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PROJECT N°	**FP7-233655**		
ACRONYM	**CITYHUSH**		
TITLE	**Acoustically Green Road Vehicles and City Areas**		
Work Package 3	**Noise and vibration control at source – Acoustically green vehicles**		
3.5	**Definition of a noise & annoyance standard for motorcycles in the urban environment**		
	Motorcycle noise evaluated in the developed noise score models for outdoor noise and indoor noise		
Written by	**Marco PAVIOTTI & Prof. Konstantinos VOGIATZIS**	**TT&E S.A.**	
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	NCC Roads	NCC	SE
	Stockholm Environmental & Health Administration	SEP	SE
	Netherlands Organisation for Applied Scientific Research	TNO	NL
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Dissemination Level

PU	Public	✓
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restrictec to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for the members of the consortium (including the Commission Services)	

Nature of Deliverable

R	Report	✓
P	Prototype	
D	Demonstrator	
O	Other	

SEVENTH FRAMEWORK PROGRAMME

1 see List of Deliverables, DoW – Annex I to the contract, p.32 (document 233655_CITYHUSH_AnnexI_DoW_M12.doc - available on the ftp-server)

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0 EXECUTIVE SUMMARY

0.1 Objective of the deliverable

The present deliverable is aimed at finding, based on appropriate and extensive noise measurements, which features of a powered two wheeler (PTW) are annoying and how annoying they may be in both outdoor and indoor conditions.

0.2 Description of the work performed since the beginning of the project

A thorough literature research was performed on conferences and congresses on acoustics, scientific journals on acoustics, other EU funded projects, and other available general literature, in order to evaluate any existing study on PTW noise and annoyance. A measurement campaign was performed in Athens in different sites (3 days day and night), recording noise from road vehicles (and many PTW) and associating each single event and specific vehicle type with the appropriate noise values. A questionnaire was submitted to pedestrians in Athens to acquire and correlate annoyance response to specific noise events.

0.3 Main results achieved so far

The database of noise levels of motorbikes, scooters and mopeds and psychoacoustic parameters, was created, and used to derive the specific acoustic signatures of noise sources. The results obtained in WG2 for outdoor annoyance as a function of noise levels were compared to those found in the specific questionnaire posed on 170 pedestrians. The questionnaire was used to obtain a new annoyance curve. A simple set of situations was used to visualise the acoustic signature results and define the relevance of the acoustic signature parameters in these situations (close or far from road, on a major or on a minor road). A conclusion is drawn concerning why and under which conditions PTW may cause annoyance, as well as how much annoyance.

0.4 Expected final results

Definition of a set of conditions under which PTW are annoying, and also definition of the degree of annoyance. Moreover, a list of suggestions to reduce annoyance is also provided.

0.5 Potential impact and use[2]

The analysis performed can be used to decide if noise reduction measures on PTW may be beneficial, and to which extent. Noise reduction measures including substitution of vehicles (e.g.: with new electric ones) have economic implications (addressed in the report 3.5.3), potential banning of PTW may moreover have social implications because it may deny the possible use of a common means of transportation.

2 *including the socio-economic impact and the wider societal implications of the project so far*

0.6 Partners involved and their contribution

TT&E S.A. has been conducting the measurements, the survey, collection of data on the urban road traffic and has performed the analysis and the reporting.

TNO has proposed the questions of the relevant questionnaire.

0.7 Conclusions

It has been prooved that the maximum noise level of a PTW pass by is, under the same running conditions as a car pass by, much higher than that of a car, in terms of average values. Moreover, a specific psychoacoustic feature, roughness, identifies univocally most of the scooters or mopeds pass-by. Annoyance from PTW follows the rules of general traffic annoyance, in all those situations when PTW are not recognisable, while is further increased if the PTW pass by can be recognised in the traffic noise created by the rest of the road traffic flow & synthesis.

1 LITERATURE REVIEW

1.1 Preliminary analyses of the issues

1.1.1 Motorbikes or PTW?

The WP description in the DoW focuses on motorbikes only as a specific type of vehicles in between all commonly used road vehicles. Most likely, the right wording would have been PTW (Powered Two Wheelers) since this is a general class that includes several sub-classes like motorbikes and mopeds/scooters. In any urban environment, not being specific countryside location far from urban area, where only exclusively motorbikes are used, all three types of PTW (motorbikes, mopeds and scooters) are present. Moreover, narrowing the analysis to the motorbikes only, would mean facing the problem of the collection of the data separately depending on appearance and not necessarily on acoustic differences. An annoyance analysis separately for motorbikes and scooters/mopeds would mean that only the half or the problem is tackled. Most likely, instead, the population suffers in a relevant way from these three types of PTW in urban environments simultaneously. Moreover, the frequent tampering of PTW applies to mopeds, scooters and motorbikes without distinction. Therefore, in this study the general term “PTW” will be used.

1.1.2 Where are PTW used, how many and how are they driven?

While analysing the locations where noise from two wheelers are relevant, it shall be kept in mind that these transportation means, within the EU, is more common in the southern European countries. Therefore In this region the problem can be more sensible. In figure 1 the estimated average passenger X kilometre driven each year on mopeds is presented, showing that Italy, Portugal and Spain share the greatest part of EU passenger x kilometre (see figure 1). This statistics shows the mopeds use, which might be different from the motorbikes use. By looking at the overall numbers of motorbikes and mopeds one would conclude that city centres in the south of EU are full of motorbikes, and have as well a relevant percentage of mopeds. But by looking on the street one would instead conclude that city centres are full of mopeds, and there is also a significant presence of motorbikes.

Indeed, it is at the moment not possible to have a precise statistics of the effective use of mopeds and motorbikes, but some conclusions can be drawn based on a few existing studies.

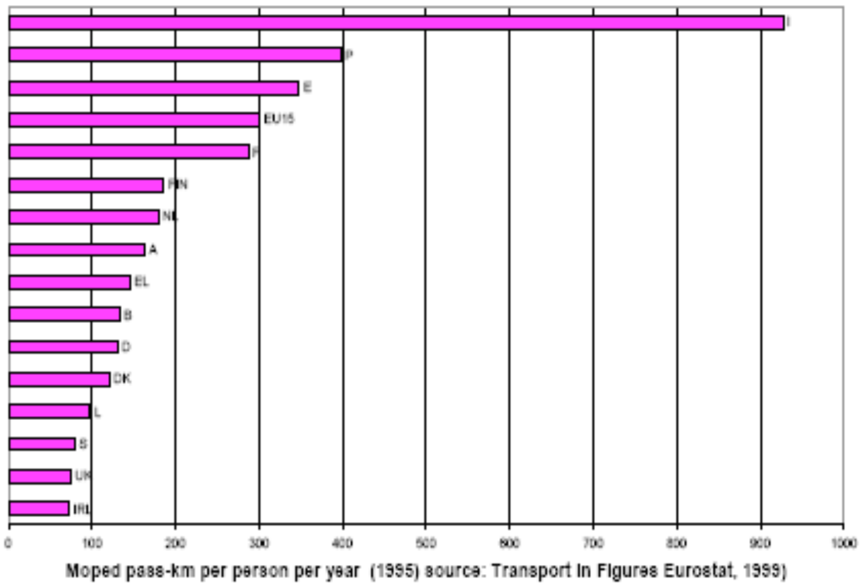


Figure 1.1 Estimated p-km driven by moped in EU.

6.3 Inland transport modal split by country in EU 27 - 2006

	Passenger cars*	Passenger cars %	Powered two-wheelers */**	Powered two-wheelers %	Bus*	Bus %	Urban rail (tram + metro)*	Urban rail (tram + metro) %	Railways*	Railways %	TOTAL
BE	109.9	78.9%	0.6	0.5%	18.1	13.0%	1.0	0.7%	9.6	6.9%	139.2
BG	31.0	68.9%	n.a.	n.a.	11.1	24.7%	0.5	1.1%	2.4	5.3%	45.0
CZ	69.6	69.4%	0.8	0.8%	16.0	16.0%	7.8	7.8%	6.9	6.9%	100.3
DK	54.0	79.5%	0.2	0.2%	7.5	11.0%	0.2	0.3%	6.1	9.0%	68.0
DE	869.0	83.9%	6.0	0.6%	66.2	6.4%	15.6	1.5%	79.0	7.6%	1,035.8
EE	11.5	77.7%	0.0	0.1%	2.9	19.6%	0.1	0.7	0.3	2.0%	14.8
EL	90.0	77.5%	1.0	0.9%	21.8	18.8%	1.5	1.3%	1.8	1.6%	116.1
ES	340.9	80.7%	4.0	0.9%	49.4	11.7%	6.2	1.5%	22.1	5.2%	422.6
FR	723.8	83.9%	2.5	0.3%	44.9	5.2%	12.7	1.5%	78.8	9.1%	862.7
IE	28.0	75.9%	n.a.	n.a.	6.9	18.7%	0.1	0.3%	1.9	5.1%	36.9
IT	692.7	80.7%	10.3	1.2%	102.7	12.0%	6.1	0.7%	46.4	5.4%	858.2
CY	5.0	78.1%	0.1	1.6%	1.3	20.3%	n.a.	n.a.	n.a.	n.a.	6.4
LV	15.5	79.1%	n.a.	n.a.	2.8	14.3%	0.3	1.5%	1.0	5.1%	19.6
LT	39.5	90.6%	n.a.	n.a.	3.7	8.5%	n.a.	n.a.	0.4	0.9%	43.6
LU	6.5	85.1%	0.0	0.5%	0.8	10.5%	n.a.	n.a.	0.3	3.9%	7.6
HU	46.9	61.1%	n.a.	n.a.	17.9	23.3%	2.3	3.0%	9.7	12.6%	76.8
MT	2.0	80.0%	0.0	0.5%	0.5	20.0%	n.a.	n.a.	n.a	n.a.	2.5
NL	148.0	83.5%	1.0	0.6%	12.0	6.8%	1.5	0.8%	14.7	8.3%	177.2
AT	71.9	75.7%	0.6	0.6%	9.3	9.8%	3.9	4.1%	9.3	9.8%	95.0
PL	219.2	82.6%	1.0	0.4%	28.1	10.6%	4.4	1.7%	18.1	6.8%	265.4
PT	72.0	81.3%	0.6	0.7%	11.1	12.5%	1.0	1.1%	3.9	4.4%	88.6
RO	60.0	69.3%	n.a.	n.a.	11.7	13.5%	6.8	7.9%	8.1	9.4%	86.6
SI	23.0	93.3%	0.0	0.2%	0.9	3.7%	n.a.	n.a.	0.8	3.0%	24.7
SK	26.3	70.1%	n.a.	n.a.	8.7	23.2%	0.3	0.8%	2.2	5.9%	37.5
FI	62.5	84.1%	0.2	0.3%	7.5	10.1%	0.5	0.7%	3.6	4.8%	74.3
SE	97.0	82.2%	0.5	0.4%	8.7	7.4%	2.2	1.9%	9.6	8.1%	118.0
UK	686.0	86.5%	1.4	0.2%	50.0	6.3%	9.1	1.1%	47.0	5.9%	793.5
Total EU 27	4,601.7	81.8%	30.8	0.5%	522.5	9.3%	84.1	1.5%	384.0	6.8%	5,623.0

Source: European Commission, ACEM.

** Bn pkm.*
*** Powered two-wheelers in use: 2005 Data.*

Figure 1.2 Percentage of passenger-kilometre for PTW, per country.

Statistics around Europe allow understanding that approximately the same number of mopeds (14 mil.) and motorcycles (16 mil.) are used in Europe, and they correspond to less than 1% of all the persons-kilometre (see figure 2), but this overall number cannot be automatically exported to all situations since it is only an average over the entire persons-kilometre movements per year.

To understand the discontinuity of the modal share (car/bus/moped-motorbike) of the overall PTW movements, as an example two situations are compared, the one being Bologna (see figure 3), a city in the south of EU, where almost 20% of the everyday life movements are performed by motorbike or moped, and Kaunas, where an analysis of the traffic shows that less than 0.5-1.0% of the vehicles in the city are PTW.

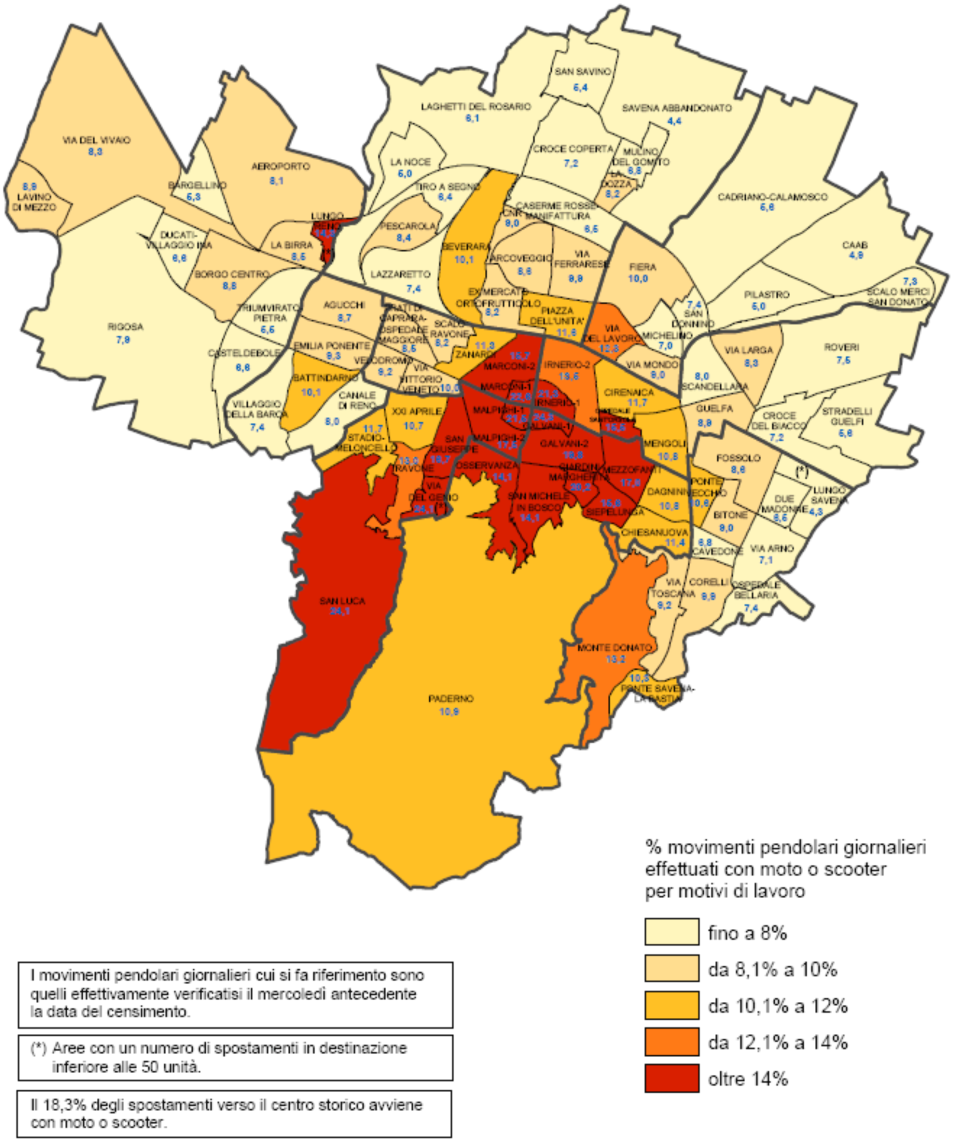


Figure 1.3 Share of PTW as transport mode in everyday life in Bologna and its suburban area

Looking again at the study performed by Bologna municipality, one may find that the percentage of everyday life movements with PTW is strongly reduced if it is outside the city centre. Again, this shows that use of PTW is a very localised phenomenon.

Specifically, it can be seen that the share of movements made by PTW during weekdays consists of the 18.3% of the movements in the city centre by motorbike or moped, while the more one moves out of the city centre the less the PTW are used, down to only 4%. In an article regarding the road traffic noise in Kaunas, representative of Nordic countries, it is possible to read that:

"in Kaunas downtown even 94 percent of all traffic flows were motorcars and minibuses and their input to the noise level was the highest. Public vehicles (buses and trolleybuses) made only 3 percent of the 24-hour traffic flow, heavy vehicles – 2.5 percent, and motorbikes – less than 1 percent. A similar situation was found in Eiguliai district: 94 percent of all traffic flows were motorcars and minibuses, public vehicles – 2.6 percent, heavy vehicles – 3 percent, and motorbikes – about 0.5 percent"

The PTW in the statistics are only classified as motorbikes or mopeds, the latter category including scooters. New registrations help evaluating the trends in their relative presence in the EU, not necessarily where and how within the road traffic (see figure 1.4 and figure 1.5). By looking at the statistics for new registrations one would conclude that the motorbikes are increasing their presence much more rapidly than the mopeds, but in fact it shouldn't be forgotten that motorbikes are mostly used for leisure, in weekends and for countryside driving.

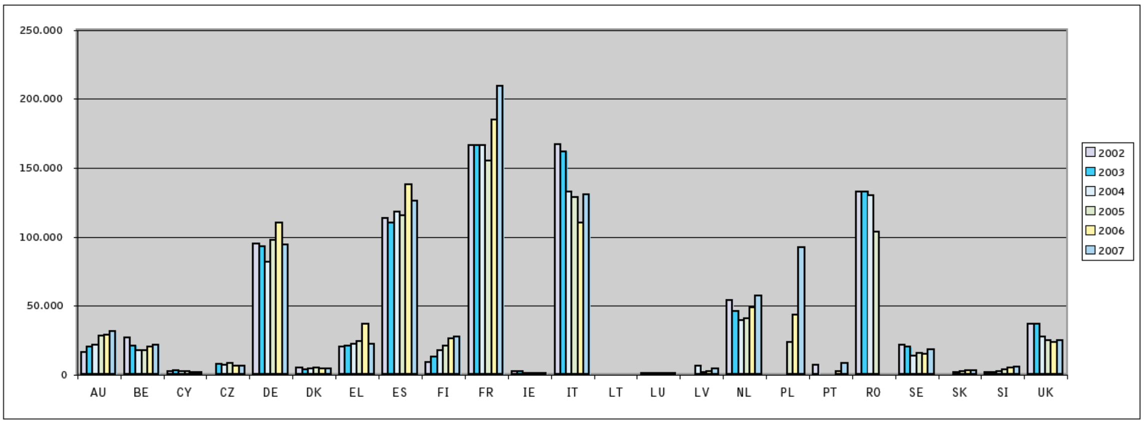


Figure 1.4 Number of moped new registrations, per country.

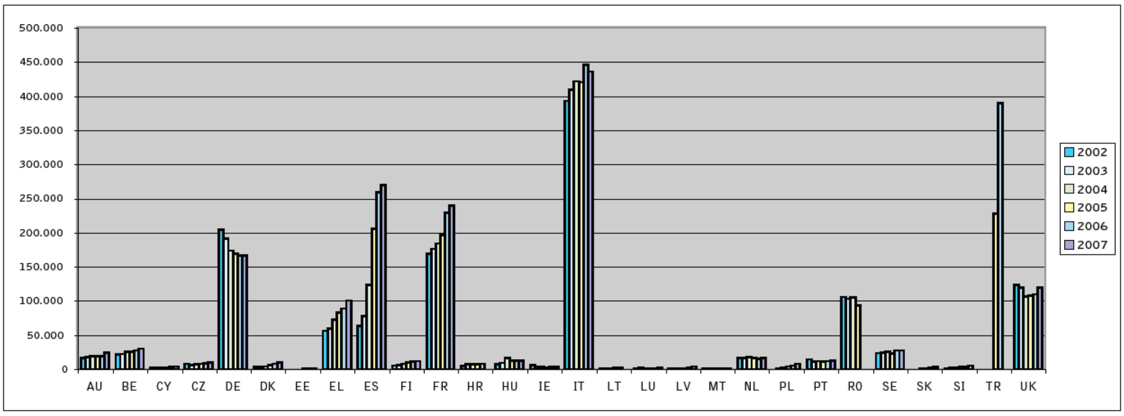


Figure 1.5 Number of motorbikes new registrations, per country.

Thus again, for any modelling of the effect of PTW on noise, a good traffic statistics or modelling is required so as to know (even approximately!) the local share of mopeds and motorbikes used. It is considered (and it has been cross checked with the acquisition of statistical data during the course of the project) that the assumption that not only motorbikes but also mopeds are very relevant in the city centres in the southern EU countries is correct.

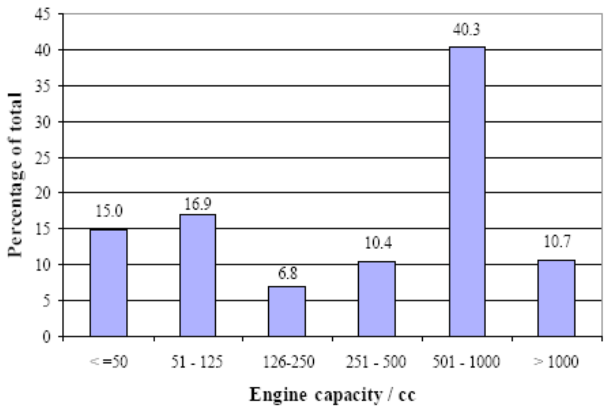


Figure 1.6 Number of motorcycles by engine size in UK.

For completeness, a statistics is presented concerning the distribution of engine sizes amongst PTW e.g.: in UK, showing that the more moves to the north of EU, the more the share of motorbikes is higher in comparison to mopeds. Again, this might be explained in relation to the combination of the weather characteristics (if it rains, it is cold and there is snow, the PTW is not used frequently) and the fact that motorbikes are mostly used for leisure in the countryside and in weekends.

1.1.3 How to classify the PTW from an acoustical perspective?

Different models of PTW are present in real situations: during the IMAGINE EU funded project measurement campaigns, a classification was performed based on a mix of acoustic needs for classification and the possibility to recognise the class of vehicle by simply looking at its external appearance.

The following figure 1.7 presents such classification developed and used. The classes agreed were 6: 5 amongst the mopeds or very similar, mainly due to engine size and their possible use. These five were: scooters 50 cc (type 1), quad (type 2), moped 4 strokes (type 3), moped three wheeler (type 4), moped 2 strokes (type 6). Only after the measurements it was clear, that some of the different classes, from an acoustic perspective, are to be anyway grouped into a single one, since the differences are mostly due to the manner the PTW are driven (accelerating fast, accelerating slowly, use of higher gears or lower gears) and to the proportion of tampering within a specific class, rather than to the apparent external difference. It was also noticed that only for the so called "quad" the rolling noise was significantly present, while in all other situations, the only noise component that dominated over the entire overall noise level was engine noise (see fig. 1.8, fig. 1.9 and fig. 1.10).

Figure 1.7 Classification of PTW (including three and four wheelers) used within the IMAGINE research project.

The following figures present the recorded values for motorbikes and scooters identified during one of the specific two-wheelers measurement campaigns during the IMAGINE project. The classification of figure 1.7 is used.

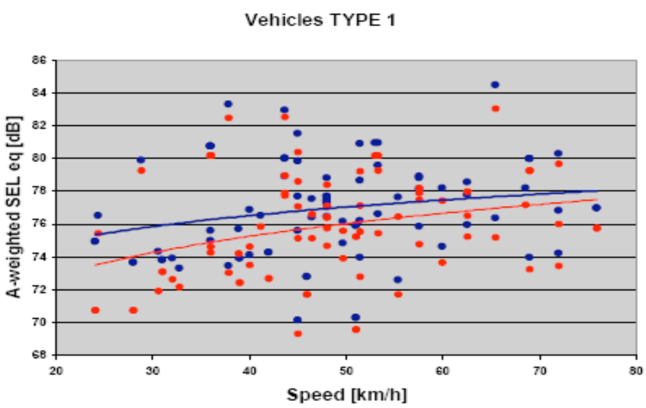


Figure 1.8 For vehicle type 1 (scooter, 50 cc) the SEL(A) values are shown together with a logarithmic trend line; at 1.2 m (in blue) and 3.0 m (in red) height as a function of the speed.

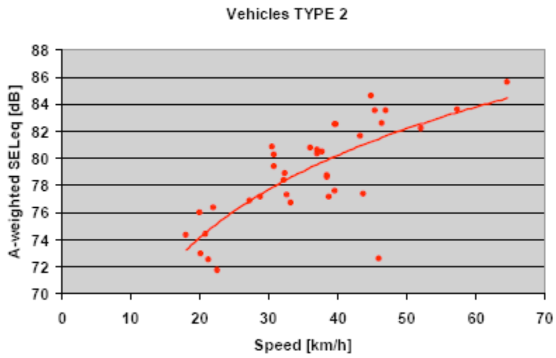


Figure 1.9 A-weighted SEL(A) for vehicles type 2 (Quads) at 3.0 m height as a function of the speed.

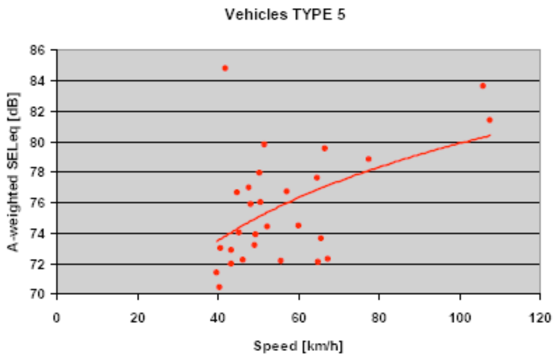


Figure 1.10 A-weighted SEL(A) for vehicles type 5 (Conventional motorcycles) at 3.0 m height as a function of the speed.

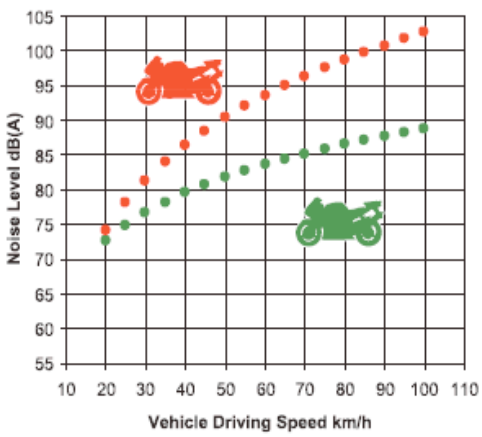


Figure 1.11 A-weighted Lmax for vehicles type 5 (Conventional motorcycles) at 1.2 m height as a function of the speed and riding style (green=normal; red=aggressive).

In the IMAGINE project, the modelling of noise levels at 7.5m/3.0m is available and it seems that there is a great modelling consistence in the trend with the average curve for normal driving of a motorbike provided by the Association of European Constructors of Motorcycles (figure 1.10), after conversion amongst the different metrics used (SEL(A) or LAmax). In the light of the limited data available for modelling of PTW, this result at least allows to claim that as far motorbikes are concerned it is approximately known what the expected increases of noise will be as a function of speed.

Concerning mopeds, for the time being the only alternative available, based on in-field measurements, is the modelling proposed in IMAGINE. By this, it can be noticed that the speed dependence seems to be very limited, and therefore in the case of the mopeds it is expected that the emitted noise levels are almost independent of speed, rather the specific engine type and potential tampering become the relevant parameters.

Finally, a comparison can be done with the official EU limits on the LAmax measured near the source (see following table). This table has also been used in the measurement campaign in Athens to verify the percentage of PTW exceeding the limits: it was found that 40% of the moped and scooters exceeded the limit (22% exceeding 80 dBA) and 38% of the motorbikes.

Table 1.1 - LAmax noise limits for PTW in the EU countries.

Motorcycle Category by cm^3	Limits in dB(A)
Up to and including 80	75
Between 80 and 175 (incl.)	77
Above 175	80
Mopeds	
less than 25 km/h	66
more than 25 km/h	71
mopeds with three wheels	76
Three wheelers	80

Unfortunately, as it was found in Athens, depending on the tampering and the ageing of the PTW, these maximum noise values are most likely to be more a guide value rather than a maximum value in real conditions. The European Community noise limits (LAmax at 7.5 m/1.2 m) applicable to new motorcycles first used from 1 April 1991 are presented in table 1.1.

1.2 Annoyance from PTW

It seems that few analysis of the effect of noise deriving from motorbikes, scooters and mopeds on health (e.g.: sleep disturbance) and in relation to annoyance were performed in the past years in Europe.

Some of these analysis mostly discuss the potential impacts of a reduction of noise from powered two-wheelers (PTW), they are missing though some statistical elements necessary for a thorough evaluation of the problem, like the approximate noise values and the distribution of the events.

Studies were conducted to find out if and how the noise from mopeds and motorbikes is annoying, and how it can or why it cannot be prevented.

The key point seems to be not a technological point, but a commercial/social fact. Mopeds, scooters and motorbikes are best sold if there is at least an option to tamper them by increasing power and emitting noise. This seems to be a wide and widely accepted procedure, and there is evidence that manufacturers, although on one hand claim that verifications against tampering shall be in place by the competent police authorities, on the other hand they clearly propose mopeds, scooters and motorbikes that can be easily fine tuned to higher power and noise (see Ulf Sandberg, Noise emission from power two wheeled vehicles – Position paper, 2002)

Interestingly, the **ASEM**, the association of motorcycle manufacturers in Europe, presents the following position concerning this potential problem on their website:

"Standard PTWs cannot be rated as noisy. The noise produced by PTWs under normal traffic conditions is essentially identical to that produced by passenger cars and much lower than that produced by heavy trucks. The low percentage of PTWs in the overall vehicle pool, i.e. a little over 10%, also contributes to the fact that the traffic noise produced by PTWs is already very low today.

The technical options for further noise reduction are very limited, as all known noise reduction technologies have been successfully applied during recent years to meet existing limits. A huge amount of costs and manpower would only result in 2 dB(A) of noise reduction potential on a long-term basis. Therefore, a further decrease in the noise limits for new PTWs will have a very limited effect.

A PTW is only perceived as loud, due to its high acoustic potential, when it is accelerated very hard in a quiet environment. This is why noise disturbance from PTWs is generally associated with single events and peak noise levels. These are mainly dependent on riding behaviour, for example the use of high engine speeds and very often arise from vehicles equipped with illegal exhaust systems."

From a more neutral perspective, in a paper from WHO, concerning the Italian situation, which may be considered as one of the most exposed to two-wheelers, it is concluded that:

"Although systematic measurements of noise emission by mopeds under real use conditions are not available, mopeds are a major source of traffic noise. Individual vehicles (especially those that have been tampered with) can reach peaks higher than 100 dB(A). For perspective, according Directive 97/24/EC, noise emissions from mopeds should not exceed 66 dB(A) when ridden at < 25 km/h and 71 dB(A) when ridden at > 25 km/h."

In his position paper on PTW noise, done by **Ulf Sandberg** for the European Commission, the position presented concerning annoyance from PTW is as follows:

"Noise from PTW's is a problem in Sweden only during the warm half of the year, since PTW's are mostly not used when it is cold. However, during the spring and summer months (mainly May-August), noise emission from PTW's is a source of serious annoyance in Sweden. Many complaints are filed on PTW noise, both to the police and to communal authorities.

The noise problem is mostly noticed and reported in urban situations. Groups of motorcycle enthusiasts often come together at certain places in cities and may also at intervals travel certain favourite roads or streets. However, Sweden is a relatively quiet country, and extreme noise events may therefore be noticed more than in other countries, due to noise levels substantially exceeding the background sound level. It is *therefore common in the warm part of the year that extreme noise events such as those of accelerating motorcycles with illegal exhaust systems may be disturbing in an area of several square kilometres around the location of the event. For example, such a noise event occurring in the centre of a small town may easily be heard over up to some 3-5 km away from the town centre, practically exposing the entire population of the town and its surroundings to an annoying noise.*

It is clear that the character of noise emission from motorcycles and mopeds annoys people more than criteria of noise annoyance with regard to traffic noise in general would suggest for the measured A-weighted sound levels. The reasons are manifold; one of them being that PTW noise is considered by many as "unnecessary" and often a matter of abuse. This calls for a more serious consideration of this type of noise than would be motivated just when looking at its peak levels and frequency of occurrence.

A Swedish noise annoyance study identified motorcycle noise as by far the most annoying of noise from various vehicle types [Berglund & Nilsson, 2000]. When the exposure time of the noise was also considered (which is very short for motorcycles in comparison to both cars and trucks), a model indicated that motorcycle noise created as much total annoyance as truck noise along the road. This is quite remarkable, bearing in mind that trucks are so much more frequent on the roads."

Another interesting evaluation is the specific test case by **Peter Lercher** done in an alpine pass in Austria, where especially during the summer time and weekends the motorbikes are used intensively (confirming their use for leisure and countryside riding). In this situation, a monitoring station was installed to understand the levels of noise emitted and try to reduce annoyance of the residents in a village along the pass.

"The available data have shown acoustic and non-acoustic aspects of this specific case:

The most important aspects can be summarized as following:

· During the day motorbikes are nearly at par with the number of cars on the weekends and also on weekdays every second vehicle is a motorcycle

· In the evenings (19-22 hrs) about every third vehicle is a motorbike both on weekends and weekdays

· Only during night (22-6 hrs) a "normal" traffic mode distribution is observed

· The road displays a slope between 5 and 14% and shows a slight canyon effect due to its slightly lower position relatively to houses

· Low background noise (L95) levels (around 40 dBA) are contrasted to high peak levels (L1 around 80 dBA)

· For the Leq (6-22 hrs) the guideline level (60 dBA) is clearly exceeded at all points

· The frequency analysis has revealed that motorcycles differ distinctly from cars – even when both vehicles comply with the speed limit

· The police monitoring data have shown a higher proportion of speed limit exceedances among motorbikes (26%) compared with cars (9%). The maximum recorded speed was also higher in motorcycles. Motorbikes appear often in groups, a fact that contributes not only to the acoustic scene but also brings in psychological moments of dominance and potentially also fear.

From literature the following facts are important:

· In two psychoacoustic studies, motorbike noise has been found to elicit higher annoyance. One study derived a 5 dBA penalty."

Birgitta Berglund has also reported in a study on the effects on annoyance of different road vehicles that the effect of a few motorbikes on annoyance can be higher than the annoyance due to average (though high level) road traffic noise, noticing how motorbikes (it is not clear if PTW were addressed in general or only motorbikes) cause disproportionate responses in the annoyance studies.

"MCs (MC corresponds to Motor Cycles) were the specific source with the greatest mean annoyance. For both resident groups, the mean source specific annoyance for MCs was greater than the mean total annoyance and less so for trucks. MC-annoyance was greater than total annoyance for 81% of the residents living close to the road and 62% of those living farther away. Corresponding percentages were for trucks 41% and 34% and for cars and buses less than 25%. Thus, only MCs show compromise in the majority of the residents. Noise from MCs was predominant only once a week. Removing the MCs totally from road traffic does not significantly change the 24hour equivalent continuous sound level although the MC was the most annoying specific source. It seems that source specific annoyance is mainly influenced by "on-time" of the noise (noisy events appear when other sources are low) from the specific source. Thus, even though noise from MCs is absent most of the time, their annoyance is high when they are present and this is what the residents are reporting. Conversely, total "annoyance" includes "on time" for noise from many sources as well as for more quiet periods. The residents have to consider both and, thus, may choose several strategies for total annoyance, for example, "arithmetic summation", "arithmetic averaging" or "strongest component".

The most interesting study concerning annoyance by PTW was conducted by TNO-RIVM: **Franssen, van Dongen, Ruysbroek, Vos and Stellato** reported that the most annoying noise in The Netherlands is traffic noise and aircraft noise, and regarding traffic noise, that of the mopeds is by far reported as the most annoying, even with respect to lorries. Motorbikes come in the second place. The following figure 11 presents the percentage of people annoyed and highly annoyed by different noise sources present in a living environment next to a road (not necessarily a major road), and the time evolution in the years (figure 1.12).

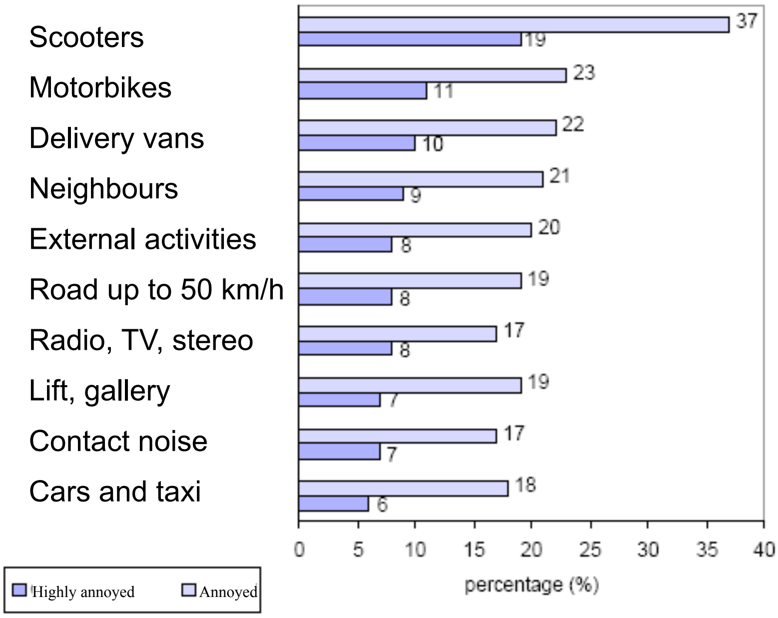


Figure 1.12 Percentage of annoyed and highly annoyed people.

1.3 Annoyance by means of listening tests

More recently, and as a result of the three research projects ROTRANOMO, SVEN and QCITY, an approach which differs from the noise levels and time history plus questionnaires approach is used, namely to derive the noise annoyance by using listening tests reproducing the major perception related to sound properties of a specific noise sources simulating a traffic scenario by means of a traffic model. Description of the objectives, methodologies and database developed can be partially retrieved by reading the Deliverable 5.12 of the Qcity project (pages. 54-64).

Overall, in a recent publication, **André Fiebig** came to the following conclusions.

"The TNS (Traffic Noise Syntesizer) technology can be used to generate psychoacoustic maps. This would be a step forward to reach the challenging goal, the development of „noise maps" instead of „sound pressure level maps". Moreover, the presented technology could be a helpful planning tool, which enables urban planners and decision-makers to consider the aspect of noise (annoyance) in their considerations.

However, to enhance the authenticity of the generated sounds and the "validity" of the created traffic noises, the typical traffic sound sources and their acoustical properties, the synthesis technology and the models and algorithms behind must be refined. Vehicle types, such as heavy vehicles, motor bikes, scooters have to be included in the data base to create most realistic (road) traffic scenarios.

Another aspect concerns the general explanatory power of maps. It has to be assumed that even advanced noise maps providing information about several acoustical parameters do not relieve from studying soundscapes and the perception of complex sonic environments more closely. The acoustical measurement (or calculation) of environmental noise constitutes only the physical representation of the urban place with the sources only considered with their acoustical emissions. The *determination of the sensational representation of the investigated urban space with its typical sound cannot be achieved without asking how residents feel about their surrounding, without experiencing the place with its visual elements. This requirement cannot be fulfilled with physical models based on calculations.*

In case this approach will be followed, intensive measurement campaigns will be required, since different information is needed to perform these kind of simulations, namely:

- recorded signal (sampled at least 10 kHz) of pass-by of the different sources, in their different running conditions, and possibly separately for each specific noise source (wheel-road contact, engine, exhaust, air intake);

- input data for the modelling of the specific source conditions within the road traffic, which includes the modelling of the driving style (e.g.: very cautious and slow, normal riding, aggressive riding), the modelling of the noises under different running conditions (acceleration, steady speed, deceleration);

- input data for the modelling of the noises from the remaining traffic (which becomes background noise);

- input data for the modelling of the sound propagation attenuation (at least in third octave bands) from the simulated source to the simulated receiver.

In fact, listening tests by using the instrumentation of HEAD Acoustics were already performed during the year 2004 to evaluate the effect of mopeds' annoyance.

This technique (listening tests of pre-recorded sounds) was adopted for the assessment of the annoyance from mopeds during the study performed by J Vos. Sounds of mopeds pass-by were recorded in real environment *"at distances of 12.5 and 25 m between the axis of the road and the Artificial Head. The driving speed was about 40 km/h. The recordings at the distance of 12.5 m were used to prepare the stimuli to be presented at ASELs of 70 dB, whereas the recordings at the distance of 25 m were used to prepare the lower level stimuli of 60 and 50 dB. The duration of a passage was equal to about 20 s. Each sound stimulus consisted of two pass by sounds that could be partly overlapping in time. The total duration of each sound fragment, including silent periods, was fixed at 45 s."*

At the same time, to have a reference to compare with the responses from the scooters, road traffic annoyance was tested on a set of subjects.

"The road-traffic sounds were recorded at distances of 12.5, 25, and 60 m between the axis of a provincial road and the Artificial Head. Each fragment consisted of partly overlapping passages of 10-12 different passenger cars and one truck, with a total duration of 45 s. The driving speed of the vehicles was about 80 km/h. The sound fragments that were presented at ASELs of 50, 60 and 70 dB were based on pass-bys recorded at distances of 60, 25, or 12.5 m, respectively."

In this study, it was clearly confirmed what the assessment performed by TNO-RIVM on a very large population and amongst many years showed, viz. the fact that mopeds are the most annoying source amongst the environmental noise sources.

Initially, an attempt was done to use four descriptors for the noise type, namely: Percentage of loudness exceedance (N5), Average sharpness (Smean), roughness (Rmean) and fluctuation strength (FSmean).

The study explored the effectiveness of these four psychoacoustic descriptors to measure the annoyance, if compared to a single noise level to be used a noise descriptor.

"In the present section, however, we explore to which extent the annoyance ratings can be predicted more precisely by psychoacoustic parameters than by ASEL (A-weighted Sound Exposure Level). Average loudness (Nmean) was one of the selected attributes. The perceived average loudness of fluctuating sounds with duration of more than a few seconds, however, is strongly influenced by the loudness of the louder events, and may be clearly higher than the mean of the perceived instantaneous loudness.

For road-traffic sounds with a total duration up to 17 min, the perceived average loudness in one study turned out to correspond to the loudness that was exceeded in 4% of the time, whereas in another study, the pertinent percentage was equal to 9%. In the present study it was in addition to Nmean decided to calculate the loudness that is exceeded in 5% of the time (N5).

Average sharpness (Smean), roughness (Rmean) and fluctuation strength (FSmean) were also selected."

After having performed the regression analysis, the following step was the conclusion (ASELadj is ASEL with an additional constant malus coefficient non related to acoustic parameters):

"Multiple linear regression analysis showed that as long as ASELadj was excluded as a potential predictor, four psychoacoustic variables were selected and together were able to explain 51% of the variance in the annoyance ratings. With ASELadj included, it was selected as the sole predictor explaining 57% of the variance in the ratings."

So, overall, it was decided to use the ASEL as the only indicator for annoyance, given its very high correlation with annoyance reported.

In the CityHush project, it is therefore suggested to benefit from this information, and possibly use the ASEL as the annoyance indicator.

The annoyance reported was such that, in the ASEL 50 to 70 dB, mopeds obtain a penalty of 4.6 dB to be comparable to road traffic annoyance from cars and trucks.

Results are displayed (in figure 1.13) and presented in the following.

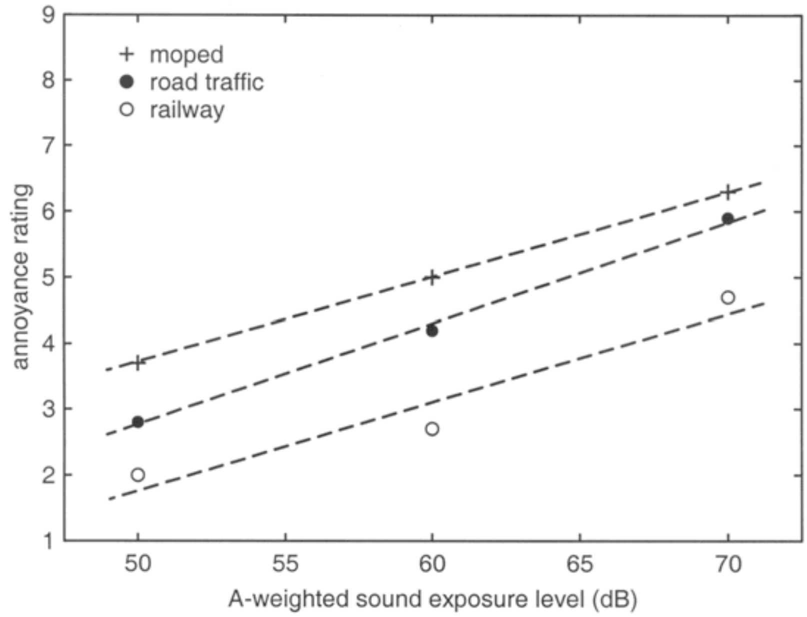


Figure 1.13 Mean annoyance ratings as a function of ASEL for three different sound types. Broken lines are linear regression functions.

Strictly by considering the evaluation of the annoyance, the following is concluded in such study, and might well be considered on the basis of any annoyance evaluation which will be performed in CityHush WP 3.5.

"Given the high percentage of "highly annoyed" respondents, as described in the Introduction, we actually had expected a penalty higher than 5 dB. An explanation for this relatively small penalty might be the fact that the moped drove past at a constant speed. The presentation of sound fragments for driving conditions in which the moped driver had been instructed to "play with the throttle," might have yielded a higher penalty.

On the basis of the differences that were obtained in the meta-analysis between the dose response relationships for aircraft and road-traffic sounds, we may conclude in the fact that the penalty for the present moped sounds was about equal to that for aircraft sounds.

In the prediction of the annoyance caused by various traffic sounds, the A-weighted sound level is not perfect: we need penalties for aircraft and moped sounds, and a bonus for railway sounds. At least, part of the differences among the various dose-response relationships might be explained by non acoustic factors."

ASELadj was selected as the first predictor, and the explained variance in the mean ratings was as high as 56.8%. At the same time, this was the final solution: none of the remaining variables were able to significantly increase the explained variance further.

1.4 Solutions proposed to reduce noise from PTW

An objective of the WP 3.5 is to provide a study on the effectiveness of potential measures to reduce the annoyance of PTW in Q-zones in addition to the evaluation of the social and some environmental (CO2, other air pollutants) implications of such measures.

Already in the text of the DoW of the CityHush project the introduction of the following measures is foreseen:

- low noise motorcycles (following the statements contained in the ASEM yearbook this is rather impossible and in any case will never be more than 2 dB(A));

- introduction of electric PTW;

- total banning of the combustion driven PTW either only during sensible night periods or eventually during daytime as well.

In any case, being that this memo reflects only the state of the art of the measures at the moment, the most interesting conclusion that was possible to have been retrieved by now and drawn on how to reduce PTW noise is the one in the position paper of Sandberg. In his document the following is reported.

"First (highest) priority level:

• Urgent work out and implement a common action plan against tampering with used PTW's for the purpose of making them noisier. That action plan should include the points raised in 3.1 of [Vergote, "Draft position paper on PTW noise 21-6-2001 (WRNT4-5)". Draft submitted to WG 8 in June 2001]. (…).

• Change the measuring method for type approval in order to use several more engine and vehicle speeds, in order to make cycle-bypassing or suboptimizations very difficult. New method(s) with such purposes is/are currently considered in ISO.

• Deliberate noisy driving shall be prohibited and such rules or laws should be enforced. Consider whether the Union may establish some common minimum rules on this or at least work out recommendations and/or exchange information.

Second priority level:

• Negotiate with the vehicle industry aiming to reach an agreement by which the industry shall undertake measures to avoid easily made modifications to their vehicles that can be made by the owners and that may potentially increase noise emission.

• Tighten RESS type approval and COP slightly with respect to allowed tolerances.

• Improve methods of checking vehicles in-use by field and laboratory inspections (stationary method). Work on this is underway in ISO. Also consider the use of new, effective test equipment.

• Offer PTW drivers hearing checks and inform them about the risk of hearing damage

• Follow-up and study the effect of all the measures undertaken

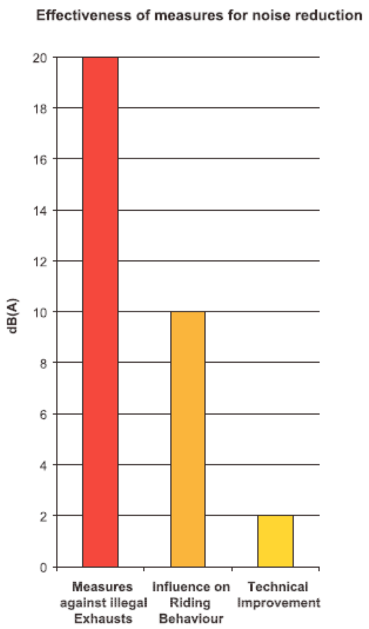
Third priority level:

• Tighten the existing emission limits for type approval with the aim to align the stringency of the requirements with those in force in Japan."

Finally, and for the sake of completeness, the position of the ACEM concerning the potential noise reduction measures is reported:

"Educating riders in matters of environmental protection therefore creates reasonable potential for reducing the noise load. The overall effect can be estimated at 5 to 10 dB(A) on a long-term basis.

The real challenge, however, is to find effective measures against illegal exhaust systems. The number of PTWs in use with illegal systems is very high, which essentially raises the average noise output. The reduction potential of 10 to 20 dB(A) is also very high, and reductions can be obtained on a short-term basis."



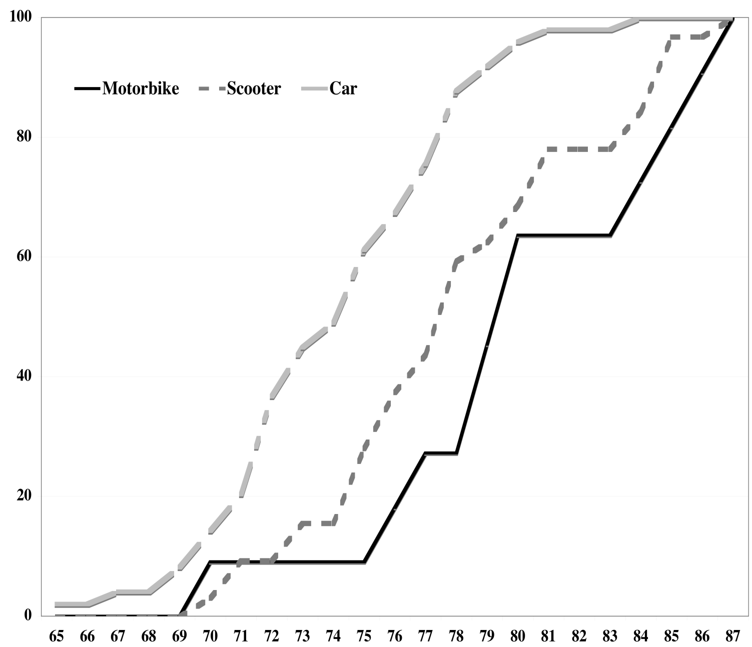


Figure 1.14 Potential noise reduction measures to reduce annoyance from PTW following the position of ACEM (left). Cumulative distribution function of L_{AMAX} found in Athens: results show that, respect to existing noise limits, the maximum potential of measures against illegal exhausts is limited to 5-7 dB, and therefore the riding behaviour potential is smaller than approximately 5 dB.

2 SPECIFIC OBJECTIVES OF ANALYSIS

2.1 SPECIFIC ANNOYING CHARACTERISTICS OF PTW

PTW's are most of the times considered by people, at first glance, as annoying.

As explained in the literature review, some data shows how to associate noise levels produced to PTW annoyance, but the intrinsic typical characteristics of the noise produced are possibly not only linked to the overall sound pressure levels but also to some of their specific characteristics. A wide set of parameters is available to describe analytically and objectively the quite unpleasant "sound" produced by a PTW.

Possible indicators of the unpleasantness of the sounds may be:

(a) SEL (Sound Exposure Level, representing the overall energy of a single event);

(b) $L_{A,max}$ (Maximum A-weighted recorded level during the pass by, relevant to explain why a specific event has been noticed by people amongst other noises, like a noisy motorbike when simultaneously less noisy cars are passing by);

(c) L_1 L_5 L_{10} L_{50} (statistical indicators to proof if there has been a steady or very unsteady presense of noise events. These set of indicators are both linked to the number of events and to the exceedance of specific noise levels respect to background noise);

(d) Loudness (represents the human perception of the noise level);

(e) Sharpness (represents the human perception of spectral content and also as a function of centre frequency in case of narrow band sounds);

(f) Roughness (represents the annoyance produced in humans by amplitude fluctuations with a fluctuation frequency between about 15 Hz to 300 Hz).

To understand the specific annoyance produced by the PTW, these possible indicators are also used to compare the values obtained for the other vehicles and in general for the other noises present in the assessment place. In particular, it is relevant to evaluate each of the given parameters in the specific context.

2.1.1 Annoyance as function of the traffic type and distribution

Therefore, the mentioned parameters to be possibly used to evaluate the annoyance of PTW shall be also contextualised. A single PTW pass-by in the middle of many simultaneous car pass bys, will most likely not be noticed. Inversely, a single pass by of a PTW in a silent road would most likely be reported as very annoying, and the annoyance reported might be more than the one on a road with many cars, though the overall noise levels (L_{eq}) might be even lower in the quiet road. So, it is necessary to consider the traffic type and the distribution of the traffic as well.

2.1.2 Annoyance as function of distance from the road

The distance from the road may also have a strong effect since two facts occur: the noise of the PTW has less chance to be again dominant or very relevant in absolute terms, since there is an increased probability that other noise will become relevant, from other vehicles and in general other sources whose distance to the listener are comparable to that of the PTW only; high frequencies are damped and therefore the spectral component of the PTW is heard differently.

2.1.3 Annoyance in the case of scooters/mopeds and in the case of motorbikes

There is a need to classify at least two macro categories of PTW, these being the small scooters and mopeds on one hand, and the motorbikes on the other. These two macro categories are expected to differ mainly because the rpm of the scooters and mopeds is higher than the one of the motorbikes and because the exhaust system is shorter and simpler for scooters and motorbikes while being tendentiously more complicated for motorbikes (including a bigger silencer). These differences are in the course of this study assumed, though it is recognised that many combinations of engine sizes and 2 or 4 strokes, number of cylinders and exhaust type exist, that a clear border line between the two macro categories cannot be drawn. Still, literature has already been prooving that SEL are different between the two, and so it is expected that loudness and roughness will also different. The latter is specifically a consequence of the combination of the silencer properties, the number of strokes, the number of cylinders and rpm of the specific running condition.

3 METHODOLOGY FOLLOWED

3.1 SELECTION OF SITES AND MEASUREMENT CAMPAIGN PERFORMED

Based on the considerations explained in the previous chapter, in order to quantify different parameters of the PTW annoyance, it was decided that:

- to obtain a correct, as much as possible unbiased estimation of the parameters in real conditions, a situation where many pass by of different types and with different drivers was needed;
- to understand both the effect of single pass by in the relatively quiet environment, single pass by in the heavy traffic, far and near, three situations were needed: one next to a major road; one next to a minor road; one far from roads;
- to link to the annoyance of people it was necessary to have many people passing by, so as to ensure finding some people available to respond to questionnaires, and also to ensure finding a statistically wide population distribution;
- to follow as much as possible the objectives of the CITYHUSH project, whose aim is to assess annoyance in Q-zones and embedded parks, zones in the heart of the city as well as include a quiet zone and a park.

After having discussed and evaluated all the possible options, four sites were identified which could fulfil the outlined requirements.

These are presented in figure 3.1, which shows two areas, the green one is an existing park area, embedded in the city, and the blue area is corresponding to a residential zone, mostly consisting of dwellings.

Initially, it was decided to separate points 1 and 2, but it was noticed that people passing by point 2 had also passed by point 1, therefore, in the analysis to derive the annoyance curve, the two positions were finally grouped together. Point 3, though it seems to be close to 1 and 2 as well, due to the fact that it was in a higher position and behind a small hill, resulted in an average difference of levels of about 7-10 dB respect to point 1, so this position was definitely considered different from position 1.

Figure 3.1 Description Map of the area at the centre of Athens were the measurement campaigns were performed. The areas are also defined where it is considered to have embedded park and where it is considered to have a potential q-zone area.

3.1.1 Possible combinations of traffic conditions

During the measurement campaign, a continuous assisted traffic counting was performed (for more than 24h), which included all vehicles on the road, in the case of the small road, and all vehicles on one direction, in the case of the major road.

In the following figure the percentages of vehicles are outlined, as well as some examples of the time pattern of the pass-by of the PTW and other vehicles. It can be noticed that different time patterns were recorded.

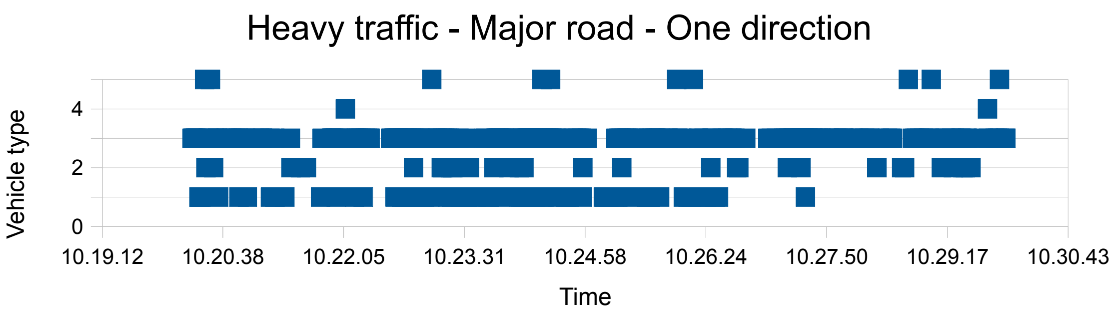


Figure 3.2 Timestamps of 10 minutes of pass by on the major road, in a single direction, two lanes, in the morning (at 10:00 a.m.) for the 5 different vehicle classes: 1-scooters/mopeds; 2-motorbikes; 3-cars; 4-buses; 5-other vehicles.

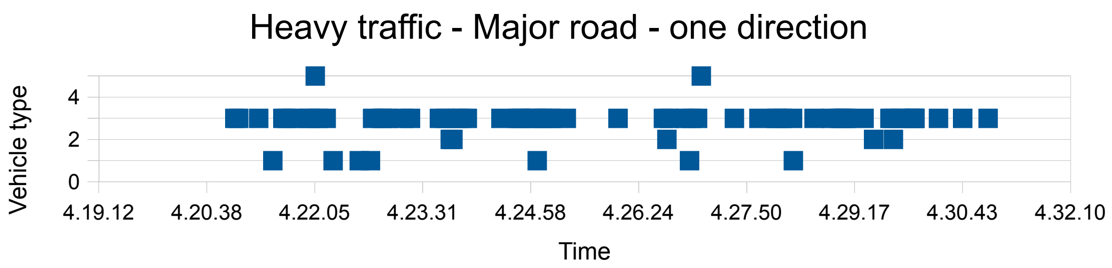


Figure 3.3 Timestamps of 10 minutes of pass by on the major road, in a single direction, two lanes, in the nighttimes (at 4:00 a.m.) for the 5 different vehicle classes: 1-scooters/mopeds; 2-motorbikes; 3-cars; 4-buses; 5-other vehicles.

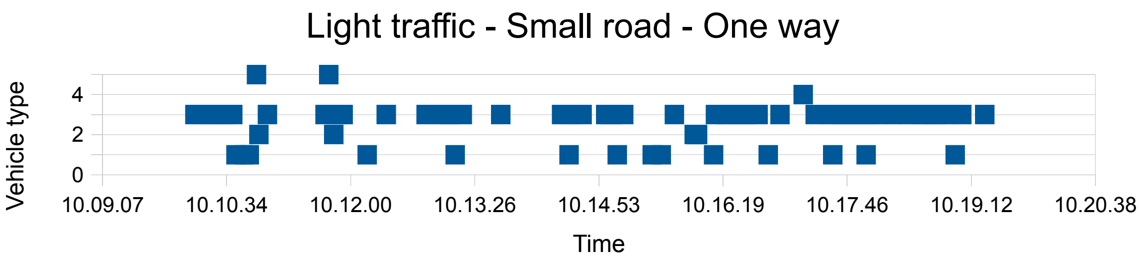


Figure 3.4 Timestamps of 10 minutes of pass by on the minor road, in a single direction (one way), one lane, in the morning (at 10:00 a.m.) for the 5 different vehicle classes: 1-scooters/mopeds; 2-motorbikes; 3-cars; 4-buses; 5-other vehicles.

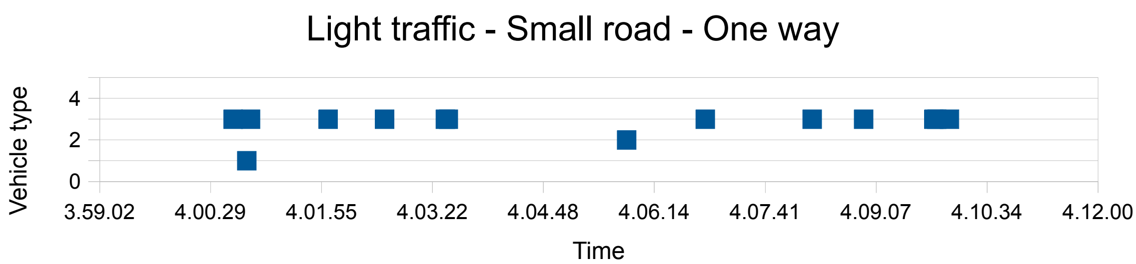


Figure 3.5Timestamps of 10 minutes of pass by on the minor road, in a single direction (one way), one lane, in the morning (at 4:00 a.m.) for the 5 different vehicle classes: 1-scooters/mopeds; 2-motorbikes; 3-cars; 4-buses; 5-other vehicles.

From the previous time patterns, and by having a look at the percentages of vehicles during the different time periods and in the different road sections, it can be noticed that vehicles' flow differs amongst the sites and the day/nighttime periods checked. It cannot, however, be concluded that the effect of such small change in the percentage of the different vehicles types would be a major cause of the overall noise levels shift.

To understand the potential change in overall noise level due to the change in percentage of vehicles, let assume that PTW have an average SEL of at least 5 dB more than car SEL. If the percentage of PTW shifts from 15% to 40% of the vehicles flow, it is possible to calculate the overall effect, which will result in an 1,8 dB increase. If the SEL difference between the average PTW and the average car is very large instead (e.g.: 10 dB) the effect can be quantified in 3,1 dB.

On the other hand, traffic flows in terms of overall number of vehicles, which are very much changing between day and night, in the two situations considered as a reference case are 5000 veh/h during daytime, and 800 veh/h during nighttime for the major road, and 400 veh/h during daytime and 30 veh/h during nighttime for the minor road.

Given, therefore, that in the calculated example the rate (max/min) of vehicle flow is 6 to 13, the effect in terms of dB difference is expected to be between 7 and 11 dB, confirming that vehicle flows remain the main parameters to be considered.

Table 3.1 Statistics over 40 minutes of traffic recording during day (10:00 a.m. to 10:40 a.m.) and nighttimes (4:00 a.m. to 4:40 a.m.), in both assessment sites.

Site/Time	% Scooter/Mop.	% Motorbikes	% Cars	% Buses	% Oth. vehicles
Major road/Day	31	8.8	57.1	0.7	2.5
Major road/Night	10.3	4.1	82.1	0.7	2.7
Minor road/Day	20.6	7.1	68.8	0.7	2.8
Minor road/Night	22.8	12.3	63.2	1.8	0

3.2 Development of the questionnaires

To assess annoyance, it was decided to perform some on site questionnaires to people passing - by, and have these as a basis for evaluating the parameters that mostly trigger the annoyance evaluation. For this purpose, the execution of the questionnaires was performed simultaneously with the recording of the acoustical parameters and the acoustical parameters were then linked to each response.

3.2.1 Preliminary considerations on the objectives of the questionnaires

By means of the questionnaire, it is foreseen that information is to be recorded on the annoyance of people, so as to feed any model to assess the annoyance. Therefore the final goal of the project is most annoying features of PTW to be identified and a limitation to be foreseen so as to consider that PTW is not annoying anymore.

Moreover, information shall be recorded on some factors that may influence the choice of the interviewed person.

3.2.2 Selection of the set of questions

The set of questions prepared included some general questions concerning the evaluation of the sounds/noise in the specific location where the questionnaire was asked, after that it included questions on the specific annoyance of the traffic noise and of the PTW, and concluded with a self evaluation of the sensibility of the interviewed person to noise. Some additional information recorded so as to classify the interviewed people was the age, gender and nationality of the person asked. Moreover in few cases it was reported that the interviewed person might have had some slight problems in understanding correctly the question posed.

The questionnaire included several questions with slight differences, so as to ensure that, whichever the understanding of the specific question was for the person, the next question would counterbalance the understanding by addressing almost the same problem (annoyance assessment) by a slightly different perspective.

It was found that simply by using the question about "annoyance of the acoustic environment", 6% less people would result annoyed, corresponding to approximately 5 dB less noisy environment. This simplification was therefore creating a bias (overestimation of annoyed people if compared to other standard questionnaires in other studies) in the analysis which shall be kept in mind, though ensuring more consistent results.

It is relevant to remark that all interviewed people were instructed clearly to think about the specific moment when they were interviewed, and the location where they were interviewed, not to answer considering their general opinion about noise. Words like "now", "in this moment", "here", "at present" were used repeatedly to make the interviewed person focus on judging the acoustic environment "there and at that time".

The following questions were asked:

What is your reason for being in this area / at this site?

(Any answer possible)

How frequently are you in this area, at this site?

(from first time to often)

How long have you been /in this area /walking along this road/ at this site so far today?

(from less than 5 minutes to more than 30 minutes)

What is your evaluation of the acoustic environment (the overall sound) during your present visit to this area / site?

(from not at all quiet to very quiet)

What is the quality of the acoustic environment during your present visit?

(from very bad to excellent)

How annoying do you consider the acoustic environment during your present visit?

(from not at all annoying to extremely annoying)

Specifically in this area / at this site, how annoying do you consider sounds heard from the following possible sources?

-General road traffic (Not at all annoying up to extremely annoying)

-Motorcycles and scooters (Not at all annoying up to extremely annoying)

Do you consider yourself, generally speaking, as being sensitive to noise in your surroundings?

(from not at all sensitive to very sensitive)

3.3 Combinations selected for the questionnaire and the test sites

Site 1

This site is the one that represents a heavy traffic and people walking next to a road with heavy traffic. Occurrences are plot in the diagram of figure 4.2.

This site allowed evaluation of the parameters above in a situation where almost constant and heavy traffic is present.

Figure 3.6Location of microphone for test site 1. The microphone is at 7.5m/1.2m from the centre of the nearby lane. People are walking along the sidewalk at the same distance from the road. The red-yellow dot represents the microphone position.

Site 3

This site is the one that represents well people walking about 100m from a road with heavy traffic, in a park. Occurrences are the same as in site 1, except for some occasional scooters/mopeds pass-by (2-4 per hour).

Figure 3.7 Location of microphone for test site 3. The microphone is at 1.2m height and 80 m from the centre of the nearby lane of the heavy traffic road. The microphone is on an elevated location, since the terrain is hilly in such location. People are walking along the sidewalk and through the grass in the park at the same distance from the road. The red-yellow dot represents the microphone position.

This site allowed evaluation of the parameters given above in a situation where almost constant and heavy traffic is present, but where many sounds and vehicles are simultaneously heard, given that it is quite far from the major road.

Site 4

This site is the one that represents a heavy traffic and people walking far from the traffic and inside a park. This site allowed evaluation of the parameters given above in a situation where almost constant and heavy traffic is present, but noises are heard from a bit far (main sources are 100m to 200m away, and screened by a low wall) and in the middle of an embedded park.

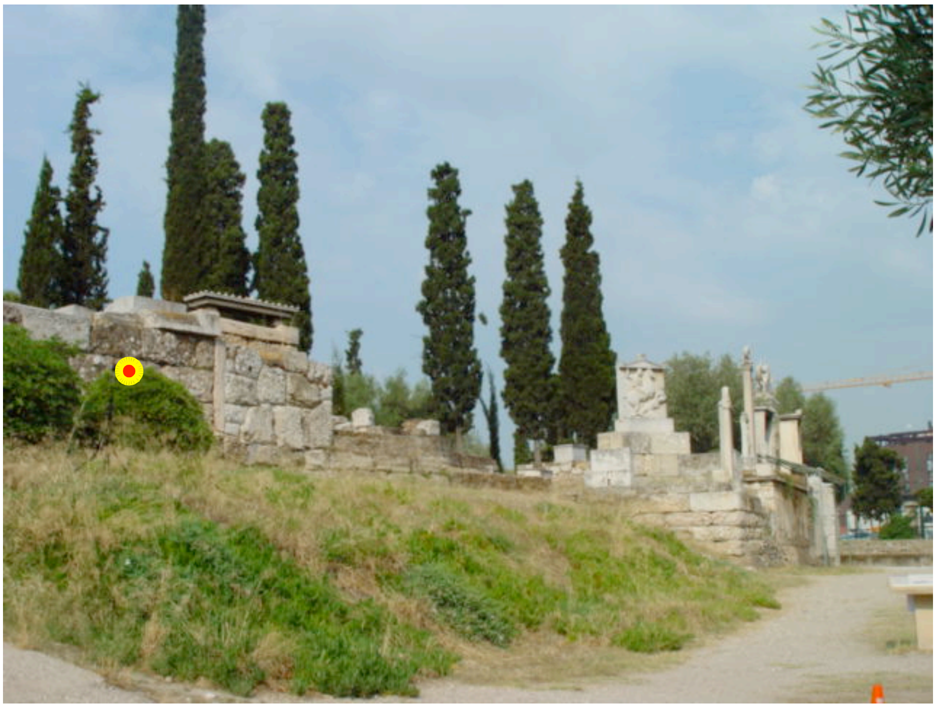


Figure 3.8 Location of microphone for test site 4. The microphone is at 1.2m height and in the middle of the monumental park. People are walking on average all around this place. The red-yellow dot represents the microphone position.

Site 0

This site is the one that represents a light traffic and people walking next to a minor road. Occurrences are plot in the diagram.

This site allowed evaluation of the parameters given above in a situation where discontinuous and light traffic is present, together with a relatively low background noise (about 55 dBA daytime and 45 dBA nighttimes). It is considered that, because this site is inside a dwelling area and because it is on a minor road and closely connected to a major road, it represents the potential Q-zone as it was defined in the CITYHUSH project.

At this site, it was also decided to use one measurement location at the facade of a nearby building. This measurement point cannot be taken as a reference, but is useful to give an indication of the variability that could be heard inside the dwellings and would eventually be used while testing the annoyance evaluation methods within the WP 5.3.

Figure 3.9 Location of microphone for test site 0. The microphone is at 7.5m/1.2m height and in a location which allows an unscreened road view on approximately 120°. People are walking on average all around this place. The red-yellow dot represents the microphone position.

3.4 Analysis of the measurement campaign

Microphones were placed at the assessment points, considered to be representative for the environment under assessment. The location of the microphones was selected close to the listener position, in the sense that the location was next to the place where people were passing by and were simultaneously interviewed (a few meters away) and at a height of 1.2 m. The height was selected so as to match at least two of the microphones next to the road, the standard assessment position used in source measurement standards, this being the 7.5 m from the source and 1.2 m above the road pavement. By this, it would be possible to directly compare the measurements performed here to any measurement performed in the past to qualify the source.

Concerning the source, this was quantified by means of a 24H/24H assistance of one or more operators, and manually each vehicle pass-by was recorded on an Excel sheet with a resolution of 1 s.

Concerning the speed of the vehicles, initially speeds were recorded by means of a radar scanner, preliminary tuned by means of the appropriate reference tuner. The speeds were typically in the range 40km/h to 60km/h. Only very exceptionally (once every 30 minutes) vehicles were found to exceed such speed. Given that it was quite difficult to measure each single vehicle's speed, and that doing it would have altered the running of the vehicles since the driver would think this was a police speed control, it was decided not to perform constant but only random checks. Indeed, in such situation of city traffic, the driving style was anyway pulsed, and all measurements included vehicles accelerating and braking, and not only running under constant speed. Overall, even if speed would have been recorded, it would not have been possible to get any relevant statistical information unless the running condition of the vehicle and its gear could be known as well. It is considered that the speed effect would in this case be of secondary matter of importance, and running condition would trigger the results a lot more.

On the microphones, the following parameters were recorded:

- L_{eq}
- L_5
- L_{50}
- third octave band levels
- loudness
- sharpness
- roughness
- and, almost during all measurements, the sound signal to allow any kind of post processing.

The data was post analysed, and three databases were created:

- the one containing information on the statistical parameters for single PTW and other vehicles pass bys (scooters/mopeds, motorbikes, cars, trucks, buses, other vehicles);
- the second containing the noise parameters of recordings with different types of time patterns for the vehicles pass-bys
- the third containing the statistical parameters of 3 minutes signal around the time of the interview, for each interviewed person (and linked to the responses to the interview).

4 RESULTS

4.1 ANALYSIS OF THE ACOUSTIC VALUES

The primary objective of the measurement campaign was to assess the vehicles' pass by noise in real running conditions and to retrieve the noise parameters of the different vehicle types in such environment, so as to compare the different noise signatures of the vehicles. In the following Table 4.1 results are presented for the pass bys recorded in the Athens site 1 (the one with the features required to perform a statistical pass-by). Only sharpness is left out since it did not varyamongst the different vehicle types and pass-bys (always between 0,9 and 1,2 Acum and mostly depending on the site).

Table 4.1- Values of the acoustic parameters for the vehicle types recorded in the Athens site, by different classifications and by different averaging. In brackets the differences in some relevant parameters if compared to the parameters found for the cars.

	L(A)eq	*L(A)max*	*L(A)5*	*SEL(A)*	*Roughness*	*RoughMAX*	*LoudMAX*		
Scooter	71,6	74,2	73,9	76,0	35,8	46,5	40,9		LinMEAN
	72,4	**74,7**	**74,5**	**76,4**	38,9	83,5	73,5		LogMEAN
	64,4	70,4	69,8	71,8	29,7	31,0	29,0		MIN
	75,6	76,8	76,7	79,4	47,1	95,0	85,0		MAX
Moto	72,3	76,9	76,1	78,4	34,0	40,5	49,8		LinMEAN
	73,4	**77,9**	**77,1**	**79,3**	35,6	43,0	50,6		LogMEAN
	66,5	70,0	69,5	72,6	25,9	34,0	43,0		MIN
	76,0	80,4	79,9	81,9	38,4	50,0	55,0		MAX
Scooter (noisy)	76,9	81,4	80,8	81,5	56,8	91,8	65,5		LinMEAN
	77,8	**82,5**	**81,9**	**82,7**	106,5	217,4	137,4		LogMEAN
	72,0	77,5	77,1	76,8	29,3	39,0	38,0		MIN
	81,8	86,7	86,3	87,0	119,0	230,0	150,0		MAX
Moto (noisy)	78,7	84,7	84,0	84,1	40,1	59,8	78,0		LinMEAN
	79,4	**85,3**	**84,4**	**84,7**	51,4	87,2	79,0		LogMEAN

	74,6	80,4	80,1	79,9	31,6	39,0	74,0		MIN
	82,2	87,3	86,1	87,2	58,1	94,0	84,0		MAX
Scooter (TOT)	74,6	78,3	77,8	79,1	48,0	**71,0**	**52,6**		LinMEAN
	76,2	**80,5 (+4,5)**	**80,0 (+4,4)**	80,9 (+3,3)	104,0	214,9	134,9		LogMEAN
	64,4	70,4	69,8	71,8	29,3	31,0	29,0		MIN
	81,8	86,7	86,3	87,0	119,0	230,0	150,0		MAX
Moto (TOT)	75,2	80,5	79,7	81,0	**36,8**	**51,2**	63,9		LinMEAN
	77,1	**82,7 (+6,7)**	**81,8 (+6,2)**	82,5 (+4,9)	48,1	83,8	75,6		LogMEAN
	66,5	70,0	69,5	72,6	25,9	34,0	43,0		MIN
	82,2	87,3	86,1	87,2	58,1	94,0	84,0		MAX
Car	70,9	74,3	73,9	76,4	33,7	**38,5**	35,2		LinMEAN
	72,8	**76,0 (+0,0)**	**75,6 (+0,0)**	77,6 (+0,0)	35,5	38,8	40,4		LogMEAN
	61,3	64,7	64,6	66,2	25,3	30,0	20,0		MIN
	80,9	84,1	83,6	84,4	45,9	50,0	55,0		MAX
Bus	73,4	77,5	76,9	80,1	**35,2**	**41,0**	**44,7**		LinMEAN
	74,1	**77,6**	**77,0**	**80,3**	35,9	42,0	46,1		LogMEAN
	70,3	75,9	75,7	78,2	31,3	38,0	40,0		MIN
	76,5	78,9	78,4	81,5	37,7	45,0	49,0		MAX

Vehicles were classified in 7 different classes (Cars, Scooters, noisy Scooters, Motos, noisy Motos, Buses, other vehicles). It shall be reminded that the primary objective of this WP 3.5 is to assess PTW effects, therefore the following choices were operated: cars and small vans were all classified as cars; the MDV and HDV corresponding to small and large trucks were classified as other vehicles and they were extremely rare, therefore are not reported in this evaluation; the PTW were divided in two classes Scooter and Moto, as described above, and moreover the operator was allowed to sub-classify these two classes to noisy Scooters and noisy Motos. This has been used mainly as a first test to see if there are evident distinguishing features to discriminate amongst standard and noisy PTW which can be appreciated clearly by a trained person on site. In the standard analysis, anyway, the standard and "noisy" were merged not to introduce a potential error in the evaluation, caused by manual differentiation amongst the PTW. An alternative approach would be to distinguish those for which the L_{Amax} is above or below the noise limit. Indeed the two classes of "standard" or "noisy" PTW are correspondingly below or above the appropriate limit. It is finally observed that on average the scooters are 3,5 dB above the limit and the motorbikes 2,7 dB. This gives an averaged indication of the tampering effect.

The assessment from here on was based on the values in bold underlined, namely: the LogMEAN (single values are averaged energetically) of L_{Amax}, L_{A5} and SEL concerning acoustic parameters, and the LinMEAN (single values are averaged algebraically) of roughness, roughMAX (maximum of the roughness derived for each 1s along the whole vehicle pass-by) loudMAX (loudness being exceeded for 5% of the pass-by). As it appears from the table of values, the L_{Amax}, L_{A5} and SEL may most likely be alternatively used as representative discriminators amongst the different vehicle classes, since the relative differences (considering a u_{sou}=(2,5/sqrt(n)))=0,5 dB potential error in the measurements) display almost identical results (e.g.: scooter L_{Amax} is 4,5 dB more than car, scooter L_5 is 4,4 dB more, scooter SEL is 3,3 dB more). This is confirmed by the statistical analysis of the cross-correlation amongst parameters measured: the three noise level related indicators are linearly linked and the correlation is very good (R^2=0,99 amongst L_{Amax} and L_{A5}, and R^2=0,81 amongst L_{A5} and SEL) thus meaning that being not independent but linearly correlated one of the three can alternatively be used.

Therefore, for simplicity in its use and in order to easily derive the L_{DEN} and L_{night} that will be used in the following analyses and due to the fact that it has been considered in past annoyance studies, the SEL is considered.

Concerning the psychoacoustic parameters, LoudMAX and roughness are considered. LoudMAX is giving a psychoacoustic interpretation of the increase in annoyance and is used in psychoacoustic studies. The roughness (linearly linked to the roughMAX, R^2=0,9) is not well correlated neither to other noise level dependent values, nor to the vehicle type, but it can be seen that the spread of roughness values (in positive) is higher in scooters than in motorbikes. The two are finally correlated amongst themselves (R^2=0,9): the roughness is chosen amongst the two as the parameter to be analysed.

Therefore, the analysis of the significant differences are reduced to the analysis of the following parameters: SEL, roughness, LoudMAX.

PTW display on average higher levels than that of cars on all three parameters. At a first guess, therefore, higher annoyance is expected. By looking at the values obtained, to explain annoyance based on psychoacoustic parameters [1], it is resulted that loudness is the essential parameter that sensibly increases the annoyance of people, and roughness plays a secondary role. Not withstanding this secondary role on annoyance, roughness is in many cases a discriminating parameter which is much higher that other vehicles for scooters and mopeds.

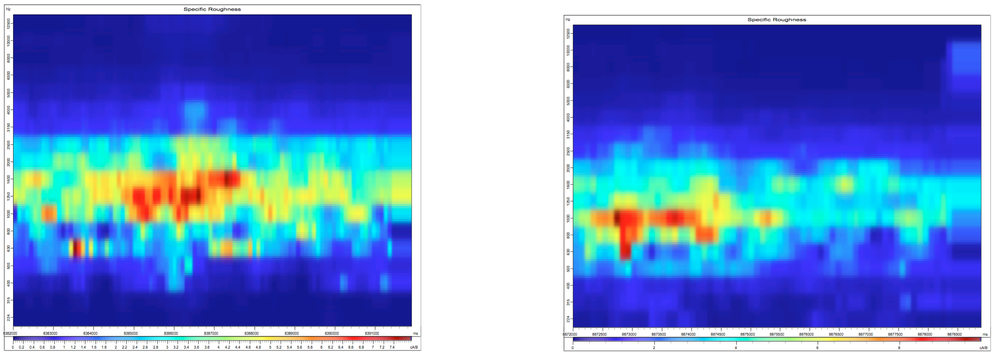


Figure 4.1 Example of the roughness of a scooter pass-by (left) and a car pass-by (right). It is evident that roughness is found for the scooter noise for a longer period of time during the pass-by and on a broader range of frequencies.

To have a simpler picture of the results obtained, the values found are normalised respectably to an average car pass-by, i.e.: the results difference is taken in respect to the SEL of a car, a relative roughness in respect to car roughness and a relative loudness in respect to the car loudness.

Results following this simplified approach are summarised in the following table 4.2:

Table 4.2 – Normalised values of the different acoustic parameters considered. The car is taken as a reference.

	SEL	Roughness	Loudness	SEL based annoyance	Psycho-acoustic annoyance
Car (reference)	+0,0 dB	1	1	1	1
Scooter	-1,2 dB	1,06	1,17		
Scooter (noisy)	+5,1 dB	1,69	1,86		
Motorbike	+1,8 dB	1,00	1,41		
Motorbike (noisy)	+7,1 dB	1,19	2,22		
Scooter (TOT)	+3,3 dB	1,42	1,49	≈1,06	1,51
Motorbike (TOT)	+4,9 dB	1,09	1,81	≈1,08	1,79

It is evident where the major differences are found: **motorbikes are commonly much louder than cars, and scooters are louder and rougher than a car pass-by.**

Approximately two car pass bys correspond to one scooter pass by and three car pass bys correspond to one motorbike pass by.

4.2 Analysis of the traffic compositions to be used

Four basic traffic conditions of day/site 1, day/site 4, night/site 1, night/site 4 are used to determine the set of cases used for the annoyance analysis and the impact assessment analysis. The percentages of vehicles are represented in the following diagram. Based on these percentages, overall levels are derived for the parameters used in the assessment.

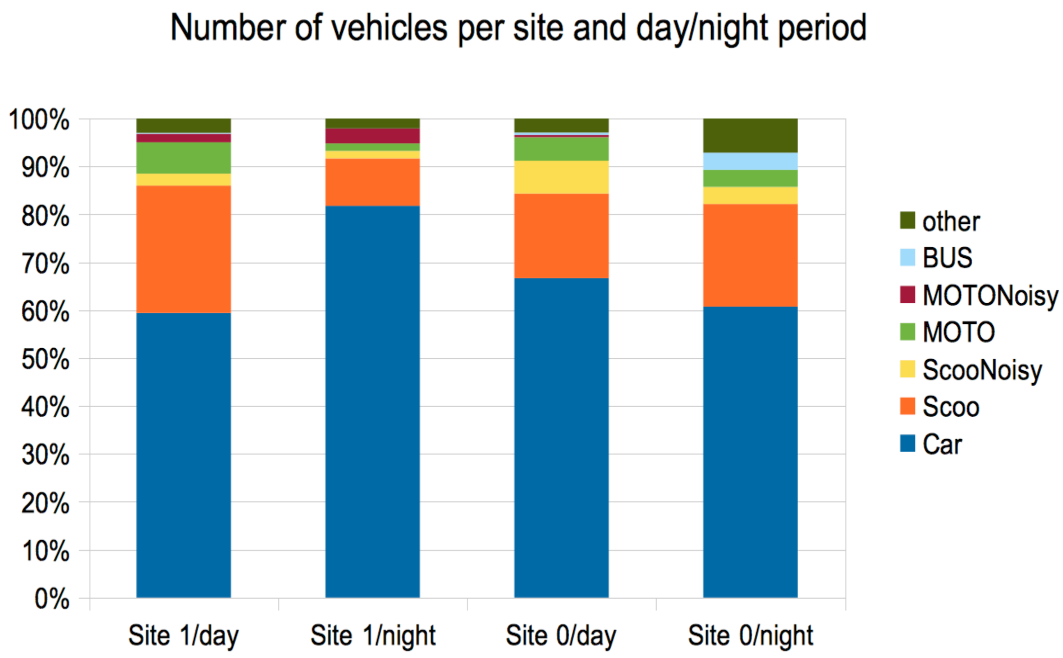


Figure 4.2 The graph represents the percentages of the different vehicle types during the day-time and night-time in site 1 and in site 0. Specifically, cars are never less than 60% of the pass-by and PTW overall are never more than 37% of the pass-by.

The equivalent noise levels representative for the different locations and night or day period are derived, to be later used to determine the annoyance foreseen indoors and outdoors at the test sites. Moreover, it will constitute the base scenario of the further analysis in the impact assessment.

To cross check that the averages found for vehicles pass bys were representative of the fleet, the noise levels obtained were compared in all cases towards the measured average noise levels, finding a consistent result (within a few tens of dB in most cases).

Table 4.3 – Noise levels attributable to specific vehicle types in the sites of assessment both for day and night times.

	Site 1/ day	Site 1/ night	Site 0/ day	Site0/ night	Site 3/ day	Site3/ night	Site 4/ day	Site 4/ night
Car	73,3	67,0	66,4	55,6	59,3	53,0	47,3	45,0
Scoo	70,3	58,3	62,2	51,6	56,3	44,3	44,3	36,3
ScooNoisy	75,9	66,2	67,5	59,7	61,9	52,2	49,9	44,2
MOTO	68,1	54,2	59,4	47,7	54,1	40,2	42,1	32,2
MOTONoisy	69,0	63,7	55,9	-99,0	55,0	49,7	43,0	41,7
BUS	55,5	-99,0	52,4	50,7	41,5	-99,0	29,5	-99,0
Other	67,8	58,5	60,2	53,7	53,8	44,5	41,8	36,5
Tot Calculated	79,6	71,2	71,5	62,7	65,6	57,2	53,6	50
Tot Measured	80	70,8	68,3	65	65	56,6	53	49,2

4.3 Analysis of the responses to questionnaires and derivation of outdoor noise annoyance curve

The questionnaires were analysed linking a person's response to each question to the noise parameters recorded in the three minutes that the questionnaire lasted. Specifically, the noise parameters were recorded and analysed from 1 minute before the beginning of the questionnaire to 2 minutes after the beginning of the questionnaire, thus considering that all the significant events that may have affected the response to the questionnaires analysis were considered (three minutes was a bit more than the average time required to perform a questionnaire).

Before choosing to relate the responses to the noise values, a thorough cross correlation analysis was performed amongst the questions posed and the noise indicators used (the L_{Amax}, L_{A5}, L_{Aeq}, roughness, sharpness and loudness), so as to find if some parameters could be used for correlation analysis.

The first hypothesis is that, amongst the parameters considered in three minutes recording (L_{Amax}, $L_{A5,}$ L_{Aeq}, sharpness, loudness, roughness), at least one would closely correlate to the responses to the questionnaires in questions regarding noise annoyance. It is found that, during the 3 minutes of the interview, sharpness correlates slightly better to the responses concerning annoyance than the other parameters (Pearson correlation coefficient 0,27-0,29). But sharpness was not acquired in all interviews, and therefore, after having compared again the correlations based on the same subset of the database containing all the parameters, it is found that both roughness and sharpness are slightly better correlated than other parameters, and that sharpness looks to better correlate only given that one single sharpness value was used for site 4, and at site 4 annoyance was usually low because of the low noise levels. Anyway, given that the Pearson correlation coefficient is always between 0,09 and 0,22, relatively low, it may not be concluded that one parameter is clearly better than others.

Potentially, other questions and noise indicators, used in combination, may improve the correlation of the results, but this was verified only in one case, namely that by averaging the answers to the three questions concerning the acoustic environment the correlation with the L_{Aeq} was improved (What is your evaluation of the acoustic environment (the overall sound) during your present visit to this area / site? - What is the quality of the acoustic environment during your present visit? -How annoying do you consider the acoustic environment during your present visit?).

Choosing for simplicity and for consistency with other past researches the L_{Aeq} and the responses to the annoyance (the three questions on the acoustic annoyance averaged) a noise annoyance curve could be obtained (R^2=0,55, curve equation %A=1,36LAeq-16), showing consistent results amongst the five sites where interviews were performed. This curve is plotted in figure 4.3. The annoyance was derived as follows: first, the each person's answers to the three questions were averaged by inverting the 0-10 scale for the first two questions (therefore a very poor acoustic environment rated 3 corresponds to 10-3=7 in the annoyance curve derived). Then, the number of people reporting more than 5 and half of those reporting exactly 5 was counted for each 2,5dB wide classes between 50 and 80 dB Laeq, and finally a linear interpolation was derived.

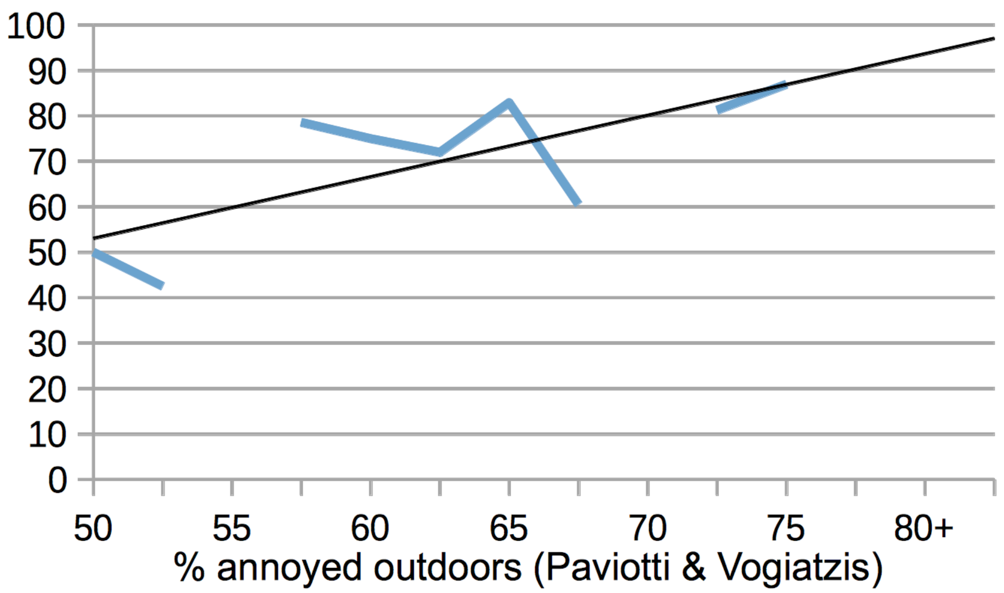


Figure 4.3 The graph represents the percentages of people annoyed at various noise levels outdoor. The line in blue are the results based on the in field survey, in classes of 2,5 dB, In black the representation of the linear interpolation derived.

Given the specific objectives of this WP, It is also necessary to compare the annoyance evaluated for the general traffic with that of the PTW specifically. Interestingly, there is an apparently unclear correlation between L_{Amax}, L_5 or roughness and the responses given by the interviewed people concerning the annoyance of general traffic and the annoyance of PTW. It seems that it is the overall environment that influences the judgment of the person, not simply the percentage of the PTW pass-by.

It is first observed that on site 4 (where PTW are 37% of the vehicles pass-bys), the annoyance due to PTW is very low and much lower than the general road traffic annoyance. Most likely this is due to the fact that the PTW noise is not easily distinguished when far from the source and when a continuous traffic is present. Though, the noise level produced specifically by PTW is the same as that produced specifically by cars.

At site 1, where PTW are passing close by, and with the same frequency as at site 4 (same road, questionnaires simultaneously asked) the evaluation of PTW annoyance is equivalently low, and in any case the general road traffic is evaluated as more annoying than the PTW.

At site 2 the responses are very few to be used.

At site 3 the major road is 70 meters away and screened by a garden which forms a hill, but in the local pedestrian road where interviews were performed scooters and mopeds accidentally passed by at very low speed. This may be the reason why respondents show that, like in site 0, the annoyance from PTW is equivalent to that of the general traffic.

At site 0, where single events are clearly distinguished (it is a small one way road where PTW are 30% of the traffic) the PTW, though their presence and contribution to L_{Aeq} is again comparable to that of the cars, the annoyance from PTW is as annoying as that from general traffic.

Table 4.4– Percentages of annoyed people from all road traffic or from PTW only in the five sites.

	%annoyed general traffic	*%annoyed PTW only*
Site 0	78	79
Site 1	89	73
Site 2	25	0
Site 3	70	70
Site 4	61	46

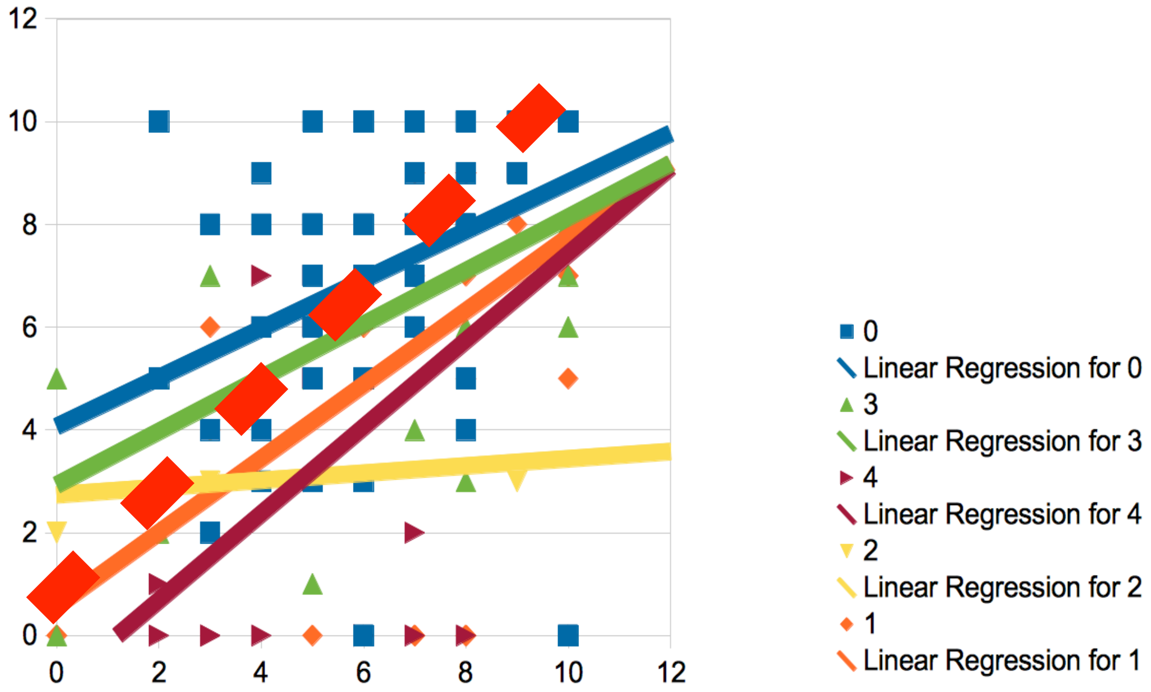


Figure 4.4 The graph represents the combinations between annoyance reported for general traffic (rated in x axis) and PTW specifically (rated in y axis), and presents regression lines showing if there is any bias in the judgment of the two annoyances (this is the difference respect to the thick red dotted line). e.g.: the blue line explains that for site 0, if general traffic annoyance is rated low, that of the PTW is rated relatively higher.

A clear conclusion regarding the specific annoyance of the PTW cannot be drawn. Probably the most relevant parameter to predict annoyance remains the equivalent noise level, eventually quantified as SEL due to the single event, not only for cars but for PTW as well.

The proposed explanation is that the annoyance is due to the noise level primarily (e.g.: SEL) given that the highest differences in annoyance responses, as well as correlation, were seen as a function of different noise levels. But other characteristics of the pass by noise may influence responses. This may be due the fact that some PTW have much higher L_{Amax} than other vehicles, and that roughness of scooters and mopeds is high. These two properties may be the ones that cause the attraction of the listener's attention (or distraction from other activities) therefore giving the impression that specifically the PTW is the source of annoying noise (e.g.: like on site 3 and on site 0). When the listener is afterwards asked to respond to the questionnaire, these facts trigger his answer. In a diluted traffic flow, the specific features of the PTW like roughness allow to identify them separately from the general traffic, while in a dense traffic flow maximums in noise levels and roughness are faded by the presense of many vehicles, therefore only the contribution to the L_{Aeq} remains relevant. If PTW are not specifically recognised amongst the traffic, they are consequently not specifically rated annoying.

This is the case e.g.: of site 1 and site 4, where though the number of PTW is consistent, the specific PTW annoyance in respect to general traffic is lower.

Overall, a possible **first rule** for annoyance may be that whenever the PTW are mixed into the traffic, they follow the same annoyance curve as road traffic in general, and the annoyance depends on the combination of the number of vehicles pass-by and average SEL. Simultaneously, the fact that L_{Amax}, L_{A5} and roughness are particularly higher than those of a car may be regarded as irrelevant because these features “are acoustically masked by the noise of many other vehicles”. Instead, whenever the pass-by can be distinguished and heard separately, the L_{Amax} is higher and roughness leads to higher annoyance than that expected based on SEL only, because distraction due to increased saliency comes in as an annoying extra factor (e.g.: [26]).

An idea to set **a second rule** for this increased annoyance is to take into account the weighting factor of Vos (4,6 dB) and look at the difference of the annoyed people in the sites 1-4 towards 3-0. Taking the annoyance curve we come up to the relationship: 4,6 dB = 8% of the population being more annoyed. Instead, given the same noise values are recorded for cars and PTW in all sites, the fact that in 3-0 there is 15% more for PTW than 1-4 may be taken as the approximate measure of the increase because of the specific noise signature of PTW. Somehow, the figures therefore show that **8-15% is most likely the range of increase of the percentage of annoyed people associable to the specific PTW noise signature features, in respect to the annoyance already foreseen due to noise level (e.g.: SEL) only**.

Based on these values and assumptions, it was decided to try fine tuning the curve as follows: the points not statistically representative (where 1 or 2 responses were available) were removed; the questionnaires posed on site 3 and on site 0 were “underweighted” by 12% annoyed people, to account for the factor proposed above to be caused by identifiable single PTW pass-by. The result is an improvement in R^2 to 0,7 and new linear relationship amongst L_{Aeq} and %A becomes:

$$\%A=1{,}27L_{Aeq}-16$$

At the moment a set of listening tests shall confirm these assumptions, but it is the only explanation found acceptable to justify the responses both of site 0, 1, 4 and 3, and having in mind what were reported by other studies as well [5],[17]. Unfortunately, it remains undetermined which specific characteristics of their noise signature (higher L_{Amax}, L_5 or roughness) is the one triggering this extra annoyance.

Such a modified curve is now quite in line with the one found for aircraft noise in US national parks by Anderson et al. (27) , The only difference is that the curve found in our study still shows at least 10% more people annoyed than those foreseen based on the results of [27]. But, again, this is approximately the expected excess due to averaging amongst three questions. Also, the curve here is based on much higher ranges of exposure.

This annoyance curve (relationship) will be used in the estimations of noise annoyance.

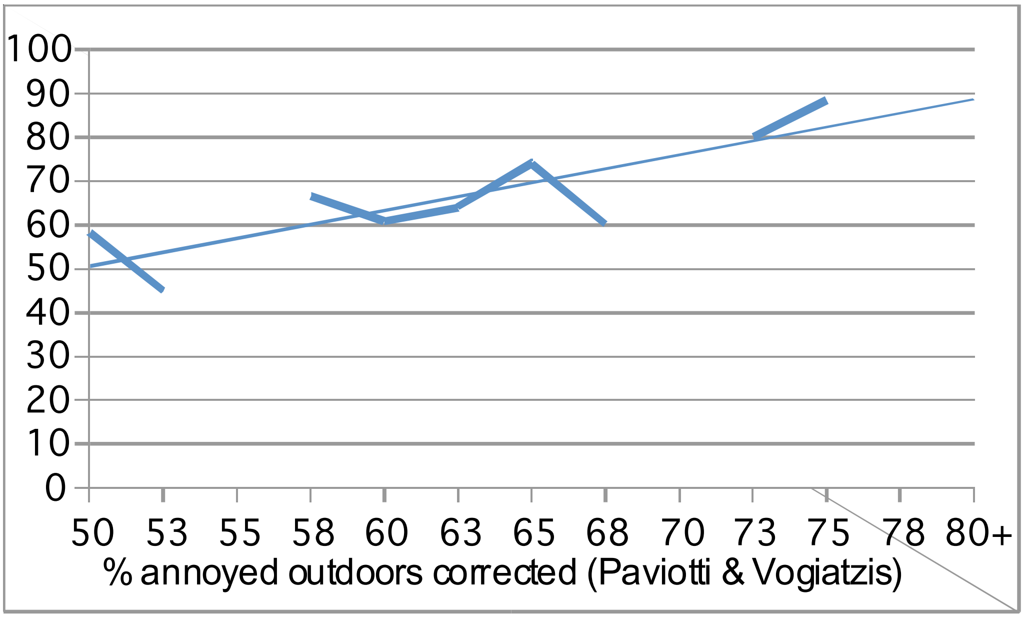


Figure 4.5 The graph represents the percentages of people annoyed at various noise levels outdoors. The thick line in blue shows the results based on the in field survey, in classes of 2,5 dB, after correction for the effect of single pass by of PTW. The linear interpolation derived is represented by the slim line.

4.4 Analysis of the annoyance indoors

To estimate the annoyance indoors, the model developed by the WP2 is used. This model specifies various possible correction factors (e.g.: building insulation, hours passed with open windows, windows insulation, presence of quiet side, etc.) depending on the specific building features next to the assessment point. The analysis of this WP is not meant to assess a specific area and specific buildings in a given city, but to simply prepare a theoretic set of cases to verify if the ban of the PTW, or simply the use e.g.: of low noise or electric ones, may improve the situation. Therefore, no correction factors proposed in WG2 work are considered here, and the general formula for annoyance rating indoors is used.

Four cases are considered for the noise annoyance indoors of a standard configuration building: the first location is at the major road, the second is at the minor road, the third is assumed to have 20 dB less than what measured next to the major road, thus representing a fictitious second row of buildings, and finally the fourth is assumed to have 20 dB less than what measured next to the minor road, again to represent a fictitious building on the second row.

The following formula is used:

$$\%HA = 9.868\cdot10^{-4}(L_{DEN} - 42)^3 - 1.436\cdot10^{-2}(L_{DEN} - 42)^2 + 0.5118(L_{DEN} - 42)$$

Table 4.5 - L_{Aeq} noise levels obtained for the different vehicles types at the assessment location.

	Site 1/day	Site 1/night	Site 0/day	Site 0/night
Car, Bus, other	75,8	67,6	67,2	60,6
Scoo	70,3	58,3	62,2	51,6
MOTO	68,1	54,2	59,4	47,7
Tot Calculated	79,6	71,2	71,5	62,7

Table 4.6 - Estimated percentage of highly annoyed people at the assessment locations based on the formula given by CITYHUSH-WP2.

	Site 1	Site 0	Site 1 (-20dB)	Site 0 (-20dB)
% HA with PTW	53,1 %	28,7 %	10,4 %	4,6 %
% HA without PTW	40,7 %	21,5 %	7,3 %	2,9 %

Indoors annoyance following this model shows that on the most exposed site about half of the population is be expected to be highly annoyed and if the PTW are banned totally, this percentage is reduced by approximately 12%. Instead, on site 0 at the most exposed building, the PTW increased annoyance indoors by approximately just 7% of the population. Lower increases (about 3% and 1%) are expected for the fictitious “second row of buildings”.

Therefore, it seems that the most visible effect of reducing or completely eliminating the PTW noise annoyance indoors is on the small site, on the most exposed building. Instead it is most likely that the formula proposed falls outside the boundaries of the noise levels for which it has been developed, and probably a large reduction effect on the annoyance can be found as well in first row on the major road.

5 PROPOSALS

The analysis performed confirmed that the PTW has some specific noise signature which is expected to be more annoying than cars. The distinguishing features can be summarised in a higher noise level (L_{AMAX}, L_5 and SEL mostly leading to higher loudness) and higher roughness. These high values of L_{AMAX}, L_5 and SEL seem to slightly effect the situations were the PTW are mixed to high traffic density and are not the most frequent vehicle type (e.g.: it was seen that on site 1 and 4 both on outdoor and indoor annoyance the effect of removing the PTW would be small), though their presence in terms of percentage of vehicles is significant. Instead, in the intermediate situations where the PTW are mixed to low traffic and each single event can be distinguished, the effect of removing the PTW can be more sensible regarding outdoor annoyance (e.g.: the questionnaires showed more annoyance from PTW in the small site) while it is not so effective on indoor annoyance, as shown in the results based on the model from WP2, displaying here low difference amongst with/without PTW).

Based on the existing evidence and having in mind the test sites used, it seems that the PTW cannot be considered to be effective on noise reduction measures without addressing the other traffic in most situations, like the case of the major roads and minor roads for locations relatively far from the road. Instead, the reduction of the L_{Amax}, (consequently and expectedly L_{A5}, SEL and loudness) and roughness mostly in low traffic roads may reduce the annoyance both outdoors and indoors.

Therefore, it is proposed as a priority to intervene by reducing the noisier PTW in small roads, and by intervening in parallel by reducing, on major roads, the number of (and possibly the noisiest) PTW together with the number of other vehicles as well.

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