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PREMiUM

Identifying the key characteristics for vehicle restraint system condition measurements

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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 **vehicle restraint systems** 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 **vehicle restraint systems (VRS)** to support maintenance/asset management decisions at the network level. 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 **vehicle restraint systems** 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 proposed 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 vehicle restraint system condition that should be monitored: Here we present our summary recommendations for the key data requirements for vehicle restraint system condition measurement, for review and comment.

3 Summary recommendations for monitoring methods for vehicle restraint systems: 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 the Condition: 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 Vehicle Restraint Systems*:* This section presents a review of current and emerging measurement technique and proposes potential condition monitoring regimes that could be implemented for vehicle restraint systems.

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 vehicle restraint system 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 vehicle restraint systems, and to support maintenance/asset management decisions at the network level.

2.1 Vehicle restraint systems

A vehicle restraint system (VRS) is a device installed alongside the road with the principal function of providing a level of containment for errant vehicles. They minimise the risk of errant vehicles colliding with oncoming traffic, running off the road, and lessen the impact severity of a crash. They protect road users from potential hazards, such as signs, lighting, culverts, weather stations, trees etc. There are five categories of restraint system: safety barriers (including transitions/terminals); arrester beds, vehicle parapets; and crash cushions.

This report focuses on permanent verge-side and central reserve vehicle restraint barriers, which are often referred to as safety barriers. These can be either rigid or deformable systems:

- Rigid systems experience minor deflections during an impact; these are typically constructed from reinforced concrete and installed in the central reservation.
- Deformable systems sustain significant deflections under impact and are typically permanently deformed once impacted; these are constructed from steel (box beam or corrugated W profile beams) and tensioning cables and wires, with deformable steel supports.

2.2 Knowledge Gathering and Consultation

A review of standards and guidance documents for safety barriers was undertaken to identify the objective characteristics defined in the current standards that could be related to the performance and condition of the 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 vehicle restraint systems. 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 safety barriers (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).

75 National Road Authorities (including regional authorities) were identified and approached. An information pack and the questionnaire were distributed to all 75 stakeholders. Responses were received from 11 of these. These include responses from the UK, Netherlands, Sweden, Austria, Ireland, Germany, and Belgium. These 11 NRAs manage a total of 136,900km of motorways, dual and single carriageways.

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 VRS condition, which are listed 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, six of the eleven NRAs did not state the lengths present on their networks, in some cases this was because they did not hold an accurate figure because of incomplete inventories. Similarly only seven NRAs held records of the technical specifications of the products they use. Only four NRAs kept active records of the dates of previous inspections and had programmed future inspections. Further to this, six NRAs did not record the date their systems were installed

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 nor 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. Risk rating may be another consideration required if funding is limited: Some VRS are located in high risk locations and usually require urgent attention if damaged in collisions, others may not be so.

2.3.1 What should an Inventory for VRS contain?

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

- Location reference
- Manufacturer's declared design and performance characteristics
- Date of Construction
- Method of post installation
- Length of barrier
- Terminals on the safety barrier
- Hazards protected
- Speed limit of road
- Historical maintenance records
- Dates and references to inspections and inspection data
- Scheme/Contract references.

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, many inventories currently 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. OSGR longitude and latitude). The inventory should also contain other useful descriptions of the asset's location, such as: unique network identification code (i.e. area and section marker), road name and number, carriage way position (nearside or offside), 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 inspection to make efficient use of time.

Manufacturer declared data held in an inventory should include all of the information contained on the EN1317 compliant product's CE marking. If this data is not held, it can be gathered from a review of historical records or by contacting a barrier specialist to identify the system – many systems have product codes and references stamped onto them.

The **date a system was constructed** 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, support stabilisation dates etc.

2.4 Key data - Condition

The consultation found that seven NRAs had some form of monitoring regime in place to assess the condition of VRS. However, only four NRAs felt they had a clear view of the condition and performance level of these assets. All participants carried out ad-hoc reactive maintenance. None of the participants based their management approach on the age of the asset.

The consultation seemed to show a range of views associated with the need to assess the condition of VRS. For the assessment of structural condition, corrosion/damage and durability PREMIUM identified a range of practices. For example: a number of those who did carry out inspections stated that condition monitoring was essential; however, four of the NRAs did not currently have a condition monitoring regime in place; and one NRA stated that unless a VRS is struck by a vehicle it will deteriorate very slowly, and thus there is no need to monitor its condition in routine surveys.

The majority of the NRAs stated that they did not use any form of measured condition threshold to determine maintenance need. However, a number of objective measures were included such as the percentage of posts/beams that are damaged. The majority of NRAs (10 out of 11) also did not make use of any formal asset management system to manage their understanding of the condition of this asset.

It is therefore clear that there is a wide range of practice applied to understand the condition of VRS across Europe, and that this practice is still relatively rudimentary in terms of routine 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 vehicle restraint systems considered important by NRAs. 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 some of the current measurement techniques 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 on measurement methods is given in section 3.

Table 1: Key condition characteristics of VRS

Rank	Property	Characteristic
1st	Durability	Presence of Damage
2nd	Durability	Presence Corrosion/Rust
3rd	Structural	Ground Bearing Capacity
4th	Clearance	Mounting Height
5th	Structural	Fixing Condition

2.5 Key Characteristic 1: Durability – Presence of Damage

Definition: There is a wide range of possible damage a system can experience over the course of its service life. The majority result from vehicle collisions/strikes, or are a result of poor installation practices (e.g. bent/leaning posts, posts installed upside down, nuts and bolts missing). For steel systems damage types include: bent/leaning/missing posts; damaged/missing fixings; damaged beams; damaged anchors/fasteners/tensioning wire; and obvious signs a system has been impacted or struck. For concrete barriers the most common forms of damage include; extensive cracking (caused by an alkali-silica reaction); exposed joints; chips; spalling; damaged ground anchors; and exposed steel reinforcement.

Standard/Guidance: BS 7669-3

Measurement Technique: A routine safety inspection (from a vehicle) can be used to identify obvious signs of damage, such as those sustained during a collision or barrier strike. However, less obvious defects can only be located and identified by a walked inspection. Thus damage is currently measured through visual inspections.

Measurement Frequency: Safety inspections to identify obvious damage should be carried out on a routine basis, at weekly/monthly intervals depending on the class of the road. Higher class roads will require more frequent inspections. Detailed inspections, highlighting less obvious damage, occur less frequently. For steel type systems every 5 years for the first 10 years then every 2 years thereafter. Concrete systems should have a detailed inspection carried out once every 5 years for the first 15 years of service, and every 2 years thereafter.

2.6 Key Characteristic 2: Durability – Presence of Corrosion/Rust

Definition: Corrosion and rust is caused when steel is exposed to oxygen and moisture over a long period of time. The oxidisation process is accelerated in the presence of salts; this is especially important considering routine winter maintenance activities such as de-icing. Whilst steel-type vehicle restraint systems are galvanised, it is possible (and common) for corrosion to form on beams, posts, and fixings. This can be due to the component being damaged during the installation process or scratched by a vehicle strike, which removes the protective zinc layer and allows iron oxide to form.

Standard/Guidance: BS 7669-3

Measurement Technique: Slow speed detailed manual visual inspections are the predominant method used for identifying areas of corrosion.

Measurement Frequency: For steel systems a detailed inspection (addressing corrosion amongst other things) should be conducted twice during the system's first 10 years of service i.e. every 5 years. After which it should be inspected more frequently, every 2 years. For concrete barriers it is recommended that a detailed inspection, for systems under 15 years old, should be carried out every 5 years. After which the asset should be inspected every 2 years.

2.7 Key Characteristic 3: Structural – Ground Bearing Capacity

Definition: The ground bearing capacity refers to the ability of the soil to support the system's posts, being able to withstand defined loading increments and maximum bending moment. This ensures the post will deflect as designed for during a collision/strike.

Standard/Guidance: BS 7669-3

Measurement Technique: Those consulted reported that the ground bearing capacity was predominantly assessed using the push/pull methodology, which is performed at slow speed.

Measurement Frequency: Push/pull tests should be carried out as part of the detailed inspection. For steel systems this is every 5 years during the first 10 years of service, then every 2 years thereafter. Each test can take between 10-20 minutes to conduct.

2.8 Key Characteristic 4: Clearance - Mounting Height

Definition: The mounting height of the vehicle restraint is defined as the height from the carriageway surface to the midpoint of the beam. In accordance with BS 7669-3, tensioned corrugated beams, un-tensioned corrugated beams, open box beams, and rectangular hollow sections should be mounted at 610mm ± 30mm for new barriers and 610mm ± 75mm for in-service barriers (BS 7669-3). For wire rope barriers, the centre of the upper pair of wires should be 585mm ± 10mm. If installed outside of these tolerances it increases the risk that a vehicle striking the barrier could either intrude beneath the system (in case of too high steel type systems) or flip over if the system is too low (BS 7669-3).

Standard/Guidance: BS 7669-3

Measurement Technique: The predominant current practice is to measure the barrier's height as part of a "walked" inspection.

Measurement Frequency: A height measurement should be made for at least every 100m of barrier. Whenever the road is resurfaced, the mounting height should be measured to confirm whether it is still within the height tolerances specified by the manufacturer. If the barrier has been in-service for less than 10 years, measurements should be taken every 5 years. For older barriers height measurements should be made as part of the detailed inspection every 2 years thereafter.

2.9 Key Characteristic 5: Structural – Fixing Condition

Definition: Fixing condition refers to the integrity of nuts, bolts, washers, mounting brackets and connections. Fixings should be free from rust and corrosion; nuts and bolts should be to the correct torque as specified in BS 7669-3. It should also consider where fixings have been damaged or are missing and whether the right fixings have been used.

Standard/Guidance: BS 7669-3

Measurement Technique: The current measurement method for assessing the condition of fixings requires a walked slow speed survey.

Measurement Frequency: During a detailed inspection all bolts and other fixings are individually inspected for torque and condition. For steel type systems this would be inspected every 5 years during the first 10 years of service, and then every 2 years thereafter.

2.10 Summary

The key characteristics that PREMIUM proposes should be measured to describe the condition of VRS 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 vehicle restraint systems

Characteristic	Current Measurement	Units	Standard Thresholds
Presence of damage	**Number or percentage of posts affected in a length or for the whole barrier.** **Number or length of beams affected**	**%** **Length in m**	**None identified**
Presence of corrosion/rust	**Number or percentage of posts affected in a length or for the whole barrier.** **Number or length of beams affected**	**%** **Length in m**	**None identified**
Ground bearing capacity	**Deflection of post when subjected to a push or pull load of up to 6000N (in 1000N steps)**	**mm**	**The post foundation is acceptable if a bending moment of:** • **6kNm can be applied without the deflection exceeding 100mm for 100 × 32 and 110 × 50 "Z" section steel posts** • **9kNm can be applied without the deflection exceeding 150mm for 125 × 90 "Z" section steel posts.** (BS 7669-3)
Mounting height	**Height of middle of beam or centre of rope pair from pavement surface (where set-back is 1.5m or less) or general ground level beneath barrier.**	**mm**	**610mm ± 75mm for tensioned corrugated beams, un-tensioned corrugated beams, open box beams and rectangular hollow sections.** 585 mm ± 10 mm (centre of the upper pair) for wire rope (BS 7669-3).
Fixing condition	**Presence of rust** Tightness of fixing	**N/A** Torque in Newton metre (Nm)	**None identified**

3 Summary recommendations for monitoring methods for vehicle restraint systems

3.1 Monitoring Vehicle restraint systems

The condition of vehicle restraint systems is very important for road safety. Measuring the condition of these assets at the network level is challenging because, as noted in Section 2, there are a number of different key characteristics of the condition which need to be measured.

In this Section (3) we will discuss the measurement techniques that have been identified within PREMIUM which 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.

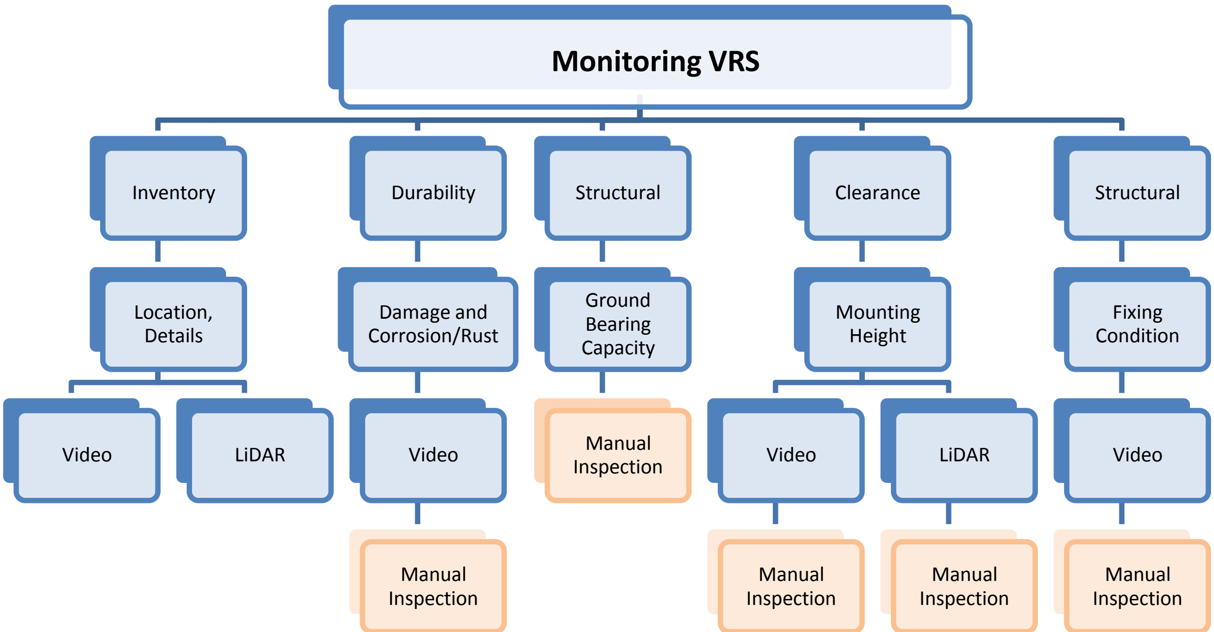


Figure 1: Typical measurement methods (current and emerging) to monitor key condition characteristics of VRS

3.2 Knowledge Gathering and Consultation

A knowledge gathering exercise was carried out to seek information on the methods available for the measurement of VRS. 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 road safety experts were used to provide more details about the characteristics that are collected. The TRIMM project was also identified as a resource for measurement techniques for measuring inventory data of Vehicle Restraint Systems.

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

3.3 Key Data - Inventory

The following methods were identified as currently being used to measure the inventory of vehicle restraint systems. These methods collect information about the inventory characteristics, including type, length, 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, 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. Depending on the extent of the closure, TM time constraints, weather, number of lanes, and general health and safety conditions, a single inspection (carried out by an experienced inspector) could survey VRS on 3-5km of the road network on foot per night.
- Traffic Speed Visual Survey: Vehicles enabled with GPS/GNSS recording devices, forward facing imaging, and odometer. 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. The accuracy of satellite imagery, such as Google Maps, can also vary; in some cases co-ordinates can be several meters out when compared with measurements taken onsite using a quality GPS device. Other descriptions of the location should be to a level of detail that would allow any survey provider to locate the assets without GPS co-ordinates.
- A desktop survey utilising up-to-date satellite and street-view maps/imagery (e.g. Google Earth Pro/StreetView, Ordnance Survey) can also be undertaken to determine the exact geographical location of assets.

In addition, several recent studies were identified that have investigated asset detection and extraction using Video and algorithms or LiDAR technology. The results of the review show that it is practical to obtain inventory data on VRS using traffic-speed techniques, including traffic speed video surveys and LiDAR surveys, and this has already been demonstrated in practice.

Thus the following new/emerging technology can be used to provide inventory data for VRS using traffic speed surveys:

- Video based survey (traffic speed): Vehicles enabled with GPS/GNSS recording devices and cameras
- LiDAR survey (traffic-speed): Vehicles enabled with GPS/GNSS recording devices, LiDAR, and odometer. This method does not require traffic management, and is performed at any time of day, at traffic speed. However, weather conditions should be dry and clear.

For Inventory data PREMIUM therefore recommends that:

- NRAs should 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 VRS.

In order to implement a reliable and accurate high-speed, network level survey for inventory of VRS, it would be necessary to:

- Perform a large scale experiment with different devices to provide more information and obtain better understanding of capability of current high speed systems
- Most methods for extraction of asset types, which are described in section 5 in this document, are manual. Thus just collecting video and LiDAR data will not provide a practical network level survey. Thus there would also be a need for development of automated extraction processes for LiDAR and image surveys.

3.4 Key Characteristic 1: Durability – Presence of Damage

3.4.1 **Measurement techniques**

Routine traffic speed visual inspection via a “drive by survey” is commonly used for detection of damaged VRS. This method can be used to identify obvious signs of damages such as damage resulting from vehicle impact. The damage is recorded by the inspector in the vehicle as the vehicle is driven along the road. Small defects are not visible and can be located only by manual visual inspection.

Video surveys could be used as an alternative to these visual inspections for the identification of damage. The images are accurately geographically referenced and can be kept as a historical record of a barrier’s condition. However, this method would only provide significant advantage (i.e. in time and cost) over routine visual inspections (which are carried out as a matter of course) if the damage could be identified automatically.

Also, as with routine visual inspections, video surveys cannot be used to detect small defects or defects not visible from the road.

3.4.2 **Recommendations for measurement of Presence of Damage**

PREMIUM was not able to identify a method or survey, at a market ready level that could be practically applied at the network level for measurement of presence of damage on VRS. Therefore PREMiUM recommends that further work be commissioned in order to develop a measurement for this. This work would include:

- The potential of video and images from the systems used to collect VRS inventory should be investigated to determine whether manual analysis of these images could be used to monitor the presence of corrosion/rust.
- Practical trials with different devices would provide more information and obtain better understanding of capability of current systems and would enable a specification for the minimum technical requirements (image resolution, positioning system) for video surveys to be derived.
- If manual analysis can be used to determine corrosion from images, then it might also be possible to extract this information automatically. This would require development of automatic analysis algorithms of the video data, and would be a long term objective.

3.5 Key Characteristic 2: Durability – Presence of Corrosion/Rust

3.5.1 **Measurement techniques**

This characteristic is assessed currently from a detailed manual visual inspection, usually carried out at slow speed (walked). The detailed inspection examines every post, beam, fixing, steel cable, and concrete section and ground anchor, individually for signs of corrosion

Currently there is no routine method that would enable the practical measurement of presence of corrosion/rust at the network level. However, during our review, PREMiUM identified a number of traffic speed methods, which have *potential* to provide information for corrosion/rust. Video and images from measurement systems that collect inventory data might be used to assess the condition of the VRS, but more research is needed to confirm this. However this method does have some limitations e.g. rust on the reverse of a VRS would not be visible.

3.5.2 **Recommendations for measurement of Presence of Corrosion/Rust**

PREMIUM was not able to identify a method or survey, at a market ready level, which could be practically applied at the network level for measurement of the presence of corrosion/rust of VRS.

As there is already some evidence that video surveys can be used to identify damaged VRS, 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 3.5.2.

3.6 Key Characteristic 3: Structural – Ground Bearing Capacity

3.6.1 **Measurement Technique:**

The ground's bearing capacity is assessed using the push/pull methodology, or cone penetration tests, which can only be performed at slow speed (as part of a detailed inspection). PREMiUM did not identify any routine methods to measure the ground bearing capacity nor any technique that could be developed to provide information at network level.

3.6.2 **Recommendations for measurement of Ground Bearing Capacity**

Since no existing or potential measurement methods were identified, no further immediate development of existing equipment can be recommended by PREMIUM. However, it is possible that alternative technologies could be employed to monitor for changes in the orientation or position of the barrier that could be used as a proxy for the ground bearing capacity (e.g. vibration sensors). However, PREMiUM did not identify any application of this type of system for the monitoring of VRS. As this is a rapidly developing field we recommend that monitoring of the technology continues.

3.7 Key Characteristic 4: Clearance - Mounting Height

3.7.1 Measurement Technique

Mounting height is measured during a detailed inspection of a barrier's clearance (measured by hand). Alternatively, coarse manual surveys undertaken at traffic speed can identify obvious differences in mounting height.

However, PREMiUM has also identified the use of video/LIDAR equipment for the measurement of the mounting height of VRS at traffic-speed. This has been applied in practice using manual methods to analyse the LIDAR data, and there is evidence to suggest that this could be automated.

3.7.2 Recommendations for measurement of Mounting Height

Although PREMIUM was not able to identify a market ready survey that could be practically applied at the network level for measurement of mounting height of VRS, potential existing methods were identified. The capability of these methods has been demonstrated at the small scale, but there would be benefit in larger scale investigation and assessment. Therefore we recommend further work be commissioned to test these:

- Large scale trials of LiDAR and/or video surveys, to provide appropriate data from which mounting height could be extracted
    - Assess the capability to survey at a network level with these systems
    - Assess the capability to measure all barriers the road at traffic speed
    - Ensure a wide and representative range of barrier type, size, and condition are surveyed
    - Assess the repeatability of the data (image quality, LiDAR data repeatability).
- Develop algorithms to automatically analyse the LiDAR or video data, to extract barrier height.
    - Thoroughly test the accuracy of these algorithms for different barrier types and conditions.

3.8 Key Characteristic 5: Structural – Fixing Condition

3.8.1 Measurement Technique

The main established method for assessing the condition of fixings is a walked slow speed survey. The inspection includes visual assessment (signs of rust) and physical inspection by hand for how tightly the fixings are attached (torque).

Due to the need for traffic management to perform these surveys and the time and man power required, it is felt that these low speed surveys are not a practical option to provide measurement data at the network level. Whilst an on-site survey is needed to assess the finer details of condition and tightness of fixings, a video-based method could potentially be used for measurement of some level of condition of the VRS's fixings that are visible from the road e.g. very loose or missing bolts. Alternatively, it might be possible to install smart technology on the fittings, if the cost is not prohibitive.

3.8.2 Recommendations for measurement of Fixing Condition

PREMIUM was not able to identify a method or survey, at a market ready level that could be practically applied at the network level for measurement of condition of VRS's fixings.

Video and images from measurement systems that collect inventory data at traffic speed could potentially be used to assess the condition of some of the fixings for the VRS, but more research is needed to confirm this. This method does have some limitations – only very loose or missing fixings could be identified on the road-side of the barrier. However, using video based measurements may be possible to indicate the places of VRS, where in-situ investigation is needed.

Therefore we recommend further work be commissioned to determine the suitability of video surveys to provide this information. The requirements for this work are the same as those for measurement of corrosion/rust (section 3.5.2).

3.9 Recommendations

A summary of the methods recommended for network measurement of the key characteristics is given in Table 3. Some of the methods proposed are not currently implemented, or fully developed. Therefore the table also summarises the recommendations on the work needed to be done in order to achieve the recommended network level measurements.

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 3: Recommended measurement methods and recommendation for work required to achieve recommended method

Property	Characteristic	Recommended measurement method to achieve network level requirement	PREMIUM recommendations for work required to achieve recommended method
Inventory	**Location**	Video LiDAR	Encourage wider adoption of video and LiDAR surveys to collect inventory data. **Obtain better understanding of capability of current imaging/LIDAR 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 automated extraction processes for LiDAR and image surveys. Test the technical capability of LiDAR for extraction of VRS from point cloud through practical trials and performance testing.

Property	Characteristic	Recommended measurement method to achieve network level requirement	PREMIUM recommendations for work required to achieve recommended method
Durability	**Presence of damage**	Visual inspection from Video	**Develop minimum technical specification for video surveys** **Develop formal manual assessment regime to use images to identify damage – 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** Develop automatic analysis algorithms of the video data.
Durability	**Presence Corrosion/ Rust**	Visual inspection from Video	**Determine if this defect can be successfully identified using this approach. If successful then:** • **Develop minimum technical specification for video surveys** • **Develop formal manual assessment regime to use images to identify corrosion – including a reporting method (e.g. % corrosion)** • **Provide NRAs with guidance on the application of high speed systems** Develop automatic analysis algorithms of the video data.
Structural	Ground Bearing Capacity	Manual inspection (push/pull method, cone penetration test) In-situ (smart technology) measurements	No further development identified for current high speed surveys. Investigate the potential for in-situ monitoring methods.
Clearance	**Mounting Height**	Video LiDAR	**Develop minimum technical specification for video and LIDAR surveys** **Develop formal manual assessment regime to use images to assess height** **Provide NRAs with guidance on the application of high speed systems to this measurement** Develop automatic analysis algorithms of the

Property	Characteristic	Recommended measurement method to achieve network level requirement	PREMIUM recommendations for work required to achieve recommended method
			video or LiDAR data and test these for performance.
Structural	Fixing Condition	Visual inspection from Video In-situ (smart technology) measurements	Investigate if video surveys are capable of delivering useful information, either for complete assessment of to help focus other manual surveys. Develop a method to cost-effectively measure fixing condition in-situ

4 Technical Background – Standards and Approach for Understanding the Condition of Vehicle Restraint Systems

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 of which could plausibly be collected during an inspection/condition survey) for determining the condition of the asset and its current level of performance.

This commenced with a review of current standards and guidance documents to identify the characteristics of VRS for which measurements are currently required. To support the review, additional information was also sourced from the HeRoad report into equipment condition assessment (Casse & Van Geem, 2012).

Table 4 identifies the different property groups, and their characteristics, for safety barriers. Project consortium members were also asked to review their national standards and guidance documents to see which characteristics were referenced, highlighting commonalities in the requirement of certain forms of data. The characteristics listed in Table 4 were the findings from the standards review.

Table 4: Property groups and their characteristics for safety barriers

Property	Characteristic	UK	Ireland	Germany	France	Austria	Bulgaria	Belgium	Australia
Inventory	Location Reference	✓	✓	n/a	n/a	n/a	n/a	✓	✓
	Asset Description	✓	✓	n/a	n/a	n/a	n/a	✓	✓
	Date of Last/Next Inspection	✓	✓	n/a	n/a	n/a	n/a	✘	✓
	Date of Installation	✓	✓	n/a	n/a	n/a	n/a	✘	✓
	Dates/Details of Maintenance	✓	✓	n/a	n/a	n/a	n/a	✘	✓
Durability	Presence of Corrosion/Rust	✓	✓	n/a	n/a	n/a	n/a	✓	✓
	Presence of Damage	✓	✓	n/a	n/a	n/a	n/a	✓	✓
Structural	Post Stability	✓	✓	n/a	n/a	n/a	n/a	✘	✘
	Fixing Condition	✓	✓	n/a	n/a	n/a	n/a	✘	✘
	Beam Alignment	✓	✓	n/a	n/a	n/a	n/a	✓	✘
	Orientation	✓	✓	n/a	n/a	n/a	n/a	✓	✘
	Ground Bearing Capacity	✓	✓	n/a	n/a	n/a	n/a	✓	✘
	Impact Acceptance	✓	✓	n/a	n/a	n/a	n/a	✓	✓

Property	Characteristic	UK	Ireland	Germany	France	Austria	Bulgaria	Belgium	Australia
Clearance	Mounting Height	✓	✓	n/a	n/a	n/a	n/a	✓	✘
	Set-Back Distance	✓	✓	n/a	n/a	n/a	n/a	✘	✘
	Working Widths	✓	✓	n/a	n/a	n/a	n/a	✓	✘
	Minimum Barrier Length	✓	✓	n/a	n/a	n/a	n/a	✘	✘
Placement	Proximity to Hazards	✓	✓	n/a	n/a	n/a	n/a	✓	✘

4.2 Review of Standards defining the performance of vehicle restraint systems

Figure 2 and Figure 3 provide an illustration of the key standards and guidance documents that relate to the safety barriers performance criteria and inspection. This section will now discuss each of these standards.

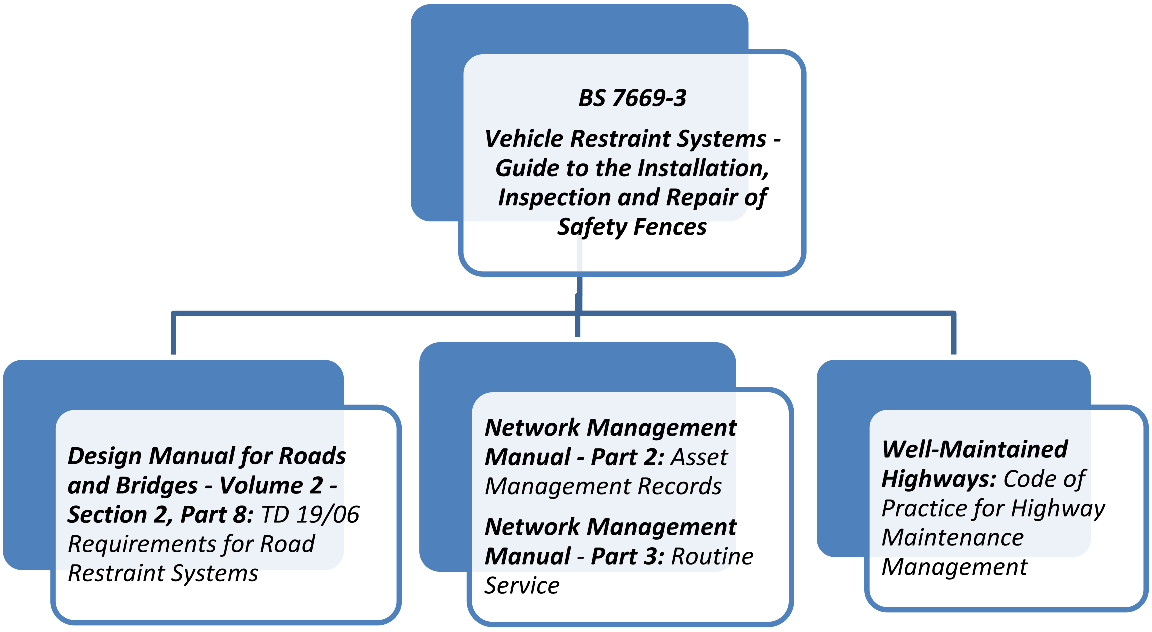


Figure 2: UK National Standards & Guidance

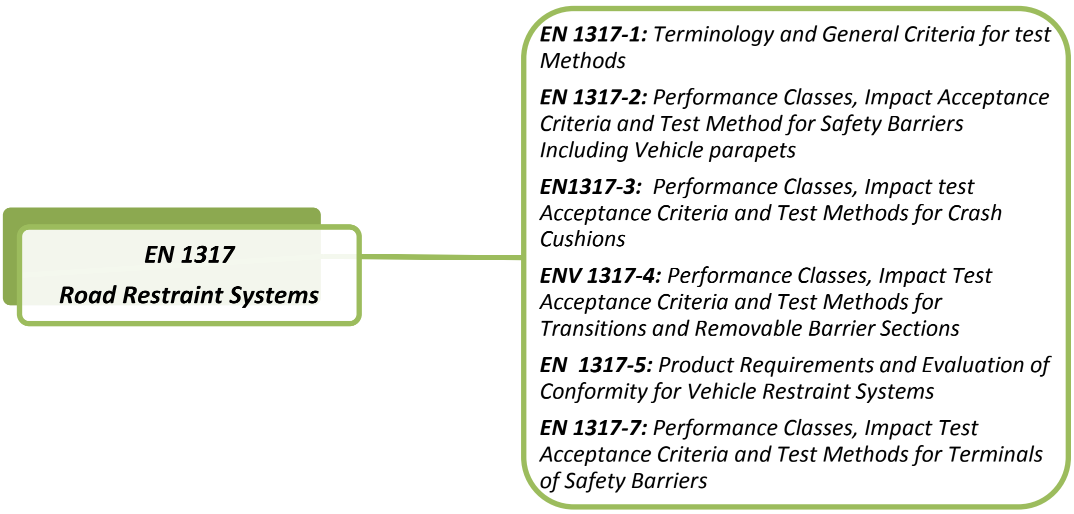


Figure 3: EN 1317 Suite Outline

4.2.1 EN 1317 Road Restraint Systems Suite

The EN 1317 suite of standards is primarily used to assess the conformity, and to classify and certify vehicle restraint products. There are 8 parts, which all relate to impact testing but do not offer condition measurements or inspection guidance.

4.2.2 BS 7669-3 - Vehicle Restraint Systems: Guide to the Installation, Inspection and Repair of Safety Fences

This Standard provides methodologies and guidance for the installation of vehicle restraint systems. It also offers in-service inspection and maintenance guidance.

Inspection guidance covers both in-service and new safety barriers and provides a standard report format containing checklists and questionnaires for each level of inspection (routine safety and detailed inspections). A routine safety inspection is designed to identify defects which pose an immediate hazard or could cause serious inconvenience to the public. These inspections can be performed in a vehicle or carried out on foot. The frequency at which these inspections occur is dependent on the type of road and its speed limit; ranging from weekly to monthly inspections. Further safety inspections may be needed in response to complaints made by police, authorities, or the public in cases of major incidents, or as a result of extreme weather events. A detailed inspection is conducted at less frequent intervals. For steel type systems detailed inspections should be carried out once every 5 years for the first 10 years of service, and then every 2 years thereafter. For concrete type systems a detailed inspection is carried out once every five years for the first 15 years of service, then every 2 years thereafter. A detailed inspection considers the condition of all the individual components with reference to a checklist. It is a manual survey performed on foot.

BS 7669-3 provides checklists for both types of survey. The routine safety inspection checklists are very brief and are really designed to identify and categorise obvious areas of damage. It considers post, beam and general defects. For posts this includes: orientation, damage, corrosion, stability and fixings to beam. For beams it includes: damage, corrosion, lap screws and adjuster assembly. The general considerations relate to: anchorage, concrete fairings, connection pieces, angle beams, and mounting brackets. For each defect the inspector finds, a record must be kept of the location and the category of the defect. Category 1 defects necessitate immediate attention (collision damage/missing screws). Category 2 defects can be left for up to 6 months before repairs need to be effected. The standard offers one standard inspection record template and one set of checklists suitable for all types of barrier.

Depending on the type of barrier that is being inspected (tension corrugated beam, open box beam, concrete and so on) the standard offers a different set of appropriate checklists for detailed inspections. In general these checklists follow the same format, split into 6 sections (inventory, general requirements, anchorages/terminals, posts, beams, and tensioner assemblies).

The inventory section requires the collection of basic information, such as location referencing and descriptions (road name; number; local authority; dates of previous and future inspections; road speed limit; and the length of the barrier to be inspected). The general section records the following data: set-back distance; clearance behind the fence; mounting heights; missing components; alignment; and ground profile. The anchorages/terminals section relates to the condition of concrete fairings, angle beam alignment and anchor bolt torque levels. The posts checklist consists of 12 questions regarding their: orientation; spacing; foundation condition (socketed, surface mounted, driven, or concreted); and the overall condition of the post. The beam’s checklist consists of

8 questions concerning: alignment (do beams overlap in the right direction), condition and torque of screws and bolts; and the general condition of the beam itself. The adjuster assemblies' checklist considers: spacing; orientation; bracket bolts, lock nuts, and adjuster bolts torque; and the overall condition of these components. For all of the questions the inspector should record the locations of the defects and comment on the extent of damage.

4.2.3 **TD 19/06 – Requirements for Road Restraint Systems**

The TD 19/06 standard sets outs the requirements and criteria for the provision, design and layout of permanent and temporary restraint systems (DMRB, 2006). The standard also covers other forms of restraint system such as: parapets, terminals, crash cushions, arrester beds and transitions/connections, which are not being considered within PREMiUM. The standard also introduces its companion document the 'Road Restraint Risk Assessment Process' (RRRAP). This is a risk assessment tool that allows designers to determine the level of risk associated with each roadside hazard (signs, utility cabins, weather stations, culverts, etc.) for sites currently without restraint systems in place. It also allows one to calculate the level of risk associated with various lengths and different performance classes of EN 1317 certified restraint systems.

4.2.4 **Well-Maintained Highways**

This is a guidance document for UK road authorities, highlighting current best practice for maintenance management (UKRLG, 2005). The document aims to encourage the uptake of asset management practices as a means of establishing value for money in the delivery of maintenance. With regards to vehicle restraint systems the guide offers limited advice with regards to condition monitoring and inspections. It reiterates many of the considerations and criteria set out in BS 7669-3. The standard provides a checklist of suggested items for inspection, and included in this are vehicle restraint systems.

4.2.5 **Network Management Manual Part 3**

Part 3 of the Network Management Manual (NMM) provides advice and guidance on how to achieve some aspects of the asset's performance requirements through routine service. The manual promotes inspections of all levels of detail (routine patrol, safety inspection, detailed inspection, general inspections, principal inspections and so on). The document highlights a number of conditions that will likely affect the performance requirements of restraint systems. These are as follows:

- corroded metal
- concrete cracking, spalling or reinforcement corrosion
- missing components
- broken, deformed or cracked components
- loose nuts, bolts and other components represent a hazard
- lack of tension
- incorrect height
- excessive under growth
- ingress of water to post sockets.

The guidance then details the intervention levels and elements that should be inspected, these are as follows:

- mounting height
- component type, ensuring correct components are used
- torque of fixings, nuts and bolts

- tension of cables
- minimum approach length of restraint system to hazard
- foundation condition
- set-back distance from carriageway.

However, no thresholds are given for these characteristics.

4.2.6 Other Standards

The standards review also identified a number of additional national standard and guidance documents from across Europe and Australia. Many of these standards highlighted the key characteristics identified in section 2.5. These include: the Austroads Guide to Asset Management (Part 7: Road-Related Assets Performance) which provides advice for NRAs (in Australia and New Zealand) on the management and monitoring of vehicle restraint systems (Austroads, 2009).

In Germany a number of standards and guidance documents are available including: RPS (Guidelines for Passive Protection on Roads by Vehicles – Restraint Systems); ZTV-PS 98 (Additional Technical Specifications and Guidelines for Passive Safety Devices); TL-BSWF 96 (Specification for Concrete Protection Wall); TL-SP 99 (Specification for Steel Safety Barriers); AND ZTV FRS Additional Technical Specification and Guidelines for VRS). In Austria national standards and guidance include: IWA 14-1 (VRS Performance Requirements); IWA 14-2 (VRS Application) and RVS 05.02.31 (VRS Requirements and Installation.

4.3 Review of practice in the assessment of the performance of vehicle restraint systems

A stakeholder engagement exercise was carried out to investigate current industry practice in evaluating the performance and condition of vehicle restraint systems. 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, stakeholders 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 themselves consider to be the most and least important characteristics, which they use to effectively manage the asset. Across the consortium, 75 National Road Authorities (including regional authorities) were identified and approached. An information pack and the questionnaire were then distributed to all 75 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?*
Of the 75 NRAs who received the questionnaire and information pack, timely responses were received from 11 of these, a 15% response rate. These include responses from the UK, Netherlands, Sweden, Austria, Ireland, Germany, and Belgium. The 11 NRAs manage a total of 136,900km of motorways, dual and single carriageways.

Q2. *What types of vehicle restraint systems are present on your network and what is the approximate total length for each type?*
Six of the eleven NRAs did not state the lengths present on their networks, in some cases this was because they did not hold an accurate figure because of incomplete inventories. For the remaining 5 NRAs, there are approximately 16,000km of median and verge side vehicle restraint systems. The NRAs stated that they had a number of different single and double sided systems with different containment levels:

- Un-tensioned corrugated steel beam
- Tensioned corrugated steel beam
- Open box steel beam
- Tensioned steel wire
- Reinforced concrete step barrier (also known as New Jersey profile).

Q3. *What is your general approach to managing and understanding the condition of vehicle restraint systems? 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)?*
c. *Is the approach based on age of the asset?*
Seven NRAs had some form of monitoring regime set in place, however only four NRAs felt they had a clear view of the condition and performance level of all their assets. All participants carried out ad-hoc reactive maintenance. And none of the participants based 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. slow speed or traffic speed tests for the:*

- *Measurement of wear or corrosion*
- *Measurement of height*
- *Measurement of structural integrity.*

Five NRAs undertook measurements of the above characteristics (wear/corrosion, height, and structural integrity). Six NRAs did not make any measurements of these characteristics. The methodologies used to assess these features were all some form of visual inspection for road safety purposes.

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).*
Four NRAs do not currently have a condition monitoring regime in place, as it is believed that that there is no need to track the condition of their assets. This was clarified by one NRA, who stated that unless a VRS is struck by a vehicle it will deteriorate very slowly, thus there is no need to monitor. Quality control measures (a visual inspection) are in place during and immediately after the barrier's installation – after this the barrier is assumed to function, unless damaged during a collision, for its estimated working life.

A number of those who did carry out inspections stated that condition monitoring was essential. One of whom said frequent vehicle strikes meant barriers were constantly being replaced. This factor complicated monitoring, especially in cases where inventories have not been updated.

Q6. *Do you use an asset management system for managing vehicle restraint systems (maintenance planning and forecasting budgets)?*
The majority of NRAs (10 out of 11) did not make use of any formal asset management system. One of these said they did not currently have a live system up and running, but one was currently being initiated. The UK's approach uses a value management process to allocate funds for maintenance, with each UK area team prioritising their schemes based on the findings of condition surveys and detailed inspections.

Q7. *What methods of maintenance are applied to restraint system e.g. replacement, repainting, cleaning, patching, post reinforcement?*
By far the most common maintenance activity was replacement. This is due to the nature of the asset, as they are often struck by errant vehicles. Aligning activities, post stabilisation/reinforcement and tensioning were also common activities for steel type barriers. Concrete barriers required little maintenance in the NRAs' experience, with only occasional patching being required.

Q8. *How do you decide if a restraint system requires each type of maintenance method listed in Q7? 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.*
As highlighted from the previous question, NRAs replaced barriers immediately if they had been struck by a vehicle. In cases of visible corrosion, structural inadequacy, and height deviations, as highlighted from the inspector's condition report, remedial actions would be taken. In the UK it is subjective; barriers are reviewed as part of the value management process, however it is dependent on the local area team to identify and prioritise maintenance works.

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?*
Seven NRAs did not use threshold values. In the UK, threshold values are not used to determine whether or not maintenance will be carried out. As previously mentioned, the process for determining maintenance is based on a value management process, which is subjective. However, there are a number of objective considerations in this, such as the percentage of posts/beams that are damaged, the age of the barrier, and the number of vehicle strikes and crossover incidents that have occurred; all contribute to the value management score. Other organisations based intervention levels on their own in-house thresholds, including percentage of posts/beams affected by corrosion, and minimum/maximum height and tilt allowances.

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 did not combine different measurements in order to decide upon their choice of maintenance. In the UK a barrier is approved for maintenance based on a number of factors (not all of which are objective) such as: air quality, noise and vibration, risk, material resources, cultural heritage, water quality, energy use, accessibility, material resources, flooding, society and community, landscape/townscape, construction waste, and soil and geometry. In Ireland the decision considers the asset's location, level of risk, and the type of barrier. In Austria, measures of concrete quality and corrosion are combined.

4.3.2 Summary of NRA responses to section 2 (monitoring VRS at the network level)

The second part of the questionnaire considered each condition characteristic identified in the standards review and asked stakeholders if these characteristics were currently monitored, and how. Finally stakeholders they 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 5 summarises the overall importance ranking of each characteristic according the NRA stakeholders. In addition to the characteristics listed in Table 21, 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 5: Key Performance Characteristics for VRS

Rank	Property	Characteristic
1st	Durability	Presence Corrosion/Rust
2nd	Durability	Presence of Damage
3rd	Structural	Ground Bearing Capacity
4th	Clearance	Mounting Height
5th	Structural	Fixing Condition

4.3.2.1 Property: *Inventory*

All of the Inventory characteristics received high importance ratings. The location and identification reference was only recorded by seven NRAs, despite receiving the highest importance rating. Location references include: area reference and section label; road name and number; chainage (start/end); and GPS co-ordinates. Similarly only seven NRAs held records of the technical specifications of the products they use. Only four NRAs kept active records of the dates of previous inspections and had programmed future inspections. Further to this, six NRAs did not record the date their systems were installed. Similarly, seven NRAs kept active records of previous maintenance interventions. With the exception of the asset's physical location, none of the other characteristics within this group can be measured in-situ. To obtain data on these features would require a review of historical records.

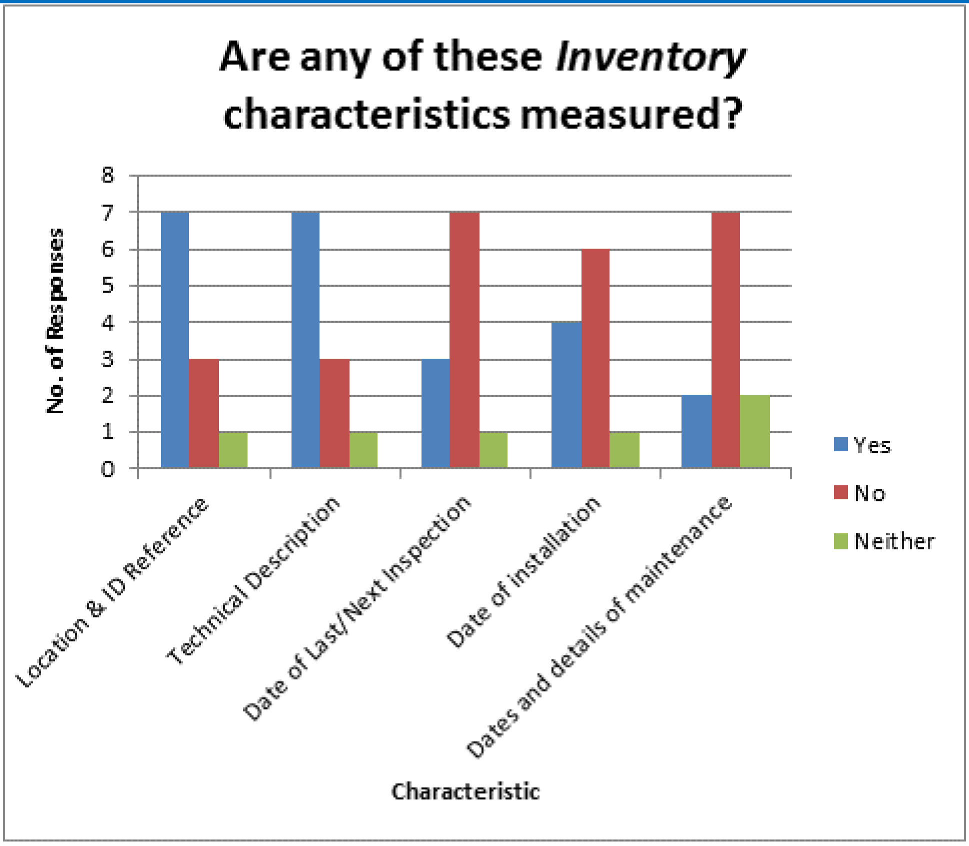


Figure 4: Inventory Characteristic Results

4.3.2.2 Property: *Structural*

As can be seen from Figure 5, the majority of NRAs did not undertake measurements of the characteristics included in the structural property group. Only one NRA assessed the stability of the supporting posts (for steel type barriers). This involves the use of a sprit level and visual inspection to check that the posts are vertical and not excessively leaning. Assessment of fixing condition (i.e. nuts, bolts and washers) was only carried out by two NRAs, due to the time consuming nature of this assessment. Each post is inspected individually, looking for signs of rust, missing components, and checking the tightness of fittings connecting the beam to the post. Measures of beam alignment were also rarely undertaken. Beam alignment is important as all of the beams should overlap in the direction of vehicle travel to ensure the systems deflect as designed when struck by an errant vehicle.

The orientation of the system is also important and should consider the local geography to ensure it has been placed in the most ideal position. Orientation will not be affected after installation but if quality control measures are not practiced during the installation it could result in a system being installed at the wrong angle, relative to the carriageway. Ground bearing capacity was only measured by three NRAs. In the UK this is done by using the push-pull methodology set out in BS 7669-3. This method uses a hydraulic arm to place a known force on the post, and deflections are recorded as incremental load increases are applied. These results are recorded and compared to threshold values. This is carried out for at least one post in every 100m, and is a very time consuming process taking between 10-20 minutes per post.

The cone penetration test (CPT) can also be used to measure bearing capacity (ASTM Standard D 3441). The test method consists of pushing an instrumented cone, with the tip facing down, into the ground at a controlled rate. Results from the CPT can be used to calculate parameters, such as the California Bearing Ratio. This takes the measured pressure required to penetrate the ground and divides this by the pressure required to achieve an equal penetration on a standard crushed rock material. The CBR test is described in ASTM Standard D4429 for soils in place, and AASHTO T193. The CBR test is also fully described in BS 1377 Part 4 and Part 9.

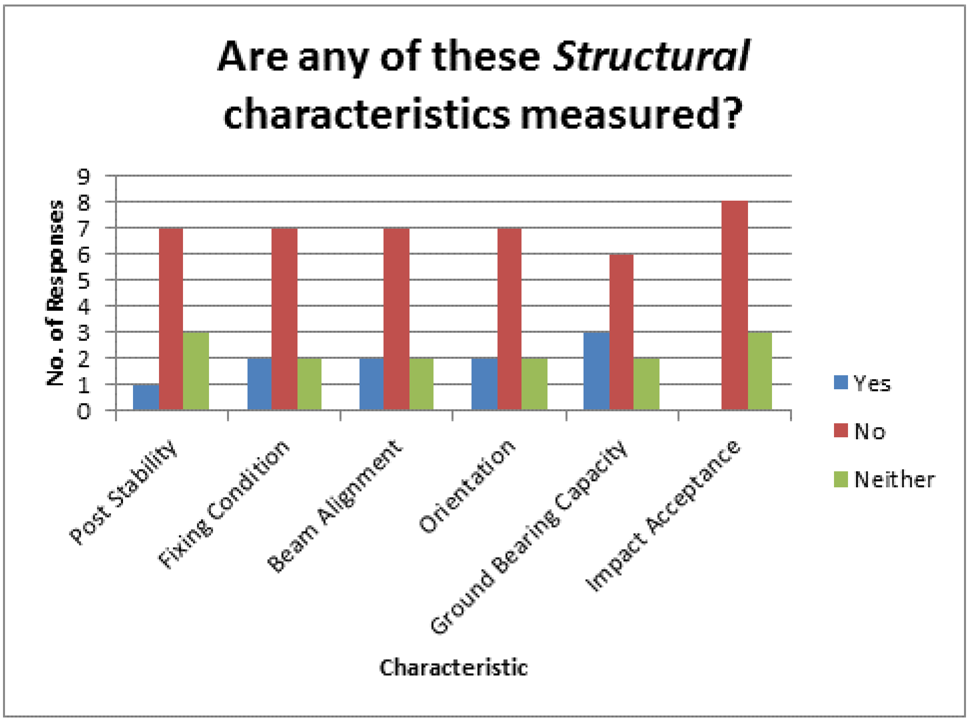


Figure 5: Structural Characteristic Results

4.3.2.3 Property: *Clearance*

Clearance characteristics refer to the geometric properties of the system relative to the carriageway. The mounting height was only measured by four NRAs during their inspections of the asset, despite being a critical design feature: A barrier set too low induces the risk that errant vehicles will overturn upon impact. Set too high and errant vehicles risk intrusion, penetrating beneath the barrier. A barrier's height can change over its lifetime, the most common cause of this is when carriageways have been resurfaced or had additional layers placed on the original surface. The setback distance refers to the lateral distance between the edge of the carriageway and the face of the barrier. If a barrier is set back too far from the carriageway there is an increased risk that an errant vehicle will impact the barrier at a higher than designed for angle, increasing the severity of the impact. If installed in this way it could mean the barrier is closer to the potential hazard, increasing the risk of a collision as less deflection can occur before the hazard is reached.

Only three NRAs measured the working widths of their barriers. The working width is a defined amount of space behind the system, free of obstructing objects, needed to ensure deflecting posts can perform as designed for under impact. It is not uncommon for sign posts and lighting systems to be installed within this zone, meaning full deflections cannot be achieved. The minimum barrier length – the longitudinal distance from the start of a barrier to the start of the hazard – was only measured by three NRAs. In the UK, a hazard must be preceded by a minimum of 30m of barrier.

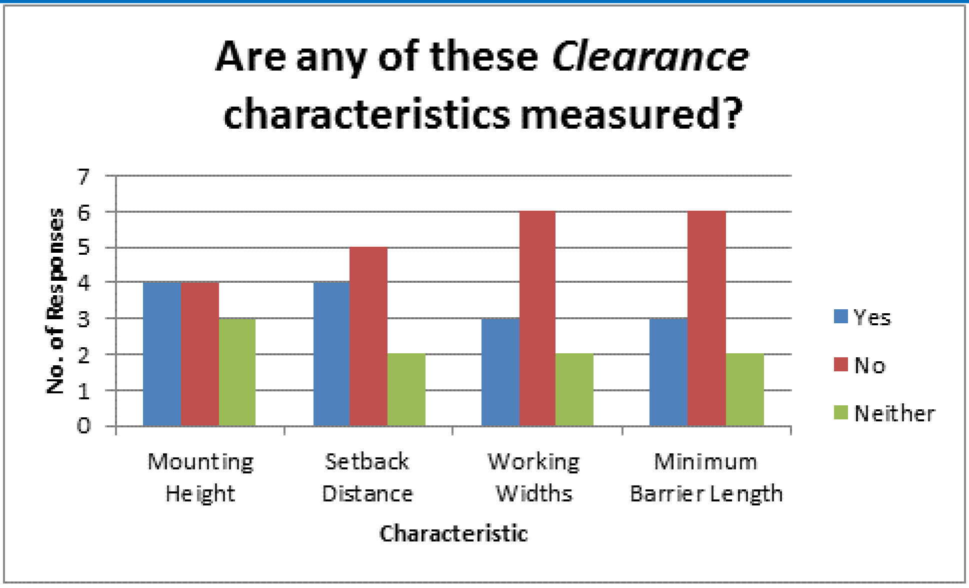


Figure 6: Clearance Characteristic Results

4.3.2.4 Property: Durability

The presence of corrosion was a factor that was only measured, or taken into account during an inspection, by five NRAs. Corrosion is caused by oxidation and moisture, and the use of road salts for de-icing purposes increases the rate at which corrosion/rusting will occur. Similarly damages, other than those caused from a vehicle strike, were only recorded by six NRAs. Damage and corrosion ultimately reduce the strength of any system, increasing the risk of impact severity.

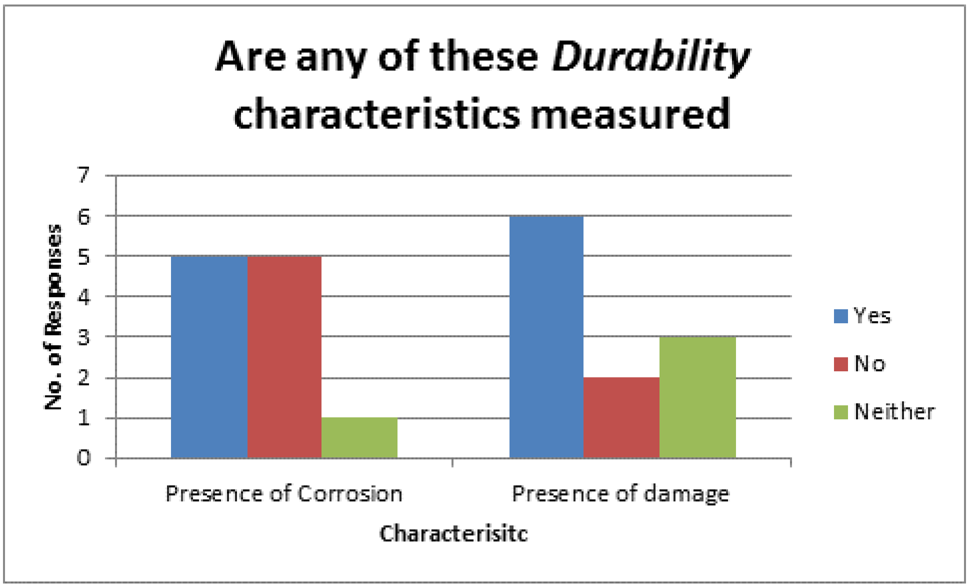


Figure 7: Durability Characteristic Results

4.4 Key characteristics of vehicle restraint systems that indicate their condition

The results from the NRA questionnaire suggested that NRAs felt that Inventory was the most important information to collect for vehicle restraint systems - without this, collecting condition data is redundant. The inventory should contain information such as location, barrier type, length of barrier, dates and details of construction, maintenance, inspection etc.

The presence of damage, a measure of the barrier's durability, was the condition characteristic considered to be most importance by the NRAs and was the most measured condition characteristic. Thus it was considered to be the first and most important key characteristic for VRS.

The presence of corrosion or rust was considered by the NRAs to be as important to measure as the presence of damage but was measured by one less NRA. Therefore this characteristic is proposed as the second most important key condition characteristic.

The third most important characteristic identified by the NRAs was the Ground Bearing Capacity. This was the most frequently measured of the structural properties of barriers and therefore is considered to be the third key condition characteristic.

Whilst the mounting height of the barrier was the third most measured characteristic (Figure 6) and the most measured of the Clearance properties, it was given a lower ranking than Ground Bearing Capacity by the NRAs. Therefore it is proposed that mounting height is the fourth key condition characteristic.

Fixing condition was condition was measured less than any of the Clearance properties but was considered to be more important to measure by the NRAs. Therefore it is proposed as the fifth 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 VRS that indicate their condition and are considered important by road owners are therefore:

- Durability - Presence of Damage
- Durability - Presence Corrosion/Rust
- Structural - Ground Bearing Capacity
- Clearance - Mounting Height
- Structural - Fixing Condition.

5 Technical Background – Methods for Measuring the Condition of Vehicle Restraint Systems

5.1 *Information Gathering -* Survey/Equipment Provider Questionnaire

A questionnaire, consisting of 8 questions relating to median and verge side vehicle restraint systems (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 29 survey/equipment providers were identified and contacted. Despite repeated efforts to engage with this stakeholder group, only six survey providers submitted completed questionnaires in the allocated time frame, a 20% response rate. 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?*
All responding survey providers carried out asset inspections on national motorways and highways.

Q2. *What survey methods/techniques do you currently use to monitor the condition of vehicle restraint systems? What measurements are recorded?*
Survey providers only identified two methods of inspection, one traffic speed and the other slow speed. The traffic speed inspection method is simply a routine patrol that identifies the locations of obvious defects that would impact the safety of road users, i.e. identifying sections that have been struck by vehicles but not reported. The slow speed method was a manual detailed visual condition survey. This method can provide measurements of: the precise location of the asset; the extent of corrosion and damage; the type of barrier, mounting height, fixing condition, geometric properties relative to hazards and the carriageway; cracking (for jersey profile barriers); post stability; beam alignment; and ground bearing capacity (if inspections also carry out push-pull tests).

Q3. *Please indicate whether any of the slow speed survey methods listed above could be performed at traffic speed.*
The survey providers that offered detailed manual inspections believed that the only data that could be obtained from a traffic speed survey would be the location of the asset, and images/video that could be analysed to assess condition. This however would not give you the level of detail acquired from the manual inspection. Further to this a traffic speed survey would only inform of the condition of the traffic side of the barrier. Extensive corrosion may be present on the rear side of the barrier; however this cannot be seen from looking at the traffic face of the barrier. This is also true for assessing the condition and tautness of fixings, and tensioning cables.

Q4. *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)*
During a traffic speed survey obvious signs of damage and their locations are recorded. The barrier is ruled to be fit or unfit for purpose based on the inspector’s professional judgement. For detailed inspections, in the UK, inspectors record a large amount of data which is then handed over to the NRA. This includes:

- The locations of any systems which do not comply with current standards
- A summary of the number and types of defects
- Percentage of beams and posts that have corroded

- Summary of push/pull post tests
- Photographs of defects
- Age of barrier (some types of barrier are date stamped)
- Mounting height, relative to carriageway
- Informed reasons for suspicions over the integrity of the barrier

Q5. *Does the inspection take place according to a standard? If so, please provide details of this.*
Two survey providers stated that they undertook surveys in accordance to a relevant standard:

- UK inspections take place according to BS 7669-3 and also consider the manufacturers inspection guidance, which is similar to BS 7669-3.
- In Ireland inspection take place according to EU Directive 2008/96/EC on Road Infrastructure Safety Management.

One survey provider did not use any form of national standard for their inspections. And one provider stated that they carried out inspections in accordance to the client's specification.

Q6. *How often does inspection take place?*
Survey providers reported different survey frequencies; biannual, annual, biennial, every 5 years or rarely at all. While there may be requirements for defined frequency intervals it is up to the NRA to decide if an inspection should take place or not.

Q7. *What are the yearly costs per km for these measures?*
Only one survey provider provided a figure for this question, the other providers declined to comment as this was commercially sensitive information. A detailed inspection costs approximately £580/km whilst the push-pull tests cost £660/km (this would cover 10 tests, approximately £66/test). These figures do not include management and report writing costs, material costs, and inspector expenses.

Q8. *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?*
None of the survey providers were aware of any emerging technologies that could enable traffic speed surveys that could yield large amounts of detailed data.

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 Vehicle Restraint Systems (VRS). This built on an interview with AIT's road safety team, combined with a review of available literature on equipment, to identify existing and emerging 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 data
- Durability: Presence of Damage
- Durability: Presence of Corrosion/Rust
- Structural: Ground Bearing Capacity
- Clearance: Mounting Height
- Structural: Fixing Condition.

These measurement technologies are shown in Figure 8. The techniques include manual inspections, video survey and novel systems (LiDAR).

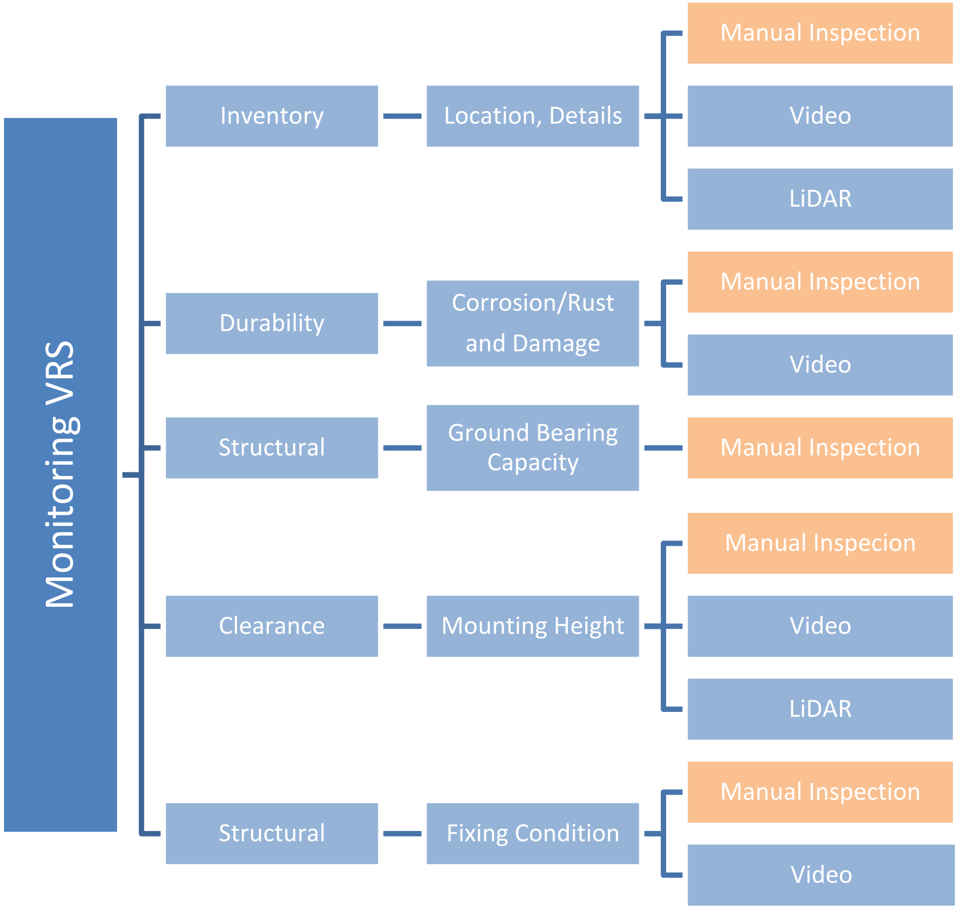


Figure 8: Measurement technologies for monitoring of VRS

5.3 Key data - Measuring the inventory of VRS

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 VRS 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.

The main established methods are:

- Historical Record Review: Reference to existing records such as construction drawings, documentation and contracts.
- Slow Speed Visual Survey: Field Inventory, a slow speed manual survey utilising a hand-held GPS data logging device.
- High Speed Visual Survey: Vehicles enabled with GPS/GNSS recording devices (e.g. Oxford Tracker/Trimble Applanix), forward facing imaging capabilities, and odometer.
- A desktop survey utilising up-to-date satellite and street-view imagery (e.g. Google Earth Pro/StreetView & Ordnance Survey) could also be undertaken to determine the exact geographical location of assets.

The TRIMM project (Spielhofer, 2014) observed that 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. The TRIMM project undertook a review of these systems and identified several including:

- The German (Lehmann+Partner) I.R.I.S – using single cameras (Figure 9)
- The Dutch Cyclomedia Measurement System, using 3600 rotating camera
- The Austrian AIT Stereo photogrammetric systems
- The Belgian KLM Aerocarto, using up to 14 cameras
- The UK Yotta Video Survey Van – using multiple cameras

Figure 9: Integrated Road Information Scanner I.R.I.S (LEHMANN & PARTNER)

These video recording methods deliver video-sequences or photos using one or several cameras, with each image accurately geographically referenced using initially aided GPS so that inventory items and some condition characteristics 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, …) for video surveys would be needed if this method were to be implemented.

The main established method for recording inventory data is a low speed visual inspection (Figure 10). Additional information can be collected at the same time for the condition of the VRS, using checklists with questions (Example 1 and Example 2).

This manual method is very difficult and complex, because it incurs additional health and safety issues – the inspector is not protected and may be in danger when he inspects the front of the VRS. Furthermore, the VRS can be several kilometres long. Therefore, this method is not practical for network level measurement.

Several recent studies have also investigated the use of LiDAR for road assets detection and extraction, and are showing reliable results. Case Study 1 shows an example of LiDAR data collection and manual extraction of the following data: location, position, type, height and condition.

Figure 10: Manual inspection of VRS

Example 1: Safety inspection - VRS[1]

Because of the large number of possible influencing factors, it is neither possible nor sensible or practical to list all possible criteria in the checklists. During a road safety inspection, all aspects that can have an influence on the safety of the respective road are examined using checklists. The checklists are an important part of the RSI and serve as a basis for the assessments, inspections, and site visits. All criteria contained in the checklist must be checked during the RSI. If relevant problems that are not included in the categories of the checklist are identified during a road safety inspection, the RS inspector should adapt the checklist.

The structure of the checklists has been kept as simple as possible, and only the headings of individual inspection criteria are listed. There are numerous questions in each of the categories that can arise during an RSI.

Checklist – Possible Questions for Motorways, Expressways, Interurban and Regional Roads

- Are there short, avoidable gaps in the vehicle restraint systems?
- Are the end elements state of the art?
- Are solid obstacles along the road adequately shielded by vehicle restraint systems?
- Can obstacles along the road be removed or replaced with more pliant systems?
- Are different systems connected correctly according to the technical standards?
- Do the lengths of the vehicle restraint systems meet the system requirements?
- Are the vehicle restraint systems in good condition?
- Are impact absorbers necessary?
- Are special precautions needed for motorcycle riders (underride protection)?

Example 2: Guardrails inspection[2]

Guardrail and end treatments are designed to reduce the severity of crashes. However, a damaged system can be a hazard and requires repair as soon as possible.

Guardrail maintenance is a key component of protecting the roadside, but there is uncertainty as to how to maintain the various guardrails and end treatments that are currently in use. Local jurisdictions continue to perform guardrail maintenance but there are no current guidelines to ensure that maintenance practices are to standard and are consistent throughout the state. These guidelines summarize current issues, the accepted approved guardrail types and end treatments used in Minnesota, inspection and maintenance practices for guardrails and resources and standards on guardrails and end treatments

Basic Inspection:

Periodic, routine inspection of roadside barriers should be part of the normal maintenance function. Examination of the following points should be included in all inspections, including routine maintenance inspections:

[1] Birgit Nadler, Friedrich Nadler, Bernd Strand - ROAD SAFETY INSPECTION (RSI) Manual for Conducting RSI, Vienna 2014

[2] MDoT - Guardrail Replacement and Maintenance Guidelines, 2010

Barrier Rail:

1) Is the barrier generally in shape, with no significant corrosion, accident damage or other misalignment?
2) Are all splice bolts and post attachment bolts in place and tight?
3) Are the rails properly attached to terminals and transitions?
4) Have any fixed objects such as small trees, poles, or other objects intruded within the deflection space?
5) Is the required rail height maintained?
6) Is there anything in front of the barrier that can cause a vehicle to vault? Typical problems include rough ground, erosion, vegetation and debris.
7) Is the barrier face smooth? Irregular curves or joints can cause a vehicle to snag and should be repaired as soon as possible.
8) Is the barrier the correct height? See designs for specific barriers. When the variation of height is greater than 2 in., plans should be made for correction.

Barrier Posts and Blockouts:

1) Are any posts missing or severely misaligned?
2) Are any blockouts missing or rotated out of the vertical position?
3) Do the posts appear firmly embedded, with no tilting or soil erosion around the posts? A minimum of 2ft of soil on a 1V:10H slope is required.

In-Depth Inspection:

A more in depth inspection should be carried out when the roadway is proposed for reconstruction or extensive repair, including the following points:

1) Rail height should be checked throughout the proposed project to ensure it will be within tolerance after completion of the road work. If necessary, height adjustment should be included in the project.
2) Are all existing barriers needed to meet the existing standards? Can the hazard be removed or modified to eliminate the need for a barrier?
3) Does the existing barrier meet length of need criteria, or are length adjustments required?
4) Do curb or embankment slopes in front of the barrier pose a risk of vehicle vaulting over the barrier?
5) Are flat slopes provided in front of terminals and transitions and traversable and clear areas behind “gating” terminals?
6) Is this type of barrier appropriate considering current highway and traffic parameters, or would another barrier type provide a significant safety upgrade?
7) Is post spacing appropriate for the available deflection distance?
8) Are terminals and transitions consistent with current standards, including proper flares and offsets?

Case Study 1: Mobile Mapping for Inventory of concrete barriers and plate beam guardrails[3]

The goals of this project were to create an inventory of roadway barriers, evaluate the viability of in-house data extraction of mobile imaging data and demonstrate the use of LiDAR data collection technology.

A consultant collected mobile imagery on 1,100 miles of roadway operated by the MnDOT Metro District, including images of all ramps, overpasses, interchanges, weigh stations, rest areas and historical sites. The consultant also collected LiDAR data at selected sites. Metro District staff reviewed the mobile images and extracted a variety of specific data, including route name; location (mainline, ramp or local road); travel direction; roadway position (right, median or left); barrier type; end treatment types; delineator type and whether it is mounted to specification; attachments; maximum and minimum barrier height; average barrier height; and barrier condition (Figure 11).

Barrier condition was evaluated according to the guidelines in Table 6 and Table 7 with a point and associated image created at the location where the condition exists.

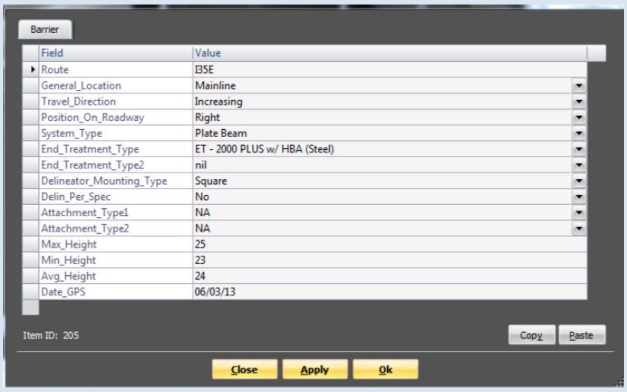


Figure 11: Barrier attribute table

Condition state 1	Spalls w/ no steel exposure
Condition state 2	Spalls w/ steel exposure
Condition state 3	Severe Deterioration

Table 6: Concrete Barrier Condition Issues

Functional	Hit that needs to be fixed
Non-functional	Open Guardrail
Cosmetic	Hit or rust that doesn't need to be fixed
End Treatment Broken	End treatment either hit or on the ground
Post Broken	Broken off post

Table 7: Plate Barrier Condition Issues

Figure 12: Identified barrier in extraction software

[3] Minnesota Department of Transportation - Metro Barrier Extraction and LiDAR Project, 2014
http://www.dot.state.mn.us/research/TS/2014/201422.pdf

5.4 Key condition data - Measuring the presence of damage

5.4.1 Slow speed measurement methods

Damage to a VRS is currently measured through a visual inspection. Whilst a routine safety inspection (at traffic-speed) can be used to identify obvious signs of damage, such as those sustained during a collision or barrier strike, less obvious defects can only be located and identified at slow speed.

The inspectors collect information about the condition of VRS using checklists with questions (Example 1 and Example 2). The location and type of damage should be recorded during an inspection. The inspector should comment on the extent of damage and provide photographic references to qualify their findings.

5.4.2 Traffic Speed measurements

As outlined above, the video-based methods, described in section 5.3, can be used to assess some of the condition characteristics of VRS. Damage can be identified in the images and its position extracted using either manual or automated methods. To enable this identification, the images need to be of high resolution and good quality. Therefore, to implement such a survey, specification of minimum technical requirements (image resolution, positioning system) for video survey would be needed.

However, small damage is not visible from video: They can only be identified through a visual inspection. Therefore, the potential of video-based methods for network level measurement of presence of all damages is currently limited. Future research/technology developments may reduce these limitations.

Figure 13: Examples for damaged VRS (visible from Video)

5.5 Key condition data - Measuring the presence of corrosion/rust

5.5.1 Slow speed measurement methods

The consultation appears to indicate that slow speed detailed manual visual inspection are currently the only robust method for identifying areas of corrosion. During a detailed inspection all steel elements are inspected individually. If corrosion is present, the inspector notes the location of the defect and categorises the level of corrosion (minor/major), whilst also taking photographs.

The detailed inspection examines every post, beam, fixing, steel cable, and concrete section and ground anchor, individually for signs of corrosion. The system is inspected from all angles, so any corrosion hidden from the traffic facing side is identified: This can be substantial especially for open box beam and hollow sections where water can sit undisturbed for long periods of time.

The exact location (GPS co-ordinates, post/beam number) is recorded and photographs are taken and referenced for a later review of the extent of the defect. For each site (or section of barrier) the number of beams and posts that show signs of corrosion is given as a percentage of the total number of posts/beams, in order to provide the NRA with an aggregate view of the how much corrosion is present. Inspectors must also note the type of beam (in case of steel type systems) and the method of post installation (driven, surface mounted, socketed, or concreted) so a suitable repair strategy can be developed.

5.5.2 Traffic Speed measurements

The video-based methods, described in section 5.3, can be used to assess the presence of corrosion/rust of VRS: They deliver images with accuracy position that may be able to provide information about corrosion/rust on the traffic side of the barrier.

However, there are some limitation of the video survey e.g. rust on reverse of VRS is not visible. In some cases corrosion/rust on the front side of the VRS is also very difficult for detection, when it is in small area. Therefore, the image quality is an important issue if such a survey were used.

Figure 14: Rust on the front side of VRS

Figure 15: Rust on reverse of VRS

5.6 Key condition data - Measuring the Ground Bearing Capacity

5.6.1 Slow speed measurement methods

The ground's bearing capacity is assessed using the push/pull methodology. A hydraulic arm places a defined set of loads to the top of the post. At each load level the post's deflection, from the normal, is recorded. This is done until the maximum load is reached. If a post can withstand the bending moment caused by the tests' maximum load without deflections outside of tolerance then the post (and its ground bearing conditions) are deemed suitable. If a post fails the push/pull test it indicates that the ground conditions are not suitable and a longer post should be installed. This test can only be applied to steel type systems.

The methodology set out in BS 7669-3 only requires one post in every 100m of barrier to be tested. The test records should detail the type and size of post being tested, carriageway setback (m), the maximum bending moment, the height at which loads were applied, the location, and finally the deflections at each loading interval. Inspectors should also provide comments regarding the test and results.

The cone penetration test (CPT) can also be used to measure bearing capacity (ASTM Standard D 3441). The test method consists of pushing an instrumented cone, with the tip facing down, into the ground at a controlled rate. Results from the CPT can be used to calculate parameters, such as the California Bearing Ratio.

5.6.2 Traffic Speed measurements

The literature review and the consultation did not identify any traffic speed method for measuring the structural characteristic ground bearing capacity of VRS. It is possible that alternative technologies could be employed to monitor for changes in the orientation or position of the barrier that could be used as a proxy for the ground bearing capacity (e.g. vibration sensors). However, we did not identify any application of this type of system for the monitoring of VRS. As this is a rapidly developing field we recommend that monitoring of the technology continues.

5.7 Key condition data - Measuring the Mounting Height

5.7.1 Slow speed measurement methods

During a detailed inspection of a barrier's clearance distance, beam heights are measured by hand, using a calibrated tape measure and a spirit level. The height is the distance from the carriageway surface to the middle of the beam. Measurements are taken for every 100m section of barrier. Additional spot measurements can be made at the inspector's discretion. Also in cases where the barrier's set-back distance is ≤1.5m from the carriageway surface additional height measurements should be made.

Each height measurement should note its exact location (GPS co-ordinates, post number, marker post, and chainage) and whether the recorded value falls within tolerance (pass/fail – too low/high).

5.7.2 Traffic Speed measurements

The video based methods, described in section 5.3 for inventory can potentially be used to measure the height of the VRS. Additionally, LiDAR survey can be used as shown in Figure 16. PREMIUM has identified an example of this applied in practice, as shown in and Case Study 2.

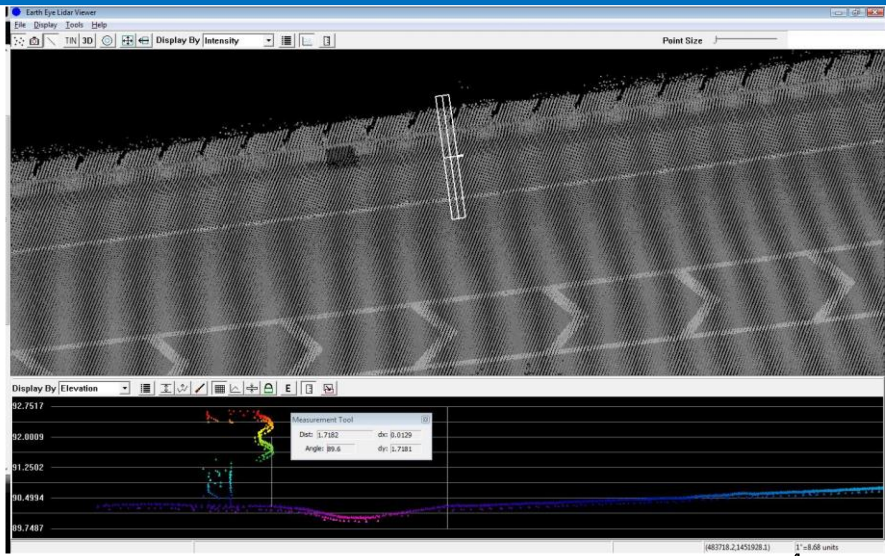
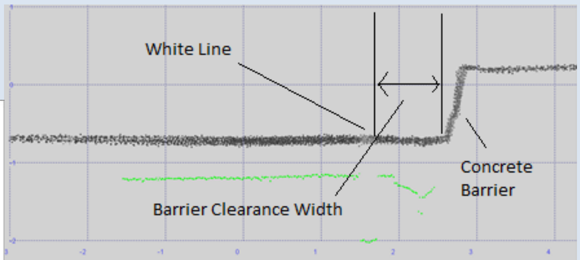
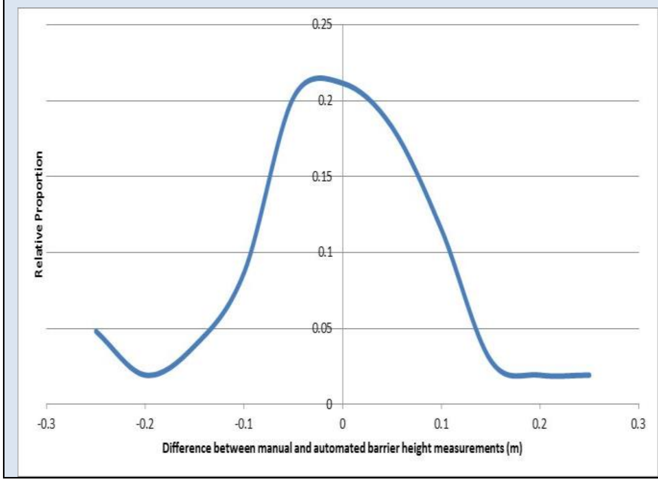


Figure 16: Measuring the mounting height using LiDAR[4]

Case Study 2: LIDAR for assessment of barrier height and clearance at the network level

A LIDAR system consisting of a rapidly-rotating head was installed on the HARRIS2 vehicle for the purposes of investigating its potential as a Traffic Speed LIDAR system. The LIDAR outputs were integrated with HARRIS2's GPS and IMU systems to provide 3D data at traffic speed. A LIDAR survey was carried on approximately 200km of the outer lane of the M25 motorway using HARRIS2. LIDAR measurements were collected by driving in the outside lane of the Motorway at a speed of approximately 80mph in live traffic. The vehicle was driven in the outside lane of the motorway to ensure that traffic to the offside would not interfere with the LIDAR scans of the barriers. The survey data was collected in a single day.





The 3D data was converted into "LIDAR slices" and a viewer was developed that allowed these to be plotted in a compressed 'direction of travel' viewpoint. This allowed the relative positions of the road and roadside barriers to be assessed by a manual assessor in the office. Tools were developed in the viewer to allow the manual assessor to record

[4] https://jasonamadori.com/category/mobile-lidar/

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the distance between the outer edge of the traffic lane and the barrier (the clearance) and the barrier height by clicking on the screen and moving the mouse to measure the distance. The measured distance was then automatically stored in relation to section, distance and coordinate. The LIDAR slice data could be scrolled forward and backward without the "view point" changing, thereby increasing the practicality of the assessment. The entire M25 was analysed in this way, with a measurement being recorded at intervals of 50m. This analysis took approximately 1 week to carry out.

Although this analysis was conducted manually, several elements of the analysis lend themselves to automated processing. In follow up research an algorithm was developed to automate the height measurement by analysing the shape of each individual slice. The performance of this was assessed using data collected on a test track (on which the barrier could be measured manually as well as surveyed with the LIDAR system). The results showed 22% of automated measurements to be within 3cm of the manual measurement, 75% of automated measurements were within 10cm of the manual measurement.

5.8 Key condition data - Measuring the Fixing Condition

5.8.1 Slow speed measurement methods

The condition of fixings is determined during a detailed inspection – a thorough visual assessment conducted on foot. All fixings present are assessed on their visual appearance (signs of rust) and are assessed by hand for torque. Fixings should be at least hand tight.

As with damage and corrosion, the inspectors use checklists with questions (Example 1 and Example 2) to collect information about the fixing condition of the VRS.

If a bolt exhibits signs of corrosion/damage or is loose, its location (using GPS co-ordinates, post number, and chainage) is recorded and photographs are taken for review purposes. In general a single damaged or missing bolt/fixture will not impact the overall performance of a system. However, if fixings are continually inadequate across a short space of barrier this could compromise the barrier's design performance under vehicle impact.

5.8.2 Traffic Speed measurements

Manual analysis of video images collected at traffic speed may be used to determine the condition of fixings of VRS: Missing or very loose fittings should be visible. However, the images collected would need to be of good enough quality to enable this. Furthermore, the video survey does have some limitations - in some situations it is not possible to see the condition of fixings e.g. a fixing that was loose but not visibly "hanging out" would not be identifiable; damaged or missing bolts on reverse of VRS would not be visible.

It is possible that smart technology could be used to measure fixing condition in-situ e.g. a sensor that could signal when a bolt is not as tight as it should be. However, such technology does not currently exist and thus would need to be developed. The price of such technology may be a barrier to its use though.

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.

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.

Length of Barrier: The longitudinal length (in meters) of the safety barrier.

***Location References*:** the location of the asset**.**

Manufacturer Declared Design and Performance Characteristics: Characteristics listed on CE marking as determined by the product manufacturer.

Minimum Barrier Length: The minimum approach distance between the start of the barrier (in the direction of travel) to the object/hazard.

Mounting Height: The height from the carriageway surface to the mid-point of the barrier beam.

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.

Set-Back Distance: The lateral distance between the carriageway edge and the traffic face of a safety barrier.

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

Speed Limit of Road: The legal maximum speed for any road.

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.

VRS: Vehicle Restraint System. This report focuses on permanent vergeside and central reserve vehicle restraint barriers, which are often referred to as safety barriers.

Working Width: The zone immediately behind the traffic facing side of the VRS. This space is free of objects and should allow posts to fully deflect.

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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.**

Retroreflective 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. Retroreflective 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 retroreflective 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 retroreflectivity using retroreflectometer (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			
	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 retroreflectivity using retroreflectometer (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.

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- 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.

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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

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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).

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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.**

Retroreflective 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. Retroreflective 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.	