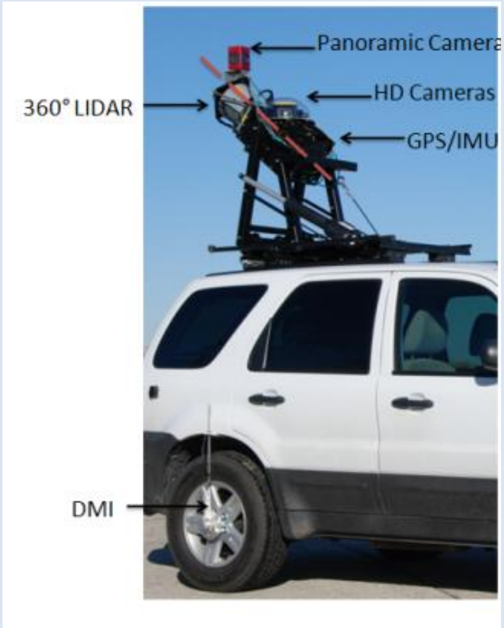


Figure 21: Data collection vehicle mounted with 360 degree LIDAR, panoramic camera, high definition cameras, IMU/GPS and DMI

[1] Xin Chen, Matei Stroila, Ruisheng Wang, Brad Kohlmeyer, Narayanan Alwar, Jeff Bach - Next Generation Map Making: Geo-Referenced Ground-Level LIDAR Point Clouds for Automatic Retro-Reflective Road Feature Extraction

Road signs have specific properties, which distinguish them from the other outdoor objects. These properties are identified by systems for automatic detection and recognition. This process has three main steps:

1. Location of the region of interest and segmentation: A number of binary masks are generated to separate the objects of interest from the background. Usually, colour information is applied since road signs are characterized by a predetermined number of relatively constant colours (white, red, and blue). As a result, regions of interest are determined as connected components, some of which are road signs.
2. Detection by verification of the hypothesis of the presence of the sign: to detect signs most authors use knowledge of their shape (e.g. equilateral triangles, circles, etc.)
3. Categorization of the type of road sign: the final step is the recognition of the sign using a fixed database of all possible road sign models. Methods ranging from template matching to sophisticated machine learning apparatus can be used to achieve robust and efficient recognition of road signs.[2]

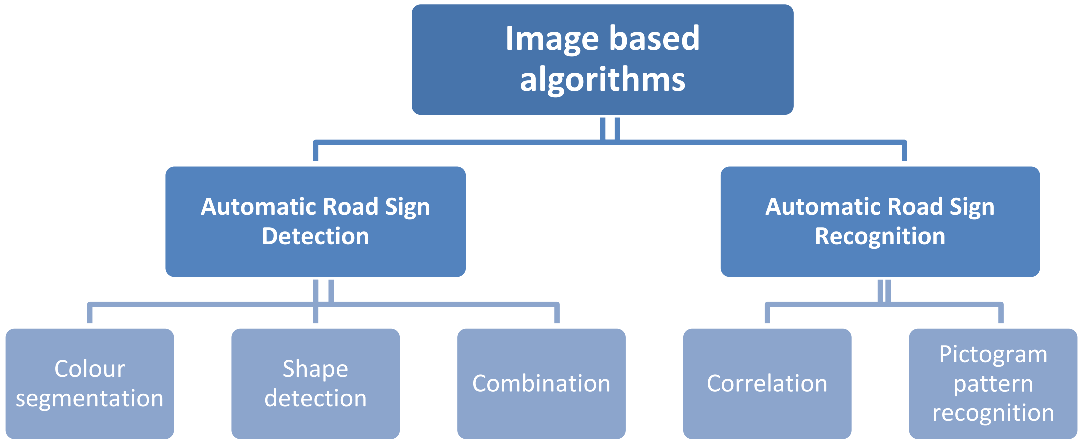


Figure 22: Road sign detection and recognition using image based algorithms

Colour segmentation is used to differentiate the unique road sign colours from the background in the video log images. The lighting condition of the collected video log images can severely distort a sign's colour, which can lead to incorrect colour segmentation results.

Shape detection is used to differentiate a sign's unique shape from other objects in the video log image.

The initial approaches for road sign recognition primarily involve **correlation methods on a pixel level**. This technique can only perform well when the template images can be aligned well with the testing images, which is rarely the case due to the background clutter and geometrical distortion. In addition, it is a challenge to differentiate road signs with slight differences, e.g. warning signs with different texts.

Because the icon and text on a road sign display unique information of different types, **pictogram pattern recognition** approaches have been developed in recent years.

[2] S. Escalera - Background on Traffic Sign Detection and Recognition, 2011

Case Study 3 and Case Study 4 present methods for automatic road sign detection and recognition using video or images and algorithms. The image based algorithms are applied to detect and recognize road signs from images. The case studies show that this method has potential to provide road signs inventory data. However, the algorithms have some limitations, e.g. the signs are not detected because of obstruction, damages etc. (Figure 23).

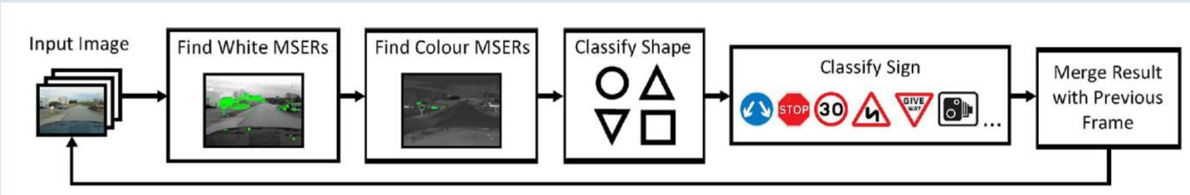
It is clear that the use of image-based algorithm has potential to provide network level inventory data of road signs. More investigation is clearly needed to develop and validate the image based algorithm. This could include further work on the algorithms and their implementation at network level measurement.

Figure 23: Examples of true positives, false positives and false negatives using image based algorithm[3]

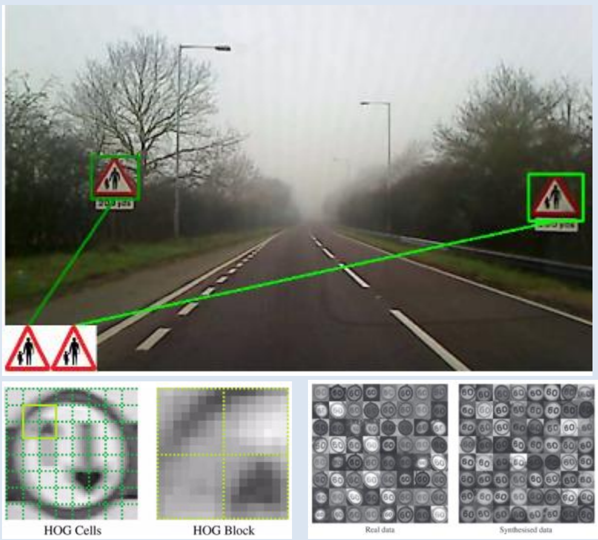
[3] Vahid Balali, Elizabeth Depwe, Mani Golparvar-Fard - Multi-class Traffic Sign Detection and Classification Using Google Street View Images, 2015

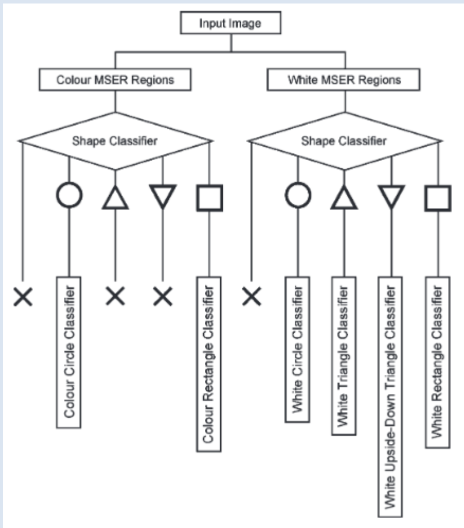
Case Study 3: Automatic road sign detection and recognition[4]

In this case study a novel system is proposed for the automatic detection and recognition of traffic signs. The proposed system detects candidate regions as maximally stable extremal regions (MSERs), which offers robustness to variations in lighting conditions. Recognition is based on a cascade of support vector machine (SVM) classifiers that were trained using histogram of oriented gradient (HOG) features. The training data are generated from synthetic template images that are freely available from an online database; thus real footage road signs are not required as training data. The proposed system is accurate at high vehicle speeds, operates under a range of weather conditions, runs at an average speed of 20 frames per second, and recognizes all classes of ideogram-based (non-text) traffic symbols from an online road sign database.



The system is compared with another one detection system that was proposed by Gómez-Moreno to illustrate the performance of the system. The accuracy achieved for this experiment was 97.6%.





4 Jack Greenhalgh and Majid Mirmehdi, Real-Time Detection and Recognition of Road Traffic Signs, 2012

Method	Gómez-Moreno et al.[11]				Proposed			
	video 1	video 2	video 3	total	video 1	video 2	video 3	total
Signs Correctly Classified	8	1	10	19	12	4	30	46
Signs Misclassified	4	0	4	8	3	0	2	5
Background Misclassified as Sign	7	2	8	17	0	0	2	2
Signs Undetected	6	4	24	34	2	1	6	9
Total Signs in Video	14	5	38	57	14	5	38	57
Precision	**42.1%**	**33.3%**	**45.5%**	**43.2%**	**80.0%**	**100%**	**88.2%**	**86.8%**
Recall	**57.1%**	**20.0%**	**26.3%**	**33.3%**	**85.7%**	**80.0%**	**79.0%**	**80.7%**
F-Measure	**0.48**	**0.25**	**0.33**	**0.38**	**0.83**	**0.89**	**0.83**	**0.84**

Case Study 4: Detection, classification and mapping of the road signs using google street view images [5]

The experiments conducted on 6.2 miles of I-57 and I-74 interstate highways in the U.S. – with an average accuracy of 94.63 % for sign classification. Using computer vision method, road signs are detected and classified into four categories of regulatory, warning, stop, and yield signs by processing images extracted from Google Street View API. Considering the discriminative classification scores from all images that see a sign, the most probable location of each road sign is derived and shown on the Google Maps using a dynamic heat map. A data card containing information about location and type of each detected sign is also created. For detection and classification of road signs a Histogram of Oriented Gradients (HOG) + Colour is used.

Using a multi-scale sliding window that visits the entirety of the image pixels, candidates are selected in each image and passed on to multiple binary discriminative classifiers to detect and classify the road signs. Thus the method independently processes each image, keeping the number of False Negatives (FN – the number of missed road signs) and False Positives (FP – the number of accepted background regions) low. It is assumed that each sign is visible from a minimum of three views. The sign detection is considered to be successful if detection boxes (from the sliding windows) in three consecutive images have a minimum overlap of 67 %. This constraint is enforced by warping the image after and before of each detection using homography transformation.

For constructing a comprehensive database and mining the extracted road signs data, a fusion table is developed including the type and geo-location information –latitude/longitude– of each detected road sign along with corresponding image areas.

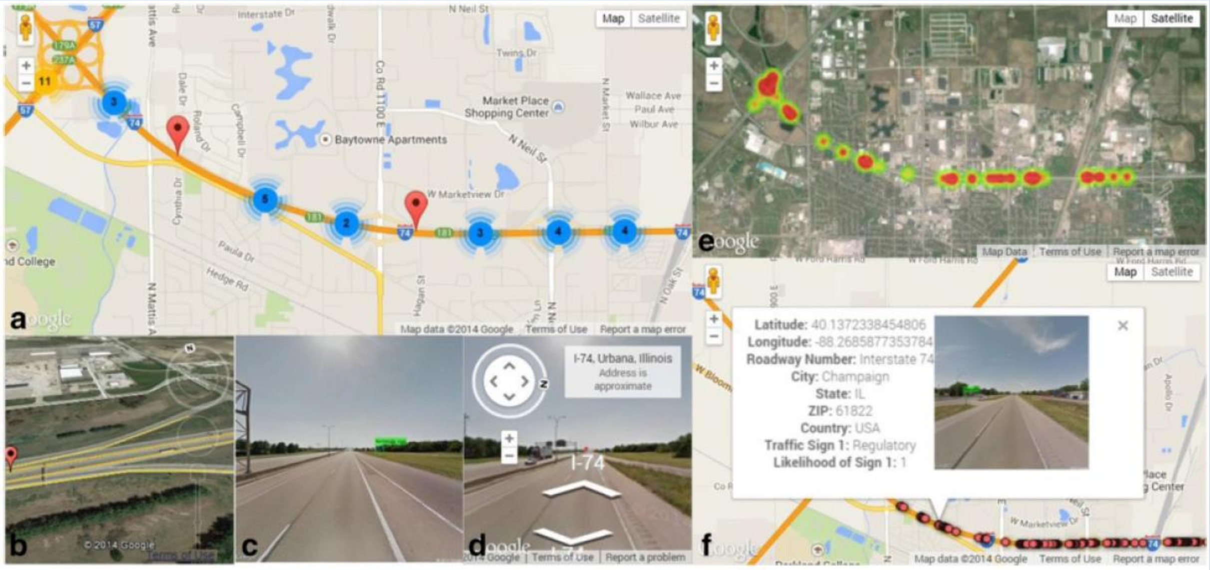


Figure 24: Web-based interface of developed system; a) clustered detected signs, clickable map; b) Google Earth view of sign location; c) detected sign in Google Street View image; d) Street View of sign location; e) likelihood of existing signs on heat map; f) Information on all detected signs

[5] Vahid Balali, Armin Ashouri Rad and Mani Golparvar-Fard - Detection, classification, and mapping of U.S. traffic signs using google street view images for roadway inventory management, 2015

5.4 *Measuring the visibility characteristics - Damage/Loss*

5.4.1 *Slow speed measurement methods*

Slow speed detailed manual visual inspections is the main established method for assessing the presence or extent of damage for a road sign. This includes information about:

- Sign Type,
- ID Code,
- Sign Dimensions,
- Sign Condition,
- Support Type,
- Support Condition,
- Street Name (On, From and To),
- Reflectivity Type,
- Retroreflectivity Rating,
- Visibility,
- Side of Road, etc.

The data are recorded using pen and paper or a tablet (Figure 25). This is a slow speed method and therefore is not practical for use at network level.

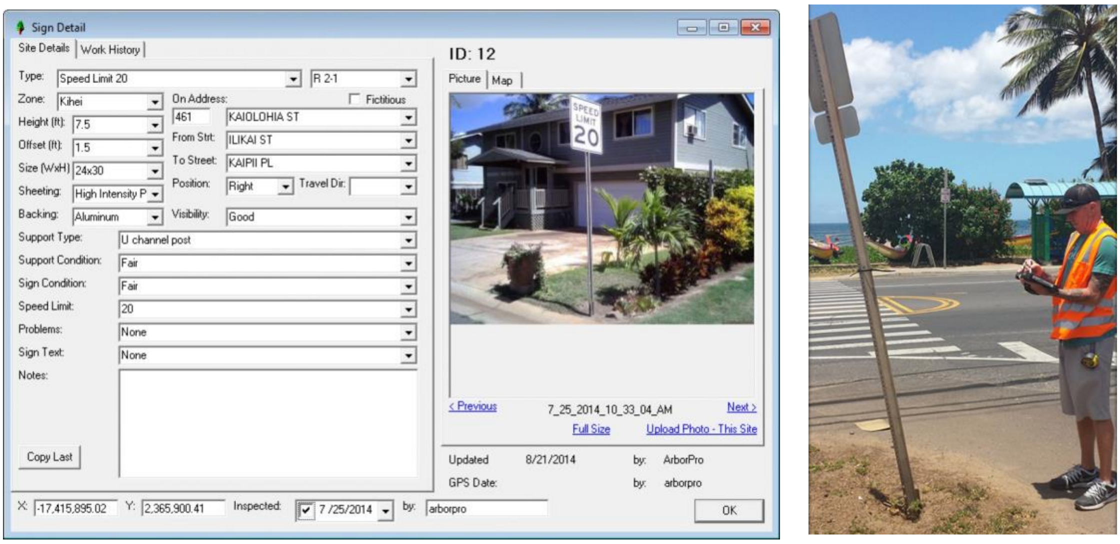


Figure 25: Manual vision inspection of road signs[6]

As we mentioned, the reasons for missing or damaged road signs are different. Case Study 5 presents a manual method for collecting data about the condition of road signs and the different damage categories.

[6] http://www.arborprousa.com/street-signs/

Case Study 5: Manual analysis of Sign Damage[7 8]

In 2011, a data collection effort was conducted by researchers at Utah State University to assess the performance of road signs under the Utah Department of Transportation's (UDOT) jurisdiction. At its completion, 1,716 road signs were recorded. The researchers determined that the sample sign population was 93 percent compliant with the minimum retroreflectivity levels. Even though the majority of road signs were performing above the minimum retroreflectivity levels, 28 percent were damaged to the degree that the legibility of the sign could be questioned.

Damage categories included bending, peeling, vandalism, cracking, and other, defined as follows:

- Bending damage described signs with significant portions of bent sheeting, which caused light to be reflected away from its origin;
- Peeling damage applied to the legend of a sign peeling off of the background sheeting;
- Vandalism, the most diverse category of damage, included damage caused by paintballs, bullet holes, beer bottle impacts, stickers, and graffiti;
- Cracking damage, only present on Type I sheeting signs, consisted of the retroreflective background cracking and degrading over time; and
- Other referred to forms of damage such as fading, tree rubbing, and tree sap.

Figure 26: Sign damage - Aging

Figure 27: Sign damage -Environmental

Figure 28: Sign damage - Vandalism

[7] Wesley Boggs, Kevin Heaslip, Chuck Louisell - Analysis of Sign Damage and Failure: A Case Study in Utah, 2013

[8] Travis Evans, Kevin Heaslip, Wesley Boggs, David Hurwitz and Kevin Gardiner - Assessment of Sign Retroreflectivity Compliance for Development of a Management Plan, 2012

5.4.2 *Traffic Speed measurements*

Traffic-speed image recording methods deliver video-sequences or photos using one or several cameras, with each image accurately geographically referenced using inertially aided GPS so that inventory items and damage can be identified in the images and their position extracted using either manual or automated methods. In this case, the quality of images or video is very important. Therefore, specification of minimum technical requirements (image resolution, positioning system, etc.) for video surveys is needed.

Figure 29: Example for image of road sign with good quality (Source: Google maps)

Automatic detection of damage using algorithms may prove difficult, because the algorithm will often not recognise the road sign when it is damaged, as it does not look like a sign to the algorithm. Furthermore, the algorithm would need to know what the sign looked like originally in order to provide any information about the condition.

However, if the analysis software had access to a good quality inventory, so that it knows where a sign should be, what type of sign should be present etc. this would facilitate the implementation of such technology relatively easily.

5.5 Measuring the visibility characteristics - Obstruction/ Obscuration

5.5.1 *Slow speed measurement methods*

Slow speed manual visual inspections are not common practice to detect obstructed road signs – this is usually monitored from a vehicle moving at traffic speed – see below.

5.5.2 *Traffic Speed measurements*

Identifying assets which are obscured by plant growth or obstructed by other assets requires a routine visual inspection and this can be performed from a vehicle travelling at traffic speed. As described in section 5.4.2 video recording methods can be used to define the condition of road signs, when the quality of the images is sufficient.

Automated assessment of the video would be the ideal approach to providing a tool to enable network level assessment. However, there are some limitations to this, in that enough of a road sign would need to be visible for the automatic analysis to be able to assess it (Figure 30, Figure 31). There may even be some situations where even a human assessor would miss the obscured road sign in the video (Figure 32).

Figure 30: Road sign obscured by plant growth

Figure 31: Road signs obscured by other signs

Figure 32: Road sign obscured by plant growth in the city

5.6 *Measuring the visibility characteristic - Orientation*

5.6.1 *Slow speed measurement methods*

A slow speed manual visual inspection is the main established method for measuring the visibility characteristic Orientation (section 5.4.1).

5.6.2 *Traffic Speed measurements*

The video based methods, described in section 5.3 for inventory can be used to measure the geometry characteristics of road signs. Additionally, LiDAR surveys could be used and Case Study 6 presents a method for 3D classification and evaluation of geometric parameters of road signs using LiDAR. The measurements are currently performed statically, but it should be possible to provide the same measurements using a mobile device, which would provide higher productivity.

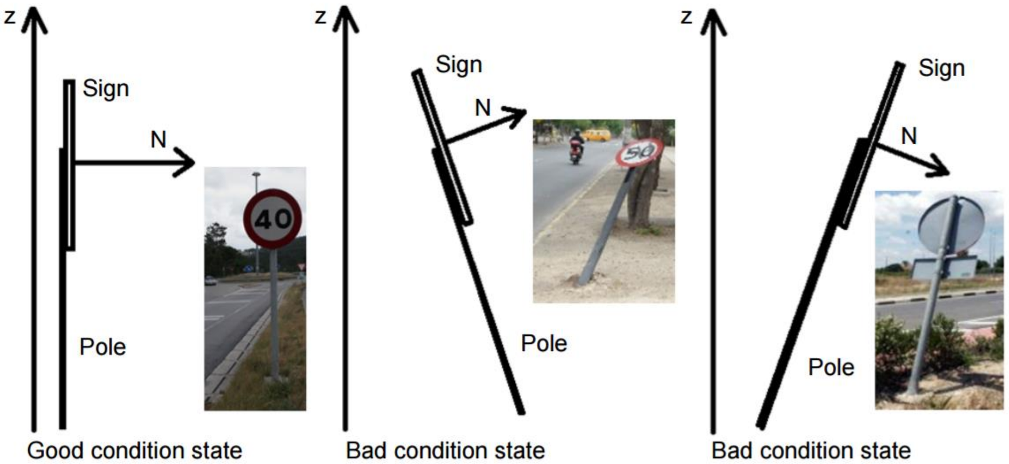


Figure 33: Examples of abnormally tilted signs

Tilted signs can be identified using video images, and their position extracted using manual methods.

Figure 34: Examples of tilted sign face

Case Study 6: Evaluation of road signs using terrestrial LiDAR[9]

In this case study, a number of road signs are evaluated, under a geometric point of view, using the laser scanner Riegl LMS Z390i. A Matlab algorithm is developed for all the data processing (3D classification and evaluation of geometric parameters). The area of the study is located in northwest Spain (The Rías Baixas A-52). The connection between the city centre of Ourense (N-120) and A-52 is particularly dangerous because of its location in mountainous terrain and along a river. Therefore, the speed and manoeuvrability are limited and enforced by a high density of road signs.

Figure 35: Area of study

Figure 36: Measurement system

A total of 16 signs were automatically segmented from the point cloud. The standard deviation of the fitted plane and the angle of the normal vector with the Z axis are shown in Table 14. All the signs under study do not present important deviations in the standard deviation of the fitted plane or the normal vector, so no evidence of damage from vandalism, vehicular collision or extreme weather conditions can be determined. No maintenance work is required for these signs.

Sign number	α [°]	Std [m]	Sign number	α [°]	Std [m]
1	90.1	0.003	9	91.7	0.004
2	89.1	0.002	10	90.3	0.003
3	91.3	0.003	11	90.8	0.002
4	90.7	0.003	12	89.3	0.004
5	91.5	0.001	13	91.3	0.002
6	89.8	0.004	14	89.9	0.002
7	89.4	0.001	15	90.3	0.003
8	91.3	0.003	16	90.1	0.001

Table 14: Summary of the results (α – angle between the normal vector of the sign plane and the Z axis and std – the standard deviation of the plane fitted to the sign data)

The procedure developed for this work uses the data obtained from a terrestrial laser scanner to automatically evaluate some important parameters for determining the condition state of the road signs. The results are obtained from a static system, although they could be easily extrapolated to a mobile unit, with higher productivity and lower labour costs. The methodology described in this technical note can be easily transferred to other tasks related to the inspection of horizontal signals, since the high reflectivity of the paint allows easy classification of the elements. Another possible application is connected with the condition state of the guardrails which use reflective markers to improve the night vision of drivers.

[9] HIGINIO GONZÁLEZ-JORGE, BELÉN RIVEIRO, JULIA ARMESTO, PEDRO ARIAS - Evaluation of road signs using radiometric and geometric data from terrestrial LiDAR, 2013

5.7 *Measuring the visibility characteristic - Panel Alignment*

Panel alignment only applies to signs that are constructed using multiple panels. If the panels are not solidly fixed, the higher panels can overlap the lower panels, obscuring the information on the sign. Or the panels can become misaligned to an extent where the text on them is very hard to read (Figure 37).

Figure 37: Examples for defected panel alignment

5.7.1 *Slow speed measurement methods*

The main established method is low speed visual inspection (section 5.4.1).

5.7.2 *Traffic Speed measurements*

Manual analysis of video images collected at high speed can be used to determine road signs that have panel alignment issues. However, the images collected would need to be of good enough quality to enable this (section 5.4.2).

5.8 *Measuring the visibility characteristic - night-time visibility*

Signs may be easy to see and read in the daytime because they are well illuminated by ambient light. At night-time road signs are less easily recognisable and visible. At night the only way to ensure that that the sign can be seen from an appropriate distance is if the sign is lit or retroreflective.[10] The night-time visibility can be assessed using measurements of retro-reflectivity.

The night-time visibility of road signs depends on different factors: the material from which it is made, the condition of the sheeting, the presence of frost or dew on the face of the sheeting, and the orientation of the sign relative to the vehicle. It is described by the coefficient of retro-reflectivity R_A (cd.lx-1.m-2). R_A can be measured using a hand-held or a mobile retro-reflectometer. Each method is described below

[10] Norbert H. Maerz, Qiang Niu - Automated Mobile Highway Sign Visibility Measurement System, Transportation Research Board, 82th Annual Meeting, January 12-16, 2003, Washington, D.C.

Figure 38: Examples of daytime (left) and night-time (right) view of road signs[11]

Figure 39: Day-time and night-time visibility

5.8.1 *Slow speed measurement methods*

Measurements of R_A can be made using a hand-held retro-reflectometer, as shown in Figure 41 to Figure 44. A number of such devices exist, including:

- Zehntner ZRS 6060 (Figure 42)
- DELTA RetroSign GR1 & GR3 (Figure 43)
- Road Vista 922

Whilst this method does bring the benefits that measurements can be easily carried out and they are usually reliable, the method is limited in that it incurs additional health and safety

[11] Vahid Balali, Mohammad Amin Sadeghi, Mani Golparvar-Fard - Image-based retro-reflectivity measurement of traffic signs in day time, 2015

issues, such as requiring a road closure to conduct the test. Sometimes it is very difficult to carry out these measurements (Figure 44), and the operator needs to assess retro-reflectivity of each sign separately. Therefore these devices do not provide a method that would be practical to use at network level.

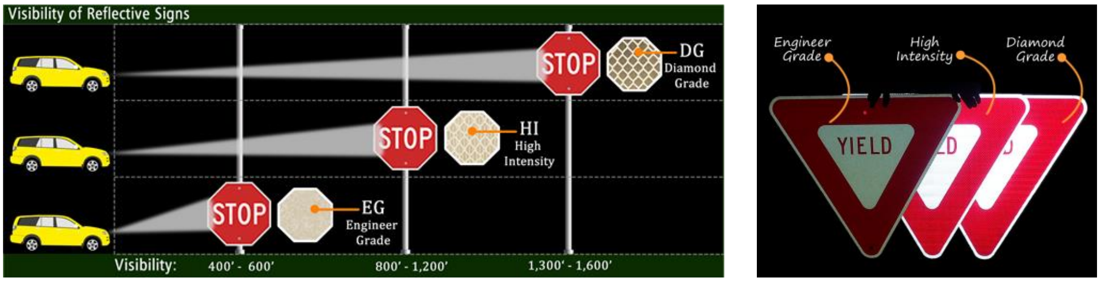


Figure 40: Night-time visibility of reflective signs

Figure 41: Hand-held retro-reflectometer

Figure 42: Hand-held retro-reflectometer Zehntner ZRS 6060

Figure 43: Hand-held retro-reflectometer RetroSign GR3

Figure 44: Measurement of the retroreflectivity of a road sign

5.8.2 *Traffic Speed measurements*

Mobile retro-reflectometers for measuring road sign retroreflectivity are highly advanced and automated systems, but most of them are currently in the testing phase. A car or van is equipped with high sensitivity cameras installed on-board or in the car, which measures the luminance (Figure 45). The system collects some inventory characteristics (location, type, details).

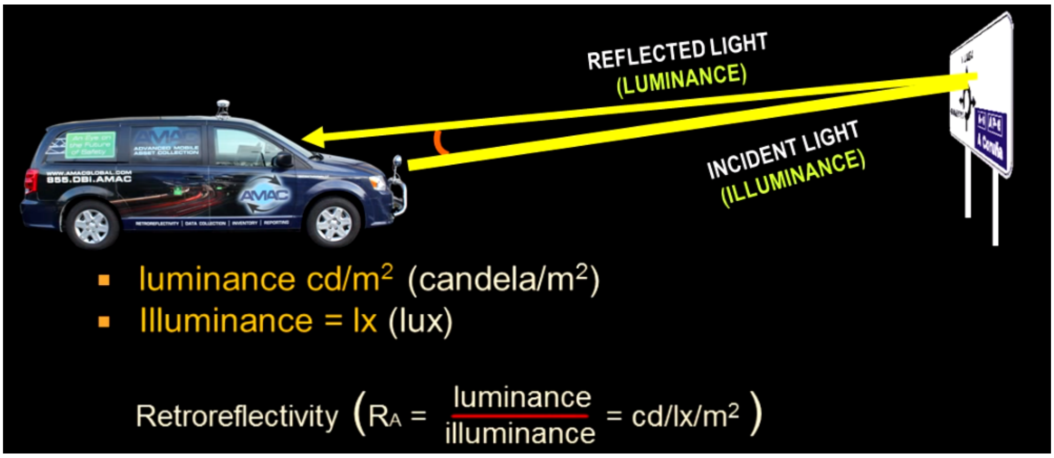


Figure 45: Mobile reflectometer for measuring the night-time visibility of road signs[12]

High sensitivity cameras installed on-board measure the luminance, even under low light conditions. The response curve of the cameras is equivalent to the human eye and allows luminance measurement consistency.

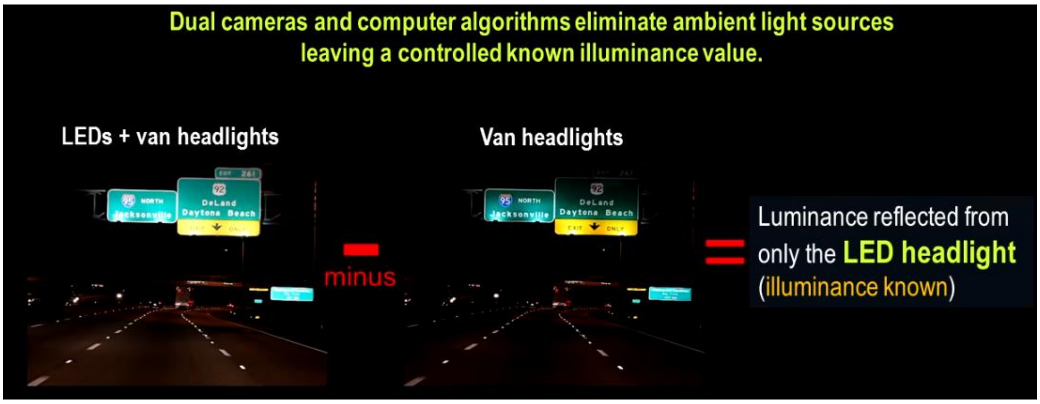


Figure 46: Traffic speed measurement of the night-time visibility of road signs

PREMiUM identified the following mobile retro-reflectivity devices:

- AMAC (Advanced Mobile Asset Collection) (Case Study 7)
- MANDLI (Retro View)
- VISUALISE (Visual Inspection of Signs and Panels)

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12 http://www.amacglobal.com/

Case Study 7: Retroreflective measurements with AMAC[13]

In 2011 TTI was approached by DBI/Cidaut Technologies LLC, a joint venture between the United States' DBi Services and Spain's CIDAUT Foundation, to evaluate their technology that was built to measure sign retroreflectivity. The system is called Advanced Asset Management Collection (AMAC). The AMAC system records images during the night-time and then processes the images to determine retroreflectivity.

The data from the AMAC measurements included background and legend retroreflectivity levels as well as sign colour. TTI research assistants measured the same signs with a calibrated handheld retroreflectometer, in accordance with ASTM E1709. The mobile and handheld retroreflective measurements were then compared. Over 100 signs were evaluated along an open-road test route through Brazos County.

Overall, the average percent difference between the measurements was 0.1 percent and the average actual difference was 21.2 cd/lx/m^2. Similar to the static testing results, the largest differences were observed for the signs with very high retroreflectivity (e.g., greater than 500 cd/lx/m^2). Since these values are much higher than the minimum MUTCD retroreflectivity levels, the larger differences on the high end were not deemed to be major issues.

In many ways, measuring the sign background is easier than the sign legend (with positive contrast signs) because there are many additional pixels of information in a digital image to analyse. In fact, measuring the legend is so difficult that some mobile technologies only offer services to measure sign backgrounds. However, the AMAC system claims to be able to measure the legend retroreflectivity of positive contrast signs. Figure 48 shows a comparison of the sign legend measurements from the handheld retroreflectometer and the AMAC van.

Overall, the average percent difference between the measurements was 5.5 percent and the average actual difference was 13.2 cd/lx/m^2. The two signs with the largest differences were both made of prismatic retroreflective materials. In general, the prismatic retroreflective materials appear to be associated with the largest differences in measurements regardless of whether the measurements were of the sign background or legend. It is possible that the signs were twisted during the mobile measurements. They were initially installed to be perpendicular to the testing path, but high winds were present during testing, which required technicians to constantly monitor and maintain the test signs.

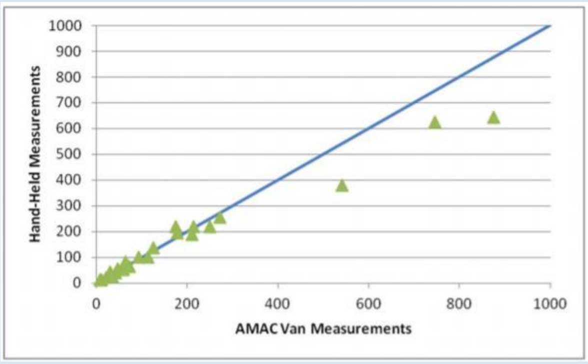

Figure 47: Comparison of Background Retroreflectivity Measurements (cd/lx/m^2)

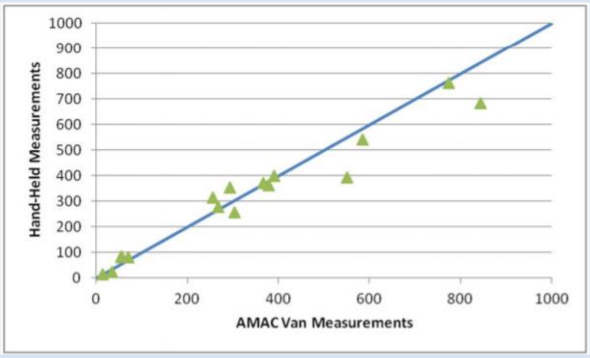

Figure 48: Comparison of Legend Retroreflectivity Measurements (cd/lx/m^2)

[13] http://www.amacglobal.com/sites/default/files/resources/AMAC_Report_TTI_Jan_20.pdf

The repeatability of the AMAC system was also tested on the closed-course. Three sets of dynamic data were recorded in order to test the repeatability of the mobile system. Figure 49 shows the cumulative distribution of the results graphically. The median COV was about 5 percent, and the 85th percentile COV was about 10 percent. In earlier reported research, the median and 85th percentile COV for handheld readings on in-service signs were about 6.5 percent and 15 percent, respectively. Therefore, based on the results reported herein, the repeatability of the AMAC van measurements is even more repeatable than handheld measurements.

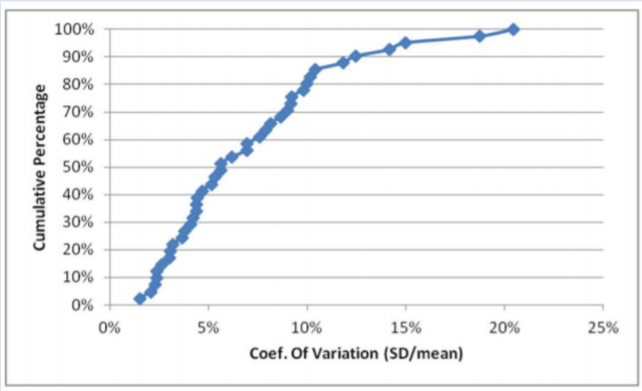

Figure 49: Cumulative Percentage of COV of Mobile Measurements

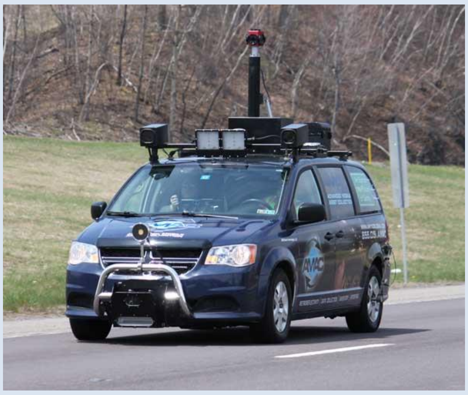

Figure 50: Advanced Mobile Asset Collection (AMAC)

Overall, the results from the mobile system were lower than the handheld device. However, this is not surprising since the mobile system measures signs in-situ rather than at a standard geometry. The mobile system is designed to make retroreflectivity measurements at an observation as close to 0.2 degrees as possible, but the entrance angle can be different from 4 degrees, depending on the roadway geometry, sign position, lean, and twist. One way to think about this difference is that the mobile system measures signs as drivers experience them while the handheld devices measure signs in accordance to a standardized test method.

Measurements made from the roadway, such as those made from the AMAC system, can provide a better realization of how the sign is seen from the perspective of the night-time driver.

Case Study 8 presents development of a prototype luminance-based measurement system to assess the night-time visibility of Traffic Control Devices and a night-time inspection method. It is noted that in some cases the data from hand-held retro-reflectometer may be different from the mobile measured data. For instance, a retroreflective sign may meet the minimum retroreflectivity requirements using a handheld retroreflectometer, but not with the mobile retroreflectometer. This may be because the fixed geometry of the handheld retroreflectometer does not account for sign twist. If a sign is twisted away from the road, a sign can be less visible to a driver. Whilst the mobile measurement would capture this a handheld retroreflectivity measurement would not. Therefore, the mobile measurement captures the real situation.

Case Study 8: Prototype mobile luminance measurement system[14]

The case study describes development of a prototype luminance-based measurement system to assess the night-time visibility of Traffic Control Devices (TCDs). One of the benefits of measuring TCDs using luminance is that drivers assess the brightness of TCDs at night in terms of luminance and not retroreflectivity.

At the time of this project, no one company had a system that could measure luminance of individual TCDs at highway speeds. Subsequently, the researchers built on their experience with their existing mobile luminance system and improved upon it. The heart of any photometric measurement system is the quality and capability of the photometer(s) used in its development. The researchers tested several different styles of cameras to be used as photometers in the mobile luminance measurement system.

TTI developed a prototype mobile luminance system and conducted a human factors study on the TCDs to develop a framework level of service (LOS) for TCDs along rural two-lane roadways using objective field measurements. The mobile luminance system consisted of two 12-bit monochromatic cameras with V lambda corrected filters and Fujinon megapixel lenses. The system also included GPS to geocode the incoming image data to within ±2.5 meters. The current system is limited to 1 Hz operation when several advanced thresholding features are used to conduct semi-automated analysis in real time. The human factors study was conducted at the Texas A&M University Riverside Campus and on a nearby open-road roadway network. There were 25 participants with emphasis on the analysis of the 18 participants aged 55 years and older. Each participant rated on a scale of 1 (e.g., poor performance requiring maintenance) to 5 (e.g., outstanding performance, not requiring any maintenance) a minimum of 40 different closed-course and 30 different open-road TCD treatments.

a) Lighting and Luminance Camera Setup

b) Headlight Controller

[14] Jeffrey D. Miles, Hancheng Ge, Yunlong Zhang - Prototype mobile luminance measurement system and level of service for evaluating rural high-speed night-time delineation, 2013

http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6647-1.pdf

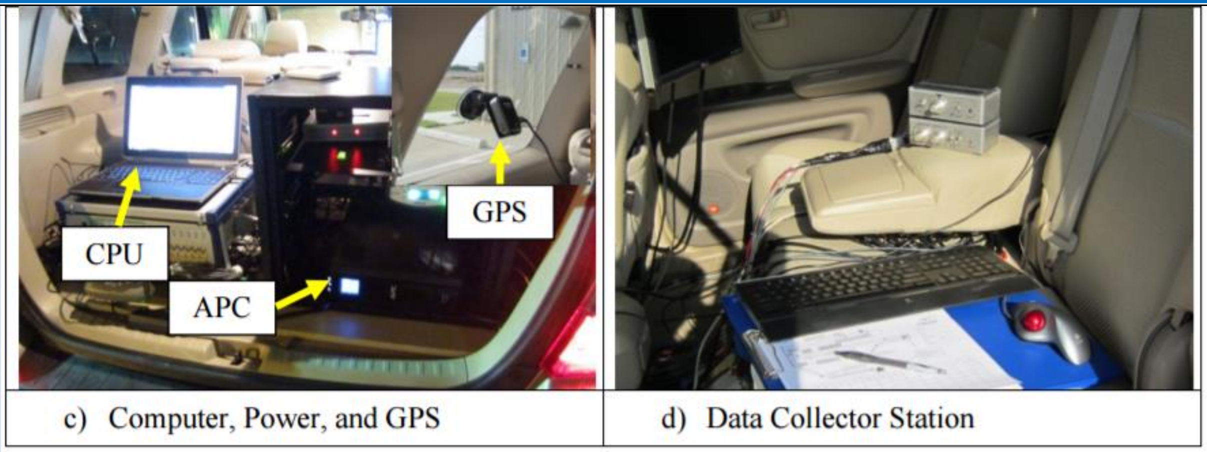

Figure 51: Prototype mobile luminance data collection system

The researchers developed two possible LOS methods that TxDOT could use to supplement their current night-time inspection method. The precise measurement method uses the mobile luminance system. TxDOT would record continuous images at 1 Hz or lower frequency and the images would be post-processed using the models developed from the human factors study. A rating of 3 or better would not require any scheduled maintenance within the coming fiscal year, while ratings of 1 or 2 would require action. The approximate measurement method also uses the mobile luminance system, but a smaller sample of images would be recorded rather than post-processing because data collectors would use the thresholding interface to make real-time objective visual assessments of the TCDs. This method would use a pass/fail rating.

5.9 Measuring the visibility characteristic Colour Fade

When the road sign colours are faded this may affect the contrast between the elements (letters and numbers) and hence its legibility (Figure 52).

Figure 52: Example for colour fade[15]

[15] TD 25/15 Inspection and maintenance of traffic signs on motorway and all-purpose trunk roads

5.9.1 *Slow speed measurement methods*

Colour fade is assessed through a low speed manual visual survey (section 5.4.1).

5.9.2 *Traffic Speed measurements*

Manual analysis of video images collected at high speed could be used to determine road signs that are faded. However, the images collected would need to be of good enough quality to enable this, in particular in relation to their ability to measure “true” colour, and the effect of ambient light on recorded colour would also need to be accounted for.

5.10 Summary of inventory and condition characteristics that can be extracted from a video survey

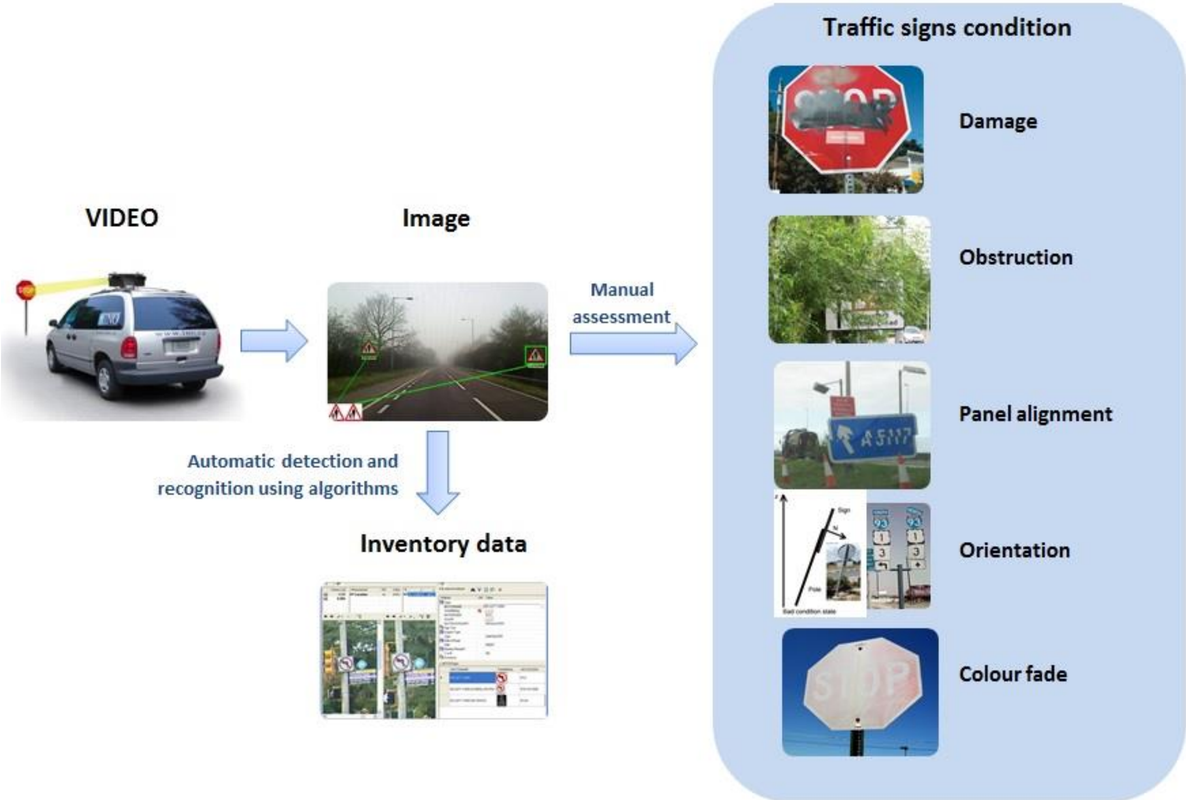

Figure 53: Summary of measurement methods for inventory and condition of road signs

6 Definitions

The following subsections list the technical terms to be used, along with the definitions of the terms as they will be used within the PREMiUM project.

Chromaticity Coordinates**:** Colour coordinate values identify the location on the standard chromaticity space diagram.

Cleaning Interval**:** The amount of time between cleaning activities.

Coefficient of Luminance**:** The quotient of the luminance of the field of the road sign in the given direction by the illuminance on the field.

Coefficient of Retro-reflection**:** the ratio between the luminance of the surface to the normal illuminance on the surface.

Date of Construction**:** The time and date the works began and the completion date.

Dates/Details of Maintenance**:** The time and dates maintenance works were carried out, alongside the contractors report.

Dates/Details of Last Inspection**:** The time and dates previous inspections took place, with access or reference to a copy of the final inspection report.

Daytime Visibility**:** A measure of the road sign conspicuity under daylight and road lighting conditions.

Identification Code**:** A unique reference (numerical, alphabetical or a combination of both) which is assigned to the asset.

Location Reference**:** The location of the asset.

Luminance Factor**:** The ratio of the luminance of the field of the road sign in the given direction to that of a perfect reflecting diffuser identically illuminated.

Manufacturer Declared Performance Characteristics**:** Characteristics included on the product's CE marking.

Minimum Clear Visibility Distance**:** The minimum distance between a sign and a driver moving at traffic speed for which the sign is clearly legible.

National Road Authority: National Road Authority (NRA): The state body responsible for the management of national motorways, and strategic dual and single carriageways. In this study NRAs also include local authorities and private road operators who have responsibility for large amounts of a strategic network.

Night-Time Visibility**:** A measure of brightness during the night-time.

Slow speed survey: A slow speed survey is any survey that cannot be performed at traffic speed e.g. manual or in-situ surveys.

Traffic speed survey: A traffic speed or high speed survey is performed at, or slightly below prevailing traffic speeds and, in general, does not require traffic management or road closures to perform. For example, a traffic speed survey on a motorway might be performed at speeds of 80km/h or at 45km/h on a residential road.

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Appendix A: NRA Questionnaire

PREMiUM Stakeholder consultation

Introduction to the PREMiUM project

PREMiUM (Practical Road Equipment Measurement Understanding and Management) has been let under the CEDR 2014 call for Asset Management and Maintenance and is being funded by the National Road Authorities in Austria, Belgium (Flanders), Finland, Germany, Ireland, Netherlands, Norway, Sweden and UK. It is a 2 year project that commenced in October 2015.

Compared to the management of pavement and bridge/structures assets, the approach to the management of road equipment assets is less well developed. Inspections are often carried out of these assets but the approaches to inspection regimes and the inspection methods vary e.g. regular condition assessment surveys versus replacement based on life expectancy with monitoring undertaken during safety inspections (which focus only on damage and failures that impact the safety of the road user). The inspections are often manual visual assessments, although there are examples of traffic-speed survey methods in some countries for the assessment of, for example, the visibility of road markings.

Even where a regime exists for the collection of information on equipment assets there is then a need to consider how this information is managed by a road authority. Many national authorities now operate powerful asset management systems, which allow data to be collated on road assets. Again, in comparison with road pavements, there is evidence of significant gaps in this area for road equipment.

Finally, where data do exist, and are accessible to the road owner, there is a need to be able to analyse and interpret this information to determine condition, identify maintenance needs and prioritise maintenance. For the equipment asset types under consideration in this work there is a range of experience in the application of analysis and interpretation methods that could allow the asset to be understood at the network level. Through the development of suitably focussed regimes and the development of appropriate indicators, there is potential to improve the ability to manage these assets

We envisage that the PREMiUM project will help road administrations to establish a maintenance regime that minimises the risk of failure of the asset and yet enables the road administration to focus maintenance expenditure on these assets in an efficient manner.

We have established a project team that includes representatives from the UK, Austria, Belgium, Ireland and Sweden. To help ensure our project outputs are relevant and focussed we are also trying to establish a “PREMiUM Reference Group” containing stakeholders from National Road Authorities; equipment manufacturers and users; researchers and users of the data.

The purpose of this questionnaire is to determine what asset properties you feel are important to know about, in order to assess asset condition, for the following assets:

- Road markings and studs
- Road signs
- Noise barriers
- Vehicle restraint systems.

We would then like to know what surveys are carried out currently, whether these are on a scheme/project level, or whether they are performed at network level. We are also seeking to know what equipment is used for monitoring, what is measured; what data is delivered, and how this data is then used to assess condition.

We will use the information, provided by stakeholders, to identify the key characteristics that need to be monitored, how these key characteristics can be monitored at a **network level**, and how the data can be translated into the information required to determine the condition.

Stakeholder details

Organisation………

Country in which organisation based…………………………………………………………………………………………

Contact person: ……

Function/job title: ………..

Email: ……..

In order to fully understand the answers given to the questionnaire, we may wish to conduct a short follow up interview, conducted via 'phone. If you would be willing to participate in this, please provide your telephone number:…………………………………………………………………………………………….
(Note that you will be asked via email for a convenient time to conduct this interview).

Definitions

Network level monitoring/surveys:
A network level survey or monitoring regime provides data for each length of asset or each individual asset on the road network. This may be achieved in just one year, or it may be organised over a number of years.

Noise Barrier
A noise barrier is a structure, usually erected at the side of a carriageway, designed to reduce the noise level experienced by neighbouring properties.

Project level surveys
A project or scheme level survey provides detailed data for a specific length (or lengths) on the road network. Project level surveys are usually performed when a need for maintenance has been identified, or where a network level survey has suggested that further investigation is requirement.

Road marking
A road marking is any kind of device or material that is used on a road surface in order to convey official information. They can be used to delineate traffic lanes, inform motorists and pedestrians or serve as noise generators when run across a road (rumble strips), or attempt to wake a sleeping driver when installed in the shoulders of a road. Road surface markings can also indicate regulation for parking and stopping.

Centre lines are the most common forms of road markings, providing separation between traffic moving in opposite directions, or between traffic moving in separate lanes. **In PREMiUM, we will only be considering lane separating markings.**

Retro-reflective road stud
A road stud is a safety device used on roads, usually made with plastic, ceramic, thermoplastic paint or occasionally metal, and come in a variety of shapes and colours. Retro-reflective studs include a lens or sheeting that enhances their visibility by reflecting vehicle headlights.

Vehicle Restraint System
A vehicle restraint system is a structure, usually fixed at the side of a carriageway, designed to prevent vehicles from leaving the carriageway

Road network

	Question	Answer
1	What is the approximate length of your road network, split by road type (e.g. motorway, strategic dual carriageway, strategic single carriageway)?	

Please answer the questions below for the assets for which you have knowledge. For those for which you don't have knowledge, please can you suggest who we might contact, who may be able to answer the questions, or please ask them directly.

Road Markings and Studs

Knowledge of Assets		
	Question	**Answer**
2	What is the approximate length of your network for which road markings are present?	
3	What is the approximate length of your network for which retro-reflective studs are present?	

Current Approach to Monitoring and Maintaining Assets and Asset Management

In this section of the questionnaire, we would like to find out whether monitoring of the assets' condition is carried out, and if it is what asset properties are monitored and how they're monitored. We would also like to know, if monitoring is not carried out, why it is not e.g. it is cheaper just to replace road markings every 3 years on a rolling basis than to monitor them and only replace those that are inadequate.

We are also seeking to find out how the assets are managed and what maintenance methods are applied to the assets and what triggers this maintenance e.g. asset age, measured condition.

	Question	**Answer**
4	What is your general approach to managing and understanding the condition of road markings (lane separating lines) and studs? For example • Do you have a clear view of the status of all assets i.e. a regular monitoring regime? • Do you perform ad hoc repairs if something goes wrong (is there a reporting system - details?)? • Is the approach based on age of the asset?	
5	Where you have a monitoring regime, what does this measure and what methodology do you use? E.g. • Measurement of retro-reflectivity using retro-reflectometer (hand held or attached to a vehicle travelling at traffic speed) • Measurement of wear or corrosion.	
6	Where you do not have a regime, do you feel there is a need for condition monitoring to map the state of these assets? If not, please tell us why not (e.g. the condition cannot be measured, regular replacement removes the need for monitoring).	
7	Do you use an asset management system for managing road markings and studs (maintenance planning and forecasting budgets)?	

8	What methods of maintenance are applied to road markings and studs e.g. replacement, cleaning?	
9	How do you decide if a road marking or stud requires each type of maintenance method listed in Q8? I.e. on what criteria are maintenance / repair decisions made: Is the decision based on e.g. the asset's age, its measured condition etc.? Please give details.	
10	If the maintenance is based on measured condition, are thresholds applied to the measurements? If so are these thresholds defined in a standard or just within your organisation?	
11	Do you combine different types of measurements, to make a decision on maintenance e.g. combine measurements of marking retro-reflectivity and wear?	

Monitoring Assets at a network level

We have reviewed the standards relating to road markings and studs and have identified a number of properties that might be used for condition assessment. These are listed in the following tables. Please indicate whether any of these measures are currently monitored for your road network. We are particularly interested in whether the measures can be monitored at a network level or not, so please indicate whether the monitoring is carried out by slow speed surveys e.g. manual inspection of road signs, push-pull test for the posts of vehicle restraint systems, or whether they could be achieved at high speed e.g. from a vehicle travelling at traffic speed.

We would then like to know which asset properties are considered to be most important to determine their condition, so please indicate this in the "Level of importance" column by rating each property as either:

- High importance – essential information to have for all assets on the network;
- Medium importance – quite useful to have this information ; or
- Low importance – nice to have but not essential information.

Property	Characteristic	Is this measured or recorded? (Yes/No)	How is it measured? (Type of instrument/test method)	What level of importance would you assign to this characteristic for assessment of condition? (Low, Medium, High)
Inventory	Location e.g. start/end chainage (m), section label, marker post, GPS, spacing/gap, length, direction, etc.			
	Type of marking/stud			
Inventory	Road Markings Details - e.g. dimensions, class, colour, material, etc.			
	Date of Construction			
	Date of Last Inspection			
	Dates and details of maintenance			
	Other (please give details)			

Visibility	Night-time visibility (e.g. proportion of light reflected back to light source)			
	Day-time visibility (e.g. Luminance Coefficient under Diffuse Illumination, brightness (Luminous Intensity) of a surface in a given direction per unit area, ratio of the luminance of the marking or stud to that of a perfect diffuser)			
	Colour (e.g. chromaticity co-ordinates)			
	Wear Index (e.g. amount of erosion)			
	Other (please give details)			
Durability	Skid Resistance			
	Removability – e.g. ease of removing the line/stud			
	Hiding Power of Paint – e.g. a measure of the paint's ability to obscure a background of contrasting colour			
	UV Ageing of the Paint			
	Resistance to UV Exposure			
	Rate of Degradation			
	Other (please give details)			
Novel techniques for measuring condition	What "novel" methods, i.e. not covered by existing standards, for measuring conditions have you tried on a project level? Were you satisfied with the results? Do you see the potential to use this method on network level?			

Road Signs

Knowledge of Assets		
	Question	**Answer**
12	Roughly how many road signs do you have on your network?	

Current Approach to Monitoring and Maintaining Assets and Asset Management

In this section of the questionnaire, we would like to find out whether monitoring of the assets' condition is carried out, and if it is what asset properties are monitored and how they're monitored. We would also like to know, if monitoring is not carried out, why it is not e.g. it is cheaper just to replace road markings every 3 years on a rolling basis than to monitor them and only replace those that are inadequate.

We are also seeking to find out how the assets are managed and what maintenance methods are applied to the assets and what triggers this maintenance e.g. asset age, measured condition.

	Question	**Answer**
13	What is your general approach to managing and understanding the condition of road signs? For example • Do you have a clear view of the status of all assets i.e. a regular monitoring regime? • Do you perform ad hoc repairs if something goes wrong (is there a reporting system - details?)? • Is the approach based on age of the asset?	
14	Where you have a monitoring regime, what does this measure and what methodology do you use? E.g. • Measurement of retro-reflectivity using retro-reflectometer (hand held or attached to a vehicle travelling at traffic speed) • Measurement of wear or corrosion. • Measurement of structural integrity	
15	Where you do not have a regime, do you feel there is a need for condition monitoring to map the state of these assets? If not, please tell us why not (e.g. the condition cannot be measured, regular replacement removes the need for monitoring).	
16	Do you use an asset management system for managing road signs (maintenance planning and forecasting budgets)?	
17	What methods of maintenance are applied to road signs e.g. replacement, cleaning, rust treatment, post reinforcement?	

18	How do you decide if a road sign requires each type of maintenance method listed in Q17? I.e. on what criteria are maintenance / repair decisions made: Is the decision based on e.g. the asset's age, its measured condition etc.? Please give details.	
19	If the maintenance is based on measured condition, are thresholds applied to the measurements? If so are these thresholds defined in a standard or just within your organisation?	
20	Do you combine different types of measurements, to make a decision on maintenance e.g. combine measurements of structural integrity and corrosion?	

Monitoring Assets at a network level

We have reviewed the standards relating to road signs and have identified a number of properties that might be used for condition assessment. These are listed in the following tables. Please indicate whether any of these measures are currently monitored for your road network. We are particularly interested in whether the measures can be monitored at a network level or not, so please indicate whether the monitoring is carried out by slow speed surveys e.g. manual inspection of road signs, push-pull test for the posts of vehicle restraint systems, or whether they could be achieved at high speed e.g. from a vehicle travelling at traffic speed.

We would then like to know which asset properties are considered to be most important to determine their condition, so please indicate this in the "Level of importance" column by rating each property as either:

- High importance – essential information to have for all assets on the network;
- Medium importance – quite useful to have this information ; or
- Low importance – nice to have but not essential information.

Property	Characteristic	Is this measured or recorded? (Yes/No)	How is it measured? (e.g. Type of instrument/test method)	What level of importance would you assign to this characteristic for assessment of condition? (Low, Medium, High)
Inventory	Location - e.g. road name, number, area, chainage, section label, GPS, etc.			
	Identification Code			
	Cleaning Interval (years)			
	Material Performance Class			
	Date of installation			
	Dates and details of maintenance			
	Other (please give details)			
Visibility	Night-time visibility of sign (e.g. – the proportion of light reflected back to light source,)			
	Daytime visibility of sign (e.g. the ratio of the luminance of the sign compared to that of a perfect diffuser)			
	Colour of sign			
	Minimum Clear Visibility Distance			

	Obstruction/Obscuration – e.g. vegetation or dirt build-up blocking clear view of sign			
	Damage/Loss			
	Vertical/Horizontal Alignment of sign panels			
	Other (please give details)			
Durability	Resistance to Weathering			
	Impact Resistance			
	Age of Material			
	Other (please give details)			
Structural	Foundation Condition			
	Missing Parts			
	Wind Load Deflections			
	Other (please give details)			
Legibility	Extent of Colour Fade			
	Contrast between Elements			
	Damage/Loss of Legend			
	Orientation			
	Other (please give details)			
	Other data - e.g. category (warning, hazard, regulatory, etc.), diagram number, photograph number, installation date etc.			
Novel techniques for measuring condition	What "novel" methods, i.e. not covered by existing standards, for measuring conditions have you tried on a project level? Were you satisfied with the results? Do you see the potential to use this method on network level?			

Noise Barriers

	Knowledge of Assets	
	Question	**Answer**
21	What types of noise barriers are present on your network and what is the approximate total length for each type?	

Current Approach to Monitoring and Maintaining Assets and Asset Management

In this section of the questionnaire, we would like to find out whether monitoring of the assets' condition is carried out, and if it is what asset properties are monitored and how they're monitored. We would also like to know, if monitoring is not carried out, why it is not e.g. it is cheaper just to replace road markings every 3 years on a rolling basis than to monitor them and only replace those that are inadequate.

We are also seeking to find out how the assets are managed and what maintenance methods are applied to the assets and what triggers this maintenance e.g. asset age, measured condition.

	Question	**Answer**
22	What is your general approach to managing and understanding the condition of noise barriers? For example • Do you have a clear view of the status of all assets i.e. a regular monitoring regime? • Do you perform ad hoc repairs if something goes wrong (is there a reporting system – details?)? • Is the approach based on age of the asset?	
23	Where you have a monitoring regime, what does this measure and what methodology do you use? E.g. • Measurement of noise absorption or reflection • Measurement of wear • Measurement of structural integrity	
24	Where you do not have a regime, do you feel there is a need for condition monitoring to map the state of these assets? If not, please tell us why not (e.g. the condition cannot be measured, regular replacement removes the need for monitoring).	
25	Do you use an asset management system for managing noise barriers (maintenance planning and forecasting budgets)?	
26	What methods of maintenance are applied to noise barriers e.g. replacement, repainting, cleaning, patching, post reinforcement?	

27	How do you decide if a noise barrier requires each type of maintenance method listed in Q26? I.e. on what criteria are maintenance / repair decisions made: Is the decision based on e.g. the asset's age, its measured condition etc.? Please give details.	
28	If the maintenance is based on measured condition, are thresholds applied to the measurements? If so are these thresholds defined in a standard or just within your organisation?	
29	Do you combine different types of measurements, to make a decision on maintenance e.g. combine measurements of structural integrity and noise absorption?	

Monitoring Assets at a network level

We have reviewed the standards relating to noise barriers and have identified a number of properties that might be used for condition assessment. These are listed in the following tables. Please indicate whether any of these measures are currently monitored for your road network. We are particularly interested in whether the measures can be monitored at a network level or not, so please indicate whether the monitoring is carried out by slow speed surveys e.g. manual inspection of road signs, push-pull test for the posts of vehicle restraint systems, or whether they could be achieved at high speed e.g. from a vehicle travelling at traffic speed.

We would then like to know which asset properties are considered to be most important to determine their condition, so please indicate this in the "Level of importance" column by rating each property as either:

- High importance – essential information to have for all assets on the network;
- Medium importance – quite useful to have this information ; or
- Low importance – nice to have but not essential information.

Property	Characteristic	Is this measured or recorded? (Yes/No)	How is it measured? (i.e. Type of instrument/test method)	What level of importance would you assign to this characteristic for assessment of condition? (Low, Medium, High)
Inventory	Date of Installation, Contract ID, Scheme			
	Acoustic Type – e.g. reflective, absorptive			
	Acoustic Element Composition e.g. timber, concrete, metal, composites, plastic			
	Geometry – e.g. height, angle			
	Location Data - e.g. road name, section label, start/end chainage, GPS etc.			
Inventory	Manufacturer Declared Performance Characteristics			
	Date of Last Inspection			
	Physical Condition Reports			
	Details of Complaints Lodged			
	Dates and details of maintenance			
	Suitable as vehicle restraint			

	system (there are combined systems).			
	Other (please give details)			
Non-Acoustic Durability	Impact from Stones			
	Shatter Resistance			
	Long-term Non-Acoustic Performance			
	Other (please give details)			
Structural Integrity	Resistance to Loads			
	Vibration & Fatigue			
	Other (please give details)			
Visibility	Light Reflectivity			
	Other (please give details)			
Acoustic Ability	Sound Reflection			
	Airborne Sound Insulation			
	Sound Diffraction			
	Insertion Loss			
	Long-Term Acoustic Performance			
	Other (please give details)			
Environment	Environmental Protection - e.g. environmental risk assessment			
	Other (please give details)			
Safety	Resistance to Brushwood Fire			
	Impact from Collision			
	Maximum allowable distance between emergency exits/doors			
	Other (please give details)			
Novel techniques for measuring condition	What “novel” methods, i.e. methods not covered by existing standards, for measuring conditions have you tried on a project level? Were you satisfied with the results? Do you see the potential to use this method on network level?			

Vehicle Restraint Systems

Knowledge of Assets		
	Question	**Answer**
30	What types of vehicle restraint systems are present on your network and what is the approximate total length for each type?	

Current Approach to Monitoring and Maintaining Assets and Asset Management

In this section of the questionnaire, we would like to find out whether monitoring of the assets' condition is carried out, and if it is what asset properties are monitored and how they're monitored. We would also like to know, if monitoring is not carried out, why it is not e.g. it is cheaper just to replace road markings every 3 years on a rolling basis than to monitor them and only replace those that are inadequate.

We are also seeking to find out how the assets are managed and what maintenance methods are applied to the assets and what triggers this maintenance e.g. asset age, measured condition.

	Question	**Answer**
31	What is your general approach to managing and understanding the condition of vehicle restraint systems? For example • Do you have a clear view of the status of all assets i.e. a regular monitoring regime? • Do you perform ad hoc repairs if something goes wrong (is there a reporting system – details?)? • Is the approach based on age of the asset?	
32	Where you have a monitoring regime, what does this measure and what methodology do you use? E.g. • Measurement of wear or corrosion (slow speed or traffic speed test). • Measurement of height • Measurement of structural integrity	
33	Where you do not have a regime, do you feel there is a need for condition monitoring to map the state of these assets? If not, please tell us why not (e.g. the condition cannot be measured, regular replacement removes the need for monitoring).	
34	Do you use an asset management system for managing vehicle restraint systems (maintenance planning and forecasting budgets)?	
35	What methods of maintenance are applied to restraint system e.g. replacement, repainting, cleaning, patching, post reinforcement?	

36	How do you decide if a restraint system requires each type of maintenance method listed in Q35? I.e. on what criteria are maintenance / repair decisions made: Is the decision based on e.g. the asset's age, its measured condition etc.? Please give details.	
37	If the maintenance is based on measured condition, are thresholds applied to the measurements? If so are these thresholds defined in a standard or just within your organisation?	
38	Do you combine different types of measurements, to make a decision on maintenance e.g. combine measurements of structural integrity and corrosion?	

Monitoring Assets at a network level

We have reviewed the standards relating to vehicle restraint systems and have identified a number of properties that might be used for condition assessment. These are listed in the following tables. Please indicate whether any of these measures are currently monitored for your road network. We are particularly interested in whether the measures can be monitored at a network level or not, so please indicate whether the monitoring is carried out by slow speed surveys e.g. manual inspection of road signs, push-pull test for the posts of vehicle restraint systems, or whether they could be achieved at high speed e.g. from a vehicle travelling at traffic speed.

We would then like to know which asset properties are considered to be most important to determine their condition, so please indicate this in the "Level of importance" column by rating each property as either:

- High importance – essential information to have for all assets on the network;
- Medium importance – quite useful to have this information ; or
- Low importance – nice to have but not essential information.

Property	Characteristic	Is this measured or recorded? (Yes/No)	How is it measured? (i.e. Type of instrument/test method)	What level of importance would you assign to this characteristic assessment of condition? (Low, Medium, High)
Inventory	Asset Number, Road Number, Location, GPS			
	Description (type & shape of beam, containment level), Length			
	Date of Last/Next Inspection			
	Date of installation			
	Dates and details of maintenance			
	Other (please give details)			
Durability	Presence of corrosion/rust			
	Presence of damage			
	Other (please give details)			
Structural	Post Stability			
	Presence and condition of fixings (Connections, Bolts, Caps, lap screws)			
	Beam Alignment/Overlap			
	Orientation (Post/Beams) - e.g. posts fitted & beam overlap follow			

	the direction of travel			
	Ground Bearing Capacity			
	Impact Acceptance			
	Other (please give details)			
Clearance	Mounting Height - e.g. height from ground level to middle of barrier beam			
	Setback Distance - e.g. lateral distance between face of barrier and the roadside.			
	Working Widths - e.g. distance between traffic and side of the barrier before impact and maximum lateral position after impact			
	Minimum Barrier Length (Approach/Departure Lengths to/from object that barrier is protecting			
	Other (please give details)			
Placement	Proximity to Hazards - e.g. laybys, bus stops, roundabouts, slip roads, water sources, etc.			
Novel techniques for measuring condition	What "novel" methods, i.e. methods not covered by existing standards, for measuring conditions have you tried on a project level? Were you satisfied with the results? Do you see the potential to use this method on network level?			

Appendix B: Survey Provider Questionnaire

PREMiUM Stakeholder consultation

Introduction to the PREMiUM project

PREMiUM (Practical Road Equipment Measurement Understanding and Management) has been let under the CEDR 2014 call for Asset Management and Maintenance and is being funded by the National Road Authorities in Austria, Belgium (Flanders), Finland, Germany, Ireland, Netherlands, Norway, Sweden and UK. It is a 2 year project that commenced in October 2015.

Compared to the management of pavement and bridge/structures assets, the approach to the management of road equipment assets is less well developed. Inspections are often carried out of these assets but the approaches to inspection regimes and the inspection methods vary e.g. regular condition assessment surveys versus replacement based on life expectancy with monitoring undertaken during safety inspections (which focus only on damage and failures that impact the safety of the road user). The inspections are often manual visual assessments, although there are examples of traffic-speed survey methods in some countries for the assessment of, for example, the visibility of road markings.

Even where a regime exists for the collection of information on equipment assets there is then a need to consider how this information is managed by a road authority. Many national authorities now operate powerful asset management systems, which allow data to be collated on road assets. Again, in comparison with road pavements, there is evidence of significant gaps in this area for road equipment.

Finally, where data do exist, and are accessible to the road owner, there is a need to be able to analyse and interpret this information to determine condition, identify maintenance needs and prioritise maintenance. For the equipment asset types under consideration in this work there is a range of experience in the application of analysis and interpretation methods that could allow the asset to be understood at the network level. Through the development of suitably focussed regimes and the development of appropriate indicators, there is potential to improve the ability to manage these assets

We envisage that the PREMiUM project will help road administrations to establish a maintenance regime that minimises the risk of failure of the asset and yet enables the road administration to focus maintenance expenditure on these assets in an efficient manner.

We have established a project team that includes representatives from the UK, Austria, Belgium, Ireland and Sweden. To help ensure our project outputs are relevant and focussed we are also trying to establish a "PREMiUM Reference Group" containing stakeholders from National Road Authorities; equipment manufacturers and users; researchers and users of the data.

The purpose of this questionnaire is to determine what asset properties you feel are important to know about, in order to assess asset condition, for the following assets:

- Road markings and studs
- Road signs
- Noise barriers
- Vehicle restraint systems.

We would then like to know what surveys are carried out currently, whether these are on a scheme/project level, or whether they are performed at network level. We are also seeking to know what equipment is used for monitoring, what is measured; what data is delivered, and how this data is then used to assess condition.

We will use the information, provided by stakeholders, to identify the key characteristics that need to be monitored, how these key characteristics can be monitored at a **network level**, and how the data can be translated into the information required to determine the condition.

Stakeholder details

Organisation………

Country in which organisation based…………………………………………………………………………………………

Contact person: ………

Function/job title: ………..

Email: …….

In order to fully understand the answers given to the questionnaire, we may wish to conduct a short follow up interview, conducted via 'phone. If you would be willing to participate in this, please provide your telephone number:…………………………………………………………………………………………….
(Note that you will be asked via email for a convenient time to conduct this interview).

Definitions

Network level monitoring/surveys:
A network level survey or monitoring regime provides data for each length of asset or each individual asset on the road network. This may be achieved in just one year, or it may be organised over a number of years.

Noise Barrier
A noise barrier is a structure, usually erected at the side of a carriageway, designed to reduce the noise level experienced by neighbouring properties.

Project level surveys
A project or scheme level survey provides detailed data for a specific length (or lengths) on the road network. Project level surveys are usually performed when a need for maintenance has been identified, or where a network level survey has suggested that further investigation is requirement.

Road marking
A road marking is any kind of device or material that is used on a road surface in order to convey official information. They can be used to delineate traffic lanes, inform motorists and pedestrians or serve as noise generators when run across a road (rumble strips), or attempt to wake a sleeping driver when installed in the shoulders of a road. Road surface markings can also indicate regulation for parking and stopping.

Centre lines are the most common forms of road markings, providing separation between traffic moving in opposite directions, or between traffic moving in separate lanes. **In PREMiUM, we will only be considering lane separating markings.**

Retro-reflective road stud
A road stud is a safety device used on roads, usually made with plastic, ceramic, thermoplastic paint or occasionally metal, and come in a variety of shapes and colours. Retro-reflective studs include a lens or sheeting that enhances their visibility by reflecting vehicle headlights.

Vehicle Restraint System

A vehicle restraint system is a structure, usually fixed at the side of a carriageway, designed to prevent vehicles from leaving the carriageway

Please answer the questions below for the assets for which you have knowledge.

General		
	Question	**Answer**
1	For which road network(s) have you had or do you have a contract to provide asset surveys for?	
2	For which of the four assets do you provide survey/monitoring services?	

Please answer the following questions, for the assets for which you provide survey services.

Road Markings and Studs		
	Question	**Answer**
3	What survey methods/techniques do you currently use to monitor the condition of road markings or studs? What measurements are recorded? Please list all methods and all relevant measurements. Please indicate whether the methods are carried out at high speed, whether they are manual etc.	
4	Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.	
5	How is the inspection performed? Please describe how the condition of road markings and studs is determined? How do you define the condition of road markings and studs? (For example: Scale 1-5; Yes/No; good condition – bad condition)	
6	Does the inspection take place according to a standard? If so, please provide details of this.	
7	How often does inspection take place?	
8	Do you register the type/position of the road markings/studs (e.g. transverse position, spacing, width, construction etc.)? If so, please provide details of this.	
9	What are the yearly costs per km for these measures?	
10	Are you aware of any novel or emerging technology that could be used to provide high speed measurements of road marking or stud condition? If so, please provide details of this	

Road Signs		
	Question	Answer
11	What survey methods/techniques do you currently use to monitor the condition of road signs? What measurements are recorded? Please list all methods and all relevant measurements. Please indicate whether the methods are carried out at high speed, whether they are manual etc.	
12	Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.	
13	How is the inspection performed? Please describe how the condition of road signs is determined? How do you define the condition of road signs? (For example: Scale 1-5; Yes/No; good condition – bad condition)	
14	Does the inspection take place according to a standard? If so, please provide details of this.	
15	How often does inspection take place?	
16	What are the yearly costs per km for these measures?	
17	Are you aware of any novel or emerging technology that could be used to provide high speed measurements of road sign condition? If so, please provide details of this	

Noise barriers		
	Question	**Answer**
18	What survey methods/techniques do you currently use to monitor the condition of noise barriers? What measurements are recorded? Please list all methods and all relevant measurements. Please indicate whether the methods are carried out at high speed, whether they are manual etc.	
19	Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.	
20	How is the inspection performed? Please describe how the condition of noise barriers is determined? How do you define the condition of noise barriers? (For example: Scale 1-5; Yes/No; good condition – bad condition)	
21	Does the inspection take place according to a standard? If so, please provide details of this.	
22	How often does inspection take place?	
23	What are the yearly costs per km for these measures?	
24	Are you aware of any novel or emerging technology that could be used to provide high speed measurements of noise barrier condition? If so, please provide details of this	

	Vehicle Restraint Systems	
	Question	**Answer**
25	What survey methods/techniques do you currently use to monitor the condition of vehicle restraint systems? What measurements are recorded? Please list all methods and all relevant measurements. Please indicate whether the methods are carried out at high speed, whether they are manual etc.	
26	Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.	
27	How is the inspection performed? Please describe how the condition of restraint systems is determined? How do you define the condition of restraint systems? (For example: Scale 1-5; Yes/No; good condition – bad condition)	
28	Does the inspection take place according to a standard? If so, please provide details of this.	
29	How often does inspection take place?	
30	What are the yearly costs per km for these measures?	
31	Are you aware of any novel or emerging technology that could be used to provide high speed measurements of vehicle restraint system performance or condition? If so, please provide details of this.	