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A Preliminary Study of the Characteristics of Noisy Vehicles Under Cruising Conditions – Results of Roadside Measurements

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Summary
In the past it has been found that the maximum pass-by noise for the most noisy of vehicles can be 6–8 dB(A) above the average for the sample. It is therefore useful to consider the types of vehicle that make excessive noise and their condition and to reach some conclusions on how best to reduce the problem. Measurements of maximum noise, pass-by speed together with video footage were taken on a busy dual carriageway road (A34) in the UK carrying a high percentage of heavy vehicles. The intention was to collect sufficient information on light, medium heavy and heavy vehicles to enable typical characteristics of noisy vehicles to be identified. Peak noise levels produced by vehicles under normal operating conditions of steady speed were recorded and not of vehicle being driven in an aggressive manner e.g. under harsh acceleration. This paper reports on the characteristics of excessively noisy vehicles that were identified under these cruising conditions in free flow traffic conditions.

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1. Introduction

Nuisance has been related to both average noise levels but also the number of noisy events and maximum levels. Noisy vehicles can have a very wide footprint and can cause widespread annoyance. Reducing maximum levels of noise in residential areas is likely to reduce sleep disturbance [1].

As an illustration the range of maximum pass-by noise levels that can be expected from a random sample of light, medium heavy and heavy vehicles travelling on a smooth surface at constant speed can exceed 10 dB(A).

This study addresses this problem by collecting and analysing data on excessively noisy vehicles from which priorities for action can be established. This will be useful for directing policy on the reduction of excessive noise levels. For example, targeting vehicles with faulty exhausts or HGVs with loose loads. This problem is most acute at night-time and previous research has begun to address the problem by investigating the noise sources made by delivery lorries [2, 3].

This paper describes measurements at a dual carriageway road (A34) with freely moving traffic, subject to the UK national speed limit. The aim was to collect sufficient information on three categories of vehicles to allow conclusions to be drawn concerning the types of vehicle that are likely to be excessively noisy. The vehicle categories used in the analysis were identical to those described in the Harmonoise traffic noise model [4]:

- Category 1 – Light vehicles and vans with 2 wheels on the rear axle,
- Category 2 – 2-axle medium heavy goods vehicles (HGVs), buses and coaches with 4 wheels on the rear axle,
- Category 3 – 3 or more axle heavy vehicles.

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2. Method

It was the intention to collect information on the noise and vibration produced by vehicles under normal operating conditions and not when the vehicle is being driven in an aggressive manner e.g. under harsh acceleration. The main reason for this is that it is the vehicle characteristics and not the manner in which the vehicle is being operated that is the main focus of the proposed research. There is a case for examining the irresponsible use of motor vehicles but the methodology adopted would need to be significantly different. Such behavioural issues lie outside the scope of the project proposed here. In this paper results of noise measurements are presented and the findings from the vibration measurements will be presented in a future publication.

The approach adopted was a development of the standard ISO 11819-1statistical pass-by method for determining tyre/road noise on different surfaces [5]. However in the present case the focus was on capturing information from the most noisy vehicles in the traffic stream by

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recording relevant images of these vehicles. For this purpose sites were sought alongside busy roads where there was a lay-by separated from the main carriageway by an island. This type of site layout enabled the study team to work in a safe location but also in close proximity and with an unobstructed view of the main traffic stream. A site was found on the northbound section of the Newbury by-pass just south of the junction with the A4. The speed limit on this section of road was 70 mile/h (112 km/h). The surface was in good condition (porous asphalt wearing coarse) and the open nature of the site allowed freely moving vehicles to be selected at random from the traffic stream. In this way it was expected to reduce the influence on recorded noise of other vehicles travelling on the carriageway. A view of the site is given in Figure 1. The cameras can be seen in the foreground and on top of the mobile laboratory. The microphone stand is just beyond the nearest camera and appears just to the right of the mobile laboratory.

Approaching vehicle speeds were obtained with a laser speed meter. The operator aimed the laser speed meter while seated out of sight in the back of the mobile laboratory. The video cameras were set up to capture images of passing vehicles in order to identify possible noise sources. One camera was mounted at a height of approximately 4 m to obtain a view of the load carried by the HGVs and a lower camera at a height of 1.5 m was used to obtain images of the rear of the vehicle to obtain information on the number plate, exhaust pipes and tyres.

A microphone was set up at a height of 1.2 m and placed approximately 7.5 m from the centre of the nearside lane. This was used to record the maximum A-weighted noise level and the corresponding third-octave band spectra of the selected vehicles. For this purpose a Brüel and Kjær third-octave real time analyser was used (B&K 2144). A DAT tape recorder was employed to provide a continuous sound record.

3. Results

Vehicle age data and engine capacity were obtained from the UK's Driver and Vehicle Licensing Authority (DVLA) using the recorded vehicle registration numbers. In a few cases the registration number was incomplete and details could not be found by DVLA.

3.1. Category 1 (light) vehicles

Figure 2 shows the scatterplot of maximum A-weighted pass-by noise levels against the logarithm of speed. The regression line has been added together with the line at 2 standard deviations above the regression line. Using normal (Gaussian) statistics it would be expected that approximately 2.3% of vehicles will exceed this line. With 219 vehicles in the sample the expected number is 5 vehicles. In Figure 2 it can be seen that 7 vehicles were above the line.

Unfortunately because of the presence of a heavy vehicle flow it was not possible to be certain in all cases that the captured spectra resulted from the light vehicle sources rather than larger, and often more noisy, vehicles in the vicinity. Table I tabulates the three vehicles where the captured vehicles were well isolated from the other vehicles and it was clear that the spectra belonged to the vehicle selected. The table lists in order of maximum recorded noise level, the descriptions of these relatively "noisy" vehicles obtained from the video records.

The following are the third octave spectra captured at the maximum A-weighted level. For comparison in each

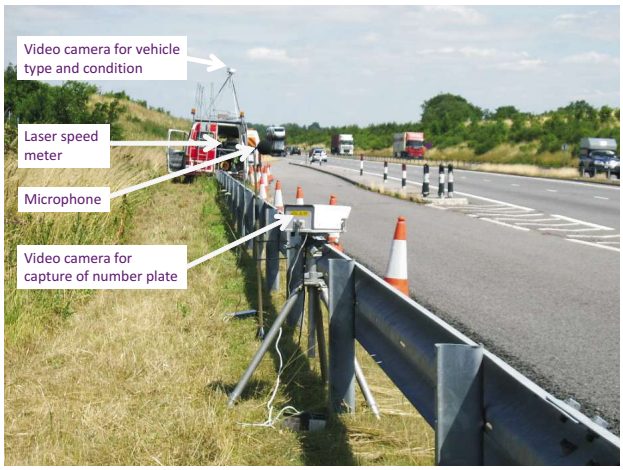

Figure 1. View of measurement set up.

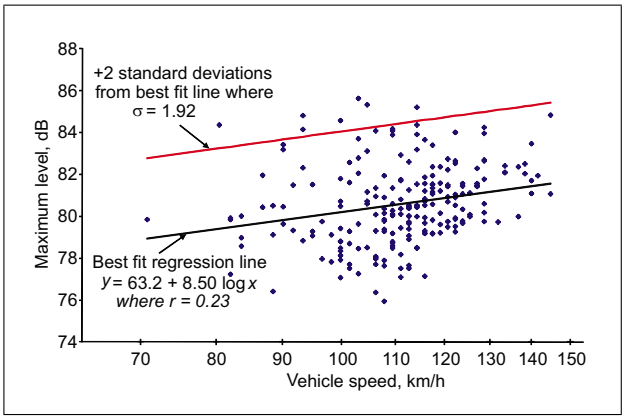

Figure 2. Category 1 (light vehicles) at Site 1.

Table I. Noisy category 1 vehicles (light vehicles).

Description	Age	Source of noise?
Two-seater vintage sports car, open topped, double exhaust	N/K	Age, exhaust
Saloon car (1997cc) in good condition hauling single axle metal framed trailer in poor condition, dirt bike strapped to trailer	6 yr	Trailer
Old SUV with single axle trailer	18 yr	Age, trailer

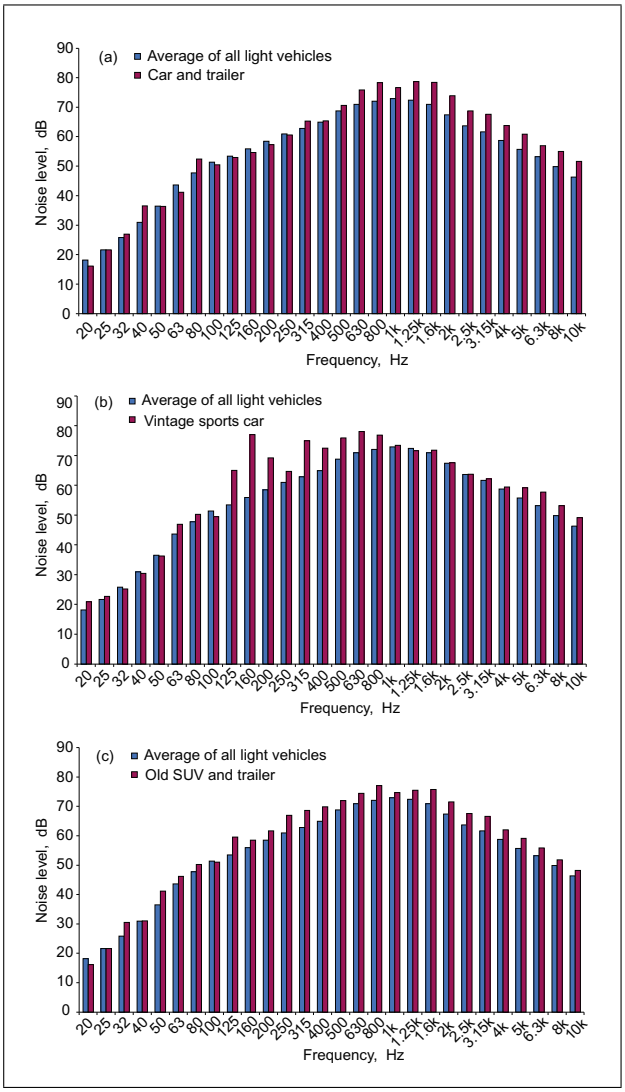

Figure 3. A-weighted spectra for light vehicles captured at the maximum A-weighted level. (a) Saloon car and trailer, (b) Vintage sports car, (c) Old SUV and trailer.

graph the average levels across all sampled vehicles in Category 1 are also given.

It can be seen in Figure 3a that in the case of the saloon car towing the trailer there is an excess of noise above 630 Hz. This is consistent with rattle noises from the relatively old trailer. For the vintage sports car (Figure 3b) there is tonal noise around 160 Hz. This is likely to be exhaust noise resulting from harmonics of the fundamental firing frequency of the engine.

Figure 3c shows that, for the SUV and trailer, the noise levels are generally higher than the average for a broad range of frequencies. This indicates that the main sources of noise on the vehicle, i.e. engine, exhaust, rolling noise, are all producing higher noise levels than the average vehicle in the sample. SUVs are generally noisier than saloon cars both in terms and of propulsion noise and rolling noise. The fact that it was relatively old is also considered to be a factor. The trailer would also have produced additional noise especially rolling and rattle noises.

Table II. Noisy category 2 vehicles (Medium heavy vehicles and buses and coaches).

Description	Age	Possible noise sources
Military truck with digging arm N/K on the back	N/K	Ancillary equipment
Small truck covered with fabric cover	7 yr	Flapping cover
Tipper truck (11.6 l) carrying tall rusty metal box container	10 yr	Vehicle rattle

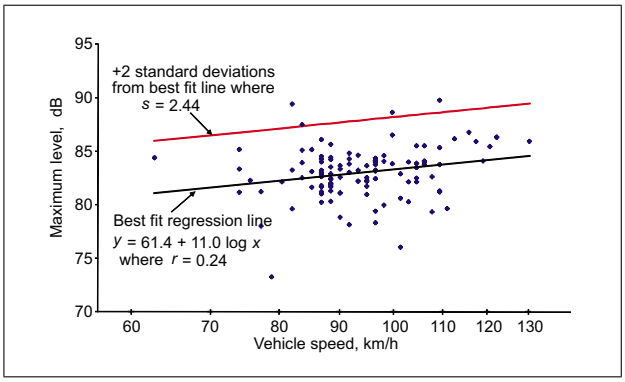

Figure 4. Category 2 (medium heavy) vehicles.

3.2. Category 2 (medium heavy) vehicles

Figure 4 shows the scatterplot of maximum A-weighted pass-by noise levels for category 2 vehicles against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line. Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 115 vehicles in the sample the expected number is 3 vehicles. In Figure 4 it can be seen that in fact 3 vehicles gave noise levels that were above the line.

The third octave band spectra of these vehicles are given in Figure 5. It can be seen that the military vehicle (Figure 5a) is excessively noisy across the spectrum. There is a sharp peak at 80 Hz suggesting exhaust noise with possibly a harmonic occurring at 160 Hz. Above 800 Hz there is a general increase suggesting either tyre noise (from possibly off-road tyres with large tread blocks)) or body rattle noise from the mechanical digger. Possible exhaust noise peaks can also be seen in Figure 5b and 5c at the lower frequencies. The flapping canvas is probably responsible for the elevated levels shown in Figure 5b. The tonal components at 1.25 and 1.6 kHz may result from transmission whine.

3.3. Heavy vehicles (Category 3)

Figure 6 shows the scatterplot of maximum A-weighted pass-by noise levels for category 3 vehicles against the logarithm of speed. The regression line has been added and the line at 2 standard deviations above the regression line.

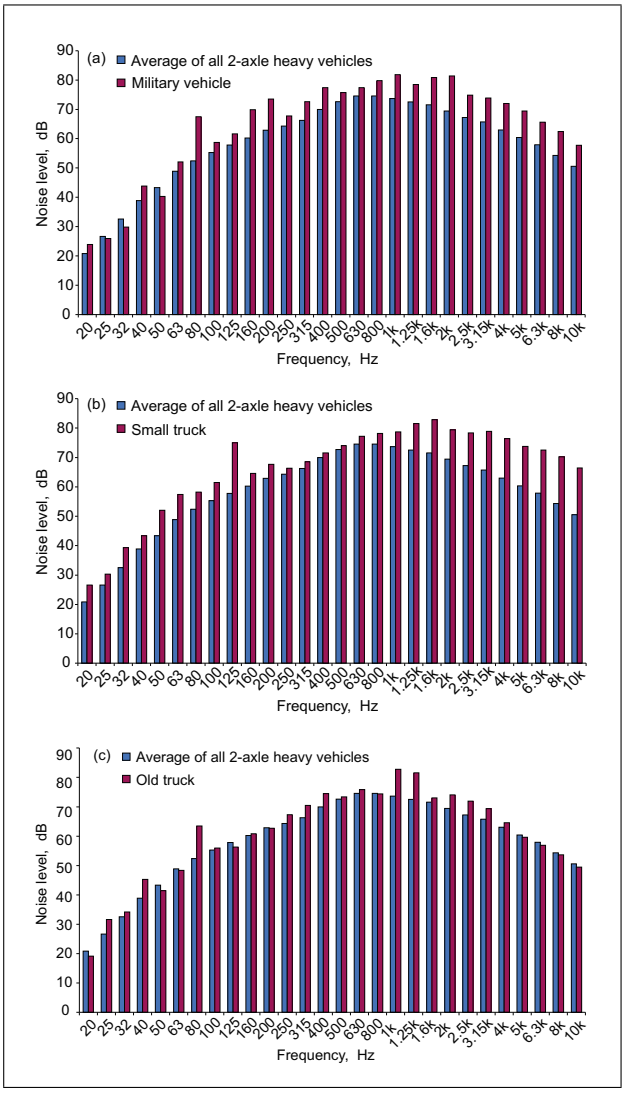

Figure 5. A-weighted spectra of medium heavy vehicles captured at the maximum A-weighted level. (a) Military truck, (b) Small truck with flapping canvas cover, (c) Old truck.

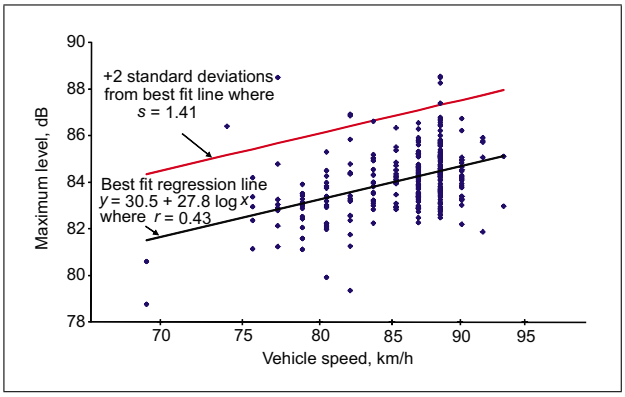

Figure 6. Category 3 (heavy vehicles).

Table III. Noisy category 3 vehicles (heavy vehicles with 3 axles or more).

Description Age	Possible source of noise
High load bed truck (3 axles) with crane attached behind cab <1 yr	Ancillary equipment
Car transporter (5 axles, 14.2 l), unladen N/K	Slack metal safety fencing on sides of transporter decks
Transporter (8 axles, 14.2 l), essentially unladen 9 yr	Small amount of construction material
Large vehicle transporter (7 axles, 12.1 l), unladen 5 yr	Large wheel ramps angled vertically, loose chains on load decks
Transporter (5 axles, 11.9 l), unladen 3 yr	Slack metal wire fence around load decks
Transporter (5 axles) carrying small digger behind cab, then large steel cage for rest of length N/K looks old	Load rattling
Heavy vehicle transporter (7 axles, 15.9 l), loaded with site vehicles 2 yr	Load rattling

Using normal statistics it would be expected that approximately 2.3% of vehicles will fall above this line. With 280 vehicles in the sample the expected number is 6 vehicles. In Figure 6 it can be seen that in fact the noise levels from 7 vehicles are on or above the line.

Table III list the characteristics of the vehicles which lay above the line drawn at 2 standard deviations from the best fit regression line. It can be seen that 6 out of the 7 noisiest vehicles were transporters. In most cases body rattle noises of the trailer was thought most likely to be responsible for these sounds.

The third octave band spectra of these vehicles are given in Figure 7. It can be seen in Figure 7a that the high load bed truck with 3 axles is noisy at low, mid and high frequencies. The relatively high levels at low and mid frequencies are probably due to engine and exhaust noise though vibration of panels (body "boom") may be a factor. At high frequencies rattle noises are probably responsible. The crane behind the cab would probably be a significant source of rattle noise. The remaining vehicles are all transporters with 4 of the 6 being unladen. Loose chains, safety fences around load beds, ramps are all source of rattle noise. The open frame and lack of streamlining would also contribute to increases in aerodynamic noise though this is thought to be relatively low at speeds around 90 km/h. The effect of these sources is a significant increase in noise levels above 800 Hz as can be seen in all the Figures 7b to 7g.

4. Discussion

At the selected site the method adopted was useful for examining the noise characteristics of larger vehicles. Because of the heavy flow of larger vehicles it was not possible to obtain a sufficiently large sample of light noisy ve-



Figure 7. A-weighted spectra of heavy vehicles captured at the maximum A-weighted level. (a) High load bed truck (3 axles), (b) Car transporter (5 axles) unladen, (c) Transporter (8 axles), (d) Large vehicle transporter (7 axles), (e) Transporter (5 axles), (f) Transporter (5 axles), (g) Heavy vehicles transporter (7 axles).

hicles and it is considered that a less heavily trafficked site is required to successfully examine the noise from these vehicles.

Examining overall levels for each vehicle category in Figures 2, 4 and 6 it can be seen that there is a tendency for L_{Amax} to increase with speed which is predicted with vehicle noise emission models that have examined both rolling and propulsion noise [6] and from roadside measurements [7]. However, although the speed coefficient (slope) is within the expected range for heavy vehicles it appears low in the case of light and medium heavy vehicles. The reasons for this are uncertain though it is clear that because the correlation coefficients are low the regression line is ill defined and the confidence limits for the slopes will be relatively large. The subsequent analysis was based mainly on the third octave analysis of pass-by noise together with the associated images from the video records. Body rattle noises were considered to cause the significant elevation of levels of around 5 dB(A) or more in several third-octave bands above 800 Hz and above. In the case of exhaust noise levels were elevated by around the fundamental firing frequency of the engine (typically in the 63 to 125 Hz range). Recent work has shown that where body rattle noise is heard from passing vehicles the frequencies in a broad band above 800 Hz are significantly elevated above similar vehicles with no identifiable noise source (see section 8.3.1 of [7]). For discernable exhaust noise the frequencies are much lower e.g. in the 63Hz octave band levels were nearly 10 dB(A) higher. This is to be expected based on the fundamental firing frequency e.g. for a V8 four stroke diesel engine running at 1000 rpm the fundamental is at 67 Hz.

In the present study there is an indication from the small sample of light vehicles that the age of the vehicle is a factor and whether a trailer was being towed. It was thought from the appearance and load carried that the trailer and contents were responsible for body rattle noises even on the relatively smooth surface at the measurement site selected. Low frequency noise from vehicle exhausts was also thought to be a factor. Examining noisy medium heavy vehicles it appeared body rattle noises were prominent and flapping covers in one case.

In the case of the heaviest vehicles sample sizes were larger so results are more robust. It was found that vehicle transporters made up the majority of noisy vehicles (6 out of 7). In most cases the spectra revealed excessive levels at mid to high frequencies indicating rattle noise. In some cases lower frequency peaks were observed which may results from vibration of body panels.

Inspection of the images reveals some of the reasons for the rattle noises on transporters. The sources are likely to be metal to metal impact sounds due to loose:

- chain safety fences along the sides of the bays,
- vehicle securing chains,
- vehicle ramps,
- components on hydraulic hoists,
- components on the vehicles being transported (e.g. construction site vehicles).

A typical car transporter is shown in Figure 8 where the loose chains are evident alongside the car decks.

The UK code of practice for body rattle noise [8] provides guidance on methods of preventing such noise. It is likely that there are particular challenges in reducing rattle noises for this type of vehicle because there are many loose metal components and more detailed investigations of the major sources and their elimination are required.

A particular feature of the observed body rattle noises was the impulsive nature of the noise peaks. Such rapid increases in noise would be particular annoying to residents living close to the road especially at night time where sleep disturbance is likely. A previous study of a number of sites along a residential road has highlighted the importance of body rattle noise in causing disturbance [9]. In this case the time histories of the A-weighted level showed peaks of nearly 10 dB(A) above expected levels which could be clearly heard indoors as a series of bangs and crashes as the vehicle travelled down the road with an uneven surface.

The WHO sets guidelines on maximum levels outside bedroom windows at night to avoid health effects [1]. Currently this is set at 60 dB(A). They state:" Even if the total equivalent noise level is fairly low, a small number of noisy events with a high maximum sound pressure level will affect sleep". It can be seen in Figures 4 and 6 that the maximum levels produced at 7.5 m can approach 90 dB(A). If we assume these transient disturbances are effectively point sources then the sound level will decay at a rate of 6 dB(A) per doubling of distance under hard ground and unobstructed propagation conditions. Consequently the WHO threshold value of 60 dB(A) level could be exceeded at over 200 m from the road. Hence the number of people that could potentially be affected at night time by such a vehicle could be substantial.



Figure 8. Typical car transporter.

In some cases the heavy vehicles were obviously relatively old and worn and there was evidence of excessive exhaust / engine noise. Over the last two decades vehicle noise limits at type approval have fallen by over 10 dB(A) so modern diesel engines are likely to be considerable quieter than older examples. In addition a worn engine / exhaust is likely to produce more noise than a new system especially if the vehicle has been poorly maintained.

The problem of noisy delivery vehicles has certainly been identified as important. Research programmes have been reported that are attempting to investigate night-time noise from heavy vehicles at source [2]. One practical approach to the problem is for city authorities to promote "environmentally friendly vehicles" such as by the use of the PIEK certification scheme [3]. However, it is unclear whether the issue of body rattle noises is being addressed in these programmes. One problem is developing a suitable test for such a noise source on heavy vehicles where the source is often on the trailer and its characteristics can depend on load conditions. It should be noted that the noise generated by power unit and related sources and tyre noise is currently subject to legislative control via European Union Directives and type approval noise limits which apply for all new vehicle types [10, 11]. At present there are no regulations or directives which relate specifically to the control of body rattle noise.

It would be advantageous in a further stage of the current project if the details of a random sample of vehicles passing the measurement point were examined from the video records in order to determine the percentage of transporters and older vehicles in the general vehicle fleet. In this way it will be possible to quantify the full extent to which these categories of vehicles are over represented as being "noisy vehicle". Further data from other road sites are required to confirm the findings from this preliminary study.

5. Conclusions

The study describes an efficient method for gathering information at the roadside on vehicles producing excessive noise. In total data from 219 light vehicles, 115 medium heavy and 280 heavy vehicles were collected. However, although the methodology adopted has proved generally successful the collection of data for lighter vehicles requires a less heavily trafficked site where there is little risk of noise contamination from larger and noisier vehicles. Further data will be required to confirm these initial findings. In particular it will be necessary to sample at other sites so that a potentially greater range of vehicle types can be measured. The approach adopted has demonstrated that the experimental technique is viable as a method of identifying the most noisy vehicles in the traffic stream. The analysis has indicated that body rattle noise produced on a relatively smooth and even road surface by heavy vehicles is likely to be the cause of most excessive noise. Excessive exhaust noise is another relatively common cause. Aerodynamic noise was not thought to be widespread although an edge tone may have been detected in one instance. Air turbulence however can have an indirect effect on noise production by causing loose covers and securing straps to vibrate and flap causing noise across a wide range of frequencies.

The age of the vehicles appears to be an important factor in some cases, probably due to worn engine / exhaust systems that are likely to emit more noise than newer ones.

Vehicle transporters were frequently identified as relatively noisy and an examination of the spectra indicates the importance of body rattle noise. The recorded images suggest a number of possible sources on the trailer but further work is recommended before definite conclusions are reached.

By establishing the causes of excessive noise and tackling the relatively small number of vehicles that are a problem could provide an effective means of reducing disturbance. For example it is known that limiting maximum noise levels is particularly important in controlling sleep disturbance. From previous studies it is recognised that serious noise problems are caused by vans and lorries making deliveries at night due to increasing congestion of highways during daytime. If the results in the current study can be sufficiently replicated then the future challenge is to effectively address the problem of the poorly or unregulated vehicle noises that have been identified.

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