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Lot 1

Task 696
Roadside Vehicle Noise Measurement

Phase 2 Final Report

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ATKINS JACOBS

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Executive Summary

The Atkins Jacobs Joint Venture has undertaken research for the Department for Transport to identify and recommend options for methods and equipment available for the detection and enforcement of excessively noisy road vehicles. These vehicles, which have often been modified, lead to annoyance and complaints from the members of the public throughout the UK. Commonly, the 'excessive noise' that leads to complaints is attributed to modified or defective exhaust systems.

Based on the strengths, limitations and the maturity of the technology identified during Phase 1 of the project, it was recommended that a noise camera solution that tests noise levels against predetermined noise limits is explored further in Phase 2 of the project. This was later approved by the Department for Transport for progression to the next phase of the project.

Phase 2 of the project involved trials of a prototype noise camera that was tested at the A32 West Meon and A326 Marchwood Bypass during November and December 2019. The noise camera comprised an omnidirectional microphone (sound level meter), a speed radar, a weather sensor and two combined ANPR and video cameras mounted to a trailer. The noise camera was deployed at each location for up to two weeks. The locations were selected as they met a number of criteria used to standardise and simplify the testing. The selected locations offered a reasonable opportunity to collect representative data of excessively noisy vehicles and driving styles.

During the trial, site visits were undertaken by the AJJV to establish the baseline acoustic conditions at the trial sites and to collect additional data of vehicle pass-bys using standard acoustic instrumentation for comparison with the noise camera output data. Data collected from the noise camera was periodically downloaded and matched to vehicle information obtained from the DVLA Bulk Dataset. Throughout the trials, no information was obtained about the driver or the registered keeper of the vehicles passing the noise camera.

The scope of the study was limited to assessing data related to cars, motorcycles, mopeds and scooters. The sample size of the collected data was limited by traffic flow rates, the set-up of the acoustic instrumentation, accuracy of the ANPR camera, availability of vehicle records from the DVLA Bulk Dataset, small time gaps between the different sensors when they detected a vehicle, and periods of noise camera inoperability preventing a full dataset from being obtained.

The measurement data collected from the prototype noise camera has demonstrated that it is possible for a noise camera to identify vehicles and for measured noise levels to be attributed to individual vehicles, demonstrating proof of concept. However, the confidence with which the measured noise levels can be assigned to an individual vehicle diminishes during heavy traffic streams where vehicles are close together as they pass the noise camera. Similarly, it is not possible for a single omnidirectional microphone to robustly assign noise levels to individual vehicles when they pass the noise camera simultaneously on different carriageways. All such noise camera systems would need to address these issues prior to approval for enforcement use.

The analysis of the data from the prototype noise camera has indicated that it is possible to numerically define what an excessively noisy vehicle might be based on the measured maximum noise levels from vehicle pass-bys, and that the use of a 'not-to exceed' noise limit is viable. The relationship between objective and subjective definitions of excessively noisy vehicles require examination to ensure that enforced pass-by noise limits achieve their aim. Further data is needed for motorcycles to robustly conclude whether it is appropriate to apply different noise limits to cars and motorcycles.

Direct application of existing vehicle pass-by measurement methodologies (ISO 362 and ISO 11819) to use for the noise camera is not possible due to logistics with placement of the measurement equipment and the difficulty of controlling variables at a roadside environment. However, some aspects have been adopted for use in the trial as they are directly relevant. Should noise cameras become commonplace, a standardised testing and installation method would be beneficial to ensure conformity of performance and optimisation to the selected enforcement criteria.

Although it was possible to identify driving styles or behaviours from the acoustic data collected by the prototype noise camera, further research is required to characterise those that are 'excessively noisy'. From an enforcement perspective, it is considered that adverse driving styles should not be enforced separately with a noise camera but any evidence that can be collected to indicate a driving style or operation, such as acceleration, would provide context in the evidence package.

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1. Introduction

Background

The Department for Transport (DfT) has commissioned a research project to identify and recommend options for methods and equipment available for the detection and policing of excessively noisy road vehicles. High levels of noise have been linked to a number of human health issues and vehicle noise is a significant contributor to this, particularly in urban environments. Excessively noisy vehicles, which have often been modified, also lead to significant annoyance and complaints from the public in both urban and rural areas of the UK.

Current in-service noise compliance of vehicles is assessed through periodic roadworthiness testing (the MOT). However, given that many vehicles are found to be in contravention of the relevant noise regulations when stopped in use on the road, the MOT test may not provide adequate outcomes. This may be due to tampering and/or substitution of components.

The DfT has procured research through the Highways England SPaTS framework to inform policy on potential improvements to policing methods for noisy vehicles and highlight any technologies that could be used as an aid to detection and enforcement. The contract was awarded to the Atkins Jacobs Joint Venture (AJJV) during November 2018.

Project Definition

The primary aim of this project is to understand if there are reliable and robust ways of ascertaining noise emissions from an individual vehicle at the roadside which could then be used for enforcement purposes. This is to be achieved by a review of best practice approaches and technology, both existing and in development, and supported by trials and validation noise measurements as necessary. This work will assist in the development of future policy and enforcement of in-service noise limits.

The project comprises two distinct phases as follows:

- Phase 1 – Identification
- Phase 2 – Trials and analysis

The first phase of the research [1] established the methods currently used across the UK and internationally for policing excessively noisy vehicles and determined whether any strategies can be used more widely within the UK. Existing and prototype technologies for the detection of excessively noisy vehicles were identified and their feasibility of use, cost and reliability were assessed. The technologies were focussed on the assessment of in-use vehicle noise, such as a roadside pass-by noise detector, rather than the assessment of stationary noise. The study identified two potential noise camera technologies that could be used for this purpose that were put forward for consideration for the next phase of research.

The second phase of research involved trials of the candidate technologies identified in Phase 1, where the capability, reliability and suitability of the technologies were appraised. Following completion of Phase 1, the Department for Transport confirmed that Phase 2 should focus on trialling the noise camera solution comprising a video camera, automatic number plate reader (ANPR) and sound measurement equipment that tests pass-by noise levels against predetermined noise limits.

This report discusses the initial results from the Phase 2 trials and identifies emerging policy implications based on the trial outcomes. The structure of the report is as follows:

- Chapter 2 – Project Scope
- Chapter 3 – Trial Methodology
- Chapter 4 – Trial Sites
- Chapter 5 – Main Trial
- Chapter 6 – Applicability of Noise Measurement Standards
- Chapter 7 – Identification of Excessively Noisy Vehicles
- Chapter 8 – Identification of Suitable Noise Limits
- Chapter 9 – Identification of Adverse Driver Behaviour
- Chapter 10 – Discussion
- Chapter 11 – Recommendations
- Chapter 12 – Conclusion

2. Project Scope

Outcomes of Phase 1

Enforcement measures

In the UK and around the world, fines and vehicle rectification notices are used as enforcement measures against excessively noisy vehicles. Some countries require vehicle owners to visit approved test centres to verify that the noisy modified exhausts have been replaced with legal, quieter models as part of the vehicle rectification notice. This is akin to the procedure used in the UK's Vehicle Defect Rectification Scheme [2].

Softer enforcement measures such as advisory signage and promotional materials help to raise awareness of the issue but can be ineffective [1]. The outcomes of educational programmes tackling excessive vehicular noise have been mixed.

According to a survey of police forces undertaken as part of the Phase 1 research [1], the majority of UK police forces subjectively assess whether vehicles cause excessive noise. This subjective assessment is undertaken by the police officer applying their judgement as to whether the vehicle is producing excessive noise and therefore does not comply with The Road Vehicles (Construction and Use) Regulations 1986 [3]. Where sound level meters are used for an assessment, the vehicles are tested against a set threshold noise level that is not bespoke to the specific vehicle (i.e. the threshold noise level does not refer to the type approval noise level specific to that make and model of the vehicle). This is consistent with approaches used worldwide.

Options for improvement

Based on the outcome of the review of existing technologies and noise appraisal methods in the Phase 1 research [1], three options were identified for improving the detection of noisy vehicles and enforcement:

- Option A – Improvements to existing reporting and enforcement practices. This would consist of minor improvements to existing online or digital reporting tools to make it easier for users to report excessively noisy vehicles / driving behaviours, and improved guidance for police officers for enforcement using subjective or objective methods.
- Option B – An automated noise camera system comprising a video camera, an automatic number plate reader (ANPR) and sound measurement equipment, where sound levels from passing vehicles are tested against a suitable noise limit. The system does not require the police to be in attendance but can be configured to provide real-time reports if required. A letter can be sent out requiring the registered owner to check, repair or replace their exhaust within a stated time period.
- Option C – An automated noise camera system comprising a video camera, an ANPR and sound measurement equipment capable of identifying acoustic signatures produced by passing vehicles, which can be used as a mechanism to reduce false positives. The acoustic signature and maximum sound levels would be compared with those associated with vehicles with illegal modified exhaust systems and appropriate noise limits. The system does not require the police to be in attendance but can be configured to provide real-time reports if required. A letter can be sent out requiring the registered keeper to check, repair or replace their exhaust within a stated time period.

Based on the strengths, limitations and the maturity of the technology involved, the noise camera solution that tests noise levels against predetermined noise limits was recommended for consideration for Phase 2 of the project (Option B). This option was later approved by the Department for Transport for progression to the next project phase.

Phase 2 Project Brief

The objectives of Phase 2 are summarised below:

- Undertake measurement trials of the selected technology to assess accuracy and repeatability.
- Determine if the selected technology could be used for taking enforcement actions against non-compliant vehicles and driver behaviour.
- Determine if a 'not-to exceed' noise limit can be identified for different situations or vehicle subcategories.

- Undertake statistical analyses of the prevalence of particularly noisy vehicles, the variability of noise levels and the uncertainties of the selected technologies.
- Identify if the method can distinguish between different reasons for exceedances of noise criteria.
- Use the outputs of these studies and analyses to make recommendations.

To meet the objectives for Phase 2, the scope of work has been split into seven tasks as shown below in Table 2.1. Tasks 1-6 were undertaken in Phase 1 of the project.

Table 2.1. Phase 2 scope

Task	Description	Location in report
7	To collate, analyse and report noise measurements from the roadside (trial of selected technology/system)	Chapter 2, Chapter 4 to Chapter 8
8	To establish the most appropriate use of vehicle ‘pass-by’ noise measurement in enforcing vehicle noise emissions legislation. For example, the potential to identify non-compliant or damaged exhaust system components (D006)	Chapter 5
9	To analyse the prevalence of very high noise emitting vehicles on the road	Chapter 6
10	To analyse the data for vehicles that are repeatedly measured and study the variability of these vehicles	Chapter 6
11	To clearly explain the uncertainties generated by the methodology and their implications for the findings	Chapter 9
12	To identify whether an upper ‘not-to exceed’ limit for each vehicle subcategory can be identified that would be suitable for enforcement use	Chapter 7
13	To establish whether roadside noise measurement can differentiate between non-compliant vehicles and excessive noise from compliant vehicles due to adverse driver behaviour	Chapter 8

In addition to the seven tasks described in Table 2.1, Phase 2 is also required to highlight the key risks and opportunities associated with the trialled technology and to recommend how noise cameras may be implemented, including implications to policy and legislation.

A glossary explaining some of the technical terminology used in this report is provided in Appendix A.

3. Trial Methodology

Noise Camera Set-up

The tested noise camera comprised the following components:

- A Class 1 integrating sound level meter with acoustic calibrator and weatherproof windshield;
- Two Hikvision combined ANPR and video cameras that were also capable of recording video footage at a rate of at least 25 frames per second;
- A meteorological sensor (wind speed and direction, rain, temperature); and
- A Smartmicro UMRR-11 Type 45 traffic radar used to measure vehicle speed.

The sound level meter used was a 01dB CUBE and set to record the following acoustic parameters during the trial:

- The equivalent continuous sound pressure level, $L_{Aeq,T}$
- The maximum sound pressure level, $L_{Amax,T}$
- Statistical parameters including $L_{A10,T}$ and $L_{A90,T}$
- Frequency results in third-octave bands

Figure 3.1 provides an annotated photograph of the noise camera to identify its key components.

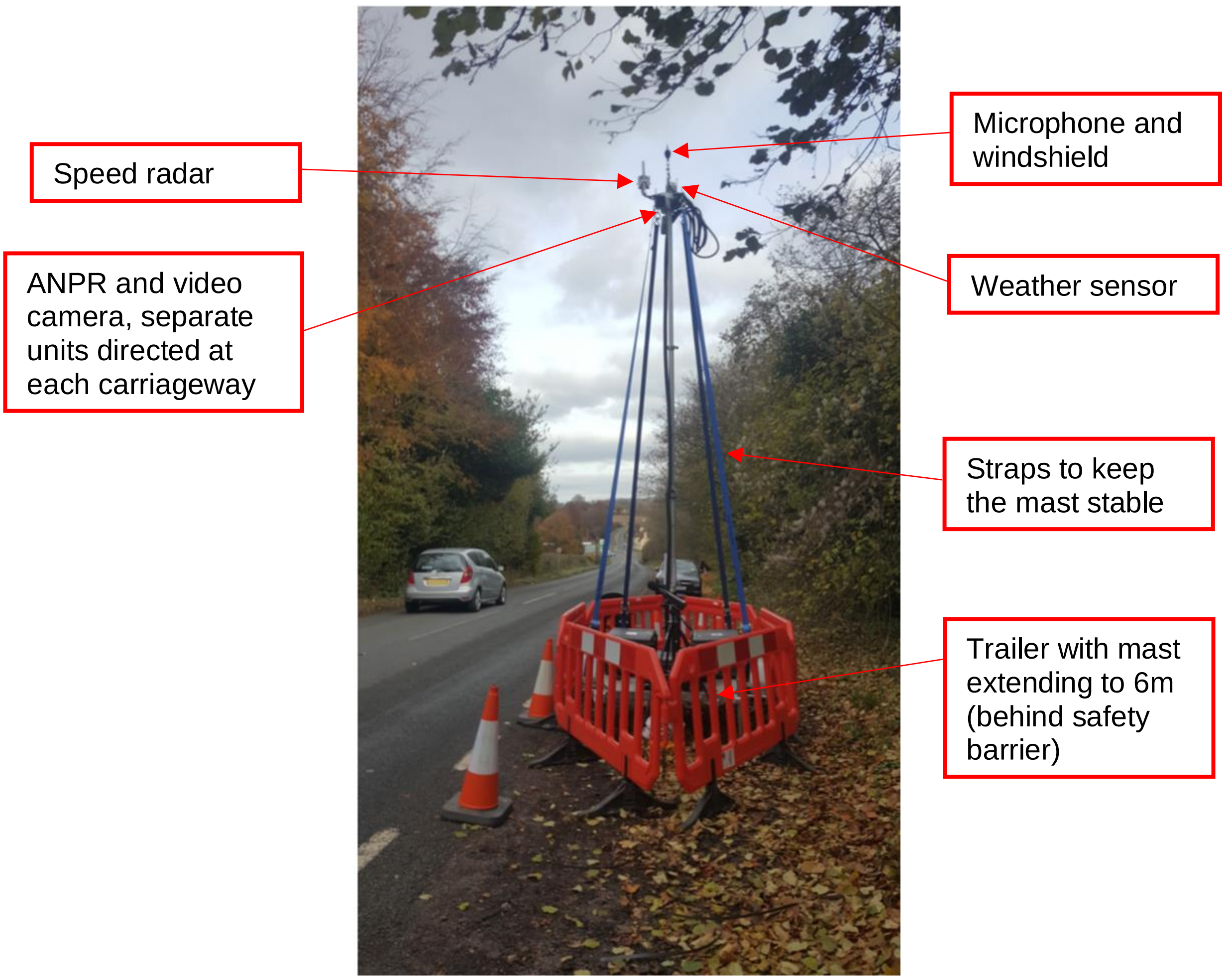


Figure 3.1. Noise camera set-up

The various components were assembled into a single unit by systems integration specialists at Smart Video Sensing Ltd (SVS), who also deployed, maintained, relocated and removed the noise camera during the trial period. The components were mounted to a trailer with a mast extending to a maximum height of 6m. The noise camera was battery powered, with the batteries stored in weatherproof boxes secured to the base of the trailer. Although the sensors were integrated for this trial, the data from each sensor was recorded and saved as separate files rather than one complete file linking together the sensor outputs.

Car Park Trial

Once assembled and integrated, the prototype noise camera was tested in a ‘car park trial’ prior to deployment for the main phase of the trials for acceptance testing and to collect sample output data. Following the car park trial, updates were made to the noise camera to fix errors identified during the testing.

The car park trial took place at SVS offices on 12 November 2019, where the noise camera was set up at the boundary of their industrial estate and the performance of the integrated system was tested for the first time for the following scenarios:

- Stationary vehicle test, where the tested vehicle was stationary in the noise camera’s field of view and revved. This test aimed to verify that the ANPR and acoustic data inputs were working together and to obtain some acoustic data for an excessively noisy driving behaviour; and
- Vehicle pass-by test, where individual vehicles passed the noise camera at low speed. The vehicles tested were a car, transit van and motorcycle. This test aimed to verify that the speed radar was working and that the noise camera would detect passing vehicles in both directions of travel.

During both the stationary and pass-by tests, simultaneous noise measurements were undertaken with a sound level meter using a microphone height of 1.2 to 1.5m above ground level adjacent to the noise camera and at distances of 7.5m and 10m from the noise camera. These distances and heights were selected in order to compare the noise camera outputs with the measurement distances quoted in pass-by noise measurement standards and methodologies, namely those used for type approval testing [4] [5] [6] and ISO 11819 [7].

Selection of Trial Sites

In order to test the prototype noise camera under a range of conditions and to collect suitable data to establish proof of concept, the noise camera trials were limited to two locations. Initial candidate trial sites were identified in England and Wales through various means including:

- recommendations to the DfT from members of the public following the publication of the Phase 1 report [1];
- local knowledge of areas where excessively noisy vehicles are likely to be more commonplace;
- word of mouth to identify popular meeting locations for car and motorcycle enthusiasts;
- advice from local authorities; and
- identifying roads near racing circuits with upcoming events.

Approximately 30 potential trial sites were identified that were subsequently assessed for suitability using Google Earth Streetview imagery. Candidate trial sites were selected based on the following criteria:

- the road is straight in both directions for up to 50m with no significant changes in topography to avoid gradient increasing noise emissions;
- the road is a two-way road with one lane in each direction (i.e. no dual carriageways) to simplify the test methodology;
- the road speed limit is equal to or below 50 mph for safety reasons;
- there is enough space adjacent to carriageway to accommodate the noise camera trailer, safety signage and cones, and to allow surveyors easy access;
- the site layout and the likelihood of excessively noisy driving styles taking place, such as acceleration when leaving a junction;

As the noise camera was being assembled by a system integration specialist based in the Meon Valley, trial sites within a two-hour drive from this area were prioritised for convenience of regular maintenance visits to the noise camera once deployed.

The candidate sites meeting all of the criteria above were shortlisted and the two sites that offered the best chances of capturing excessively noisy vehicles or driving styles were selected.

Main Trial

The trials were planned to take place continuously for a one-month period, where the noise camera would be moved from the first trial site to the second trial site halfway through the trial period. As well as testing the noise camera to see if it could identify vehicles and their associated noise emissions, the ANPR and speed radar were configured to allow estimates of traffic flow to be calculated.

It was initially envisaged that the noise camera would record data in response to an acoustic trigger. The acoustic trigger would be set artificially low when the noise camera is deployed so that a suitable higher trigger could be used based on the first set of output data received. Initial testing undertaken by SVS concluded that in traffic streams the noise camera was constantly triggering and it was more convenient for the sound level meter to continually log data without the acoustic trigger. This has allowed the potential for a larger sample size of vehicles to be assessed and to better estimate the prevalence of excessively noisy vehicles at the trial sites.

For safety reasons, all equipment was installed as far away from the edge of the nearside carriageway as practicable. The noise camera trailer was sited so that there was sufficient space around the trailer such that any site personnel carrying out servicing was a safe distance from the carriageway edge.

Once installed, the noise camera was acoustically calibrated and regular maintenance visits took place for security purposes and to maintain functionality of the system.

Staff from the AJJV visited each trial site while the noise camera was in situ in order to establish the noise climate at each site and to collect additional vehicle pass-by data to compare with the noise camera outputs.

A calibrated Class 1 integrating sound level meter was used to measure noise levels at a suitable location near the noise camera upon each site visit. Noise measurements were undertaken in compliance with the guidance set out in BS 7445-1:2003 [8]. The equipment consisted of a microphone, with its proprietary wind shield, mounted to a tripod which was set to approximately 1.5m above ground level. At each site, the sound level meter was placed directly adjacent to the noise camera so that the horizontal distance between the microphones and the passing vehicles was the same. This meant that the horizontal distance between the sound level meter and the edge of the carriageway was different for each trial site. The sound level meter was calibrated prior to each survey with an acoustic calibrator. The sound level meter was set to log continuous L_{Aeq}, L_{AFmax}, L_{A10} and L_{A90} noise levels for all attended noise measurements. Ambient noise levels were recorded in 15-minute period whilst pass-by levels were recorded over approximately one hour to capture a suitable number of vehicles with data logged every second for comparison with vehicle pass-bys.

Calibration certificates and details of the acoustic instrumentation used for undertaking the attended site visits and the noise camera are provided in Appendix B.

SVS issued data collected from the noise camera to the AJJV periodically throughout the trials to expediate analysis.

Data Analysis

Separate data files were saved for each of the sensors shown in Figure 3.1. The data from the sound level meter and ANPR cameras were aligned together for further analysis.

With the dataset containing sound level and ANPR data, analysis has been undertaken to extract time periods where only one vehicle passes the noise camera within a 10-second period. This approach allows a high degree of confidence that the maximum sound level recorded was due to a pass by from the individual vehicle captured by the ANPR camera, and that a suitable interval of unaffected data could be taken before and after the maximum sound level was recorded to analyse the variation of sound over time.

Where the recorded maximum sound level exceeded 75 dB L_{Amax} for a single vehicle pass-by, vehicle information from the DVLA Bulk Dataset was requested to allow further analysis of other variables, such as vehicle age and different vehicle subcategories. Vehicles speeds and meteorological data collected by the noise camera were then matched to the final dataset containing vehicles identified in the DVLA Bulk Dataset.

As the noise camera system would collect number plate data while it is deployed during the main trial, it is essential that data privacy is taken into account. A notice was installed next to the noise camera during the trial to inform motorists and members of the public of the purpose of the trial and how to get in contact regarding their personal data or privacy concerns. No queries were received during the trial regarding personal data or privacy concerns.

Furthermore, the details of individual vehicles that are analysed in this report have been anonymised to avoid traceability to a specific vehicle.

4. Trial Sites

Selected Sites

Using the site selection process detailed in Chapter 3, the following two locations were considered suitable to undertake the trials:

- Site 1: Meon Valley - Layby along the southbound carriageway of the A32, north of West Meon.
- Site 2: Marchwood Bypass – Layby along the southbound carriageway of the A326, north of the Dibden roundabout.

Prior to the noise camera deployment, both sites were visually assessed via Google Earth Streetview and preliminary site visits were arranged to confirm the suitability of the sites and to take attended noise measurements of the ambient noise conditions.

Hampshire County Council granted licences to place the noise camera in the laybys for both sites, and Hampshire Constabulary was also informed of the locations and duration of the trials prior to commencement.

Further information about the trial sites is provided in the following sections.

Site 1: West Meon

Site description

Site 1 is situated in the rural area of West Meon Hut which is primarily dominated by agricultural land. To the south of the site along the A32 is the village of West Meon and to the north of the site at the A32/A272 junction is Loomies Moto Café, a petrol station, and a local pub. There are a few residential dwellings along the A32 and some along the adjacent rural roads. The area is considered sparsely populated. A map of the site location is shown in Figure 4.1.

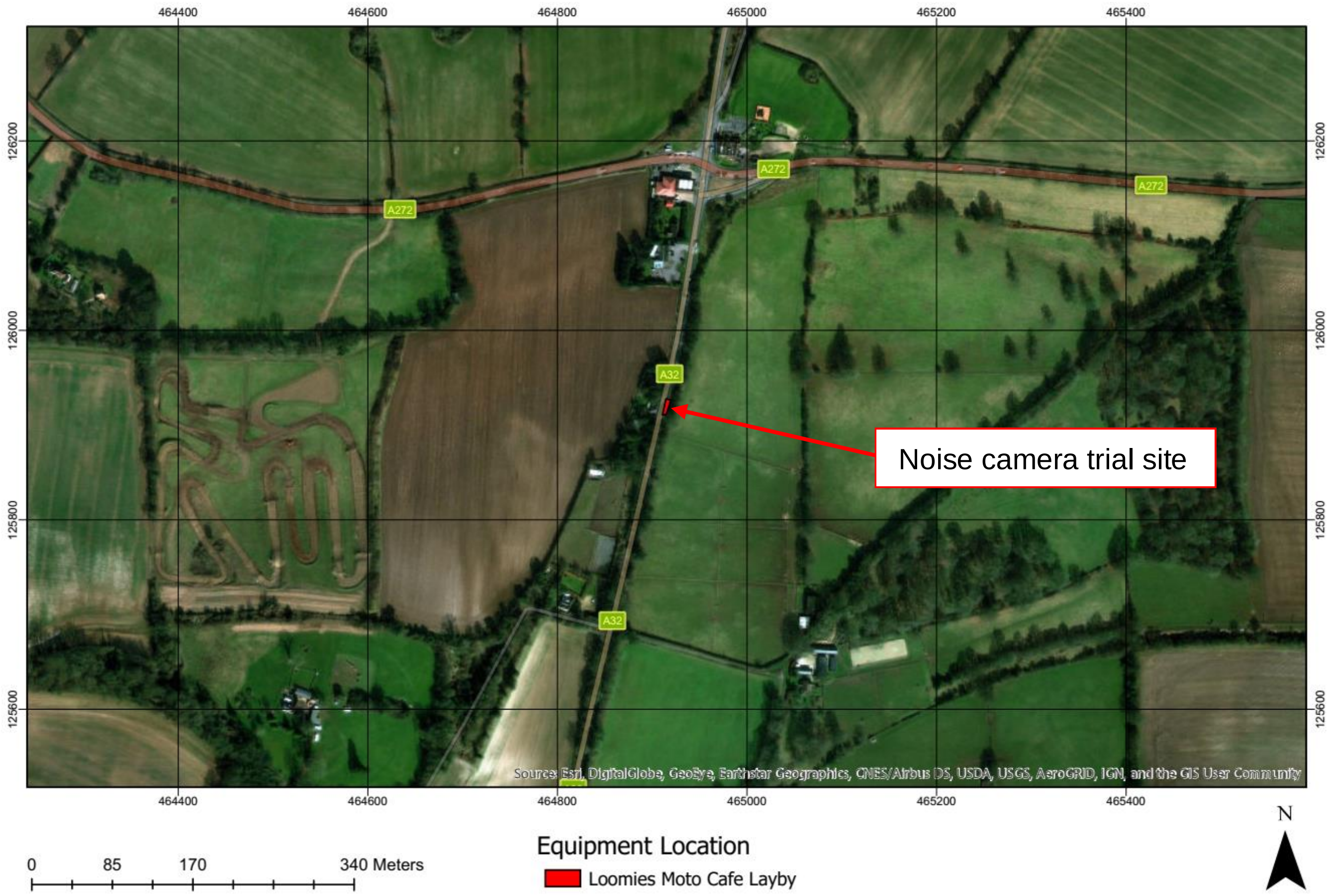


Figure 4.1. West Meon noise camera trial location

The two main roads in the vicinity of the site are A32 and A272 which dominate the noise environment. The A32 has a slight downhill gradient at the trial site towards the junction with the A272. The road surface was noted to be asphalt for both the A32 and the A272, in good condition and with no visible imperfections or discontinuities along the section of the A32 chosen for the trial. On all site visits the road surface was slightly damp but not with enough surface water to cause spray. Traffic counts were undertaken along the A32 during site visits for a period of 5 minutes and the number of vehicles passing by in both directions ranged between 27 and 47. The traffic count included all vehicle types, including HGVs. In between vehicle pass-bys, non-road related noise sources were more prominent such as rustling trees, birdsong, and agricultural noises (i.e. livestock and equipment). However, noise from these sources was significantly lower than that generated by vehicles on the road and did not affect the test results.

The noise camera was installed on the southernmost end of the A32 layby across from Hut Cottage, south of Loomies Moto Café, a distance of 1.8m from the nearside carriageway edge and at 6m height. The noise camera was deployed from Saturday 16th November to Thursday 28th November 2019. It was sectioned off with a barrier, cones, and signage. A photograph of the site set-up is provided in Figure 4.2 below.

Figure 4.2. Noise camera installed on the A32 north of West Meon

Ambient noise measurements were conducted on site on 12th November 2019 prior to the noise camera being deployed at the site. Once the noise camera was installed on site, ambient noise and vehicles pass-by measurements were conducted on 20th November 2019.

Rationale for selection

Site 1 was identified through local recommendations and discussions with the local police that highlighted this location as an area that attracts motorbikes due to the presence of a biker-run café on the A32, Loomies Moto Café, that hosts weekly motorbike meetings on Wednesday evenings. The surrounding area is considered to experience adverse vehicle noise as evidenced by the presence of local anti-noise action groups.

Due to the site geometry, Site 1 was considered to have the potential to capture data for noisy driving styles. A crossroad (A32/A272) controlled by traffic lights was located approximately 250m north of the trial site, which presents the possibility of measuring noise levels from vehicles accelerating past the noise camera in the nearside (southbound) carriageway and vehicles braking in the far side (northbound carriageway).

The layby was also considered to be a safe site for deployment of the noise camera and for site personnel to undertake maintenance visits and additional short-term vehicle pass-by noise measurements next to the noise camera. The trial was undertaken at this location between the 16th and 28th November 2019.

Site 2: Marchwood Bypass

Site description

Site 2 is in a semi-rural area where the A326 serves as a major access road connecting towns such as Totton, Marchwood, Dibden Purlieu, Holbury, and Beaulieu. The noise camera was deployed in a layby located south of Marchwood and north of Dibden Purlieu. There are a number of fields and small residential suburbs are located to the east and west of the site. A map of the site location is shown in Figure 4.3.

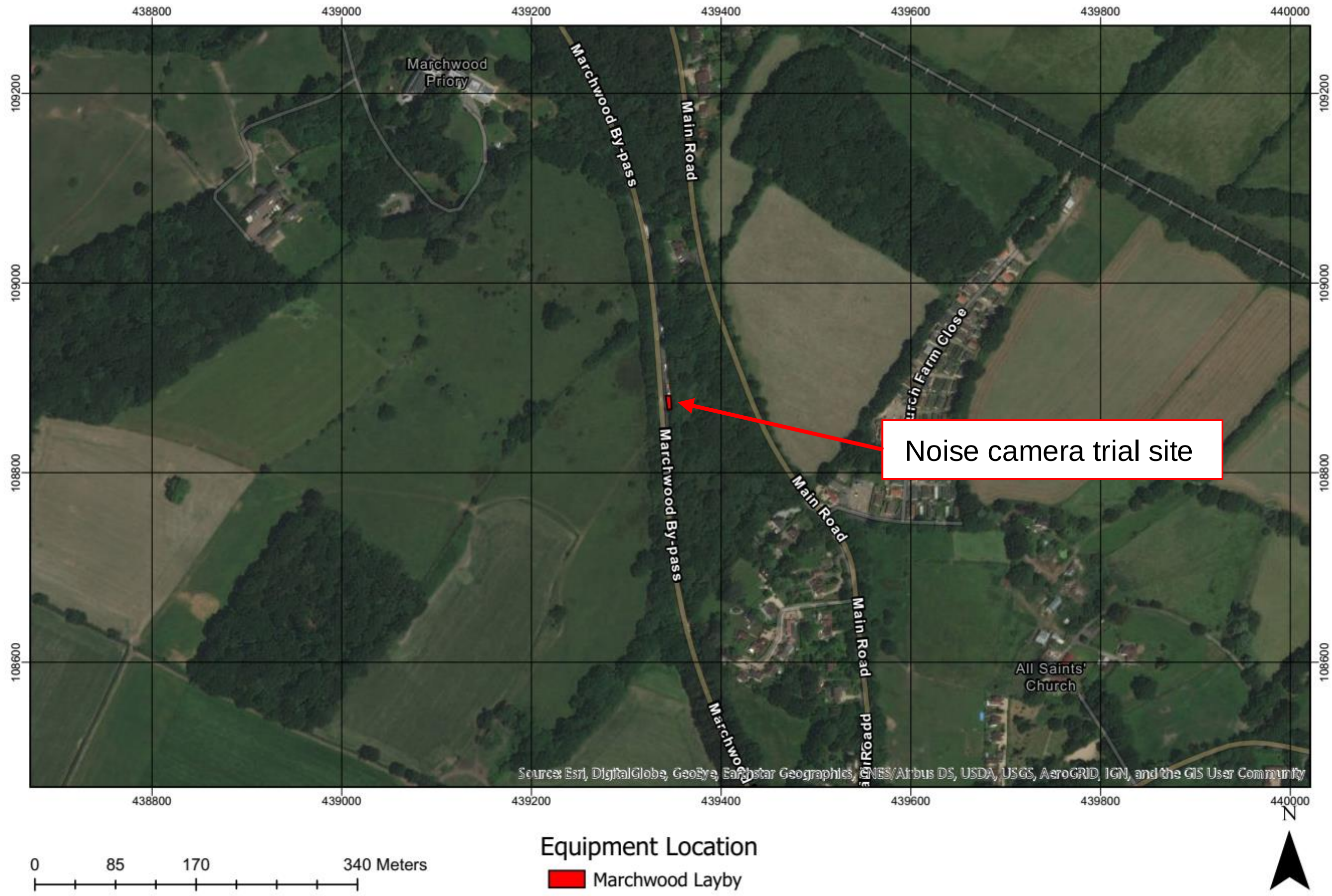


Figure 4.3. Marchwood Bypass trial location

The noise environment at the site was dominated by the continuous free-flowing traffic from both directions on the A326. The road surface is asphalt with no visible imperfections or discontinuities along the section of the A326 chosen for the trial. During site visits the road surface was mostly dry. Over a typical 5 minute period the traffic flow under normal conditions was up to 180 vehicles in total for both directions. The traffic count included all vehicle types including HGVs. There were some intermittent breaks in traffic where other noise sources are audible such as birdsong and rustling leaves.

The noise camera was installed at the southernmost part of the A326 layby. The microphone was approximately 5m horizontally from the centre of the southbound carriageway and 8m from the northbound carriageway, at a height of 6m. The noise camera was deployed at this site from Thursday

28th November to Monday 9th December 2019. It was sectioned off with a barrier, cones, and signage. A photograph of the noise camera at Site 2 is provided in Figure 4.4.

Figure 4.4. Noise camera installed on the A326 Marchwood Bypass

Ambient noise measurements were conducted on site on 20thth November 2019 prior to the noise camera being deployed at the site. Once the noise camera was installed on site, ambient noise and vehicles pass-by measurements were conducted on 3rd December 2019.

Rationale for selection

Site 2 was identified as one of the major access roads for the Beaulieu Motor Museum which hosts a number of motor events throughout the year. The Marchwood Bypass was expected to be subject to higher traffic volumes compared to Site 1, potentially including modified or excessively noisy vehicles driving to the Motor Museum on special events. The trial was undertaken at this location between the 28th November and the 9th December 2019, timed to coincide with the New Forest VW Santa Run being held at Beaulieu Motor Museum on the 1st December 2019.

The site conditions suggested that traffic would be in a steady-state with continuous traffic flow. In steady-state traffic conditions, driver behaviours that may cause noise increases such as acceleration or braking are less likely to occur. For these reasons Site 2 is considered representative of a typical A road in a semi-urban environment.

Additionally, the layby and pedestrian walkway were considered to provide safe access for site personnel to undertake maintenance visits and attended noise measurements adjacent to the noise camera.

5. Main Trial

Summary of Trial Dates and Noise Camera Data

The sequence of events and data collection activities that took place during the trial is shown in Table 5.1, with a summary of the collected data provided in Table 5.2.

Table 5.1. Key Trial Milestones and Data Collected

Date	Location	Activity/Data Collected
12 November 2019	West Meon	Site visit to obtain pre-trial ambient noise levels
16 November 2019	West Meon	Deployment of the noise camera at Site 1
20 November 2019	West Meon	Site visit to obtain further ambient noise levels and to measure sound levels from vehicle pass-bys adjacent to the noise camera
20 November 2019	Marchwood Bypass	Site visit to obtain pre-trial ambient noise levels
28 November 2019	West Meon	Noise camera removed from Site 1
28 November 2019	Marchwood Bypass	Noise camera deployed at Site 2
3 December 2019	Marchwood Bypass	Site visit to obtain further ambient noise levels and to measure sound levels from vehicle pass-bys adjacent to the noise camera
9 December 2019	Marchwood Bypass	End of trial

Table 5.2. Summary of Trial Data

	West Meon	Marchwood Bypass	Both trial sites
Number of vehicle pass-bys during trial period (including HGVs)	9,902	51,941	61,843
Number of successful ANPR matches to DVLA data (cars and motorcycles only)	754	116	870
Sample size of cars	751	115	866
Sample size of motorcycles	3	1	4

As shown above, the prototype noise camera was installed at West Meon for 12 days and the Marchwood Bypass for 11 days. A total of 61,843 vehicle pass-bys were recorded by the prototype noise camera during the trial, however, the sample size used for analysis is comparatively small, accounting for 1.4% of vehicle pass-bys that took place. The reasons for this are as follows:

- The total number of vehicle pass-bys shown in Table 5.2 includes HGVs, which are not considered in this study. Successful matches to HGV data were excluded from the analysis;
- As the prototype noise camera is not fully developed, there were time periods where a full dataset could not be obtained, for example, where the ANPR camera recorded ‘no plate’ or where limited ANPR data were available but vehicle pass-bys were counted by the speed radar. The ‘no plate’ records accounted for 34% of the vehicles detected by the ANPR camera. As no vehicle data could be obtained, these vehicles and time periods were excluded from the analysis; and
- Vehicle data from the DVLA Bulk Dataset was requested for approximately 2,000 vehicles. These were vehicles where ANPR data was successfully matched to the noise levels using the method described in Chapter 3. Approximately 1,600 of the requested vehicles were successfully matched to the DVLA Bulk Dataset and from this reduced dataset entries where HGVs were identified were excluded from the analysis. Those vehicles that could not be matched to the DVLA Bulk Dataset were either vehicles registered in the UK where the alphanumeric combination recorded by the ANPR camera were not similar to any records held by the DVLA or vehicles that were registered abroad.

The final dataset has been matched to data collected from the speed radar where available. Although only four motorcycles were successfully matched, further analysis has been undertaken by reviewing video footage to identify motorcycles and their corresponding noise levels. This analysis was limited to reviewing video footage on Wednesday 27 November from 17:00 to 22:00 where motorcyclists were expected to attend a weekly event at the Loomies Moto Café. An extra 17 motorcycles were identified using this method but no vehicle information could be obtained for detailed analysis to be undertaken. No imported vehicles or vehicles registered before April 1990 were identified in the dataset. There is no evidence to suggest that vehicles temporarily parked in the laybys at the trial sites affected the performance of the prototype noise camera.

Attended Site Visits

Ambient noise levels

An attended site visit was conducted at the West Meon site on 12th and 20th November 2019. Weather conditions were dry during both visits, with a damp road surface on the first visit. It was observed during the site visit that traffic flow on the A32 was the dominant noise source, with frequent pass-bys of single vehicles and occasional traffic streams driving from each direction. Cars were most common, with some HGVs and infrequent motorbikes. During lulls in traffic on the A32, the main noise sources included rustling vegetation, distant road traffic noise on the A272 and birdsong. These noise sources did not significantly influence the noise levels measured of individual vehicles during the noise camera trial.

Vehicles on the northbound carriageway were occasionally found to decelerate gently approaching the A32/A272 junction, while vehicles on the southbound carriageway could be heard to accelerate past the junction, however once near the test location most vehicles would be travelling at a constant speed of approximately 40 mph. The gentle downhill slope towards the junction may also have had different effects on the engine speed of vehicles travelling in either direction. One subjectively noisy motorbike pass-by was noted whilst on site, which was due to high and varying engine speed while the vehicle was accelerating.

The existing ambient noise levels were obtained using 15-minute noise measurements before and after the pass-by measurements and are shown in Table 5.3. The background noise level ranged from 48.6 dB to 54.5 dB L_{A90}.

Table 5.3. West Meon Ambient Noise Levels

Date	Time	Measured Noise Levels (dB)			
		L_{Aeq}	L_{AFmax}	L_{A10}	L_{A90}
12/11/2019	15:43 – 15:58	77.5	90.3	81.4	54.5
20/11/2019	11:26 – 11:41	72.7	92.5	77.8	48.6
	12:37 – 12:52	76.3	107.5	78.2	51.2

An attended site visit was undertaken at the Marchwood Bypass trial site on 20th November and 3rd December 2019 during dry weather conditions. It was observed during the site visit that the traffic flow was fairly continuous, frequently consisting of a continuous traffic stream driving from each direction. Cars were the most common vehicle type using the road, with some HGVs and occasional motorcycles. Noise levels from individual vehicle pass-bys were collected for both directions, however, the individual vehicles were typically followed by several other vehicles in quick succession within several seconds. Vehicles were observed to be going at a constant speed of approximately 50 mph with no apparent changes in acceleration or deceleration. No irregular or atypical driving styles were noted whilst on site.

The existing ambient noise levels were obtained using 15-minute noise measurements before and after the pass-by measurements, as shown in Table 5.4. The background noise level ranged from 63.3 dB to 66.2 dB L_{A90}.

Table 5.4. Marchwood Bypass Ambient Noise Levels

Date	Time	Measured Noise Levels (dB)			
		L_{Aeq}	L_{AFmax}	L_{A10}	L_{A90}
20/11/2019	15:30 – 15:45	79.0	89.2	81.4	73.7
03/12/2019	11:08 – 11:23	77.2	89.8	80.5	63.3
	12:06 – 12:21	77.4	91.5	80.4	66.2

Comparison with noise camera data

AJJV site personnel recorded noise measurements with a second microphone in conjunction with the noise camera and manually recorded the single vehicles pass-by times, vehicle type, direction, and the license plates to correlate the acoustic data from the sound level meter and the noise camera.

Table 5.5 lists the measured noise data from Marchwood Bypass, as the conditions at this site best represent those required for statistical pass-by measurements in accordance with ISO 11819 [7]. The $L_{AFmax,1s}$ data from the sound level meter is presented alongside the highest of the ten $L_{Amax,100ms}$ values from the noise camera from the entire one second range. For example, ID 2 presents the $L_{AFmax,1s}$ of 81.4 dB at 11:27:10 and the $L_{Amax,100ms}$ of 80.7 dB as the maximum for the period 11:27:10:00 to 11:27:10:09.

The data has been synchronised to account for time differences between the sound level meter and the noise camera and filtered to identify records for vehicles of interest (cars, motorcycles, mopeds and scooters) with corresponding noise camera data (the noise camera data distance corrected to the sound level meter's position). Vehicles where a full noise camera dataset was unavailable were omitted from the analysis. In total, 37 suitable pass-bys were captured during the attended survey, consisting of 21 northbound vehicles and 16 southbound vehicles.

Table 5.5. Marchwood Bypass Measured Pass-by Noise Levels

ID	Pass by time	Vehicle type	Vehicle direction	Sound level meter (dB) $L_{AFmax,1s}$	Noise camera (dB) $L_{Amax,100ms}$	Noise level difference	Corrected noise camera (dB) $L_{Amax,1s}$	Corrected noise level difference
2	11:27:10	Car	North	81.4	80.7	0.7	82.3	-0.9
3	11:28:03	Car	North	77.0	79.4	-2.4	81.0	-4.0
5	11:31:21	Car	North	76.1	76.6	-0.5	78.2	-2.1
6	11:31:44	Car	North	77.7	77.6	0.1	79.2	-1.5
7	11:32:22	Car	South	79.4	80.3	-0.9	83.7	-4.3
8	11:33:33	Car	South	84.0	80.7	3.3	84.1	-0.1
9	11:34:00	Car	South	78.8	80.6	-1.8	84.0	-5.2
10	11:34:23	Car	North	78.0	78.4	-0.4	80.0	-2.0
11	11:34:38	Car	North	78.4	78.4	0.0	80.0	-1.6
16	11:36:42	Car	South	80.9	77.8	3.1	81.2	-0.3
17	11:37:39	Moto	North	72.5	76.7	-4.2	78.3	-5.8
19	11:39:38	Car	South	84.0	80.5	3.5	83.9	0.1
20	11:40:20	Car	South	82.1	78.8	3.3	82.2	-0.1
21	11:41:52	Car	South	79.9	78.7	1.2	82.1	-2.2
23	11:44:03	Car	North	80.7	80.8	-0.1	82.4	-1.7
24	11:45:08	Car	North	77.0	78.6	-1.6	80.2	-3.2
25	11:46:03	Car	South	80.0	76.6	3.4	80.0	0.0
27	11:47:09	Car	North	77.8	75.8	2.0	77.4	0.4
28	11:48:33	Car	South	75.6	72.1	3.5	75.5	0.1
29	11:48:57	Car	North	81.4	80.7	0.7	82.3	-0.9
30	11:49:30	Car	South	79.9	75.3	4.6	78.7	1.2
31	11:50:44	Car	North	77.6	72.3	5.3	73.9	3.7
32	11:51:09	Car	North	75.9	77.2	-1.3	78.8	-2.9
33	11:51:33	Car	North	80.3	77.4	2.9	79.0	1.3
34	11:52:37	Car	North	72.5	75.8	-3.3	77.4	-4.9
35	11:53:38	Car	North	75.2	76.5	-1.3	78.1	-2.9
36	11:54:13	Car	South	78.2	78.3	-0.1	81.7	-3.5
37	11:54:53	Car	South	78.1	78.1	0.0	81.5	-3.4

ID	Pass by time	Vehicle type	Vehicle direction	Sound level meter (dB) $L_{AFmax,1s}$	Noise camera (dB) $L_{Amax,100ms}$	Noise level difference	Corrected noise camera (dB) $L_{Amax,1s}$	Corrected noise level difference
38	11:55:29	Car	North	76.8	78.3	-1.5	79.9	-3.1
39	11:56:32	Car	North	74.2	75.9	-1.7	77.5	-3.3
40	11:57:13	Car	North	74.3	73.7	0.6	75.3	-1.0
41	11:57:50	Car	South	78.3	78.1	0.2	81.5	-3.2
43	12:00:49	Car	South	75.7	74.1	1.6	77.5	-1.8
44	12:01:25	Car	South	83.7	82.3	1.4	85.7	-2.0
45	12:02:58	Car	North	75.4	76.6	-1.2	78.2	-2.8
46	12:04:01	Car	South	80.4	78.0	2.4	81.4	-1.0
47	12:04:18	Car	North	81.2	79.8	1.4	81.4	-0.2

The variation in the noise level difference column over the measurement data in Table 5.5 above shows that there is considerable variance in noise levels between those measured by the sound level meter and the noise camera. This could be attributed to the noise camera microphone being further away from the passing vehicle compared to the sound level meter (both measurement positions were at the same horizontal distance but the vertical distance was larger for the noise camera). Noise levels decrease over increasing distances, and distance effects were estimated to be approximately 1.6 dB for vehicles travelling on the far side (northbound) carriageway and 3.4 dB for vehicles travelling on the nearside (southbound) carriageway.

Distance corrections have been calculated to enable comparison of measurements taken at the sound level meter and at the noise camera. These were calculated as described in Appendix C. Once distance corrections are taken into account, better alignment is found for some vehicles (e.g. ID 8, 16, 19, 20, 25, 27, 28, 30 and 46 and 47) although measurements at the noise camera are still on average comparatively higher than would be expected based on distance considerations only.

Furthermore, based on distance considerations, only positive differences would be expected in Table 5.5. For some measurements however, the maximum sound pressure level from the noise camera was higher than those from the sound level meter taken at the same time. For northbound vehicles there are more instances of the noise camera readings being higher than the sound level meter’s noise readings, compared to the southbound vehicles. This suggests that there were other variables influencing the sound pressure levels measured at each microphone, particularly when the effect of differences in distance attenuation between the two measurement positions become less significant.

When measurements at the sound level meter were higher than the noise camera, factors that may have affected the measurement included influence of surface reflection from the hard ground or by air turbulence due to the proximity to the moving vehicle. Instances where the noise camera microphone recorded higher noise levels than the sound level meter could be explained by the placement of the microphone being better able to detect other noise sources such as oncoming vehicles. Based on site observations, other noise sources including birdsong and wind were not considered to have significantly affected the measured noise levels at either the noise camera or the sound level meter.

Figure 5.1 shows the linear regression analysis between the noise levels measured by the sound level meter and the noise camera.

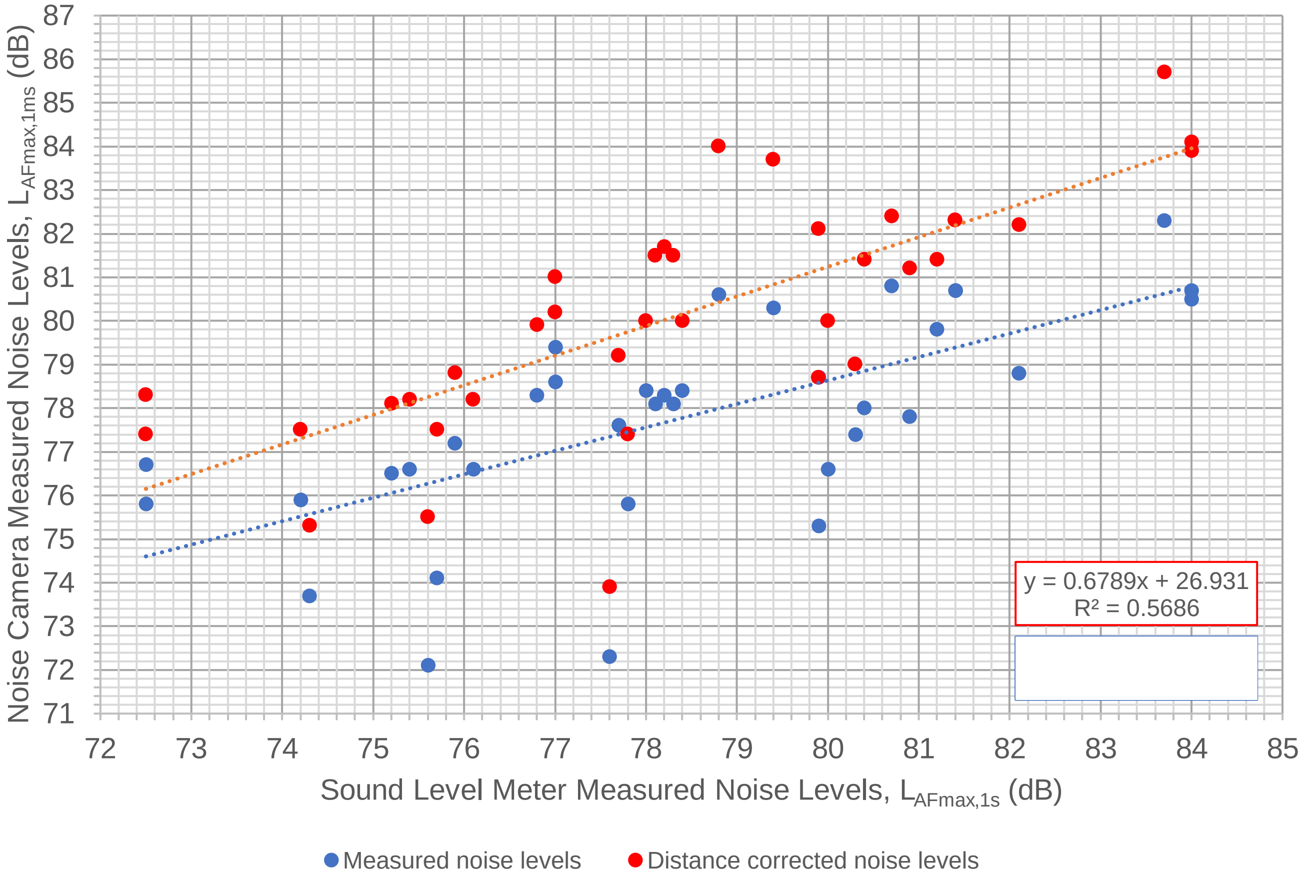


Figure 5.1. Regression analysis of simultaneous noise camera and attended noise measurements at the Marchwood Bypass for the northbound carriageway

Figure 5.1 shows that for the measured noise data the coefficient of multiple correlation, R_2, of the measured noise data, was 44.5% which indicates weak to no correlation between the two measurement types (blue data in figure). However, when distance corrections were applied to the measured noise levels (red data in figure) the correlation improved and R_2 was increased to 56.9%.

Correlation was significantly affected by a number of outliers for which large discrepancies were measured. The largest difference was measured for a motorbike (vehicle 17 in Table 5.5), for which the noise levels measured at the noise camera corrected for distance was almost 6 dB higher than the relevant measurement at the sound level meter. The vehicle was travelling on the far side carriageway. The second largest difference was registered for a car (vehicle 9) travelling on the nearside carriageway. No further information on the type of motorbike, speed or other features was able to be captured by the ANPR or by direct site observation. Further investigation is required to understand what affected the outliers in order to improve the correlation between the measured noise levels.

In terms of absolute noise levels, Table 5.5 shows that there was no clear trend between vehicle direction, and thus distance from the centre of the lanes, and the recorded noise levels by either the sound level meter or noise camera. Vehicles in one carriageway were not consistently higher in terms of sound pressure levels than the opposite carriageway. This indicates that distance between the vehicle and the microphone is not the dominant variable that influences noise levels. This could suggest that variables such as individual driving style, vehicle type, mass, exhaust location, and engine size of the pass-by vehicles have more influence on the overall L_{AFmax} in conjunction with the minimal distance between the vehicle and the microphone.

Another factor affecting this could be the directionality of the microphone. The sensitivity of microphones varies with the direction from which the soundwave reaches it. For an omnidirectional microphone like the one used for the noise camera, these differences are limited. However, directions approaching an 180° angle from the microphone axis are normally associated with lower sensitivity. The different angle of incidence of sound coming from vehicles travelling on the two carriageways could be one of the factors influencing the difference in noise levels from the sound level meter and the noise camera. This factor is likely to be small as the instrumentation used includes corrections for microphone direction.

6. Applicability of Noise Measurement Standards

The noise camera set-up described in Chapter 3 is considered to be a new technology. There are no standardised test methods for using them to undertake roadside vehicle noise measurements, nor a method for correcting the noise camera data for a fair comparison to type approval drive-by noise levels. It was suggested in Phase 1 [1] that suitable methodologies for roadside noise measurements and vehicle identification can be established or derived from already existing standardised testing methodologies. The standards most relevant to the measurement of vehicle pass-by noise are ISO 362 [4] [5] (used for type approval tests) and ISO 11819 [7]. The differences between the vehicle pass-by noise measurement standards and the method used by for the noise camera trials are summarised in Table 6.1.

Table 6.1. Difference between the noise camera test method and existing pass-by noise measurement standards

Variable	Noise camera during trial/analysis	ISO 362	ISO 11819
Remit of test standard/ method	Measurement of noise emitted by road vehicles and their speeds as they pass a fixed point. Vehicle information collected by an ANPR camera operated simultaneously.	Measurement of noise emitted by road vehicles under typical urban traffic conditions. This is done using a constant speed test or an acceleration test.	Measurement of tyre-road noise using the statistical pass-by method. This requires measuring the noise level and speed of individual vehicles passing a fixed point.
Microphone height	5-6m above ground subject to site conditions	1.2m	1.2m
Microphone orientation	The microphone body was vertical with the diaphragm parallel with the road	The microphone body should be horizontal with the diaphragm perpendicular to the road	The microphone body should be horizontal with the diaphragm perpendicular to the road
Microphone distance from vehicles	Variable subject to site conditions. The minimum horizontal distances used in the trial were approximately 2-5m	7.5m horizontally from the centre of the lane of travel (test lane). Microphones place on each side of the test lane.	7.5m horizontally from the centre of the lane of travel (test lane).
Primary measurement metric	L_{AFmax}	L_{AFmax}	L_{AFmax}
Background noise	No specific requirements	Sound pressure level prior to measurement to be 10 dB below the sound pressure level when the vehicle passes the microphone, or a suitable correction added if this is not possible	Sound pressure level prior to measurement to be 6 dB below the maximum noise level when the vehicle passes the microphone
Acoustic equipment requirements	Class 1 sound level meter. Measurements in third-octave bands	Class 1 sound level meter. No requirements stated for octave or third-octave band measurements	Type 1 sound level meter. Measurements in third-octave band (50 Hz to 10 kHz)
Vehicles appraised	All vehicles (analysis focusses on cars and motorcycles)	Subcategories of cars and motorcycles	Cars and HGVs
Vehicle speed	All speeds, noting these are dictated by the speed limit of the test road	Constant speed test at 50 km/h. Wide Open Throttle test specifies a target acceleration	All speeds, noting these are dictated by the speed limit of the test road

Variable	Noise camera during trial/analysis	ISO 362	ISO 11819
Vehicle behaviour characteristic	Constant speed, braking and acceleration	Constant speed and acceleration	Constant speed only (no acceleration, braking or other extraneous noise)
Test environment	Live carriageway, approximate free-field conditions	Standardised, specified in ISO 10844:2014. Free-field conditions. Requirements on the condition of the vehicle, including mass and tyre pressure	Live carriageway, approximate free-field conditions
Road layout	30 - 50m section of road that is relatively straight and flat	Flat with no large reflecting objects within 50m of the centre of the test track	30 - 50m section of road that is relatively straight and flat
Road surfacing	Variable, dry	Dry, acoustically reflective, compliant with ISO 10844:2014 [9].	Variable, dry
Post-processing calculations	Matching output data from different sensors. Further calculations may require adjusting the measured sound levels for comparison with type approval noise levels.	Arithmetic average of noise levels from each side of the vehicle, corrections for difference in acceleration from the test and a typical urban environment	Road surface influence based on the noise levels and speeds of 100 cars and 80 HGVs
Weather conditions	Ideally dry, air temperature above 5°C and wind speed below 5 m/s.	Dry, air temperature 5-40°C, wind speed below 5 m/s	Dry, air temperature 5-40°C, road surface temperature 5-50°C, wind speed below 5 m/s

Table 6.1 shows that ISO 362 [4] [5] and ISO 11819 [7] control far more variables than the testing set-up and method used for the noise camera. ISO 362 [4] [5] stipulates the most stringent testing conditions, with specifications for the testing environment and test vehicles that would not be achievable in the roadside environment where a noise camera could be deployed. The constant speed test is at 50 km/h (approximately 30 mph) to represent an urban road, however, a noise camera may be used on roads with higher speed limits. This means that the measured noise levels from the noise camera would not be directly comparable to results from type approval drive-by tests without adjusting the noise camera data to account for the difference in vehicle speed. Additionally, the road surfacing required for the ISO 362 tests may not be laid at potential noise camera deployment sites. An appropriate road surface correction may also be required to fairly compare the noise camera data with type approval drive by noise levels.

ISO 11819 [7] is more pragmatic for using with a noise camera as the standard is designed for use on a live carriageway, and accounts for this by allowing for a greater variation of test conditions. For example, the required noise difference during and prior to a measurement taking place is less onerous than in ISO 362 [4] [5], allowing for noise contributions from approaching traffic.

The placement and orientation of the microphone relative to the test lane is the same for both existing standards. The microphone height of 1.2m above the road is not appropriate for a noise camera as it would make it vulnerable to vandalism or theft when deployed and unattended. The prescribed set-back distance from the test lane may also be difficult to realise at preferred noise camera deployment locations as it is dependent on the physical space available.

To confirm whether measured roadside noise levels could be robustly appraised against type approval noise levels for enforcement, measurement results from the trials have been corrected for distance and speed in order to enable a comparison with type approval noise levels for a number of vehicles. The analysis was undertaken for Marchwood Bypass, where the site and traffic conditions better match those stated in ISO 362 [4] [5] and ISO 11819 [7]. Distance and speed corrections were calculated as described in Appendix C. This comparison is shown in Figure 6.1, where noise levels measured at the noise camera (horizontal axis) are plotted against the relevant type approval noise level (vertical axis).

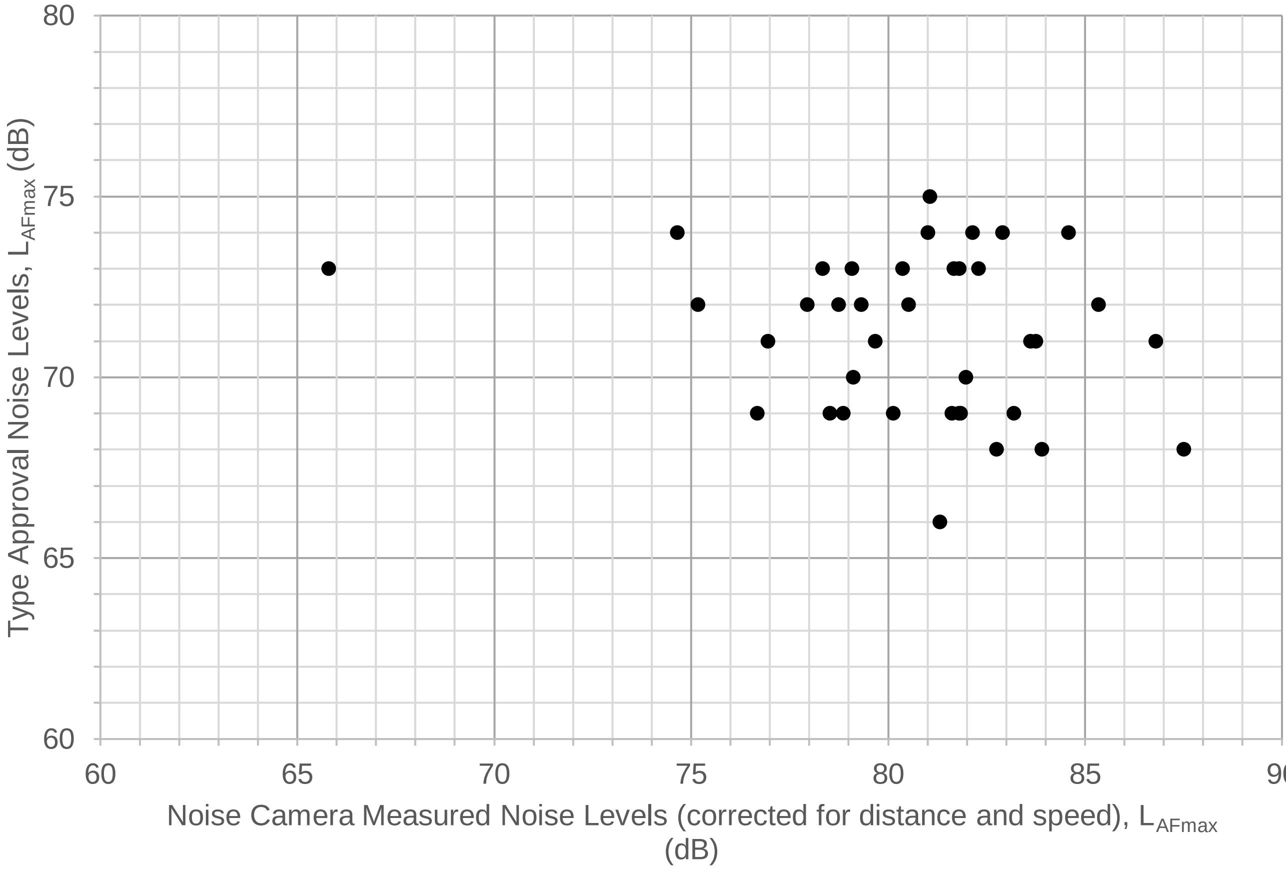


Figure 6.1. Comparison of type approval sound levels with noise camera measurements at the Marchwood Bypass.

The corrected noise levels were found to be generally significantly higher (on average +9 dB) than type approval noise levels for the vehicle, with maximum drifts up to 19.5 dB. Therefore other variables need to be considered, which might include road surface and directivity of the noise source, as well as potential contributions from other noise sources and differences in driving style during type approval tests compared to live carriageways. It should be noted that the majority of vehicles included in this analysis were travelling on the nearside carriageway, as more information on speed was available for these vehicles.

7. Identification of Excessively Noisy Vehicles

Numerically Defining Excessively Noisy Vehicles

If a noise camera is to be deployed for enforcement, an important task is to determine how an excessively noisy vehicle may be defined numerically based on the maximum sound pressure level measured when a vehicle passes the noise camera.

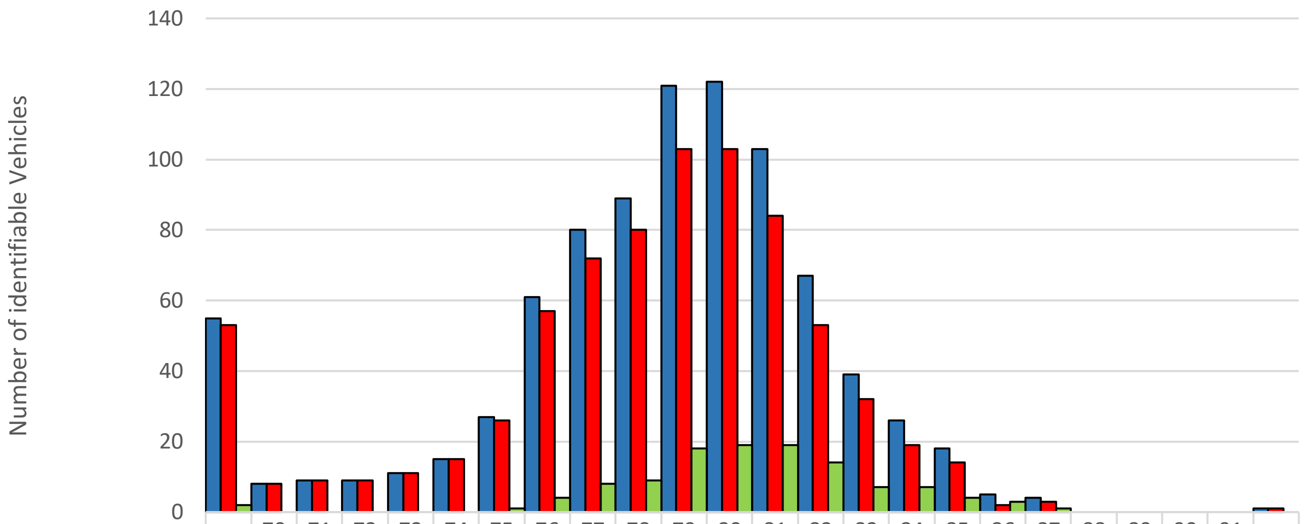
Identifiable Vehicles

As a starting point, Figure 7.1 shows the range of maximum sound pressure levels measured by the noise camera over the entire trial period at both trial sites. The sample size of vehicles considered in Figure 7.1 consists of:

- Pass-bys from any car or two/three-wheeled vehicle in either direction of travel;
- Data from time periods where at least ANPR and sound data was obtained;
- Data where there was a single vehicle pass-by within a 10-second time interval (for certainty of attributing a sound level to a specific vehicle); and
- Pass-bys where ANPR data was successfully matched to vehicle records in the DVLA Bulk Dataset.

It should be noted that the majority of vehicles fulfilling all of these criteria were from the West Meon site. This is due to the Marchwood site having a higher traffic flow and therefore fewer periods where the measured sound level could be attributed to a single vehicle.

Vehicle pass-bys that meet all of the above requirements are hereafter referred to as 'identifiable'.



	x ≤ 70	70 < x ≤ 71	71 < x ≤ 72	72 < x ≤ 73	73 < x ≤ 74	74 < x ≤ 75	75 < x ≤ 76	76 < x ≤ 77	77 < x ≤ 78	78 < x ≤ 79	79 < x ≤ 80	80 < x ≤ 81	81 < x ≤ 82	82 < x ≤ 83	83 < x ≤ 84	84 < x ≤ 85	85 < x ≤ 86	86 < x ≤ 87	87 < x ≤ 88	88 < x ≤ 89	89 < x ≤ 90	90 < x ≤ 91	91 < x ≤ 92	92 < x
Whole Trial	55	8	9	9	11	15	27	61	80	89	121	122	103	67	39	26	18	5	4	0	0	0	0	1
West Meon site	53	8	9	9	11	15	26	57	72	80	103	103	84	53	32	19	14	2	3	0	0	0	0	1
Marchwood site	2	0	0	0	0	0	1	4	8	9	18	19	19	14	7	7	4	3	1	0	0	0	0	0

Figure 7.1. Maximum sound pressure levels measured by the noise camera from vehicle pass-bys

Figure 7.1 depicts a Gaussian-shaped distribution of maximum sound pressure levels from vehicles passing the noise camera, for pass-by noise levels above 70 dB L_{AFmax}. The most commonly measured noise levels from an individual vehicle were 79-81 dB L_{AFmax} – this is the same for both the overall trial and the West Meon site. The most commonly measured levels at the Marchwood site were 80-82 dB L_{AFmax}. The highest measured maximum noise level was 92.8 dB L_{AFmax}, and this was at the West Meon site.

A breakdown of how the maximum noise levels varied by carriageway is shown in Table 7.1. Prior to a configuration change to the ANPR camera partway through the trial at West Meon, there are some instances where the noise camera did not record which carriageway the identified vehicles were using. These records are grouped together in the 'unknown' columns.

Table 7.1. Overall variation of measured maximum noise levels by carriageway

		Whole Trial				West Meon				Marchwood Bypass		
		Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
Vehicles	Total	27,245	31,826	2,772	61,843	2,797	4,333	2,772	9,902	24,448	27,493	51,941
Vehicles	Identifiable Cars and Motorbikes	336	283	249	870	271	233	249	754	65	50	116
L_{AFMax} (dB)	Minimum	66.5	68.7	49.3	49.3	68.0	68.7	49.3	49.3	66.5	76.4	66.5
L_{AFMax} (dB)	Maximum	87.9	92.8	85.8	92.8	87.9	92.8	85.8	92.8	87.1	86.2	87.1
L_{AFMax} (dB)	Mean	79.7	79.9	75.4	78.5	79.6	79.6	75.4	78.2	80.2	81.6	80.8
L_{AFMax} (dB)	Standard Deviation	3.2	3.2	8.1	5.5	3.2	3.3	8.1	5.7	3.4	2.4	3.1
L_{AFMax} (dB)	90th Percentile	83.3	83.9	81.9	83.2	83.1	83.5	81.9	83.0	83.9	85.0	84.8
L_{AFMax} (dB)	95th Percentile	84.3	84.9	83.1	84.4	84.1	84.4	83.1	84.1	85.0	85.8	85.8
L_{AFMax} (dB)	99th Percentile	86.9	85.9	85.2	86.1	86.9	85.8	85.2	85.9	86.5	86.1	86.2

* Pass-bys where the prototype noise camera did not identify the carriageway of the detected vehicle.

† Statistical information in the 'combined' columns are based on the entire dataset, not necessarily based on the values shown in the nearside, far side and unknown columns.

Table 7.1 shows that, although the difference between the highest and lowest measured maximum noise levels varied by 20-40 dB within each carriageway, the mean, percentiles for maximum noise level were broadly similar for each carriageway. The standard deviations where the carriageway has been recorded by the noise camera were broadly similar, and in the range 2.4-3.4 dB. The calculated standard deviation where the carriageway was not recorded at the West Meon site was 8.1 dB, which was much higher than that calculated for known carriageways. Because of this, the standard deviation over all carriageways and sites was also higher.

Table 7.2 shows the outcomes of further statistical analysis that has been undertaken using the same dataset to establish a potential threshold noise level that could be used to define a vehicle that is 'excessively noisy'. These threshold levels assume that high noise-emitting vehicles can be identified based on the distribution of measured noise levels obtained from the noise camera and statistical indicators, such as the mean, standard deviation and percentiles.

Table 7.2. Potential excessively noisy vehicles based on the mean and standard deviation of the measured maximum sound pressure levels

	Whole Trial				West Meon				Marchwood Bypass		
	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
Threshold Level: Mean + 1 Standard Deviation											
Mean (dB)	79.7	79.9	75.4	*78.5*	79.6	79.6	75.4	*78.2*	80.2	81.6	*80.8*
Standard Deviation (dB)	3.2	3.2	8.1	*5.5*	3.2	3.3	8.1	*5.7*	3.4	2.4	*3.1*

	Whole Trial				West Meon				Marchwood Bypass		
	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
Mean + Standard Deviation (dB)	82.9	83.1	83.5	*84.0*	82.8	82.9	83.5	*83.9*	83.6	84.0	*83.9*
Vehicles Above Threshold	41	39	9	*54*	31	31	9	*42*	7	8	*16*
Threshold Level: Mean + 2 Standard Deviations											
Value (dB)	86.1	86.3	91.6	*89.5*	86.0	86.2	91.6	*89.6*	87.0	86.4	*87.0*
Vehicles Above Threshold	6	1	0	*1*	5	1	0	*1*	1	0	*1*
Threshold Level: 90th Percentile											
90th Percentile (dB)	83.2	83.9	81.9	*83.2*	83.1	83.5	81.9	*83.0*	83.9	85.0	*84.8*
Vehicles Above Threshold	34	29	25	*81*	27	24	25	*76*	7	5	*12*
Threshold Level: 95th Percentile											
95th Percentile (dB)	84.3	84.9	83.1	*84.4*	84.1	84.4	83.1	*84.1*	85.0	85.8	*85.8*
Vehicles Above Threshold	17	12	13	*41*	13	11	13	*35*	4	2	*5*
Threshold Level: 99th Percentile											
99th Percentile (dB)	86.9	85.9	85.2	*86.1*	86.9	85.8	85.2	*85.9*	86.5	86.1	*86.2*
Vehicles Above Threshold	4	3	3	*8*	3	3	3	*6*	1	1	*1*

* Pass-bys where the prototype noise camera did not identify the carriageway of the detected vehicle.

† Statistical information in the 'combined' columns are based on the entire dataset, not necessarily adding together the data from the nearside, far side and unknown columns.

There are a small number of vehicle pass-by maximum noise levels exceeding two standard deviations of the mean for any carriageway, however, overall these vehicles represent 0.1% of the identifiable vehicles. Several vehicles were measured with maximum noise levels higher than one standard deviation above the mean. The total of these vehicles was approximately 6% of the identifiable cars and motorbikes for the entire trial period.

Comparing the percentiles for each trial site, where the carriageway was identified by the noise camera, the levels were broadly similar. It is noted that the 'Unknown' carriageway had a smaller effect on the overall percentiles than it did with standard deviation.

Looking at both statistical approaches, the Mean + Standard Deviation had a threshold broadly similar to the 90th percentile and the 99th percentile shows reasonable correlation with the Mean + 2 Standard Deviations on identifiable carriageways.

Based on the vehicle counts associated with pass-by noise levels exceeding those for each of the statistical parameters detailed in Table 7.2, it is considered that the 99th percentile could be chosen to define an excessively noisy vehicle. Vehicles with pass-by noise levels above the 99th percentile represent the top 1% pass-by noise levels that can be considered excessively noisy. From the trial data, a pass-by noise level of approximately 86 dB correspond to the 99th percentile, accounting for 8 vehicles identified by the noise camera from the whole trial period where the direction of travel was known. The use of the 99th percentile to identify excessive noise has precedent as this is the approach used by Defra to identify Noise Important Areas for road and railway noise in strategic noise maps.

The value of the 99th percentile pass-by noise level identified above would only be suitable on roads similar to those used for the trial (roads with a 50 mph speed limit that are laid with a hot rolled asphalt surface) and for vehicles classified by the DVLA as ‘Car’ or ‘2/3 Wheelers’. Different pass-by noise levels would correspond to the 99th percentile for roads with different combinations of speed limits and road surfacing.

Non-identifiable Vehicles

This section investigates the measured noise levels from the noise camera collected across the entire trial where ‘No Plate’ was recorded by the ANPR cameras. A ‘No Plate’ record is where the camera has not been able to read a number plate for any reason. As no number plate was read for these records, no further information was able to be requested for them, therefore this dataset potentially includes all types of motorised vehicle using the road, including heavy goods vehicles.

Figure 7.2 and Figure 7.3 show the range of maximum sound pressure levels measured by the noise camera. The sample considers all vehicles where no plate data was recorded and therefore the vehicles do not fit the parameters for ‘identifiable’ as described above. The noise levels shown in Figure 7.2 are not necessarily attributed to individual vehicles; if multiple vehicles passed the noise camera within a 10-second time window then entry in Figure 7.2 represents the noise levels of multiple vehicles passing in quick succession. Figure 7.3 represents a smaller dataset where ‘No Plate’ records were able to be assigned to a single vehicle pass-by within a 10-second time window and the results shown in this figure are directly comparable to the data presented for ‘identifiable’ vehicles.

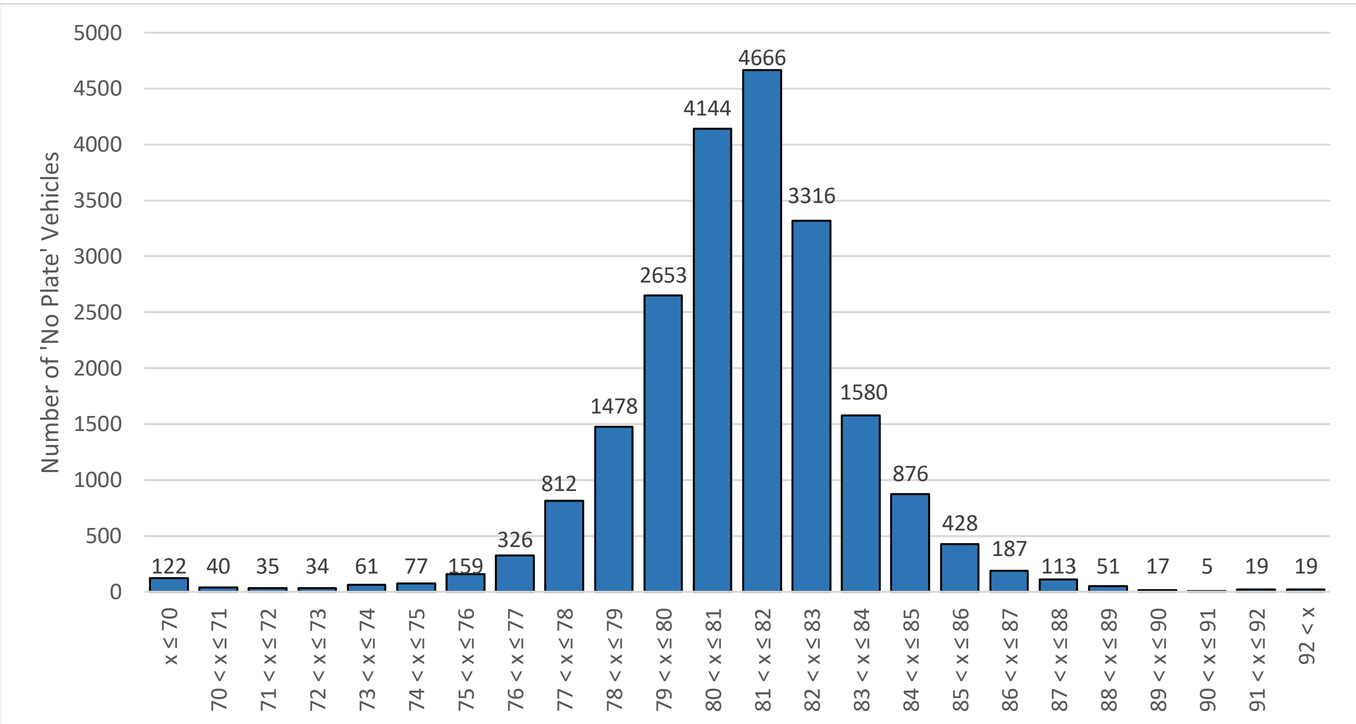


Figure 7.2. Maximum sound pressure levels measured by the noise camera from vehicle pass-bys for ‘No Plate’ records, including HGVs and vehicles passing the noise camera in quick succession

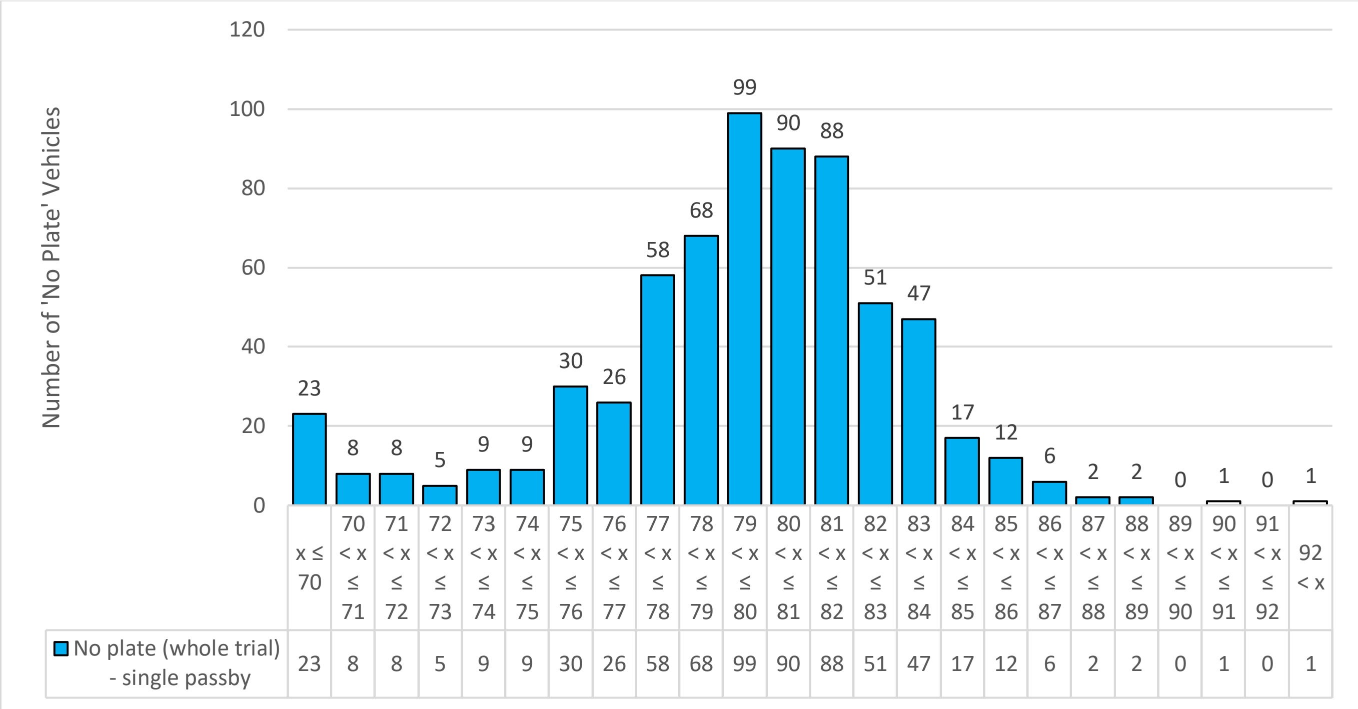


Figure 7.3. Maximum sound pressure levels measured by the noise camera from single vehicle pass-bys for 'No Plate' records

Figure 7.2 and Figure 7.3 depict a similar Gaussian-shaped distribution of maximum sound pressure levels to Figure 7.1. For pass-by noise levels above 70 dB L_{Amax}, Figure 7.2 indicates that most commonly measured maximum noise levels from individual vehicles and vehicles passing the noise camera in quick succession were slightly higher at 80-83 dB. Figure 7.3 shows that the most commonly measured noise levels from an individual vehicle were 79-82 dB, which is similar to the outcome for the 'identifiable' vehicles. The highest measured maximum noise level was above 100.5 dB.

A breakdown of how the maximum noise levels varied by carriageway is shown in Table 7.3.

Table 7.3. Variation of measured maximum noise levels by carriageway for 'No Plate' records

		Whole Trial				West Meon				Marchwood Bypass		
		Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
Number of 'No Plate' single vehicle pass-bys		139	481	40	*660*	133	356	40	*529*	6	125	*131*
L_{AFMax} (dB)	Minimum	59.8	60.6	68.8	*59.8*	59.8	60.6	68.8	*59.8*	80.2	70.4	*70.4*
	Maximum	88.2	91.0	100.5	*100.5*	85.6	91.0	100.5	*100.5*	88.2	87.6	*88.2*
	Mean	78.5	79.7	79.1	*79.4*	78.3	79.3	79.1	*79.0*	83.2	80.9	*81.0*
	Standard Deviation	4.1	3.8	5.7	*4.0*	4.1	4.0	5.7	*4.2*	3.1	2.9	*3.0*
	90th Percentile	82.4	83.6	83.6	*83.4*	82.1	83.3	83.6	*83.1*	86.8	84.5	*84.6*
	95th Percentile	84.2	84.4	85.5	*84.4*	83.7	83.9	85.5	*84.0*	87.5	85.8	*85.9*
	99th Percentile	85.5	86.7	95.1	*86.8*	85.2	86.2	95.1	*86.3*	88.1	87.1	*87.4*

* Pass-bys where the prototype noise camera did not identify the carriageway of the detected vehicle.

† Statistical information in the 'combined' columns are based on the entire dataset, not necessarily adding together the data from the nearside, far side and unknown columns.

Table 7.3 shows similar patterns to identifiable vehicles, with the mean, 90th and 95th percentiles for maximum noise level being broadly similar for each carriageway. The standard deviation for vehicle pass-bys where the carriageway was recorded by the noise camera was consistent for each direction at each trial site, although it is noted that the data collected as West Meon has a higher standard deviation than the data collected at the Marchwood Bypass.

The calculated standard deviation where the carriageway was not recorded by the noise camera is 5.7 dB, which is much higher than that calculated for known carriageways. However, due to the small sample size compared to those on defined carriageways, the 'Unknown' has little influence on the standard deviation when looking at all carriageways.

Table 7.4 shows the outcomes of further statistical analysis undertaken on the 'No Plate' records to establish the difference between the threshold established for 'identifiable' noisy vehicles and non-identifiable vehicles.

Table 7.4. Analysis of maximum sound pressure levels for 'No Plate' records

	Whole Trial				West Meon				Marchwood Bypass		
	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
Threshold Level: Mean + 1 Standard Deviation											
Mean (dB)	78.5	79.7	79.1	*79.4*	78.3	79.3	79.1	*79.0*	83.2	80.9	*81.0*
Standard Deviation (dB)	4.1	3.8	5.7	*4.0*	4.1	4.0	5.7	*4.2*	3.1	2.9	*3.0*
Mean + Standard Deviation (dB)	82.6	83.5	84.8	*83.4*	82.4	83.3	84.8	*83.2*	86.3	83.8	*84.0*
Vehicles Above Threshold	13	49	4	*65*	11	34	4	*51*	1	19	*17*
Threshold Level: Mean + 2 Standard Deviations											
Value (dB)	86.7	87.3	90.5	*87.4*	86.5	87.3	90.5	*87.4*	89.4	86.7	*87.0*
Vehicles Above Threshold	1	3	1	*5*	0	2	1	*3*	0	3	*3*
Threshold Level: 90th Percentile											
90th Percentile (dB)	82.4	83.6	83.6	*83.4*	82.1	83.3	83.6	*83.1*	86.8	84.5	*84.6*
Vehicles Above Threshold	14	45	4	*65*	14	34	4	*52*	1	12	*13*
Threshold Level: 95th Percentile											
95th Percentile (dB)	84.2	84.4	85.5	*84.4*	83.7	83.9	85.5	*84.0*	87.5	85.8	*85.9*
Vehicles Above Threshold	7	23	2	*33*	7	17	2	*24*	1	7	*7*
Threshold Level: 99th Percentile											

	Whole Trial				West Meon				Marchwood Bypass		
	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Unknown *	Combined †	Nearside	Far side	Combined †
99th Percentile (dB)	85.5	86.7	95.1	*86.8*	85.2	86.2	95.1	*86.3*	88.1	87.1	*87.4*
Vehicles Above Threshold	2	5	1	*7*	2	4	1	*6*	1	2	*2*

* Pass-bys where the prototype noise camera did not identify the carriageway of the detected vehicle.

† Statistical information in the 'combined' columns are based on the entire dataset, not necessarily adding together the data from the nearside, far side and unknown columns.

As shown in Table 7.4, there are a number of vehicle pass-by maximum noise levels exceeding two standard deviations of the mean for any carriageway. Overall these vehicles represent 0.01% of all 'No Plate' records. Approximately 10% of the 'No Plate' records were above the Mean + 1 Standard Deviation which is higher than for equivalent for the 'identifiable' vehicles.

As with the 'identifiable' vehicles, the percentiles for 'no plate' records were broadly similar across all carriageways.

Comparing Table 7.4 (single vehicle 'No Plate' records) with Table 7.1 (Identifiable vehicles) all statistics show good correlation, indicating that the potential use of the 99th percentile as means of identifying 'excessively noisy' vehicles could be reasonable.

Given the volume of vehicles where no number plate was read, there is potential to increase confidence in the levels derived by improving the read accuracy of the ANPR camera.

Variability of Data from Repeatedly Measured Vehicles

The objective of this part of the analysis is to assess the repeatability and the range of variability of the results obtained from the noise camera's vehicle pass-by measurements. To assess this, data from both trial site have been filtered to obtain a subset of vehicles that had passed the noise camera more than once during the trial. The overall maximum noise levels measured by the noise camera from these vehicles have been compared.

Figure 7.4 presents the maximum noise levels measured for seven vehicles that had passed the noise camera at least twice on the same carriageway at West Meon so that the distance between the noise camera and the passing vehicle would be approximately the same. The average of the maximum noise levels measured during each pass-by is plotted together with the minimum and maximum values registered within each dataset.

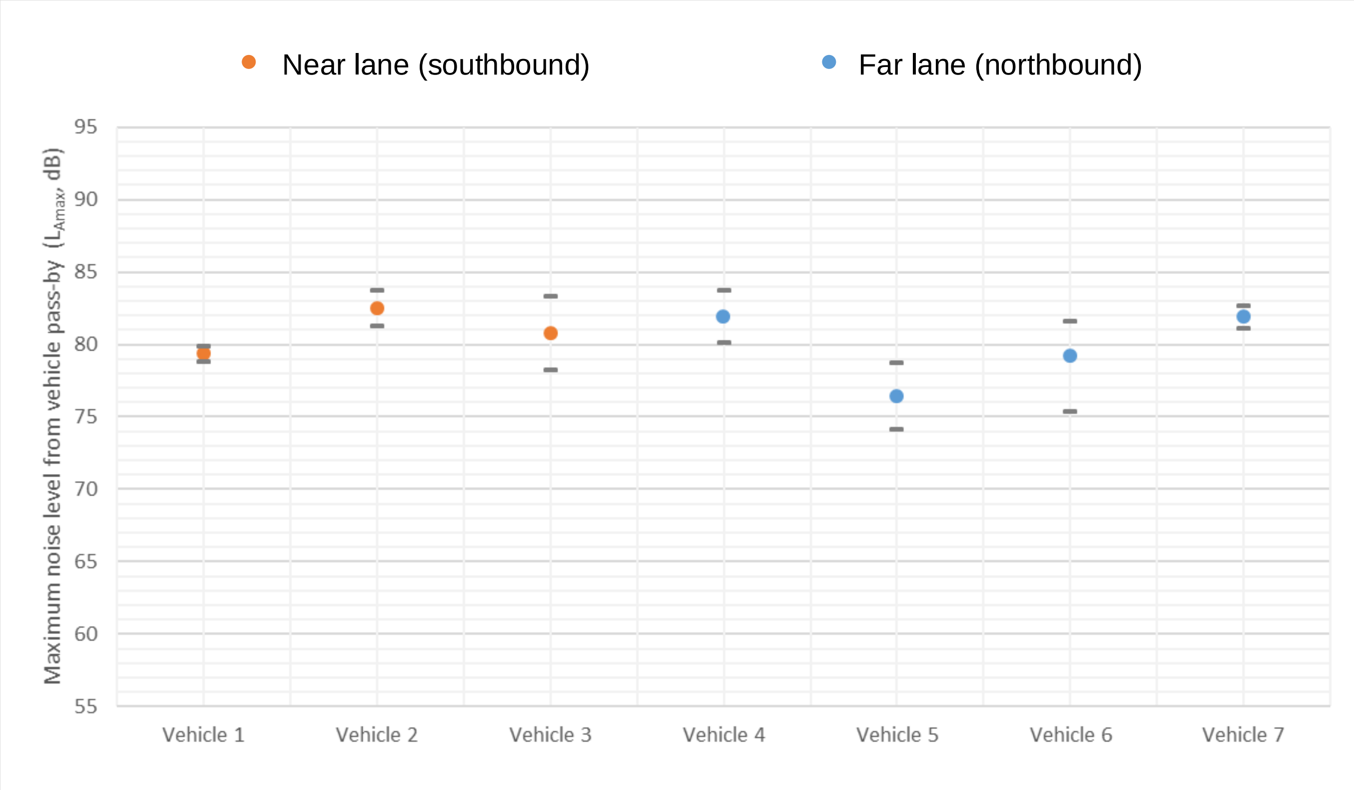


Figure 7.4. Average of maximum noise levels L_{Amax} measured for vehicles that passed at least twice during the monitoring period. Results are grouped for travelling direction

Figure 7.4 shows that for the repeatedly measured vehicles, similar noise levels were measured for vehicles travelling on the carriageway closest to the noise camera where there was less distance attenuation. This correlates with trial-wide data presented in Table 7.1.

The variation in measured maximum noise levels from pass-bys of the same vehicle ranged from 1 dB (vehicle 1) to 6 dB (vehicle 6). The variations can be attributed to many factors, including the following:

- Different vehicle speeds on each occasion the vehicle passed the noise camera;
- Status of the traffic lights at the junction north of the trial site; and
- Presence of any surface water on the road surface that may affect the measured noise levels.

Differences in wind speed and direction each time the same vehicle passed the noise camera were not found to substantially influence noise levels measured by the prototype noise camera.

Speed data for each pass-by of the repeatedly measured vehicles was limited and investigated where available. The pass-by noise levels and speeds for two of the vehicles (Ford Kuga and Smart Forfour) are reported in Figure 7.5. The measured pass-by noise levels and speeds of the Ford Kuga show that speed influenced the measured sound level more than the horizontal distance to the noise camera. This is because the measured noise level was 2 dB higher when it travelled in the far side carriageway at 73 km/h than the nearside carriageway at 20 km/h.

The results for the Smart Forfour shown in Figure 7.5 indicate that travelling 9 km/h faster in the nearside carriageway (to 39 km/h) corresponded to a 4.5 dB increase in the measured pass-by noise level (to 83 dB).

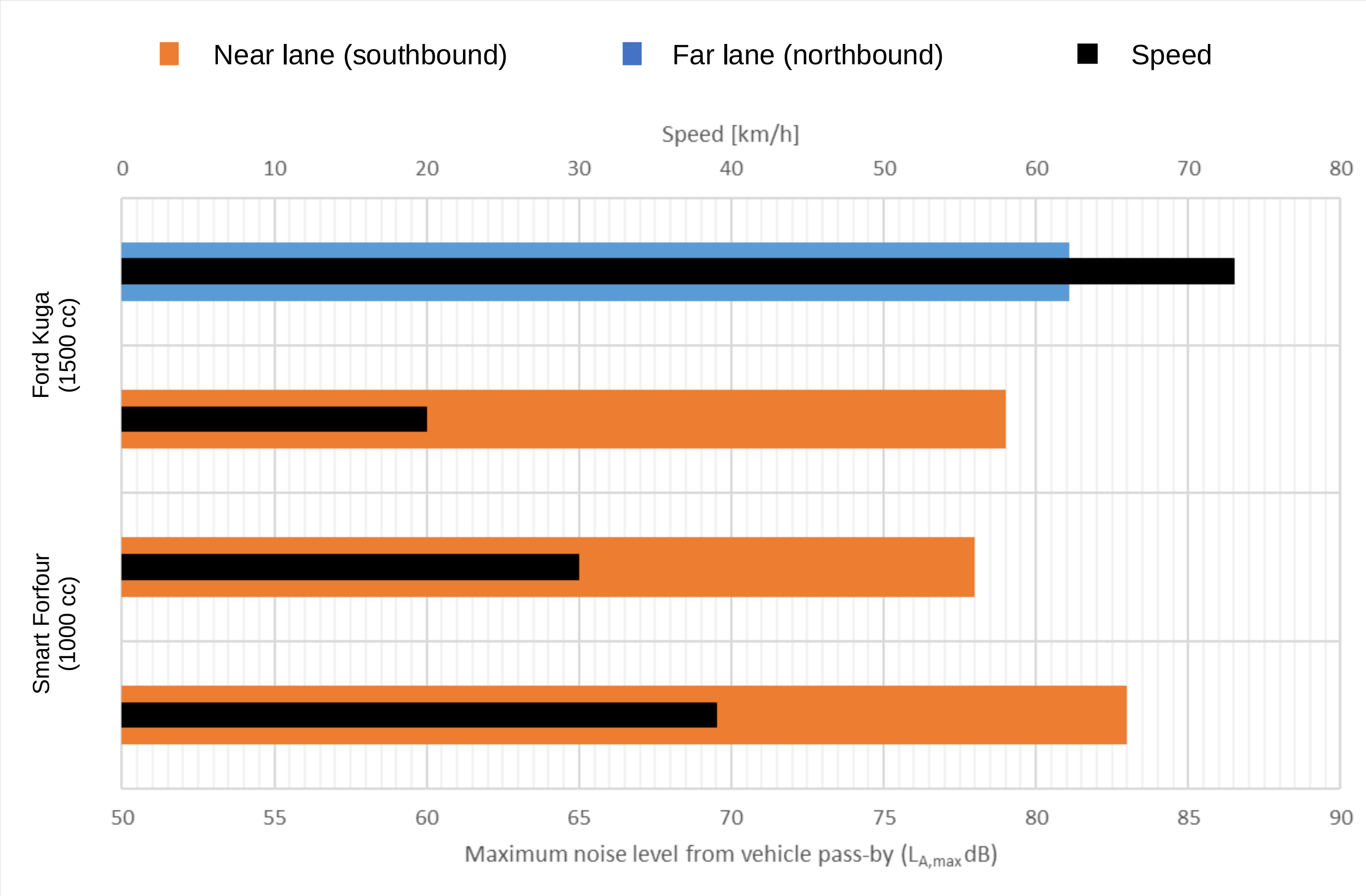


Figure 7.5. Comparison between average of maximum noise levels L_{Amax} and speed data measured for vehicles that passed at least twice during the monitoring period. Results are grouped for travelling direction.

The difference between the measured vehicle speeds on the nearside carriageway (20-39 km/h) and the far side carriageway (73 km/h) may be due to the status of the traffic lights at the junction north of the trial site. The presence of the noise camera may have had an effect vehicular behaviour as drivers may decrease the speed of their vehicles at sight of the noise camera on the nearside carriageway. The noise camera was partly hidden behind vegetation when approaching the crossroads from the northbound direction, so drivers may have travelled at faster speeds when passing the noise camera from this direction.

Further analysis has been undertaken to widen the dataset to consider maximum noise levels associated with the pass-by noise levels of vehicles of the same make and model rather than individual vehicles. Several vehicles of the same make and model that were found to travel more frequently through the trial sites were analysed, including samples of vehicles from different categories (city car, executive car and SUV). Figure 7.6 and Figure 7.7 present the maximum noise level measured from individual vehicle pass-bys grouped by vehicle type, together with the average (large black dot) and the standard deviation. The results reported in Figure 7.6 and Figure 7.7 are related to West Meon trial site only. Not enough data have been recorded for the Marchwood site to allow a similar comparison of pass-by noise levels to be undertaken.

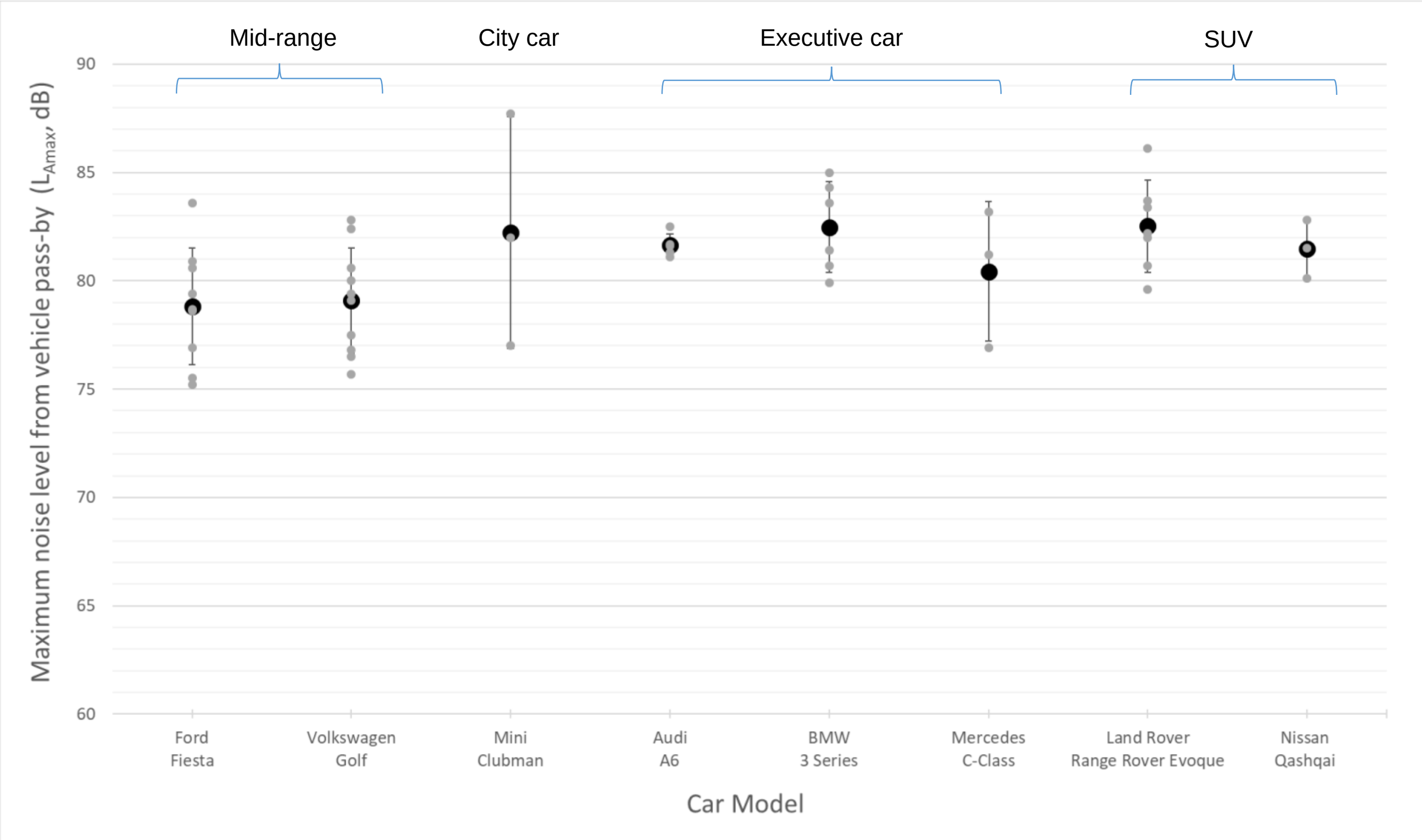


Figure 7.6. Maximum noise levels L_{Amax} measured for pass-by of similar vehicles on A32 West Meon southbound carriageway (closest to the noise camera)

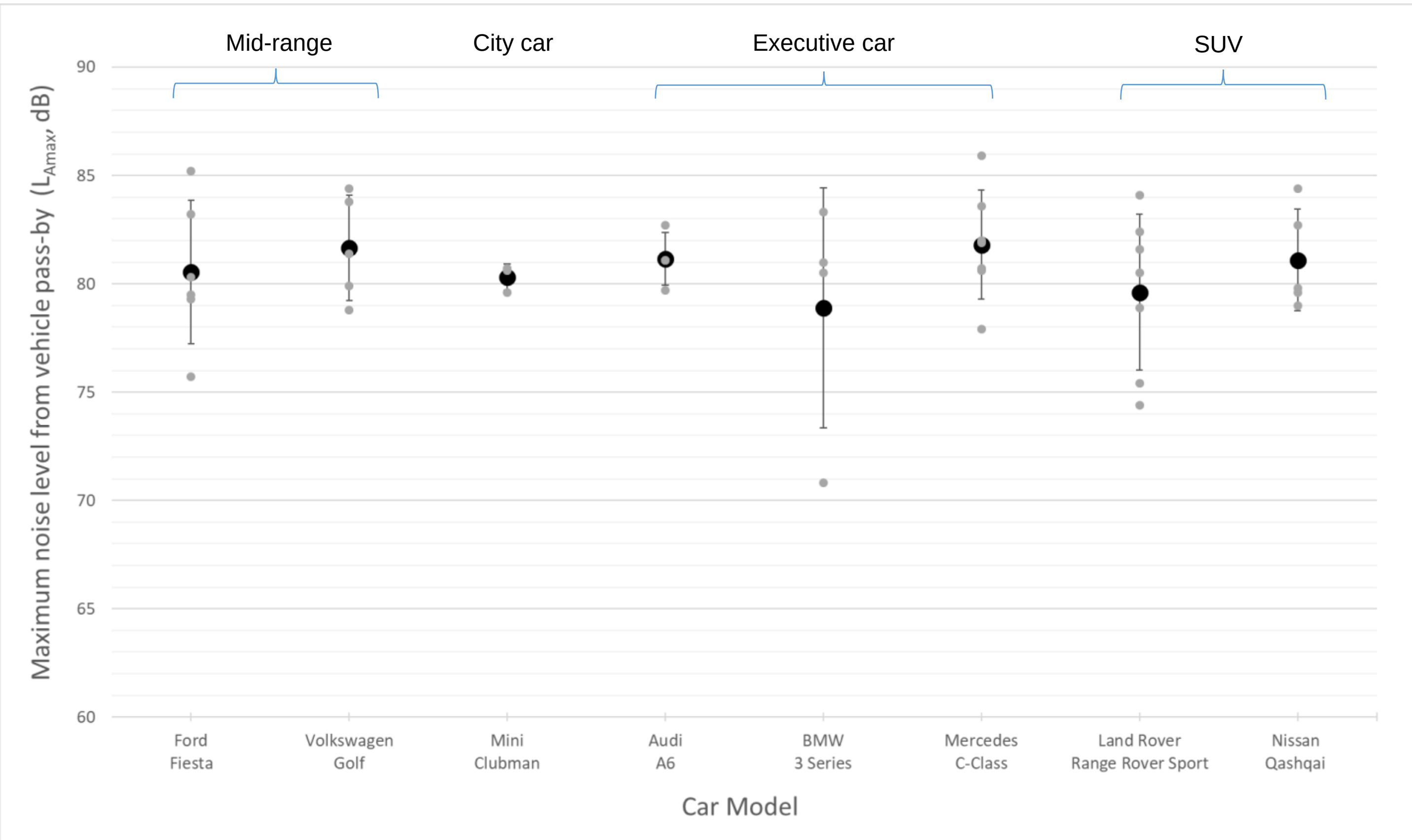


Figure 7.7. Maximum noise levels L_{Amax} measured for similar vehicles on the A32 West Meon northbound carriageway (furthest from the noise camera)

Figure 7.6 and Figure 7.7 show that there is no clear trend on whether the mean noise levels for difference vehicle types are higher on the northbound or southbound carriageway, and the standard deviation for the same vehicle type is inconsistent between carriageways. For example, the measured maximum noise levels for the Mini have less variation in the northbound carriageway whereas the converse is shown for the Nissan and BMW. In other cases, similar levels of variation are shown (Volkswagen and Ford).

The level of variation is subject to the speed of travel for each pass-by and the age and engine size of the vehicle. This was investigated and results are presented in Figure 7.8. One car model for each travelling direction and at least three samples for each car model were selected. The samples differ in terms of date of manufacture and engine capacity.

The results show that the measured noise levels are linked to speed, year of manufacture and engine capacity, but not enough data are available to conclude which of these factors is most influential on noise levels for the same vehicle type. For example, the measured noise level for the Range Rover (2006, 2700 cc) is the lowest value in its category and this could be explained in terms of engine capacity as it has the smaller capacity, even though the speed and the year of manufacture may suggest different expected result. Higher noise levels could be connected to the vehicle's age, as shown by the Audi data in Figure 7.8. The Audi A6 (2000, 1900 cc) travelled at a slower speed past the noise camera and has smaller engine capacity than the other Audis shown on Figure 7.6. However, the noise camera measured higher noise levels for the Audi A6 registered in 2000 than a newer, more powerful model travelling faster Audi A6 (2004, 2500 cc).

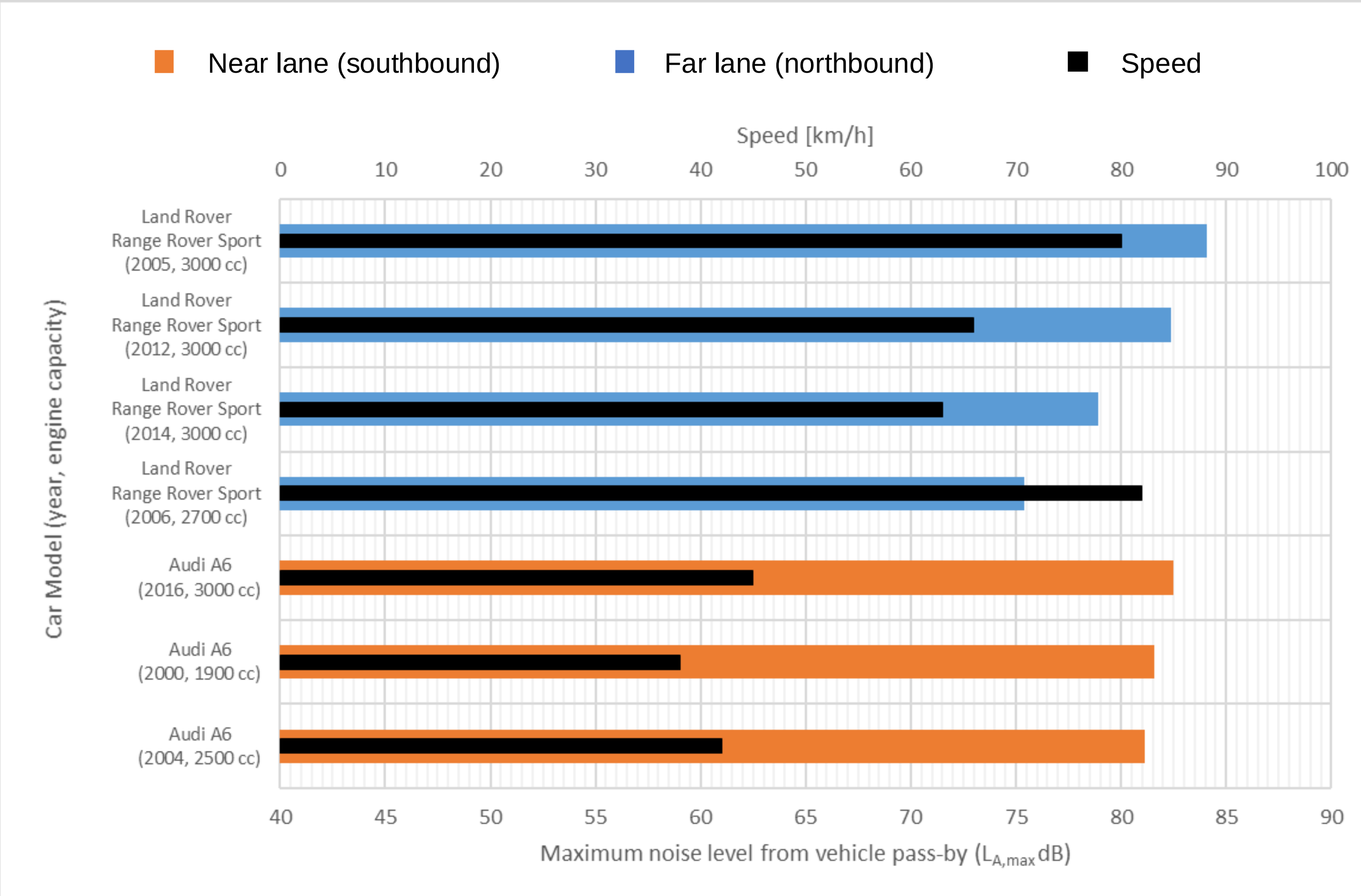


Figure 7.8. Comparison between average of maximum noise levels L_{Amax} and speed data measured for two different car model, year of manufacture and engine capacity, that passed during the monitoring period. Results are grouped for travelling direction.

8. Identification of Suitable Noise Limits

Measured Noise Levels for Vehicle Subcategories

The pass-by noise levels measured by the noise camera at both trial sites have been assessed to determine the degree of variation between vehicle subcategories. The dataset was subdivided into categories of vehicles, with the aim of identifying whether the pass-by noise levels were similar for cars of varying engine sizes, and motorcycles. The statistics analysed for each vehicle category are shown below in Table 8.1.

Table 8.1. Excessively noisy threshold for cars and motorcycles based on engine size

Vehicle Category	Size of Dataset	Statistics	
		Mean (L_{Amax}, dB)	Standard deviation (dB)
Cars (excluding off-road cars)			
Less than 1500cc	282	78.0	5.8
1500-2000cc	366	78.7	5.4
2000cc and higher	83	78.7	5.1
Cars (off-road only)			
Less than 1500cc	3	79.0	3.4
1500-2000cc	64	79.0	6.2
2000cc and higher	68	79.4	4.7
Motorcycles and scooters (powered 2/3 wheelers)			
Matched by the noise camera	4	80.2	2.6
Matched by the noise camera and video footage	21	80.7	2.2
Unknown			
'No Plate' entries	660	79.4	4

The results shown in Table 8.1 for the vehicle subcategories show that the average pass-by noise levels were similar, ranging 78-81 dB L_{Amax}. The mean pass-by noise levels were consistent with those shown in Table 7.2 and Table 7.4. For cars, the mean L_{Amax} increased marginally as engine size increased, with some differences in the level of increase depending on whether the vehicle is for off-road use.

ANPR did not capture a number plate in all situations, with 660 vehicles in this 'Unknown' category where a vehicle type was unable to be derived. The mean for 'Unknown' vehicle category was consistent with that derived for cars below 1500cc and 2000cc.

As the prototype noise camera identified only four motorcycle pass-bys during the trials, an analysis of video footage was undertaken for the West Meon site for the evening period of 27th November 2019. A best fit strategy was adopted to match the measured noise levels to each motorcycle pass-by due to the time lag between the vehicle appearing on the ANPR camera's field of view and the corresponding maximum noise levels recorded by the noise camera's microphone. The range of matched motorcycle noise levels is shown in Figure 8.1.

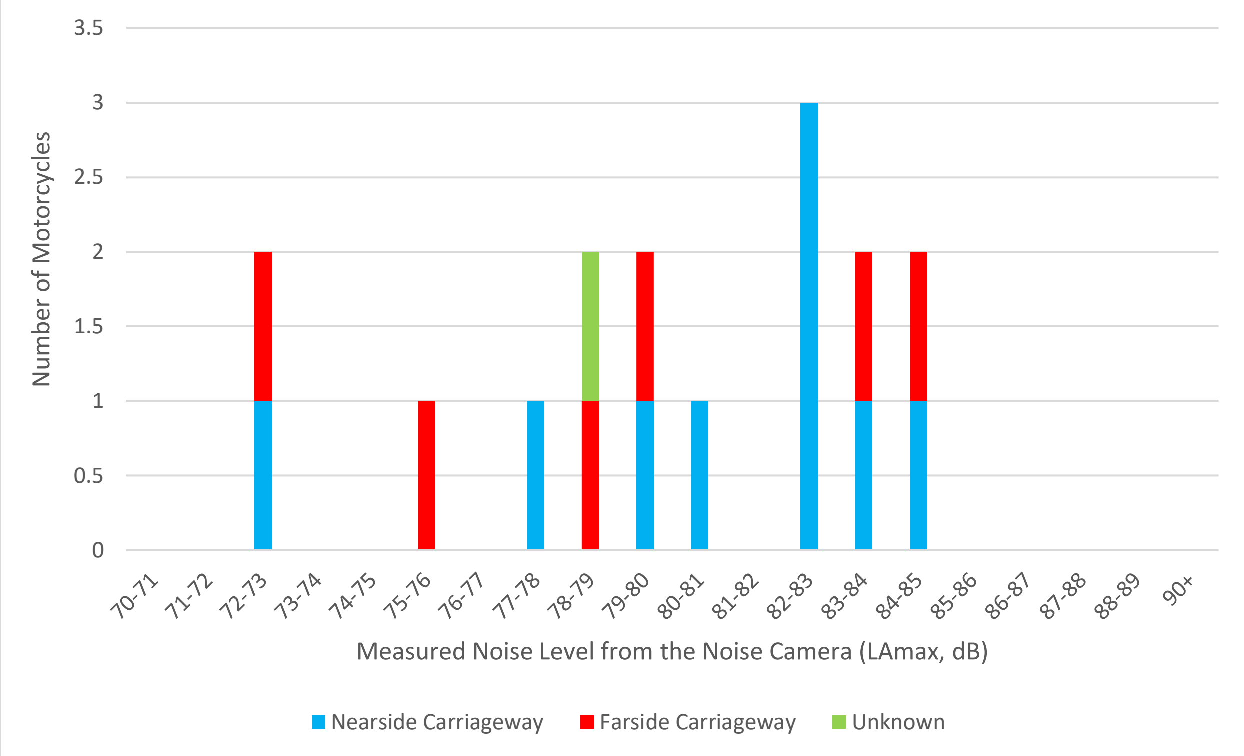


Figure 8.1. Measured noise levels for motorcycles identified by the prototype noise camera and from cross-referencing video footage

Figure 8.1 shows that the limited dataset of measured maximum noise levels for motorcycles were not particularly higher than those shown in Figure 7.1 and Figure 7.3. One continuous traffic event of seven motorcycles passing the noise camera within a 14 second time window resulted in the highest maximum noise levels between 84 and 85 dB L_{Amax}.

Identification of Appropriate Fixed Noise Limits

There are a number of approaches that can be used to base enforcement noise limits, and these are linked to three main strategies:

1. Bespoke noise limits for each individual vehicle based on the drive-by type approval noise levels associated with the vehicle. This would be the most accurate approach as the age of the vehicle would be fully taken into account but would require post-processing of measured noise levels to establish compliance and identification of the relevant type approval noise levels;
2. Setting noise limits based on the distribution of noise levels within the population of the vehicle subcategory using statistical parameters (similar to the approach used in the previous sections), which would also require post-processing to determine compliance. As the noise levels of newly registered vehicles tested at type approval would decrease over time, any threshold noise level determined by statistical parameters would also decrease as newer, quieter vehicles join the UK vehicle fleet.
3. A fixed noise limit can be implemented that is selected taking into consideration the age distribution of the UK vehicle fleet. Alternatively, a fixed noise limit may be based on statistical parameters for the noise emissions from the current vehicle fleet and reviewed as necessary.

The strengths and weaknesses of each of these strategies is reviewed in Table 8.2.

Table 8.2. Appraisal of the prototype noise camera's performance

	Bespoke Noise Limit	Statistical Noise Limit	Fixed Noise Limit
Description	Customised noise limits for individual vehicles based on type approval drive-by noise levels.	Setting noise limits using statistical parameters such as the 99th percentile.	Setting a fixed noise limit for all vehicles or vehicle subcategories.
Strengths	• Easier to tie into the Road Vehicle (Construction and Use)	• Independent of speed limit, age distribution of the vehicle fleet and	• Easier for enforcement and public awareness campaigns.

	Bespoke Noise Limit	Statistical Noise Limit	Fixed Noise Limit
	Regulations [3]. • Most accurate approach.	position of the noise camera. • Takes into account local conditions, such as road surface type and condition.	• Fixed noise limits can be set based on statistical data and research to provide an objective basis to justify the selected values.
Weaknesses	• Would make post-processing more complicated. • Tolerances needed for the age of the vehicle, road surfacing type and condition. • Each vehicle treated slightly differently. • Difficult for police officers to enforce without easy access to bespoke noise limits.	• Different noise limit for each site as local conditions would be taken into account (e.g. road surfacing), which could provide grounds for a legal challenge. • Possible requirement to change law.	• Post-processing required to account for differences in the noise camera position. • Tolerances needed for road surfacing type and condition. • Different noise limits may be needed depending on the speed limit and urban/rural conditions. • Possible requirement to change law.
Opportunities	• Generation of database of type approval noise levels. • Means for public to find out their type approval noise levels.	• Allows for flexibility to adapt with changes to the vehicle fleet, avoiding the need to regularly update laws or legislation. The law would need to be updated first to accommodate this approach.	• May change consumer behaviour when considering aftermarket products.
Threats	• Time intensive to obtain and maintain an up-to-date library of type approval noise levels for all vehicles on UK roads that would be eligible for enforcement. • Uncertainty from members of the public of what the noise limit is.	• Statistical noise limit can be changeable over the deployment period. An approach to dealing with this would need to be determined in advance of installation. • Uncertainty from members of the public what the noise limit is.	• Perceptions of what an excessively noisy vehicle might be may change over time as the vehicle fleet changes. The fixed noise limit may need to be revised accordingly. • Would need to be set high enough to take into account higher noise levels produced by older vehicles.

Of the three strategies, setting a fixed noise limit based on statistical parameters of the current vehicle population is the most pragmatic option as it offers an objective noise limit for all vehicles of the same subcategory to comply to, making enforcement easier and more efficient than bespoke noise limits.

Due to road layout constraints, it is unlikely that a noise camera could be installed at the same distance from the nearside carriageway as stated in ISO 362 for type approval drive-by tests. It would be more practical to standardise the vertical and horizontal distance between the noise camera and the vehicles using the nearside carriageway and set a fixed noise limit at the noise camera position. Correction factors may then be applied if there is a need to cross-reference against type approval noise levels, for example, if bespoke noise limits are preferred.

No imported vehicles or vehicles registered before April 1990 were identified by the noise camera during the trial. Any vehicles that would be exempt from a fixed noise limit could be identified during the post-processing of the noise camera data and review of the evidence package should a false positive occur.

Table 8.2 indicates that tolerance factors would be required should a maximum noise limit be used for enforcement purposes. This is needed to ensure that the burden of evidence is robust and can withstand a legal challenge in a similar way to automated speed cameras.

Tolerances for any post-processed noise levels using any of these approaches would need to consider vehicle speed, road surface type and meteorology (including whether the road surface is likely to be wet). A further tolerance may need to be applied to account for uncertainties relating to speed and noise levels so that the accuracy and reliability of the noise camera components cannot be disputed.

Although further work is required to calculate numerical values for these tolerances or to determine whether different noise limits are required for roads with different speed limits, the noise camera data suggests that a fixed noise limit of approximately 86 dB L_{Amax} at the noise camera plus tolerances could potentially be suitable to cover all vehicle subcategories on a 50 mph road.

9. Identification of Adverse Driver Behaviour

As part of this study the trial dataset has been analysed to establish if it is sufficient to determine whether individual exceptionally noisy pass-by measurements arose from modified/poorly maintained vehicles or from compliant vehicles being driven in a particular style. Due to the low number of motorcycles successfully matched to the DVLA Bulk Dataset from both trial sites, this task has mainly been undertaken on cars.

Pass-bys of single vehicles associated with a maximum noise level above 83 dB L_{Amax} (based on the mean + 1 standard deviation values calculated in Chapter 7) were analysed and compared to the maximum noise level corresponding to pass-bys of similar vehicles measured during the trial. Both the overall A-weighted noise level and the associated frequency content were studied.

A number of factors that could affect the measured noise levels from the noise camera and aid the explanation of any differences were considered. Speed would be a major factor affecting the measured noise level, with vehicles travelling at faster speed expected to be louder.

The distance between the vehicle and the microphone is expected to have an effect, and due to the larger distance from the microphone vehicles passing on the far side (northbound) carriageway would be expected to have lower pass-by noise levels compared to pass-bys on the nearside (southbound) carriageway.

The age of the vehicle is also considered a significant variable, with older vehicles likely to be more noisy due to factors including higher type approval noise levels and a larger variability in the maintenance status, as highlighted by previous research undertaken by the Transport Research Laboratory [10].

Categories of adverse driving behaviour such as excessive speed, aggressive acceleration and sudden deceleration have been considered as potential causes for high noise levels.

Figure 9.1 to Figure 9.3 show the third-octave band frequency content associated with pass-bys of different types of vehicles. Vehicles included in each graph were of the same make and model, engine capacity and type of fuel. Vehicle 1 is always the noisiest of the group, with Vehicle 2 to Vehicle 7 being progressively quieter.

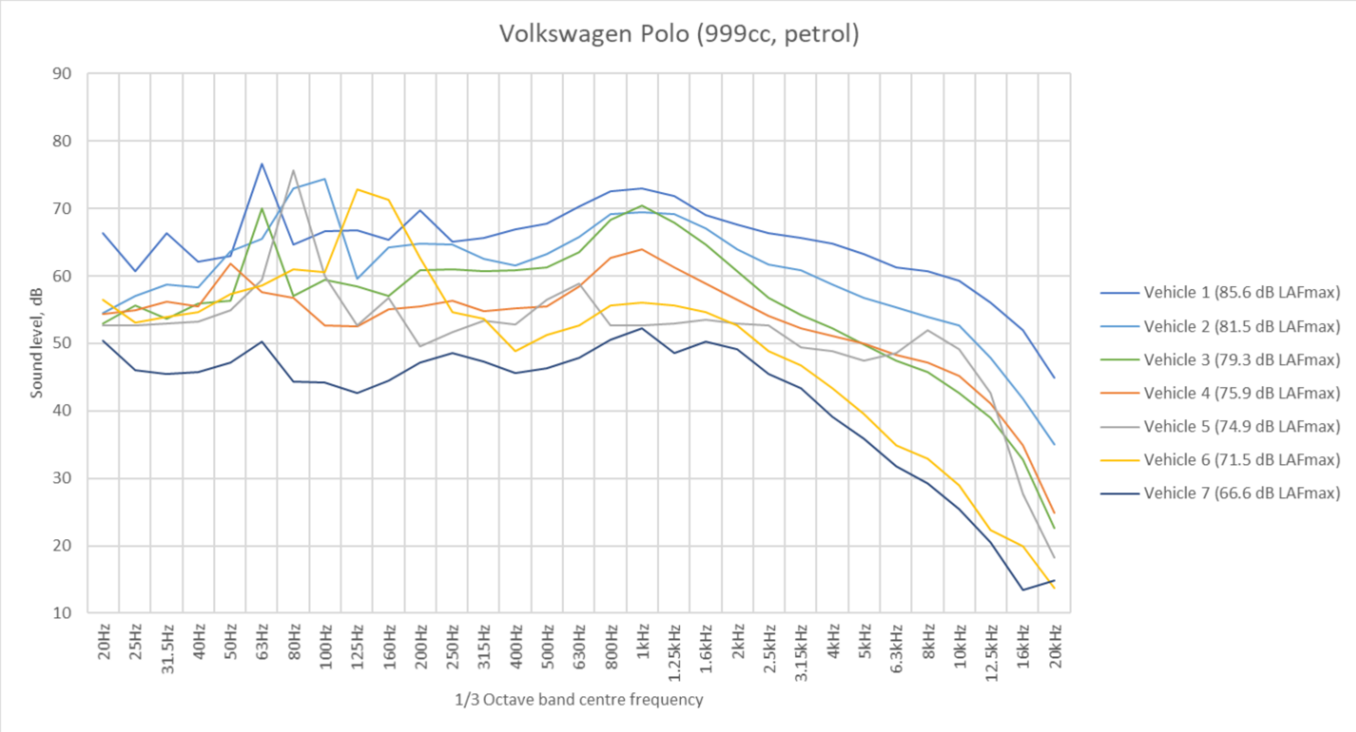


Figure 9.1. Measured maximum noise levels L_{Amax} in third-octave bands for Volkswagen Polos

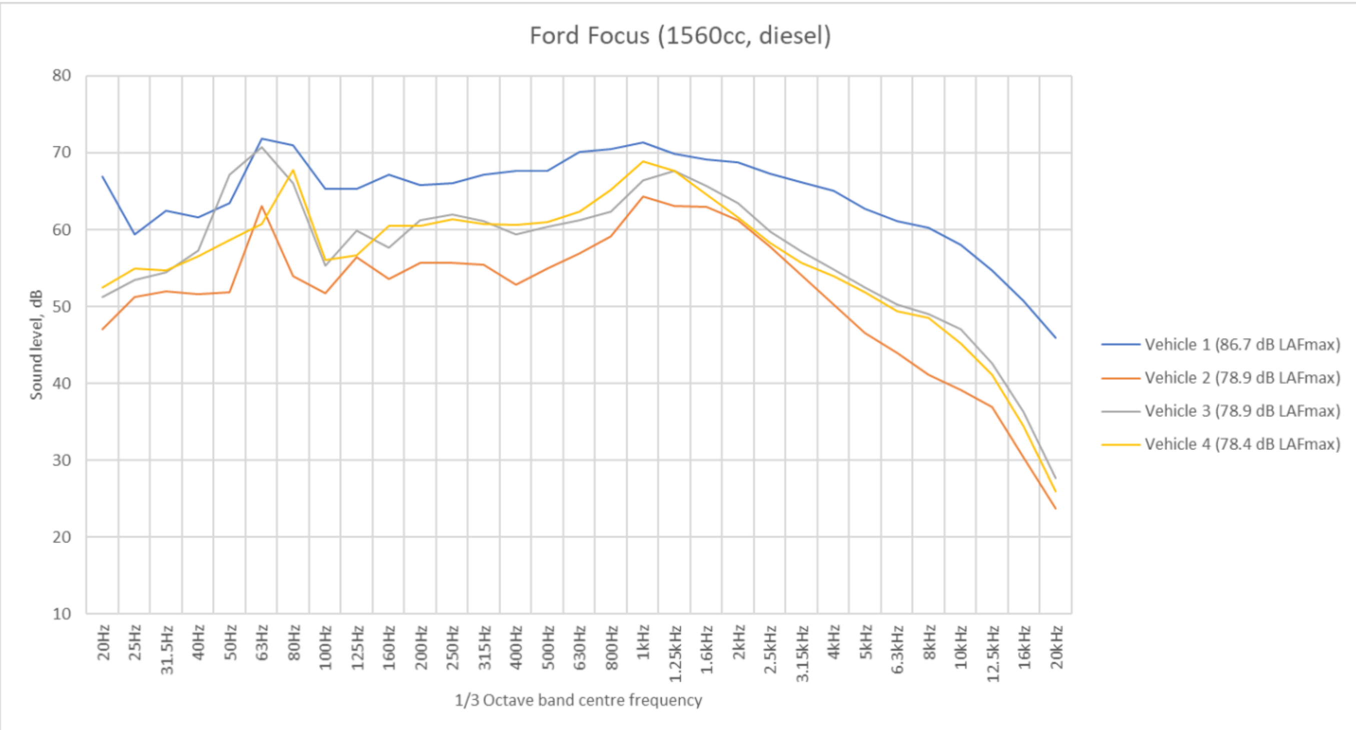


Figure 9.2. Measured Ford Focus maximum noise levels L_{Amax} in third-octave bands

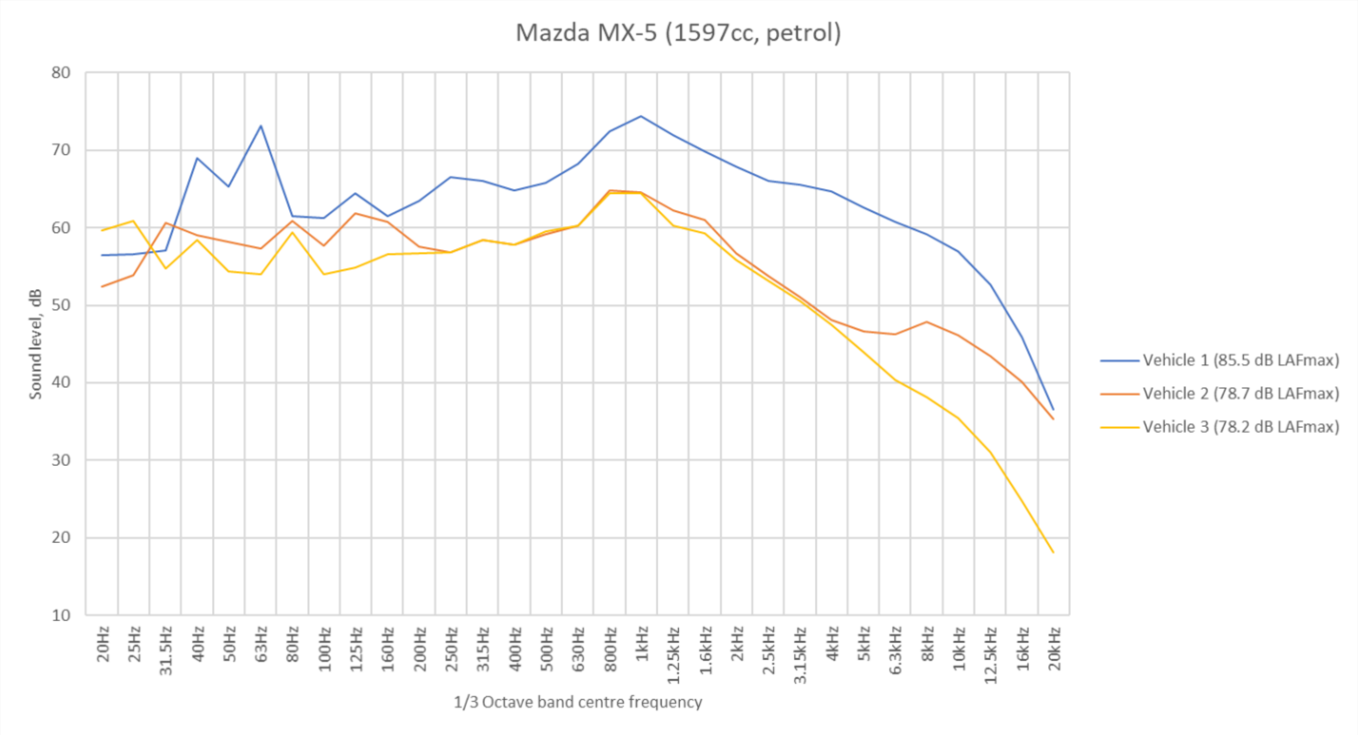


Figure 9.3. Measured maximum noise levels L_{Amax} in third-octave bands for Mazda MX-5s

Figure 9.1 shows that the frequency profile of the Volkswagen Polos was consistent, with peaks at 63-100 Hz and approximately 1 kHz for each of the seven vehicles. Vehicle 6, while measured one of the lowest maximum noise levels, has a slightly different profile at 125-160 Hz, which could be associated with exhaust noise levels, vehicle speed or driving style. Vehicle 5 was measured higher noise levels at approximately 8 kHz which is potentially due to the vehicle braking.

Figure 9.2 also shows that the Ford Focus frequency profile was consistent for each of the four vehicles assessed. There are no discrepancies between the frequency profiles to suggest that their noise emissions were affected by driving styles that cause excessive noise. Furthermore, speed data are available for vehicles 1 (41 km/h), 3 (54 km/h) and 4 (57 km/h), showing that in this instance speed was not the dominant variable.

Figure 9.3 shows that the frequency profile for the Mazda MX-5 was similar for vehicles 2 and 3, but the maximum noise levels from vehicle 1 were approximately 10 dB higher than the others at 40-80 Hz. This is potentially indicative of an excessively noisy vehicle in general or one that is being driven to cause excess noise.

Further analysis of the data was undertaken to identify potential ‘acoustic signatures’ associated with different driving styles. For this part of the study the noise profile over time and the changes in its 1/3 octave band frequency content were analysed for several pass-bys. The frequency content of emissions from an accelerating vehicle may change over time and some differences may become apparent when compared to vehicles decelerating or travelling at constant speed.

Figure 9.4 to Figure 9.6 show the noise profile of some vehicles recorded over a 10-second period with data logged every 100ms. The frequency content over time is also displayed along the vertical axis. Further examples are provided in Appendix C.

Vehicle information: Toyota Yaris (2003), 1299cc, petrol, type approval drive-by sound level not available.
Pass-by information: Site 1 (West Meon), far side carriageway, speed 68 km/h, maximum noise 92.8 dB L_{Amax}.

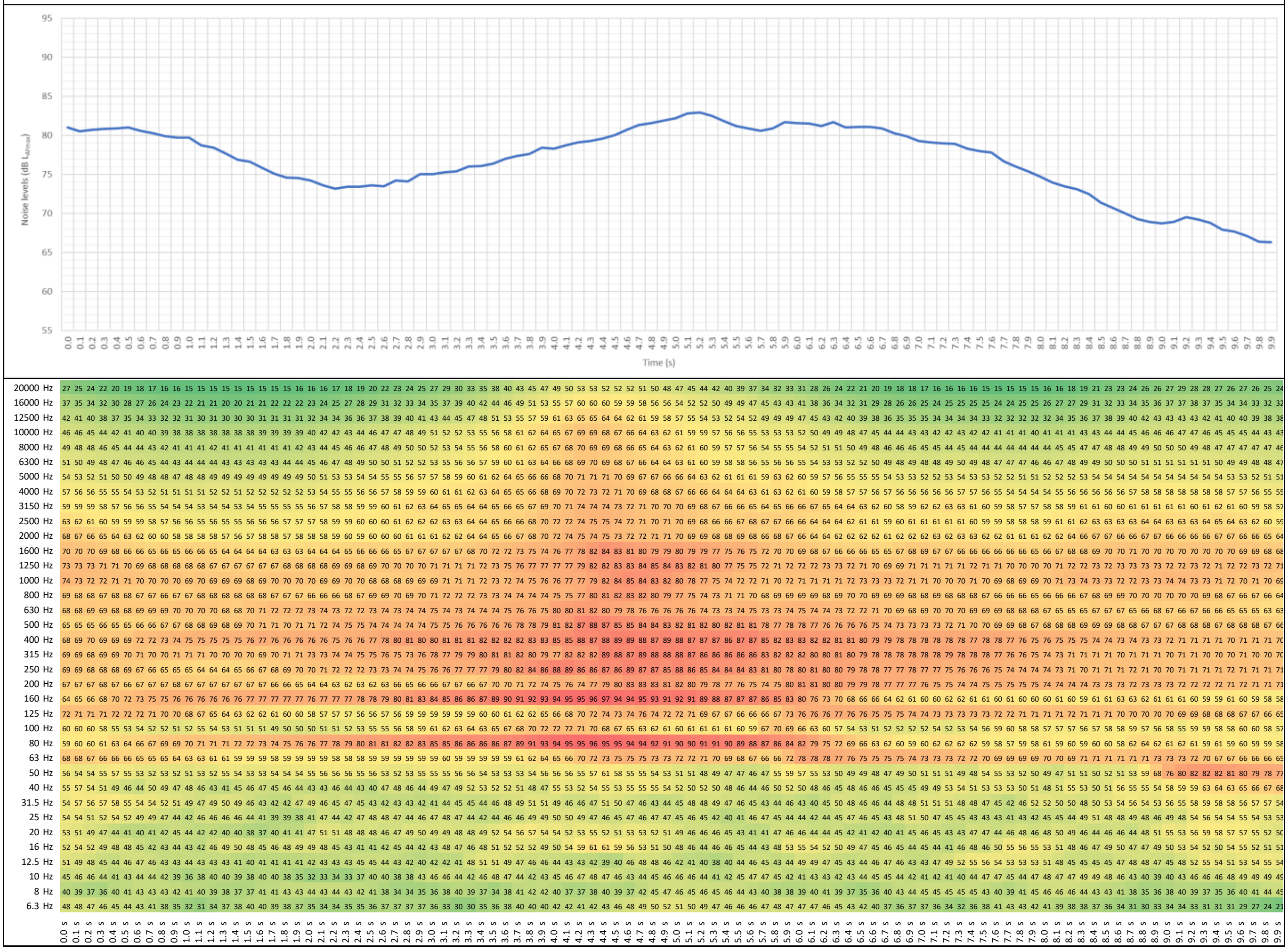


Figure 9.4. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for a Toyota Yaris

The vehicle whose noise profile is represented in Figure 9.4 had a very high pass-by level, driven by emissions in the 80 Hz and 160 Hz 1/3 octave bands, possibly due to engine resonances. The fairly constant emissions in the mid/high frequency region over the pass-by may be an indication of the vehicle decelerating as it approached the noise camera and subsequently accelerating again.

Vehicle information: Honda Jazz (2004), 1339cc, petrol, type approval drive-by sound level 71 dB L_{Amax}.
Pass-by information: Site 2 (Marchwood bypass), far side carriageway, speed n/a, maximum noise 84.6 dB L_{Amax}.

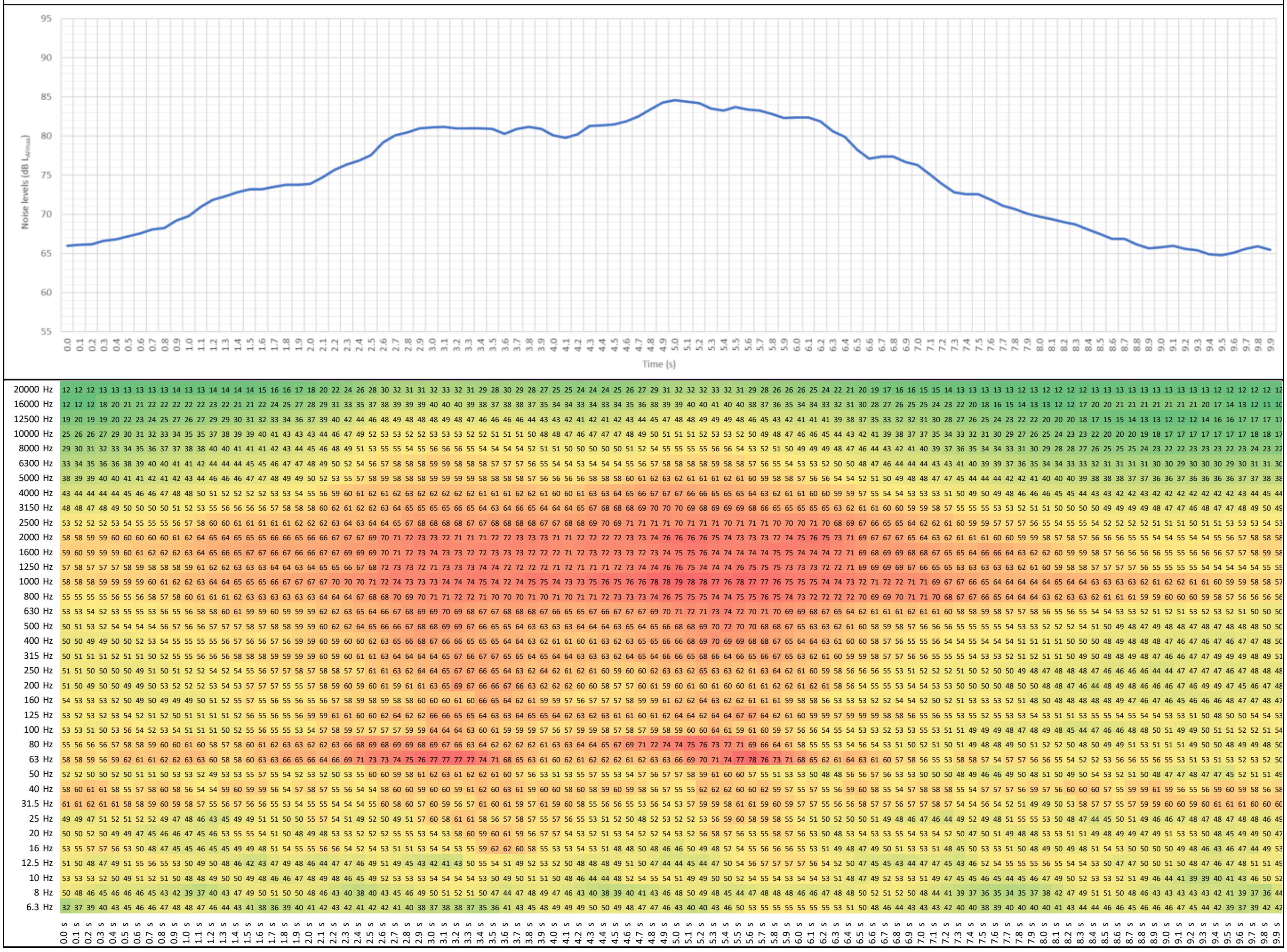


Figure 9.5. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for a Honda Jazz - 1

The spectrum presented in Figure 9.5 presents two marked regions of higher emissions separated by a few seconds 63-80 Hz and in the frequency range between 1000 Hz and 2500 Hz. This may indicate that the vehicle was revving the engine during the pass-by.

Vehicle information: Honda Jazz (2004), 1339cc, petrol, type approval drive-by sound level 72 dB L_{Amax}.
Pass-by information: Site 2 (Marchwood by-pass), far side carriageway, speed 36 km/h, maximum noise 83.6 dB L_{Amax}.

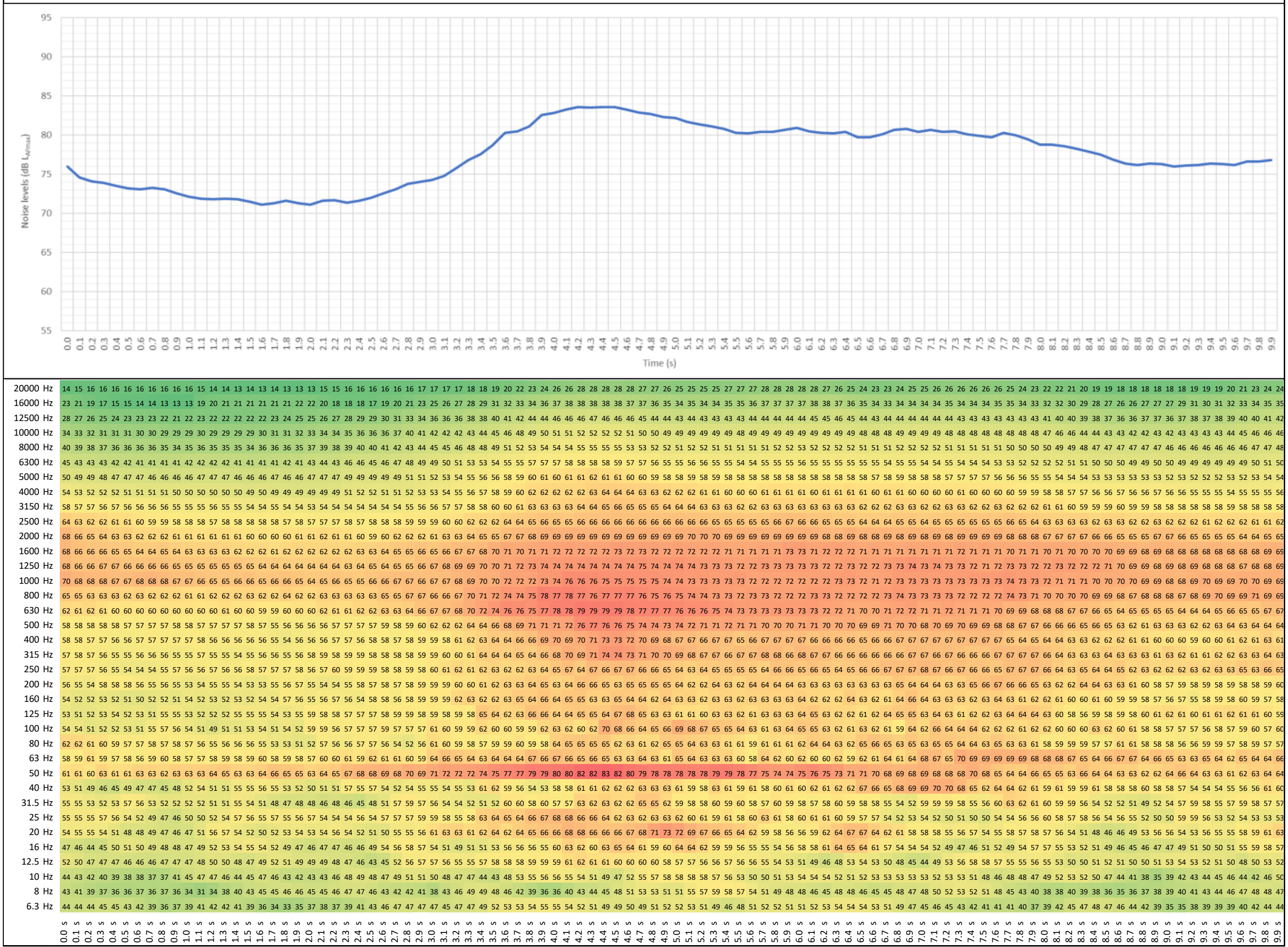


Figure 9.6. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for Honda Jazz - 2

The vehicle in Figure 9.6 was similar to that of Figure 9.5. The frequency profile is different in that a tone is identifiable during the whole pass-by around 50 Hz, and a tail of high noise emission in the mid/high frequency region can be seen after the vehicle has passed the noise camera. This emission was absent in the left part of the chart, and may be an indication that the vehicle was decelerating with the engine disengaged approaching the noise camera, and was subsequently accelerating again.

The discussions above can only be considered hypothetical at this stage, and further investigation of ‘acoustic signatures’ is required to support any analysis. Some elements of the varying frequency content during the pass-bys analysed seem to provide indications of a specific driving style being adopted, however at this stage there is not enough information to determine whether any of the behaviours identified would be considered noisy or inappropriate. Especially useful would be tests undertaken in controlled conditions and for a large number of vehicle types.

10. Discussion

Performance of the Prototype Noise Camera

As shown in Chapters 5 to 9, it is possible for a noise camera system to identify individual vehicles and to assign noise levels and traffic speeds to them on a two-way road. This demonstrates proof of concept for the system.

However, the confidence with which the measured noise levels can be assigned to an individual vehicle diminishes during heavy traffic streams where vehicles are close together as they pass the noise camera. There were several instances where the prototype noise camera detected the presence of a vehicle but did not read its number plate, or where technical issues with one or more components prevented a full dataset from being obtained for all vehicle pass-bys. The prototype noise camera system requires further development and testing to overcome these issues before it would be suitable for enforcement use.

Table 10.1 summarises the performance of the prototype noise camera deployed for the trial and key development areas for a future noise camera system.

Table 10.1. Appraisal of the prototype noise camera's performance

Factor	Performance	Comment
Detection of cars	Good	The majority of successfully identified vehicles were cars.
Detection of motorcycles	Limited but resolvable	Although the prototype noise camera successfully detected a small number of motorcycles during the trial, this can be improved with further development through selection of purpose built ANPR cameras or modification of the noise camera's set-up.
Detection of vehicles with foreign number plates	Limited and unlikely to be resolvable	The prototype noise camera was capable of detecting vehicles with foreign number plates. However, cross-referencing the noise camera data with entries in the DVLA Bulk Dataset is not possible and would be a limiting factor unless enforcement against such vehicles is managed separately.
Detection of vehicles with illegal number plates	Limited but resolvable	It is not possible to verify whether the prototype noise camera successfully identified vehicles with illegal number plates. However, further development through selection of purpose built ANPR cameras or modification of the noise camera's set-up can improve the likelihood of successful detection of illegal number plates.
Ability to assign noise levels to passing vehicles	Good	Vehicle pass-bys can be identified in the time history of the acoustic data and matched to ANPR camera records.
Vehicles passing the noise camera close together	Limited but resolvable	The noise camera technology itself requires further development to automate post-processing of individual noise camera components so that the data outputs are linked together, taking into account the small time differences between each component encountering a vehicle as it passes the noise camera. Development of this front-end component would allow a noise camera to better cope with vehicles passing in quick succession. Further testing would be required to confirm that the noise camera could operate successfully on highly trafficked roads, such as the Marchwood Bypass.
Identification of direction of travel	Limited but resolvable	The prototype noise camera was mostly successful at identifying the carriageway that the detected vehicle was travelling on, after modifications were made partway through the trial at West Meon. Spurious occurrences of incorrect carriageway identification were found when cross-referencing the output data with video footage. Further development of the technology could overcome this issue.
Road surfacing	Limited but resolvable	The road surfacing at both trial sites was hot rolled asphalt that was considered to be in good condition. The type and condition of the road surfacing would not affect the noise camera's ability to

Factor	Performance	Comment
		operate but would influence the measured pass-by noise levels and how they would need to be interpreted for enforcement. Higher noise levels would have been recorded if the road was in poor condition (e.g. pot holes) or constructed from concrete, and lower noise levels if a thin surface course system was laid. Engine and exhaust noise are independent of tyre-road noise and are therefore not influenced by road surfacing.
Road layout (gradient, bend)	Limited but resolvable	The road layout and site conditions can affect the measured noise levels and the ability of the noise camera to identify vehicles. Site conditions will always be a constraint on a noise camera system and should be considered when selecting sites to install such a system.
Objective identification of noisy driving styles	Limited and unlikely to be resolvable	It is possible to identify driving styles or behaviours from the noise camera output data but there is not enough information to clearly identify an ‘excessively noisy’ vehicle without subjectively listening to audio. Obtaining further acoustic data on driving styles may be helpful for automating detection of driving styles, noting that driving styles or behaviours vary according to the driver, road layout and traffic conditions. These factors may impact on the repeatability and reproducibility of the driving styles data, and their application to enforcement.

In addition to the development areas highlighted in Table 10.1, the trial demonstrated that it is not possible for a single omnidirectional microphone to robustly assign noise levels to individual vehicles when they pass the noise camera simultaneously on different carriageways (instances of this were excluded from the analysis). A future noise camera system would need to address this issue, potentially by incorporating more than one microphone in its design. Directional microphones may be more useful for a potential noise camera system as they could reaffirm the direction of travel for the identified vehicle, providing an additional self-check for the noise camera system to improve its performance and integrity.

The analysis of the noise camera data has indicated that it is possible to numerically define what an excessively noise vehicle might be, based on the measured maximum noise levels from vehicle pass-bys, and use this to set a noise limit for enforcement. Speed, engine size and vehicle age were shown in Chapter 7 to influence the measured noise levels of individual vehicles, however, the sample size for repeatedly tested vehicles was too small to draw robust conclusions determining which of these factors was most influential.

The trial data has shown that it is theoretically possible to identify driving styles objectively, but further information is needed to determine whether the driving style is adverse for detection of driving styles to be automated without subjective assessment of audio recordings. Although the speed radar fitted to the prototype noise camera does not include any output data for acceleration, future noise camera trials should consider deriving this metric at predefined intervals for the period that the measured vehicle is in the detection field. This could enable further comparisons to the ISO 362 [4] [5] test and may be used as a potential indicator for adverse driving styles if enforcement against excessively noisy driving styles is to be pursued.

The sample size for two/three-wheeled vehicles that were successfully matched to the DVLA Bulk Dataset was smaller than expected, noting that the West Meon trial site is on a road popular with motorcyclists. This is due to the noise camera’s low ANPR recognition rates of motorcycles and limitations of the assessment methodology for matching together the separate noise camera data outputs (where non-blank ANPR records were matched to 10-second time intervals where only one vehicle passed the noise camera). With further development and an automated front-end component to match the data outputs together, it is considered that this issue can be overcome and it would be possible for the noise camera to identify individual vehicles in a busier traffic stream (multiple vehicles in a 10-second time period).

Nevertheless, the outcomes of the trial indicate that there is potential in the technology being able to be used for identifying excessively noisy vehicles efficiently once further testing and development work has been undertaken.

Limitations, Uncertainties and Practical Issues

As mentioned in the previous subsection, the trial methodology has limitations related to the project scope, technology tested and weather conditions during the trial period. Uncertainties relating to the noise camera components, data outputs, trial sites and external factors could also influence the outcomes of the noise camera trial. These limitations and uncertainties are discussed in the subsections below.

Trial arrangements

The noise camera trial has been limited to the identification of cars and motorcycles and their corresponding sound levels. This includes vehicle subclasses, such as scooters and off-road cars. The identification and analysis of noise levels associated with heavy vehicles and commercial vehicles (where not car-derived) are excluded from the analysis.

The noise camera trials are limited to two sites that meet the requirements previously discussed. The trial duration was for up to two weeks for each site, and the outcomes of the analysis are dependent on the traffic passing the noise camera during that time period. Testing over a longer time period would provide more data to appraise the noise camera against and would increase the sample size of vehicle subcategories to enable more robust trends and conclusions to be drawn. A longer trial would also increase the sample size of potential occurrences of excessively noisy driving styles within the dataset.

The project scope also restricts the assessment to appraisal of the noise camera during dry conditions only. This is consistent with the test conditions used in existing standards for measuring vehicle pass-by noise [4] [5] [7] and best practice for environmental noise measurements.

ANPR camera and vehicle information

It is understood that the combined ANPR and video camera installed on the noise camera is a new model. During the car park trial, it was found that firmware updates were required to allow the product to function properly. The implication of this is that any technology forming part of the noise camera requires regular maintenance, software and firmware upgrades to address any bugs or vulnerabilities in the technology unknown to the user. This is vital for any system to be robust especially when used for enforcement.

Sometimes the video image processing algorithms used in the ANPR camera were unable to correctly read text from a number plate image. This results in ‘no plate’ records (with 0% validity) or incomplete number plates with misrecognised characters (with 66% validity). Most of the time, the processing algorithm identified characters on number plates with 90% or higher accuracy. For the purposes of this trial, data classified with validity of at least 66% were considered for analysis and this resulted in the exclusion of 34% of the ANPR records that were those classified as “no plate”. Further vehicle records were excluded where the combination of alphanumeric characters recorded by the ANPR camera could not be matched directly to records in the DVLA Bulk Dataset, even with ‘cleaning’ techniques applied to identify incorrect characters. For a noise camera deployed for enforcement, this can result in instances where action against an excessively noisy vehicle cannot be taken. This could be improved by better configuration of the ANPR camera or selection of a purpose built ANPR product.

The ability of the ANPR used in the prototype noise camera to recognise different number plate shapes and font sizes was limited to those for legal number plate specifications in Europe. The technology may struggle to accurately process illegal number plates. Similarly, in an enforcement scenario, it would not be possible to retrieve vehicle information from the DVLA Bulk Dataset for vehicles fitted with illegal number plates or not registered in the UK. Instances where no vehicle data could be retrieved were excluded from the analysis.

Occasionally the ANPR cameras produce multiple records for a single instance of a vehicle passing its field of view. For this project, duplicate entries were discounted from the analysis, however an operational noise camera would need to minimise instances of this to avoid multiple offences being indicated from one single pass-by.

Measured sound levels

The sound level meter collected data at 100 millisecond and 10 second time intervals. Due to small time differences between individual vehicles registering on speed radar and ANPR camera, accurately matching records to the 100 millisecond data has not been achievable for the majority of the data assessed in this report. This post-processing issue would need to be addressed for a future noise camera. The majority of the analysis undertaken was based on the 10 second data. Instances where multiple vehicles passed the noise camera within the 10 second period were excluded from the analysis. In practical terms, a smaller time interval would be required for an enforcement noise camera to ensure that more vehicles are able to be identified individually. The extent to which the time interval can be decreased is limited by the requirement for measured pass-by noise levels to be assigned to individual vehicles with high confidence, without significant noise contributions from other nearby vehicles.

There are several well-documented factors that can affect the accuracy and reliability of sound monitoring instrumentation when installed outdoors over a long time period. High and low temperatures affect power consumption and the appliance's performance, however, these would not be issues for a noise camera with a direct mains power connection. The battery life was monitored throughout the trial and depleted batteries were replaced during maintenance visits. Another factor is calibration of the sound level meter. Calibration drift can occur between measurements and if not regularly calibrated against a standardised reference acoustic signal, the accuracy and reliability of the measured sound levels can be affected. Routine acoustic calibration will be required for an operational noise camera, which could be undertaken remotely using an electronic calibration depending on the acoustic instrumentation used. For example, daily electrostatic calibration can be operated remotely if the acoustic instrumentation has the capability to do this. Otherwise, manual calibration would be required at the beginning and end of each measurement period (for a temporary installation) and when there are changes to the external environment, such as the power supply [11] [12]. Manual calibration would also be required regularly during the deployment of a permanent noise camera, noting that most sound level meters will hold their calibration for several days and often weeks [12]. The regularity of manual acoustic calibration would need to be determined based on the supplier's recommendations.

Assembled technology

Due to a commitment to complete the noise camera trial by December 2019, the prototype noise camera was designed and assembled in less than six weeks. This allowed some time for fixing potential issues prior to deployment, however, the first real test of the noise camera's capabilities occurred on deployment to the first trial site. As this was an untested technology outside of a controlled environment, the potential for individual components to fail during the trial was a risk that resulted in periods where a full dataset was not obtained. Periods of unexpected inoperability therefore reduced the size of the dataset to analyse when the trial was complete.

As the noise camera was moved from one trial site to the next on the same day, this prevented further development work from being undertaken to improve the performance of the noise camera based on data gathered at the first trial site.

The output data from the sensors were saved as separate data files and the noise camera was not able to combine outputs into a single timestamped file that would be expected in an enforcement situation where a burden of proof is required. This approach has allowed the prototype noise camera to be constructed quickly but has hindered the ability to join the data outputs together. Due to small time delays between the various sensors, this has proved more difficult than initially anticipated. Future versions of the prototype noise camera should look to integrate the sensors to produce a single data output to provide an automated enforcement solution.

Weather

A meteorological sensor was integrated into the noise camera to identify periods of adverse weather. It was set to record weather conditions every 100 seconds, which is a lower logging frequency than the other noise camera components, which causes some uncertainty of the weather conditions within the 100 second time period. The risk of this to the accuracy of the prototype noise camera used during the trial is considered to be low.

Site layout and driving conditions

As discussed above, the trial sites were selected to meet a number of requirements and to control some variables that could affect pass-by noise levels or the ability of the prototype noise camera to achieve the project's objectives. Trial sites with a reasonably flat road gradient were selected for a consistent approach to the trials. The road surfaces were hot rolled asphalt and well maintained at both trial sites.

The measured noise level at other sites with higher gradients, different road surfaces and maintenance conditions may indicate a different range of pass-by noise levels to those presented in this report.

The traffic characteristics at the trial sites also influenced the data collected. Roads with higher traffic flows (Marchwood Bypass) provided a more challenging environment for the noise camera to successfully detect and identify an individual excessively noisy vehicle. These roads would also require the system to have a sufficiently large storage space to save information.

Implications to Policy and Legislation

The existing legislation that can be applied to the enforcement of excessively noisy vehicles is contained within The Road Vehicles (Construction and Use) Regulations 1986 [3], but this does not provide any fixed noise limits to enforce against. It states that vehicle exhausts must not be altered or replaced in a manner which increases the noise levels so that they exceed those emitted by the type approved exhaust fitted by the manufacturer. In addition, the Regulation requires avoidance of excessive noise from the vehicle and also considers the behaviour of the driver in operating the vehicle.

To use existing legislation, one of these offences must be proved. From the research undertaken, establishing a relationship between the measured noise level from the noise camera with that from type approval has been inconclusive (Figure 6.1). In order to use such legislation a large margin would be required to ensure that no drivers are prosecuted incorrectly. This limitation could be reduced through further work and account being taken of localised circumstances (e.g. weather conditions, road surface).

To determine if a vehicle is producing more noise than the type approved noise level for that vehicle would require a defendable correlation between the noise level from the noise camera and the type approval level to be established.

Reliance on type approval noise levels creates issues for enforcement against vehicles that have no corresponding type approval drive-by sound emissions to compare against in the DVLA Bulk Dataset. This occurred for 344 vehicles that were identified by the prototype noise camera. In these cases, such vehicles could either be automatically exempt or assessed against a different noise level, such as an upper 'not-to exceed' noise level appropriate for the vehicle subcategory.

Direct application of existing vehicle pass-by measurement methodologies [4] [5] [7] in their current form to use for the noise camera is not possible. This is due to logistics with placement of the measurement equipment and the difficulty of controlling variables at a roadside environment. However, some aspects such as the acoustic data requirements have been adopted for use in the trial as these are directly relevant. Should noise cameras become commonplace, a new standard testing method for them would be beneficial to ensure conformity of performance and to link the measured noise levels to the selected enforcement criteria.

11. Recommendations

Development of Noise Camera Systems

Even with the limitations of the prototype noise camera and the assessment methodology, the noise levels of individual vehicles were able to be matched to ANPR records and vehicle speeds, which establishes proof of concept for noise camera systems. Noise camera systems are in their infancy and it is clear from the trial that further development is required to overcome various technological and acoustic challenges before one can be deployed for enforcement.

As the technology improves, the developers of noise camera systems will need to test their products in a wider range of conditions and scenarios, including:

- Roads with different speed limits;
- Different road layouts;
- Instances of vehicles passing the noise camera simultaneously in both carriageways or passing the noise camera in quick succession in the same carriageway;
- Deployment in an urban or residential environment, which may help with collection of data for repeatedly tested individual vehicles; and
- Different traffic conditions and environments, including highly trafficked roads. Dual carriageways could be considered if it is desired to use the noise camera for enforcement on these roads.

The trailer-mounted solution used for the prototype noise camera was theft-proof and suitable for the test environment used during the trial. However, a different approach would be required for testing in an urban environment where there are greater space constraints. As excessively noisy vehicles tend to disturb people in residential settings, this could affect the viability of a noise camera as an enforcement option if deployment in these environments is not feasible.

If it is intended that noise cameras for enforcement would be permanent fixed installations, further research should be undertaken of individual vehicular noise levels in wet conditions to identify an appropriate tolerance for this in any enforcement noise limit. Not doing so would result in large time periods where the noise camera outputs could not be used for enforcement, or a higher risk of false positives and successful legal challenges. Temporary installations can mitigate this risk by timing enforcement campaigns with periods of better weather, such as during the summer months.

Usage for Enforcement

As the technology becomes more developed, there will become an increasing need to confirm the integrity of the evidence package that the noise camera collects for enforcement. The use of a noise camera testing and installation specification would ensure product conformity between noise cameras from the same and different suppliers. This would add integrity to a noise camera system when used for enforcement. It is recommended that any future noise camera testing and installation specification includes the following:

- Appropriate installation parameters detailed in a similar style to those in ISO 11819 [7] and ISO 362 [4] [5], noting the environments that noise cameras are likely to be installed in. The parameters should specify (with tolerances) the height of the noise camera’s microphone(s) relative to the road and distances to the nearside carriageway;
- Restrictions and advice on the testing and installation environment, such as positioning of the noise camera and identification of suitable installation locations;
- The use of purpose built ANPR cameras to improve the ability of the noise camera to read alphanumeric characters on illegal number plates and motorcycle number plates;
- Setting the ANPR camera to a fixed focal length with its field of view directed away from traffic signs and other light-reflective roadside furniture to improve the ANPR data validity rate;
- Quality of the video imagery (particularly under low light conditions);
- Use of more than one directional or omnidirectional microphone (depending on the noise camera’s design);
- Details of recommended acoustic parameters and settings;
- Requirements for post-processing tools or a system front-end that matches the data sources together, which would be required to form an evidence package; and
- Data security and storage requirements.

The noise camera trial found that while it may be possible to objectively identify driving styles from acoustic data, further research is required to identify objectively those that are ‘excessively noisy’. From an enforcement perspective, to enforce against excessively noisy driving styles the noise camera would need to demonstrate that beyond the balance of probabilities an offence has occurred. Obtaining data on driving styles is difficult as they are highly variable and may not withstand legal scrutiny if applied to an enforcement noise camera. It is considered that adverse driving styles are best enforced using current methods or by using the noise camera to detect an excessively noisy vehicle without further distinction.

Next Steps for the Project

As testing of the prototype noise camera has established proof of concept, it is recommended that noise cameras are taken forward for further investigation. This includes appraisal of new noise camera systems that have been publicised or trialled by others since Phase 1 of the project and confirming with suppliers that noise cameras can distinguish individual vehicles and their noise levels in traffic streams.

Chapters 7 and 8 show that it is possible to numerically define an excessively noisy vehicle using statistical parameters, and that the use of a noise limit is viable. As ‘excessively noisy’ is a subjective quality, it is recommended that objective and subjective testing is undertaken on compliant and non-compliant vehicles in a controlled environment as they drive past a fixed point. The aim of the testing is to check that what is considered subjectively to be an ‘excessively noisy’ vehicle matches numerical definitions and validates potential noise limits that could be used for enforcement.

If it is desirable to use type approval drive-by noise levels as a basis for enforcement rather than a fixed or statistically derived noise limit, further work would be required to investigate how to apply type approval noise levels to measured noise levels on live carriageways. This would need to consider vehicle pass-bys on roads with different speed limits and how to link them to the type approval test speed of 50 km/h.

Summary of Phase 2

The outcomes of Phase 2 are summarised in Table 11.1, with reference to the objectives specified for Phase 2.

Table 11.1. Summary of Phase 2 outcomes

Task	Description	Summary of outcome
7	To collate, analyse and report noise measurements from the roadside (trial of selected technology/system)	• The prototype noise camera was installed at two trial sites and collected data in November and December 2019. Additional data was collected from site visits. • A positive correlation was found between measurements taken from the noise camera and site visits once distance was controlled for (R_2 = 57%). • The majority of the vehicles successfully identified by the noise camera were cars. A small sample size of motorcycles was collected. Further testing is required to draw robust conclusions specifically for motorcycles and other powered two or three-wheeled vehicles.
8	To establish the most appropriate use of vehicle ‘pass-by’ noise measurement in enforcing vehicle noise emissions legislation. For example, the potential to identify non-compliant or damaged exhaust system components	• ISO 362 and ISO 11819 are the most appropriate existing standards that can be applied to the noise camera. ISO 11819 is more pragmatic than ISO 362 as it is designed for use on live carriageways. • The relationship between the measured pass-by noise levels and the corresponding type approval noise levels for a selection of identified vehicles was inconclusive, with differences of up to 19.5 dB L_{Amax} between datasets.
9	To analyse the prevalence of very high noise emitting vehicles on the road	• Statistical analysis was undertaken to determine numerically how an ‘excessively noisy’ vehicle may be defined. It was found that the 99th percentile pass-by noise level could be a reasonable method for identifying a

Task	Description	Summary of outcome
		high noise-emitting vehicle. The use of the 99th percentile to identify excessive noise has precedent as this is the approach used by Defra to identify Noise Important Areas for road and railway noise in strategic noise maps • Noise levels for individual vehicles that where the number plate was not read correctly showed a similar distribution to those where vehicles were ‘identifiable’. A greater proportion of vehicles were shown with higher pass-by noise levels, several of which were likely to have been HGVs.
10	To analyse the data for vehicles that are repeatedly measured and study the variability of these vehicles	• The measured noise levels for the same individual vehicle when passing the noise camera varied by 1-6 dB, which was attributed to differences in vehicle speed between each pass-by. • Larger degrees of variation were found when comparing measured noise levels for the same vehicle make and model. These differences were related to vehicle age, speed and engine size, but not enough data were available to be able to rank these variables in order of influence.
11	To clearly explain the uncertainties generated by the methodology and their implications for the findings	• As the prototype noise camera simply collected data from different input sensors and did not match them together, the methodology limited the assessment to instances where one vehicle passed the noise camera in a 10-second time period. While this improved confidence that the correct vehicle was matched to the correct speed and noise level, it meant that more data were successfully matched for trial sites with lower traffic flows (West Meon) than those with higher traffic flows (Marchwood Bypass), where multiple vehicles were more likely to pass the noise camera within this time period. This also significantly decreased the sample size of noise camera data appraised in the study. While this is a limitation of the trial, the sample size was sufficient to determine whether a noise camera is a potentially viable solution that warrants further research. It is expected that a future noise camera system would overcome this issue by including a front-end component that matches the inputs together and would therefore be able to collect information when vehicles pass the noise camera with smaller time gaps between them. • The trial methodology was also limited by the duration of testing at each site and the sites selected, which were reasonably flat 50 mph road. Testing at different sites or during different seasons may have resulted in a different traffic mix with different vehicle or driver behaviours. • The ANPR technology integrated with the prototype noise camera provided some limitations to the trial and the size of the dataset of ‘identifiable’ vehicles. This can be overcome by configuration changes or selecting a different product that is better suited to ANPR for enforcement.
12	To identify whether an upper ‘not-to exceed’ limit for each vehicle subcategory can be	• Statistical analysis of the vehicle subcategories indicated that the pass-by noise levels measured by the noise

Task	Description	Summary of outcome
	identified that would be suitable for enforcement use	camera were broadly similar across vehicle subcategories. The limited sample size of motorcycles prevented a detailed study on subcategories of motorcycles to be undertaken, however, the measured pass-by noise levels of identified motorcycles (from the noise camera and review of video footage) were similar to those for cars. • Setting a fixed noise limit for all cars and motorcycles or vehicle subcategories can be achieved based on the distribution of noise levels from individual vehicles in the current UK vehicle fleet. Fixed noise limits would need to include a tolerance to improve certainty that the vehicle is 'excessively noisy' to withstand a legal challenge. • No imported vehicles or vehicles registered before April 1990 were identified during the trial. Any vehicles that would be exempt from a fixed noise limit should a noise camera be installed could be identified during the post-processing of the noise camera data and review of the evidence package should a false positive occur.
13	To establish whether roadside noise measurement can differentiate between non-compliant vehicles and excessive noise from compliant vehicles due to adverse driver behaviour	• Interrogation of the time history and third-octave band noise levels for vehicle pass-bys can theoretically be used to identify differences in driving style or vehicle behaviour. • Further research is needed to determine how to objectively class a driving style or behaviour as 'adverse' from vehicle pass-by data.

12. Conclusion

The measurement data collected from the prototype noise camera has demonstrated that it is possible for a noise camera to identify vehicles and for measured noise levels and speeds to be attributed to individual vehicles. This establishes that noise camera systems can identify individual vehicles and assign noise levels to them under certain conditions, theoretically and in practice.

Noise camera systems are in their infancy and the technology has the potential to be used to identify excessively noisy vehicles. However, it is clear from the trial that further development is required to overcome various technological and acoustic challenges before one can be considered proficient for enforcement. For a noise camera to become a worthwhile technological solution for enforcement against excessively noisy vehicles, the key priorities for further development are:

- Automating post-processing of individual noise camera components so that the data outputs are linked together, taking into account the small-time differences between each component encountering a vehicle as it passes the noise camera. Without this, the task of manually linking together datasets would prove too onerous and it is considered likely that the system would not be used;
- Identifying vehicles and matching noise levels to them for more complex traffic scenarios, such as vehicles passing the noise camera in quick succession or at similar times in opposite carriageways;
- Using purpose-built components to improve the identification of vehicles; and
- Developing a more portable solution that could be deployed in residential or urban environments.

Any further development or trials of noise cameras should consider the use of a microphone array and the collection of acceleration data as a potential indicator of an adverse driving style and excessive noise being produced. Although it was possible to identify driving styles or behaviours from the acoustic data collected by the prototype noise camera, further research is required to characterise those that are 'excessively noisy'. From an enforcement perspective, it is considered that adverse driving styles should not be enforced separately with a noise camera but any evidence that can be used to demonstrate that a driving style may have resulted in a vehicle being logged as 'excessively noisy' would be useful in the evidence package.

The analysis of the data from the prototype noise camera has indicated that it is possible to numerically define what an excessively noisy vehicle might be based on the measured maximum noise levels from vehicle pass-bys, and that the use of a 'not-to exceed' noise limit is viable. The relationship between objective and subjective definitions of excessively noisy vehicles require examination to ensure that enforced pass-by noise limits achieve their aim. Further data is needed for motorcycles to robustly conclude whether it is appropriate to apply different noise limits to cars and motorcycles.

As the potential application of noise cameras for addressing the issue of excessively noisy vehicles is leading to the development of technologies that could one day be deployed for enforcement, the use of a design and installation specification or standard will become increasingly important. Direct application of existing vehicle pass-by measurement methodologies (ISO 362 and ISO 11819) to use for a noise camera is not possible due to logistics with placement of the measurement equipment and the difficulty of controlling variables at a roadside environment. However, some aspects can be adopted for such a standard. The standard will ensure that certain criteria are met to maximise the performance of the noise camera and that there is uniformity in their performance (so that two noise cameras behave the same). It would also enable prospective suppliers to optimise their products to the selected enforcement criteria. The development of a design and installation specification will be a requirement to preserve the integrity of the evidence package and to withstand legal challenges.

13. References

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14. Appendices

APPENDIX A – Glossary and abbreviations

Acoustic signature	The spectral profile and acoustic characteristics of a single noise source or collection of noise sources or components forming a system. In the context of this project, the acoustic signature refers to detailed information about the sound produced by a passing vehicle.
AJJV	Atkins Jacobs Joint Venture.
ANPR	Automatic Number Plate Reader.
A-weighting	The process by which noise levels are corrected to account for the non-linear frequency response of the human ear. A-weighted sound is often denoted by 'A' in noise indices, for example L_{Aeq} and L_{Amax}.
dB, dBA	Decibel, A-weighted decibel.
Decibel	The unit of measurement for sound.
DfT	Department for Transport.
Directional microphone	A microphone that receives sound from a certain direction or number of directions.
DVLA	Driver and Vehicle Licencing Agency.
Fast response	Noise measurement with a 125 ms time constant, meaning that the sound pressure level is sampled every 125 ms. This is sometimes denoted in noise indices by 'F', such as L_{AFmax}.
Frequency	Rate at which sound wave crests reach a given point (cycles per second), measured in Hertz (Hz). Low frequency sounds have long wavelengths, resulting in a bass sounds (e.g. engines, thunder). High frequency sounds have short wavelengths and have a higher pitch (e.g. bird song, emergency vehicle siren).
ISO	International Organization for Standardization.
$L_{Aeq,T}$	The equivalent continuous A-weighted sound pressure level during time period T.
Identifiable vehicle	A vehicle detected by the noise camera where its number plate and noise levels were matched together, and vehicle information was retrievable from the DVLA.
$L_{Amax,T}$	The maximum A-weighted sound pressure level measured during time period T.
HGV	Heavy goods vehicle.
GDPR	General Data Protection Regulation
$L_{A10,T}$	The A-weighted sound pressure level exceeded 10% of the time during time period T. This metric correlates well with annoyance from road traffic noise.
$L_{A90,T}$	The A-weighted sound pressure level exceeded 90% of the time during time period T. This metric is used to represent the background noise level.
Noise	Unwanted sound.
Noise camera	System comprising a sound level meter, ANPR and video camera that can be used to identify vehicles producing excessive noise.
No Plate	Instances where the ANPR camera detected a vehicle and did not read its number plate.
Omnidirectional microphone	A microphone that receives sound with equal gain from all directions

Slow response	Noise measurement with a 1 second time constant, meaning that the sound pressure level is sampled once every second.
Sound pressure	Sound pressure is the difference between the pressure caused by a sound wave and the ambient pressure of the media the sound wave is travelling through.
SVS	Smart Video and Sensing.
Type approval	A procedure whereby a manufacturer can obtain certification from a competent authority that their product meets the requirements of a certain European Directive or Regulation.
Wavelength	The distance between the two peaks (or two troughs) of a sound wave, measured in metres.

APPENDIX B – Calibration Certificates

The details of the acoustic instrumentation integrated with the noise camera or utilised on site visit are summarised in the table below. The front pages of the calibration certificates are provided to demonstrate that laboratory calibration has been undertaken within an appropriate time period preceding the noise camera trial. Full calibration certificates are available upon request.

Table B.1. Summary of Phase 2 outcomes

Item	Manufacturer and model	Serial number	Date of laboratory calibration
Fitted to the prototype noise camera			
Sound level meter	01dB CUBE	10688	03/07/2018
Microphone	GRAS 40CD	224126	03/07/2018
Preamplifier	01dB PRE22	10749	03/07/2018
Calibrator	01dB CAL21	35183004	16/04/2019
Site visits			
Sound level meter	01dB FUSION	11200	02/11/2018
Microphone	GRAS 40CE	226400	02/11/2018
Preamplifier	01dB PRE22	1605098	31/10/2018
Calibrator	Bruel and Kjaer 4231	2385276	05/11/2019
Sound level meter	Rion NL-52	01032415	04/09/2019
Microphone	Rion UC-59	5790	04/09/2019
Preamplifier	Rion NH-25	32443	04/09/2019
Calibrator	Rion NC-74	34936363	04/09/2019

# Certificate of Calibration Issued by University of Salford (Acoustics Calibration Laboratory) UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801	UKAS CALIBRATION 0801
APPROVED SIGNATORIES Claire Lomax [x] Andy Moorhouse [ ] [redacted] Gary Phillips [ ] Danny McCaul [ ]	
acoustic calibration laboratory The University of Salford, Salford, Greater Manchester, M5 4WT, UK http://www.acoustics.salford.ac.uk t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk	University of Salford MANCHESTER

Certificate Number: 03816/3 Date of Issue: 3 July 2018

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	Acoustic 1 The Barns Overdale Manordeilo Llandeilo Carmarthenshire SA19 7BD
FOR THE ATTENTION OF:	[redacted]
PERIODIC TEST DATE:	03/07/2018
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	01dB	
Model	CUBE	
Serial number	10688	
Class	1	
Hardware version	LIS001A	Application FW: 2.40. Metrology FW: 2.12

Associated Items	**Microphone**	**Preamplifier**
Manu	GRAS	01dB
Model	40CD	PRE22
Serial Number	224126	10749

Test Engineer (initial): *GP* Name: Gary Phillips

Calibration Certificate

CE-REP-10131.xls

ISSUED FOR : acoustic1

overdale
manordeilo

sa19 7bd llandeilo
uk

Name and location of the laboratory of calibration:
Acoustic1 - Overdale Manordeilo, Llandeilo
Carmathenshire UK SA19 7BD

TESTED INSTRUMENT

Designation : Sound calibrator

Manufacturer : 01dB-Metravib

Type : CAL21

Serial number : 35183004

Identification number :

Date of issue : 16/04/2019

This certificate includes 3 pages

The measurements are performed according to the IEC 60942: 2017, Electroacoustics, - Sound calibrators.

Steve THOMAS
Head of calibration laboratory at Acoustic 1

[redacted]

François MAGAND
Head of calibration laboratory at ACOEM-01dB

[redacted]

THIS CERTIFICATE is compliant with THE FD X 07-012 STANDARD DOCUMENTATION

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

APPROVED SIGNATORIES
Claire Lomax [X] Andy Moorhouse [ ]
Gary Phillips [ ] Danny McCaul [ ]
[redacted]

UKAS CALIBRATION 0801

University of Salford MANCHESTER

acoustic calibration laboratory
The University of Salford, Salford, Greater Manchester, M5 4WT, UK
http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

Certificate Number: 04017/10 Date of Issue: 2 November 2018

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	Atkins Acoustics The Hub 500 Park Avenue Aztec West Bristol BS32 4RZ
FOR THE ATTENTION OF:	[redacted]
PERIODIC TEST DATE:	1/11/2018
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	01dB	
Model	FUSION	
Serial number	11200	
Class	1	
Hardware version	LIS006E	Application FW: 2.40. Metrology FW: 2.12

Associated Items	**Microphone**	**Integrated Preamplifier**	**Calibrator**
Manu	GRAS	-	Bruel & Kjaer
Model	40CE	-	4231
Serial Number	226400	-	2385276
Calibrator Adaptor	-	-	UC 0210

Test Engineer (initial): GP Name: Gary Phillips

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

UKAS CALIBRATION 0801

University of Salford MANCHESTER

APPROVED SIGNATORIES
Claire Lomax [X] Andy Moorhouse [ ] [redacted]
Gary Phillips [ ] Danny McCaul [ ]

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http://www.acoustics.salford.ac.uk
t 0161 295 3030/0161 295 3319 f 0161 295 4456 e c.lomax1@salford.ac.uk

Certificate Number: 04017/4 Date of Issue: 31 October 2018

PERIODIC TEST OF A SOUND LEVEL METER to IEC 61672-3:2006

FOR:	Atkins Acoustics The Hub 500 Park Avenue Aztec West Bristol BS32 4RZ
FOR THE ATTENTION OF:	[redacted]
PERIODIC TEST DATE:	31/10/2018
TEST PROCEDURE:	CTP12 (Laboratory Manual)

Sound Level Meter Details

Manufacturer	01dB	
Model	FUSION	
Serial number	11200	
Class	1	
Hardware version	LIS006E	Application FW: 2.40. Metrology FW: 2.12

Associated Items	**Microphone**	**Preamplifier**	**Calibrator**
Manu	GRAS	01dB	Bruel & Kjaer
Model	40CE	PRE22	4231
Serial Number	226400	1605098	2385276
Calibrator Adaptor	-	-	UC 0210

Test Engineer (initial): GP Name: Gary Phillips

MEASUREMENT SYSTEMS

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 05 November 2019

Certificate Number: UCRT19/2226

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory [redacted]

K. Mistry

Customer	Nova North 11 Bressenden Place Westminster London SW1E 5BY
Order No.	[redacted]
Test Procedure	Procedure TP 1 Calibration of Sound Calibrators
Description	Acoustic Calibrator

Identification	*Manufacturer*	*Instrument*	*Model*	*Serial No.*
	Brüel & Kjær	Calibrator	4231	2385276

The calibrator has been tested as specified in Annex B of IEC 60942:2003. As public evidence was available from a testing organisation (PTB) responsible for approving the results of pattern evaluation tests, to demonstrate that the model of sound calibrator fully conformed to the requirements for pattern evaluation described in Annex A of IEC 60942:2003, the sound calibrator tested is considered to conform to all the class 1 requirements of IEC 60942:2003.

ANV Job No.	UKAS19/11724	
Date Received	05 November 2019	
Date Calibrated	05 November 2019	
Previous Certificate	*Dated*	30 October 2018
	Certificate No.	04017/3
	Laboratory	0801

ANV MEASUREMENT SYSTEMS

CERTIFICATE OF CALIBRATION

ilac-MRA

UKAS CALIBRATION 0653

Date of Issue: 04 September 2019

Certificate Number: UCRT19/1982

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory [redacted]

K. Mistry

Customer: Nova North
11 Bressenden Place
Westminster
London
SW1E 5BY

Order No. [redacted]

Description: Sound Level Meter / Pre-amp / Microphone / Associated Calibrator

Identification	*Manufacturer*	*Instrument*	*Type*	*Serial No. / Version*
	Rion	Sound Level Meter	NL-52	01032415
	Rion	Firmware		2.0
	Rion	Pre Amplifier	NH-25	32443
	Rion	Microphone	UC-59	05790
	Rion	Calibrator	NC-74	34936363
		Calibrator adaptor type if applicable		NC-74-002

Performance Class: 1

Test Procedure: TP 2.SLM 61672-3 TPS-49

Procedures from IEC 61672-3:2006 were used to perform the periodic tests.

Type Approved to IEC 61672-1:2002 YES Approval Number 21.21 / 13.02

If YES above there is public evidence that the SLM has successfully completed the applicable pattern evaluation tests of IEC 61672-2:2003

Date Received: 03 September 2019 ANV Job No. UKAS19/09582

Date Calibrated: 04 September 2019

The sound level meter submitted for testing has successfully completed the class 1 periodic tests of IEC 61672-3:2006, for the environmental conditions under which the tests were performed. As public evidence was available, from an independent testing organisation responsible for approving the results of pattern evaluation tests performed in accordance with IEC 61672-2:2003, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1:2002, the sound level meter submitted for testing conforms to the class 1 requirements of IEC 61672-1:2002.

Previous Certificate	*Dated*	*Certificate No.*	*Laboratory*
	07 August 2017	UCRT17/1648	0653

MEASUREMENT SYSTEMS

CERTIFICATE OF CALIBRATION

0653

Date of Issue: 04 September 2019

Certificate Number: UCRT19/1980

Issued by:
ANV Measurement Systems
Beaufort Court
17 Roebuck Way
Milton Keynes MK5 8HL
Telephone 01908 642846 Fax 01908 642814
E-Mail: info@noise-and-vibration.co.uk
Web: www.noise-and-vibration.co.uk
Acoustics Noise and Vibration Ltd trading as ANV Measurement Systems

Approved Signatory [redacted]

K. Mistry

Customer	Nova North 11 Bressenden Place Westminster London SW1E 5BY			
Order No.	[redacted]			
Test Procedure	Procedure TP 1	Calibration of Sound Calibrators		
Description	Acoustic Calibrator			
Identification	*Manufacturer* Rion	*Instrument* Calibrator	*Model* NC-74	*Serial No.* 34936363

The calibrator has been tested as specified in Annex B of IEC 60942:2003. As public evidence was available from a testing organisation (PTB) responsible for approving the results of pattern evaluation tests, to demonstrate that the model of sound calibrator fully conformed to the requirements for pattern evaluation described in Annex A of IEC 60942:2003, the sound calibrator tested is considered to conform to all the class 1 requirements of IEC 60942:2003.

ANV Job No.	UKAS19/09582	
Date Received	03 September 2019	
Date Calibrated	04 September 2019	
Previous Certificate	*Dated*	08 April 2019
	Certificate No.	UCRT19/1434
	Laboratory	0653

APPENDIX C – Distance and Speed Corrections

Distance correction

The noise level generated by a point source at a given location can be calculated once the sound pressure level from the source at a reference point is known, according to the following expression:

$$L_p = L_{p\prime} - C_d,$$

where:

$L_{p'}$ is the sound pressure level at the reference location; and

C_d is a distance correction factor.

Distance corrections take into account the attenuation of noise with distance due to the spherical propagation of the sound wave from a point source, and are calculated according to:

$$C_d = 20 \cdot log_{10}\left(\frac{d}{d\prime}\right),$$

where:

d is the distance from the source at which the sound level is being calculated; and

d' is the distance from the source of the reference location.

Speed correction

Speed corrections have been applied to the noise levels measured at the noise camera to enable a comparison with drive-by type approval noise levels based on ISO 362.

Corrections are based on the expression provided in Calculation of Road traffic Noise [13] for “Chart 4 – Correction for mean traffic speed *V* and percentage heavy vehicles *p* ”. The equation shown in Chart 4 is reproduced below:

$$Correction = 33 \cdot \log_{10}\left(V + 40 + \frac{500}{V}\right) + 10\ \log_{10}\left(1 + \frac{5p}{V}\right) - 68.8 \text{ dB(A)}$$

where *V* is the speed of the vehicle in km/h.

For the purpose of the analysis, the term p has been set equal to zero as heavy goods vehicles were excluded from the study. Therefore, the expression used to speed-correct vehicles was the following:

$$C_s = 33 \cdot log_{10}\left(V + 40 + \frac{500}{V}\right) - 68.8 \text{ dB(A)},$$

ISO 362 test conditions assume a constant drive-by speed of 50 km/h, corresponding to a correction factor C_{50} equal to -2.8 dB(A). Speed corrections were applied to noise camera measurements to enable direct comparison with type approval conditions and resulted in positive correction factors (increasing the noise camera measured level) for vehicles travelling at speed lower than 50 km/h, and negative corrections (reducing the noise camera measured level) for vehicles travelling faster than 50 km/h.

APPENDIX D – Additional Frequency Profiles of Vehicle Pass-bys

Figure D.1 to Figure D.4 show the noise profile of some vehicles recorded over a 10-second period with data logged every 100ms. The frequency content over time is also displayed along the vertical axis.

Figure D.1 and Figure D.2 show the frequency profiles of two different Audi A4s passing the prototype noise camera. Figure D.3 and Figure D.4 show the frequency profiles of two motorcycle pass-bys.

Vehicle information: Audi A4 (2014), 1968cc, diesel, type approval drive-by sound level 71 dB L_{Amax}.
Pass-by information: Site 1 (West Meon), far side carriageway, speed 47 km/h, maximum noise 84.5 dB L_{Amax}.

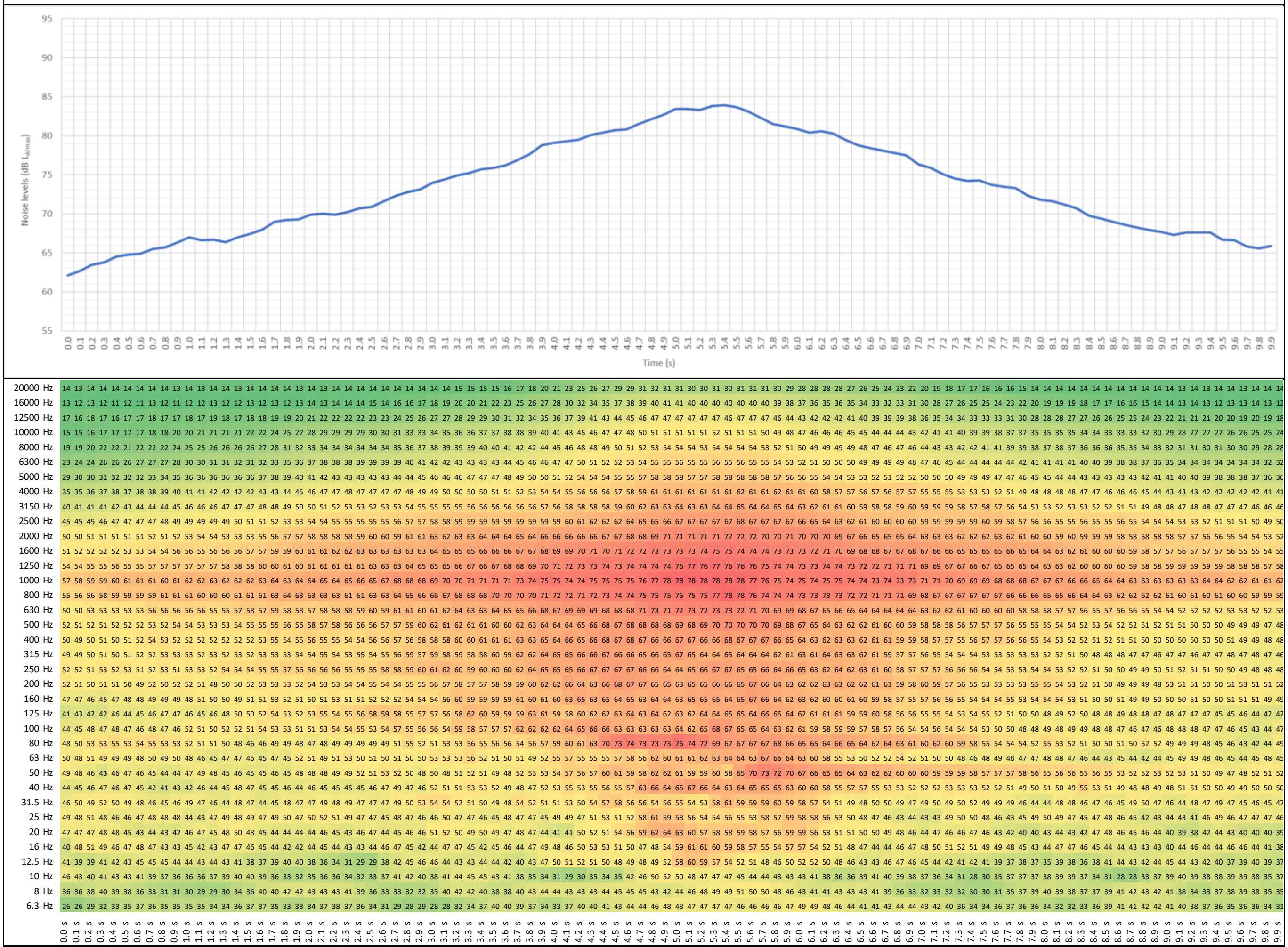

Figure D.1. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for an Audi A4 registered in 2014

The frequency chart in Figure D.1 shows gradual increase and decrease in noise emission in the mid and high frequency range reflecting the varying distance of the vehicle from the noise camera during the pass-by. Noise in the region around 1 kHz is likely due to tyres/road surface interaction. In proximity to the noise peak some frequency component around 80 Hz and 50 Hz become more prominent, possibly indicating a change of gear.

Vehicle information: Audi A4 (2015), 1968cc, diesel, type approval drive-by sound level 73 dB L_{Amax}.
Pass-by information: Site 1 (West Meon), far side carriageway, speed 47 km/h, maximum noise 80.9 dB L_{Amax}.

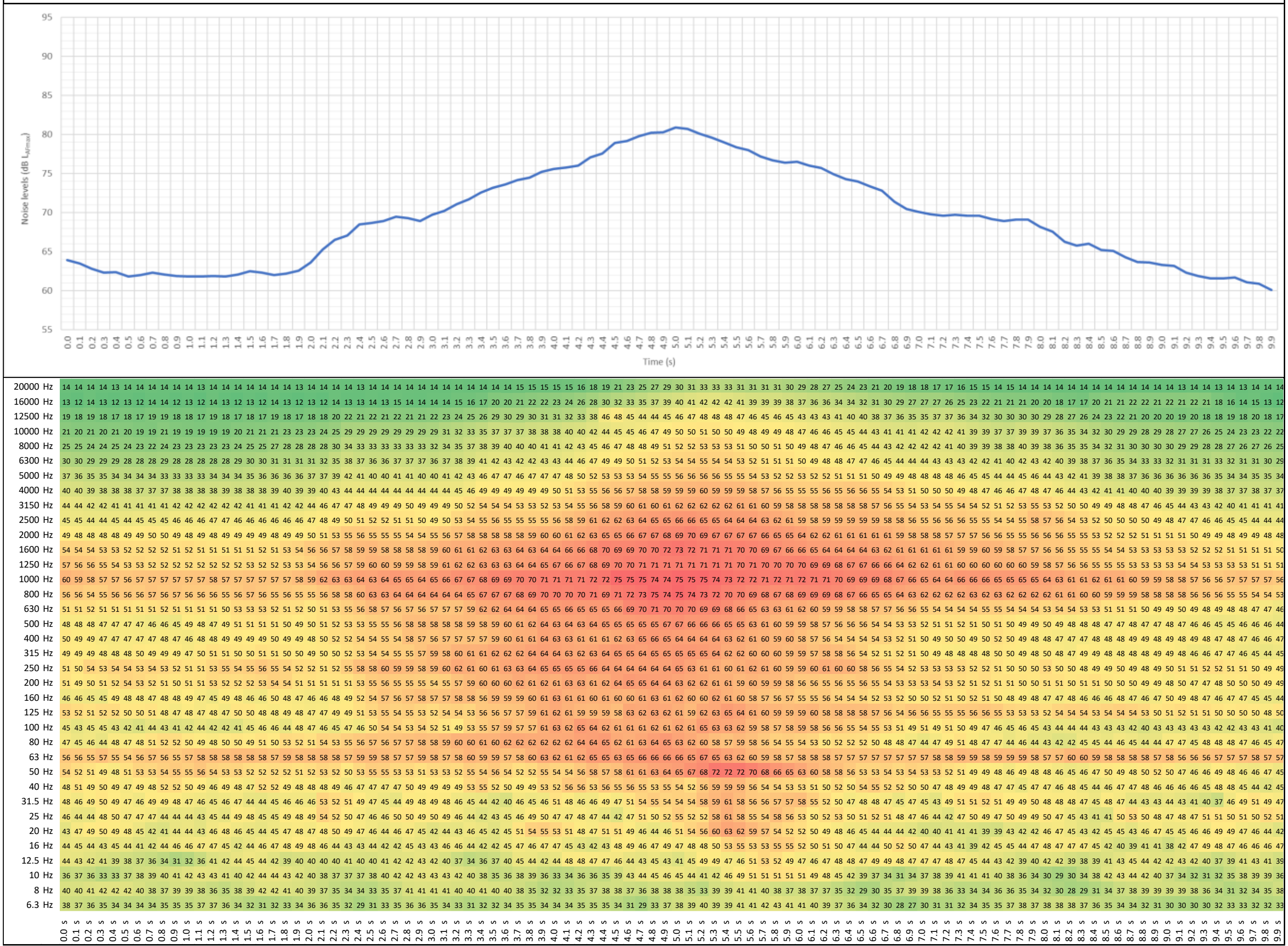

Figure D.2. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for an Audi A4 registered in 2015

Figure D.2 presents the frequency emission of a vehicle similar to that in Figure D.1. In addition to the emissions in the 1 kHz region, a tone around 63 Hz is also noticeable, possibly due to an engine resonance. Speed and distance from the noise camera are similar for both vehicles, however the maximum pass-by level for this vehicle is lower by 2.6 dB.

Vehicle information: Yamaha XP530 (2017), 530cc, type approval sound level 75 dB L_{Amax}.
Pass-by information: Site 1 (West Meon), far side carriageway, speed n/a, maximum noise 84.1 dB L_{Amax}.

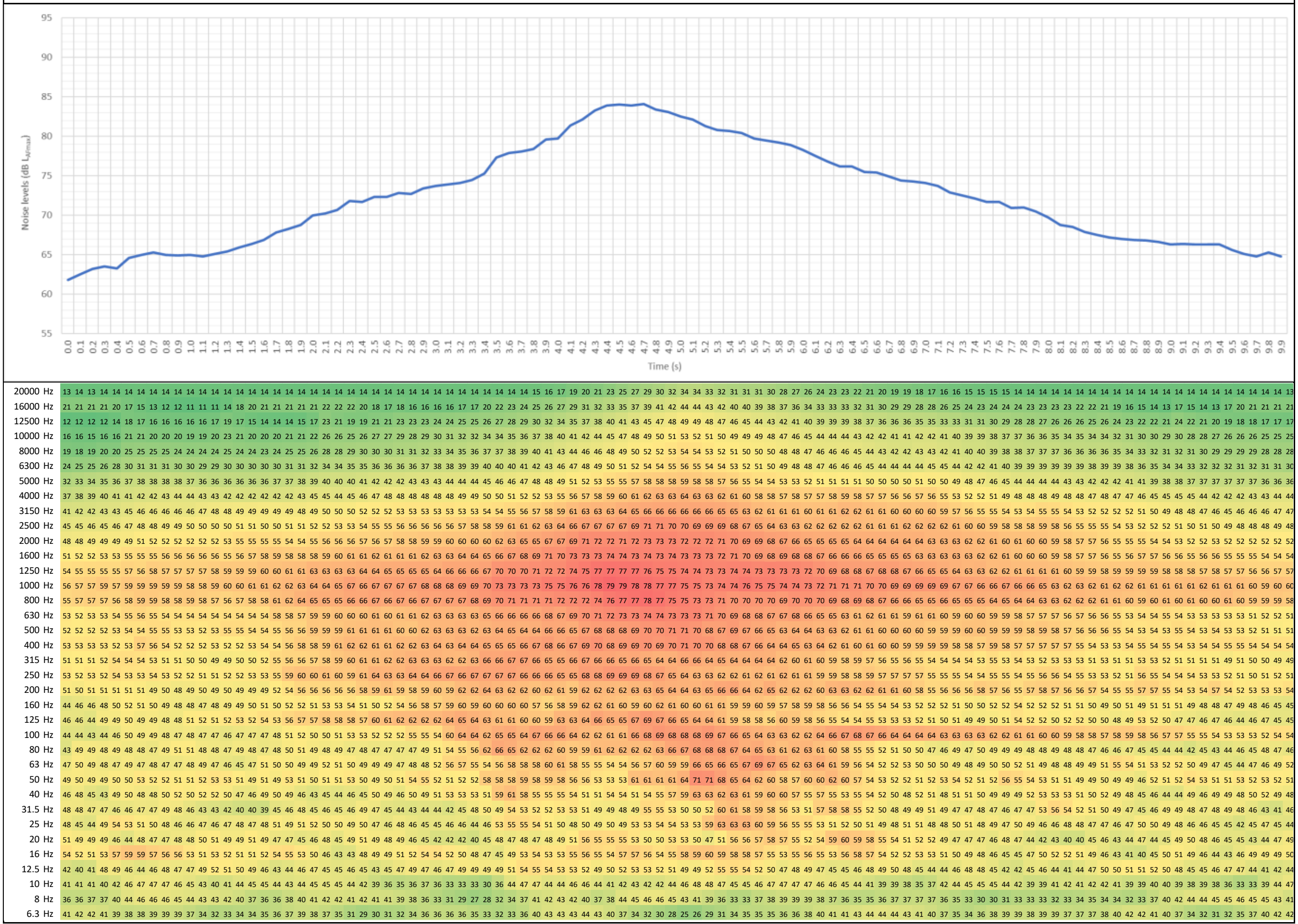

Figure D.3. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for Yamaha XP530

The overall noise profile in Figure D.3 displays a steeper slope on the left side immediately before the peak and a constant decrease to the right of the peak. The frequency content has the highest emissions around 1000 Hz at every time during the pass-by. As the vehicle approaches the noise camera position more contributions in the low frequency region become apparent, approximately at the same time when the steeper part of the slope commences. This could be an indication of the engine becoming engaged just before reaching the nearest point to the noise camera and then accelerating past the noise camera, possibly with a shift of gear at around 5 seconds (resonances at 125 Hz and subsequently 100 Hz).

Vehicle information: Norton model not specified (1990), 588cc, type approval sound level 75 dB L_{Amax}.
Pass-by information: Site 1 (West Meon), far side carriageway, speed n/a, maximum noise 82.7 dB L_{Amax}.

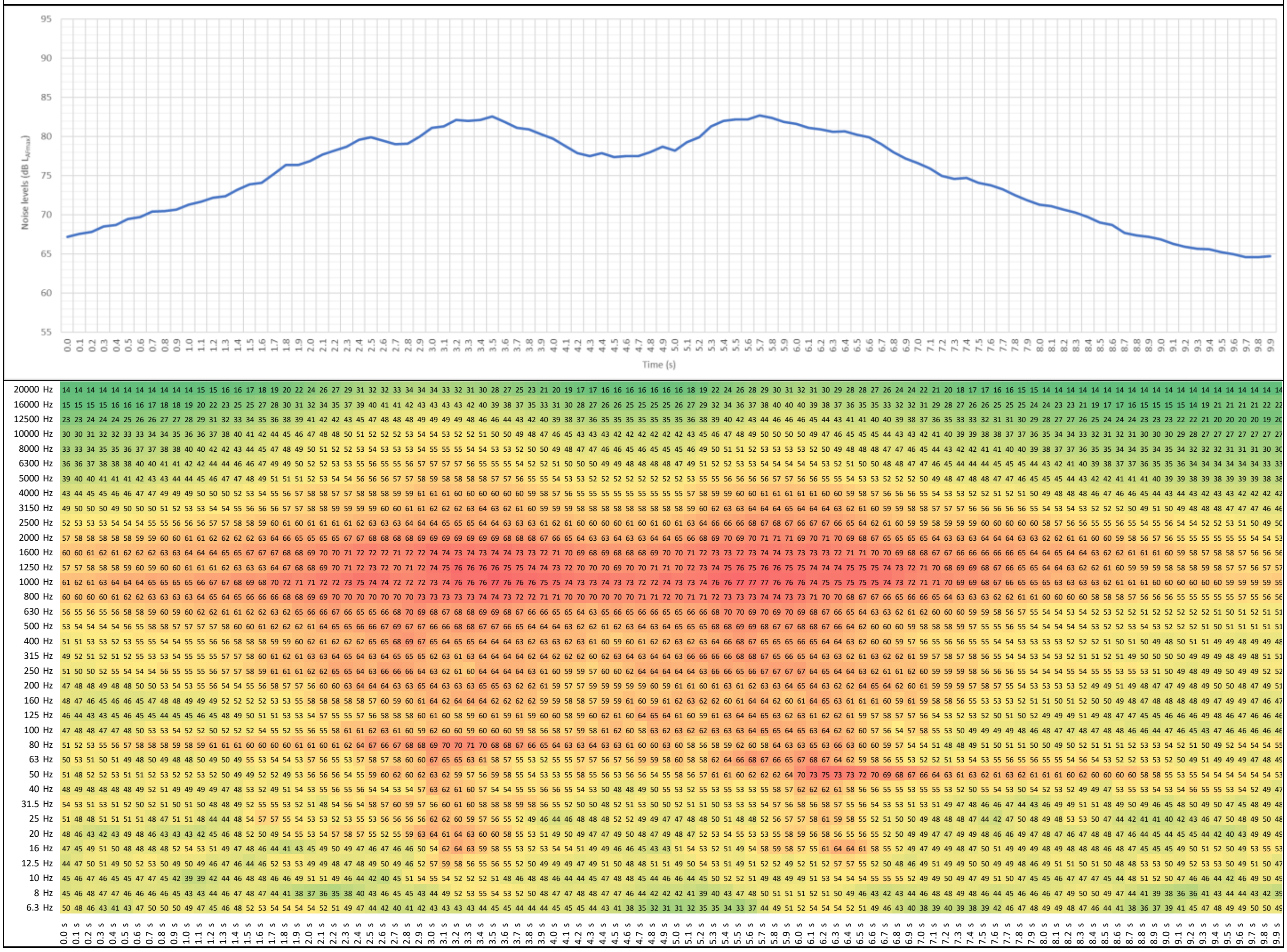

Figure D.4. Measured maximum noise levels L_{Amax} in third-octave bands as a function of time for Norton

The overall noise profile in Figure D.4 is somewhat similar to Figure 9.5 in that it presents two regions of higher emissions in the low frequency region, potentially indicating the engine being revved with a change of gear potentially also occurring, as highlighted by the shift of emissions between 80 Hz and 50 Hz.