DELIVERABLE 2.10

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Work Package 2.1	**Identify/Rank Perception of Noise Sources**
	Identification and ranking of noise source elements
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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

The following report describes the work done and results gained in WP 2.1.1 during month 13 to 18 of QCITY.

The first objective for these six months is the completion of the database, which compilation was started during the first twelve months of QCITY (see D2.1). The gathered data is presented including an evaluation of the single vehicles by means of spectra and dB(A). This database is used for the qualitative analysis of vehicle noise sources (e.g. engine, tires, etc.) as well as an input for the subjective evaluations in WP2.2.2, WP5.12 and the sound library of the TrafficNoiseSynthesizer software generated in WP2.2.3.

The second objective is qualitative comparison and analysis of the different vehicles and their noise sources to generate a ranking. As a first approach conventional parameters like spectra and dB(A) are used for the comparison. Further the results of the subjective evaluations of WP2.2.2 (see D2.8) are used to compare the vehicles with respect to their perception.

0.2 STRATEGY USED AND/OR A DESCRIPTION OF THE METHODS (TECHNIQUES) USED WITH THE JUSTIFICATION THEREOF

The generation of the database during the first twelve months of QCITY started with an evaluation of the existing databases of the work package partners. Hereby, already existing data could be implemented and unnecessary measuring efforts could be avoided (see D2.1). Since the exploitation of the existing databases did not provide a sufficient amount of data, a measurement campaign for the extension of the database was launched. It uses a method for measuring emissions of main noise sources and immission at an observer position for typical urban driving situations. The measuring procedure for this overview cannot be very in-depth but is rather qualitative due to the large number of vehicles to consider. This data acquisition could not be finished within the first twelve months and was therefore continued.

The compiled data is an essential input into WP2.2.2 to generate a tool for the calculation of perceived annoyance of vehicle exterior noise. The procedure and final calculation method EI (evaluation index) is presented in D2.8.

The evaluation of single vehicles begins with a qualitative analysis by means of spectra to correlate source emissions and far field immission. This is followed by the determination of the main noise sources for each vehicle and driving situation. Based on this, a ranking is generated.

For the comparison of the vehicles the contributions of the single noise sources at specific driving situations are analyzed to get insights about similarities and differences regarding vehicle classes and characteristics. An evaluation of the specific maximum

SPL leads to a comparison of the relative importance of vehicles for the SPL of traffic noise.

The results of the listening tests of WP2.2.2 are integrated into the comparison. Hereby, the vehicles and their noise sources are not only compared regarding their physical parameters but regarding their subjective perception. This reflects the generated annoyances of the vehicles.

0.3 PARTNERS INVOLVED AND THEIR CONTRIBUTION

HEAD acoustics (HAC) did all the measurements to complete the database. The evaluation of the compiled data was performed by HEAD acoustics.

STIB/MIVB (STIB) supported the tram measurements.

0.4 CONCLUSIONS

A database was completed which gives a rough but comprehensive overview over a large number of vehicles and transportation means and their noise sources. It provides input for different deliverables and work packages (WP2.1, WP2.2, and WP5.12).

The analysis by means of spectra and dB(A) shows only small deviations within the passenger car fleet. The power train is generally the main noise source at the considered driving situations regarding commercial vans and public transport busses. Regarding the passenger cars combustion noises is relevant for acceleration situations. Primarily rolling noise is emitted at approach and deceleration and during the pass-by with a constant speed above 50 km/h.

Following the dB(A) the influence of the power train noise is small comparing roll50 and const50. The subjective evaluations of WP2.2.2 show that the presence of combustion noise influences essentially the perception. Improvements of the traffic noise level in inner cities can be gained by introduction and support of new and quieter driving systems and traffic control measures. Rolling noise becomes important for constant pass-by at speeds above 50 km/h. Here quiet road surfaces and tire designs can improve the noise situation.

The most important factor for noise generation is the driving condition. For accelerations and low speeds the combustions noise is dominant. It had to be differentiated between strong engine noise – especially diesel engine noise – and moderate / low engine noise. Regarding constant pass-by at speeds above 50 km/h the type of tire and road surface will be decisive for the perception.

0.5 RELATION WITH THE OTHER DELIVERABLES (INPUT/OUTPUT/TIMING)

D2.1: Development of measuring procedure and start of database compilation

D2.8: Input of database, Output of subjective evaluations

TrafficNoiseSynthesizer (WP2.2.3 & WP5.12): Input of database and data for traffic flow scenarios

1 INTRODUCTION

In WP2.1 data about different transportation means and their respective noise sources is collected and evaluated to rank the noise source elements (D.2.10) and draw conclusions about the future potential of the noise sources (D2.9). Two different approaches are chosen to collect the data. On the one hand, a comprehensive overview over a large number of vehicles and transportation means and their noise sources is needed to get an impression how the current urban traffic noise is composed – beginning from the single noise sources up to vehicle classes and groups. The measuring procedure for this overview cannot be very in-depth but rather qualitative due to the large number of vehicles to consider. On the other hand selected vehicles will be analyzed more thoroughly to determine quantitatively the contribution of single noise sources to the overall noise of a specific vehicle. The former method is subject of WP2.1.1 and its progress and analysis is described in this deliverable. The latter is the objective of WP2.1.2 and the evaluation subject of D2.9.

WP2.2.2 relies on all the gathered time signals to carry out listening test and psychoacoustic analyses. The exterior noise of the various vehicles is compared and the determined contributions of the noise sources are evaluated. The qualitative results of the listening tests are used to define a calculation method using quantitative psychoacoustic parameters and to prepare a bonus-malus-system for vehicles and their noise sources. Hereby, a tool for the calculation of the subjective annoyance of pass-by noise – called evaluation index EI (see D2.8) – is created and implemented in the TrafficNoiseSynthesizer software (WP 2.2.3). This will be further enhanced and improved for traffic flow noise and filtering in WP5.12. Concerning WP2.2.3 the recorded data is a part of the sound library of the TrafficNoiseSynthesizer software and therefore accessible for all the partners within QCITY. It can be subject to filtering. The filters can be calculated in respect to various mitigation conditions defined within ISO 9613 or imported from other measurements or calculations of mitigation measures.

All the topics mentioned above are strongly related to the enhancement of the TrafficNoiseSynthesizer in WP5.12. The gained recordings of and information about single vehicles and their noise sources in specific driving situation will be combined for the auralization of a traffic flow at a specific road section with a specific vehicle fleet composition. The synthesized traffic flow can then be analyzed concerning its subjective perception using the results of the psychoacoustic analysis.

The following report describes the work done and results gained in WP 2.1.1 during months 13 and 18 of QCITY. The objective for these six months is the completion of a database, which gives a rough but comprehensive overview over a large number of vehicles and transportation means and their noise sources. Further a qualitative comparison of the main noise sources of the different transportation vehicles (e.g. engine, tires, etc.) is carried out.

First of all, the database of D2.1 has to be completed. The database has to include data of different vehicles in different driving situations concerning the emissions of the noise sources and the immission at a chosen observer position. It should be sufficient to guarantee the rough but comprehensive overview. Most important is the fact that the included data has to be time signals, since it also serves as an input for further work in different work packages (WP2.1, WP2.2, WP5.12). It will be subject to various analyses, auralization and listening test.

The final step for the compilation of this database is the completion of the extensive measurements campaign started during the first twelve months of QCITY.

Starting from the acquired data, the single driving situations of the single vehicles were analyzed for the contribution of the single noise sources to the overall far field noise at the observer position. The analysis starts with using standard objective means like spectra and dB(A). The results for the single vehicles are combined and compared to find similarities and differences between certain groups or classes of vehicles. The second step is the integration of the listening test results of WP2.2.2 (see D2.8) into the comparison. Here the effect of the different noise sources on the subjective perception can be analysed. This helps to identify characteristics that really improve the living quality in cities by reducing annoyances and not only dB(A).

2 FURTHER DATA ACQUISITION FOR VARIOUS TRANSPORTATION MEANS

The exploitation of the existing databases does not provide a sufficient data base for the qualitative analysis. Therefore, an additional measurement campaign aims on a rough but comprehensive survey over a large number of vehicles and transportation means. This includes vehicles of different classes, motorbikes, trucks and public transport like busses, trams and metros.

Due to the large numbers of measurements necessary a new test procedure for further data acquisition is developed. The main criteria are a fast and flexible application and the consideration of the most important noise sources.

For this method a fastening system for microphones was developed, that allowed fast and adaptive instrumentation at the vehicle. It consists of different magnetic bases, a linkage system and BNC mounts for the microphones (see Figure 1).

Figure 1: Examples of microphone positioning with developed fastening system. top: tire trailing edge, tire leading edge; middle: engine, engine, exhaust; bottom: exhaust, gear box (from WP 2.1.2)

The complete measurement procedure for a vehicle can be carried out within one working day. This includes instrumentation, actual measurements and demounting.

Hence, it is possible to react flexibly to vehicle availability at short notice and keep down costs.

The later evaluation of the recorded data is called **Qualitative Component Analysis**. The term "qualitative" indicates that no quantitative figure results from this analysis. The aim is a ranking of the main noise sources by objective and subjective evaluation of the far field recordings. Striking or annoying patterns which occur in the far field recordings can be related qualitatively to the different components. Since no transfer functions – as in WP 2.1.2 – are measured it is not possible to get a quantitative link between far field and near field recordings.

2.1 MEASUREMENTS FOR THE QUALITATIVE COMPONENT ANALYSIS

The measurements are conducted on a street near HEAD acoustics in the surrounding of Aachen. A real street instead of a test track was chosen for several reasons. On the one hand a representation of a real urban pass-by sound is rather realized with real tarmac then with ISO 362 surface. On the other hand it is independent of test track reservation etc. and it avoids additional costs, especially regarding the number of measured vehicles.

In principle, any driving situation can be considered. For QCITY five typical urban driving situations are chosen:

- constant 30 km/h – *const30*,
- constant 50 km/h – *const50*,
- medium acceleration from 30 km/h – *med_acc30*,
- rolling from 50 km/h – *roll50*,
- traffic light situation: approach with 30 km/h – deceleration – standing with idle engine – drive away – *stop-start*.

The sound of the horn and an engine run-up at idle mode are recorded, too.

The exterior noise of these situations is recorded with an artificial head in 7.5 m distance at a height of 1.2 m. Five microphones are installed in and at the vehicle for later evaluation of the dominant noise source of the vehicle. The microphones record the near field signals of the components, which are in general the main noise sources:

- intake,
- engine (top position),
- front tire trailing edge,
- rear tire leading edge,
- exhaust.

If additional relevant noise sources are heard in the far field, they are listed in the measurements protocol or if necessary equipped with an additional microphone.

2.1.1 Vehicle Setup

Each vehicle to be measured is equipped with microphones at the five positions stated in the paragraph above (Figure 2). The microphones at the tires are usually mounted on the right side of the vehicle. If additional relevant noise sources are identified or the vehicle is equipped with a multiple intake / exhaust system necessary additional microphones are applied.

Figure 2: Exemplary microphone positions. top: intake, engine (top position); bottom: rear tire leading edge and front tire trailing edge, exhaust

2.1.2 Measurement

The five chosen driving situations are conducted on a street with a regular clean tarmac (Figure 3).

Figure 3: Measurement setup

The recorded signals derive from the near field microphones in the car and the artificial head at 7.5 m distance. Since the near field and far field signals are recorded on separate systems a signal for later synchronization is needed. This can be achieved by using the horn at each approach or installing a light barrier at the street and on the vehicle which will trigger simultaneously. In the latter an additional channel has to be recorded on both systems.

Each driving situation is recorded two times as a pass-by from the left and from the right including a safety repetition. The point of acceleration, deceleration or rolling is always at -10 m, meaning 10 m before the artificial head position.

2.1.3 Recorded Vehicles

The additional measurement campaign expands the exploitable data to the numbers of vehicles listed in Table 1.

Table 1: Acquired recordings for the Qualitative Component Analysis sorted by transportation mean / vehicle class

mini class	3
sub-compact class	2
compact class	3
medium class	3
upper medium class	2
luxury class	1
cabriolet/roadster	2
van	2
SUV	1
commercial van	2
truck	1
public transport bus	2
tram	1
Total	**25**

The choice of vehicles includes different engine types (Otto / Diesel), gear types (manual / automatic), drive concepts, number of cylinders and a wide range of engine power and cubic capacity. Most of the vehicles are current models. Nevertheless, some older models are included for comparative considerations.

The first 20 vehicles were recorded and analysed during the first 12 months. These results are presented in D2.1. The additional measurements carried out in the months 13 – 18 are presented in the following.

3 PRESENTATION OF SINGLE VEHICLES AND THEIR NOISE SOURCES (SPECTRA, SINGLE VALUES)

During the qualitative component analysis the different pass-by noises recorded with the artificial head are analyzed for characteristic noise components. These noises components are assigned to their noise source using the near field recordings of the vehicle components.

By this, it is possible to determine the most important noise source regarding transportation means / vehicle type and driving situation.

The final results of the analysis are subject of the following chapter 4. The data presented in the following is the starting point for this analysis. For each transportation mean / vehicle class that has not been presented in D2.1 a detailed example and the basic results are presented.

For the interpretation of the following spectrograms two points have to be considered:

- The quantitative link between the near field and far field recordings, like a transfer function[1], has not been measured here. Hence, the absolute level and even certain frequency or time patterns of the near field recordings do not necessarily relate to the far field. But, it is possible to identify pattern in the far field signals and try to find correspondents in the near field signals.
- Cross talking occurs for the near field recordings of the tire noise. For one thing, tires do not emit much noise in the low frequency range. This can be seen e.g. in Figure 7 regarding the strong engine order below 100 Hz. In this case only in the frequency range above 250 Hz the tire noise is dominating in the respective signals. For another thing, tires emit no noise while standing and are low-noise at low speeds. Therefore, at the end of deceleration, while standing and at the beginning of acceleration the noise recorded with the tire microphone does not represent the actual noise emitted by the tires.

[1] An acoustic transfer function describes how a signal is transmitted from the source to the observer. It is influenced by the properties of the respective transfer path, like medium or obstacles. It is can be calculated as the quotient of observer signal and source signal. For example, in free field conditions the transfer function is only defined by the distance. By putting a vehicle chassis around the source the source signal won't change but the signal at the observer point will. Therefore, the transfer function changes too and includes now the characteristics of the chassis, like damping or refraction. For a quantitative relation between source and observer it is absolutely necessary.

3.1 Mini Class

For completeness the updated tables for the mini class vehicles are presented.

vehicle	engine	gear	drive	cylinders	power [kW]	capacity [cm^3]	model
Mini01	otto	manual	front	4	29	899	not current
Mini02	otto	manual	front	4	44	1100	current
Mini03	diesel	automatic	front	3	45	1191	current

vehicle	stop-start				const30	const50	med_acc30
	approach	deceleration	idle	drive away			
Mini01	tires	tires/intake	intake	engine	tires	tires	tires/engine
Mini02	tires/engine	tires	exhaust	engine/exhaust	intake/tires	tires/intake	exhaust/intake
Mini03	tires	tires/engine	engine	intake/engine/exhaust	intake/engine	tires/intake/engine	intake/engine

3.2 Luxury Class

The presented vehicle features eight cylinders, an automatic transmission and a front wheel drive. The spectrograms of the far field (monaural, left and right side of the car) and near field tire recordings of the traffic light situation are shown in Figure 4.

At the approach of the vehicle the tires clearly dominate the emitted noise. Engine orders are hardly visible in the spectrograms. The main share of the tire noise surely originates from the respective leading edge.

During the deceleration the level of the tire noise decreases and the second engine order – mainly coming from the engine – increases. Thereby both contributions are balanced.

During standing in idle mode the engine noise forms the noise perception. The second engine order dominates the low frequency range. Nevertheless, more dominant in level and for the hearing impression is the emitted noise in the broad frequency range between 500 Hz and 2 kHz.

During the drive away the engine is the dominating noise source. Especially at the beginning the engine is clearly audible, whereas the exhaust contributes at the end of the acceleration.

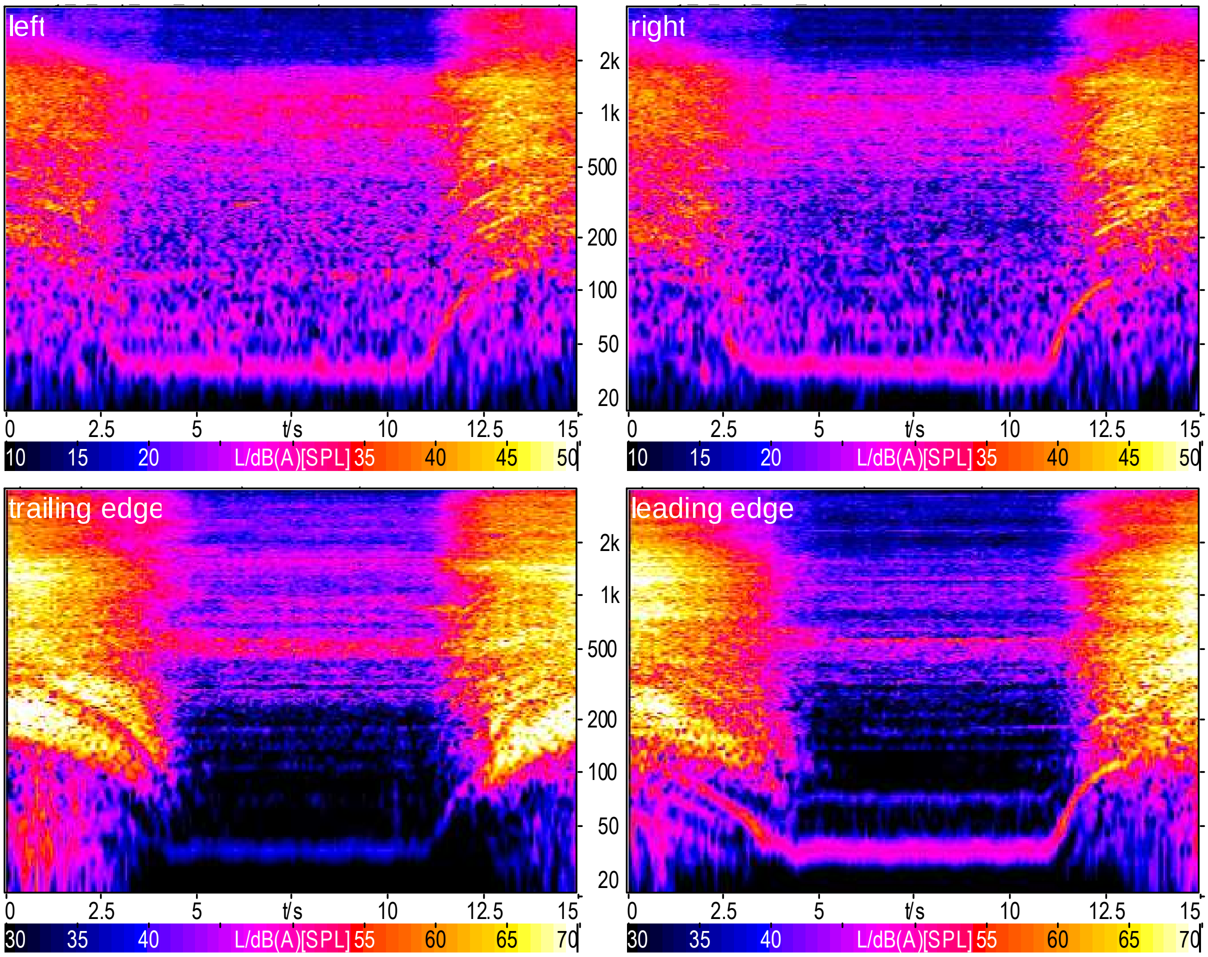

Figure 4: FFT vs. time. Traffic light situation of a luxury class vehicle. top: monaural recording; bottom: near field signals of tire trailing edge, tire leading edge

The features of the measured vehicle within this class and the detected main noise sources for each driving situation are listed below.

vehicle	engine	gear	drive	cylinders	power [kW]	capacity [cm^3]	model
Luxury 01	otto	automatic	front	8	225	4966	current

vehicle	stop-start				const30	const50	med_acc30
	approach	deceleration	idle	drive away			
Luxury 01	tires	tires/engine	engine	engine/exhaust	tires/engine	tires	tires/engine

3.3 SUV

The presented vehicle features six cylinders, a manual transmission, a four wheel drive and a diesel engine. The spectrograms of the far field (monaural, left and right side of the car) and near field recordings of the traffic light situation are shown in Figure 5.

Concerning the approach situation is dominated by high frequency emitted by the tires and the engine. The highest levels in the high frequency range originate from the tires. They appear around 1 kHz. Engine orders are hardly visible.

The same applies for deceleration phase. Still high frequencies from the tires and the engine (diesel knocking) dominate the perception. Here the increasing rolling noise is the main noise source for the far field.

While standing at idle mode engine orders are audible in the far field. The resonances at 210 Hz and 800 Hz account for the engine as main noise source.

The drive away phase is again characterized mainly by the engine orders. Here the second engine order is again the strongest one. The can be led back to the intake and engine, as well as the exhaust at the end of the drive away.

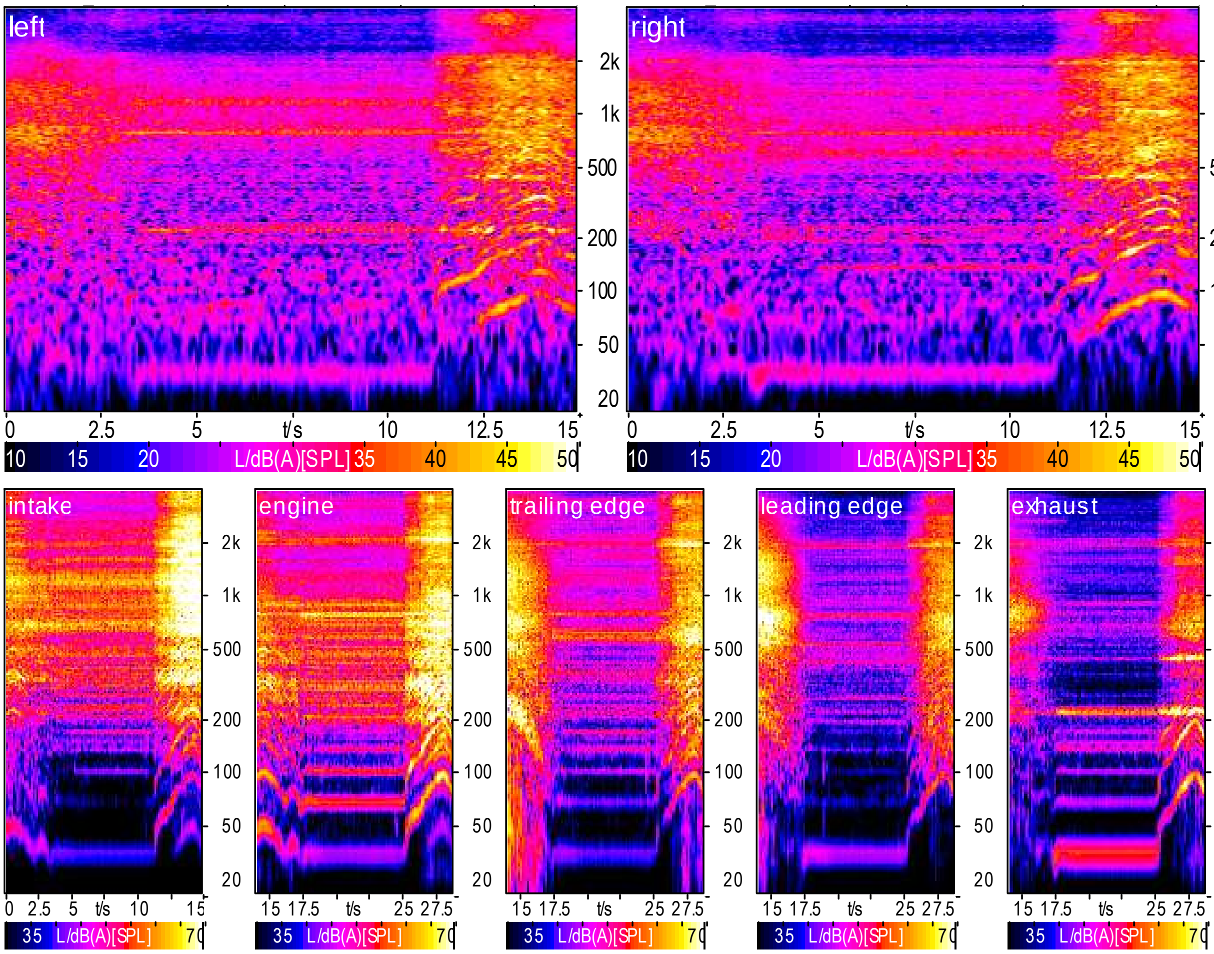

Figure 5: FFT vs. time. Traffic light situation of a SUV vehicle. top: monaural recording; bottom: near field signals of intake, engine, tire trailing edge, tire leading edge, exhaust

The features of the measured vehicle within this class and the detected main noise sources for each driving situation are listed below.

vehicle	engine	gear	drive	cylinders	power [kW]	capacity [cm^3]	model
SUV 01	diesel	manual	4 wheel	6	160	2996	current

vehicle	stop-start				const30	const50	med_acc30
	approach	deceleration	idle	drive away			
SUV 01	tires/engine	tires/engine	engine	intake/engine/exhaust	intake/engine	tires/intake/engine	intake/engine

3.4 TRUCK

The presented vehicle features four cylinders, a manual transmission and a rear wheel drive. The spectrograms of the far field and near field recordings of the traffic light situation (approach from right) are shown in Figure 6.

During the approach of the vehicle the exterior noise is created by rolling noise and engine noise. Tire orders can be found in the high frequency range above 2 kHz (mainly from the trailing edge) and also in the low frequency range (mainly leading edge at 180 Hz). The engine is emitting a broad range of frequencies.

The deceleration phase shows very similar characteristics. The tire orders are clearly audible and the intake contributes significantly to the power train noise.

At idle mode very specific pattern can be seen and allocated to the noise sources. The broad noise between 1 kHz and 2 kHz originates from the intake and the engine. The pattern between 50 Hz and 100 Hz can be found in the near field recordings of the intake. The same applies for the resonance at 200 Hz. The very low and strong second engine order is created by the exhaust.

During the acceleration of the drive away the engine orders are very pronounced. Rolling noise is hardly audible; the tire orders of the deceleration phase do not show here. Main noise source during the drive away is the whole power train.

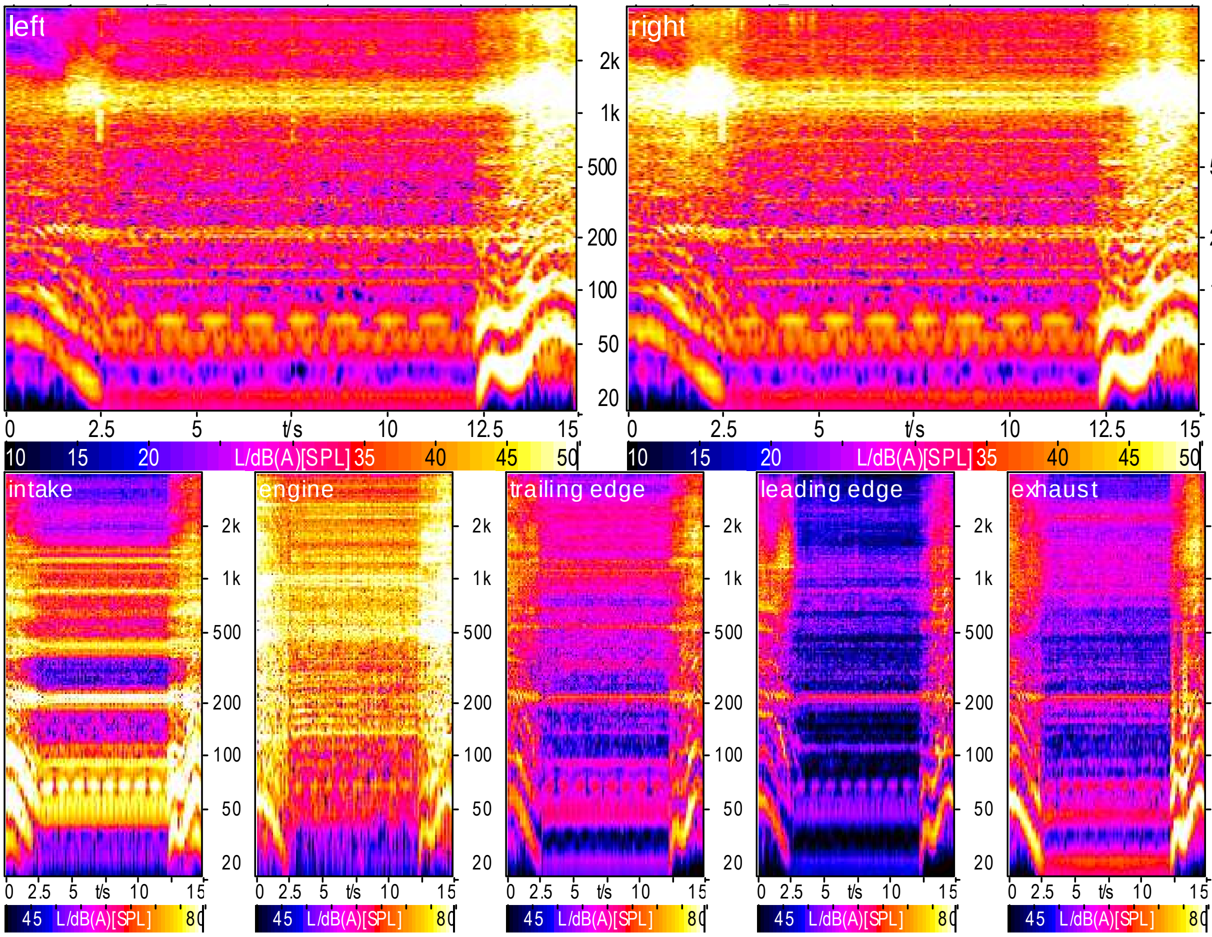

Figure 6: FFT vs. time. Traffic light situation of a truck vehicle. top: artificial head recording; bottom: near field signals of intake, engine, tire trailing edge, tire leading edge, exhaust

The features of the measured vehicles within this class and the detected main noise sources for each driving situation are listed below.

vehicle	engine	gear	drive	cylinders	power [kW]	capacity [cm^3]	model
Truck 01	diesel	manual	rear	4	132	4600	current

vehicle	stop-start				const30	const50	med_acc30
	approach	deceleration	idle	drive away			
Truck 01	tires/engine	tires/intake/ engine	intake/engine/ exhaust	intake/engine/ exhaust	intake/engine/ exhaust	intake/engine/ exhaust	tires/engine

3.5 TRAM

The presented vehicle differs fundamentally from the vehicles described so far. It features no combustion engine but is driven by an electric engine and is rail-bound. The spectrograms of the far field and near field recordings of the medium acceleration from 30 km/h (approach from left) are shown in Figure 7.

The main noise sources of this vehicle are its tires. The rolling dominates the perception at almost all driving conditions. Even the near field signals of the microphones at the engine are recording mostly rolling noise. Only during the acceleration the electric engines can be heard well and seen in the spectra.

Regarding the traffic light situation, the tram emits principally no noise during standing. Only the fan is running very quietly. And even at the drive away the engines are hardly audible. Nevertheless, during a stop at a tram station the doors will be opened and closed (after a warning signal) and the drive away is signalled by a warning bell. These sounds can be very annoying to people living nearby the station.

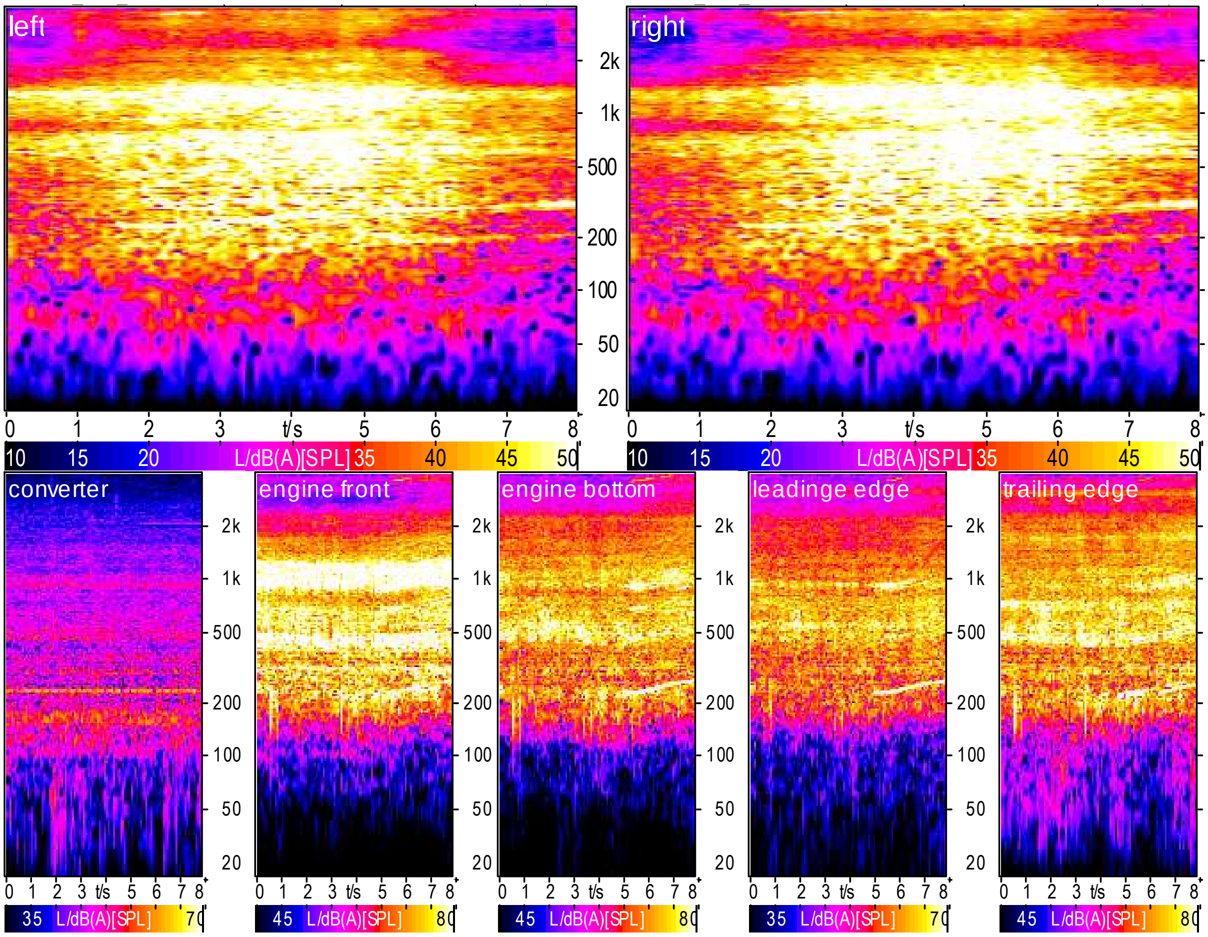

Figure 7: FFT vs. time. Medium acceleration from 30 km/h of a tram. top: artificial head recording; bottom: near field signals of converter, engine front, engine bottom, tire leading edge, tire trailing edge

The features of the measured vehicle and the detected main noise sources for each driving situation are listed below.

vehicle	length	width	max. passengers	bogies			model
Tram 01	32 m	2.3 m	184	3 / wheel set	low floor	bidirectional	current

vehicle	stop-start				const30	const50	med_acc30
	approach	deceleration	idle	drive away			
Tram 01	tires	tires	-(fan)	tires	tires	tires	tires/engine

4 COMPARISON OF VEHICLES AND DRIVING SITUATIONS

An overview of the main noise sources is depicted in Table 2. It shows the results for each vehicle and each considered driving situation. As already mentioned during the analyses of the single vehicles, sometimes it was necessary to define several noise sources as dominant, e.g. if their characteristics appear at separate frequency ranges.

The three vehicles with component measurements of the SVEN project do not provide recordings of the driving situation *med_acc30*. For two vehicles no main noise source is defined for idle mode since these vehicles – the hybrid car *Toyota Prius* and the electric powered *tram* - shut off their engine while standing. The driving situations of the busses were performed with a speed of 38 km/h since the recordings originate from WP2.1.2, where ISO 362 measurements were performed.

In the last rows of Table 2 the occurrences of each noise source is stated for the respective driving situation. By this, the relative importance of a noise source for the specific driving situation can be detected.

The considered noise sources can be assigned to different noises emissions: rolling noise and combustion noise.

The rolling noise presents the prevalent noise for the approach and deceleration situation.

For the comparison of rolling noise and combustion noise the occurrences of intake, engine and exhaust have to be summed up. Therefore, rolling noise is not prevalent for the constant pass-by with 30 km/h but still for the pass-by with 50 km/h. Since the influence of the rolling noise increases with rising speed, it can be assumed that constant pass-by situations with speeds higher than 50 km/h are generally dominated by rolling noise.

To avoid misinterpretations this conclusion must be restricted to vehicle fleets mainly consisting of passenger cars. The combustion noise of the commercial vans, truck and the public transport busses are at least as loud as the rolling noise, due to their diesel engines under heavy load. There is also a tendency for louder combustion noise of diesel engine passenger cars. This effects mainly the approach and deceleration situations, whereas the constant pass-by with 50 km/h is not significantly influenced.

The combustion of the power train is obviously prevalent for the idle condition, further for the two acceleration situations drive away and medium acceleration from 30 km/h. The higher load at the two latter situations causes higher levels of the combustion noise.

The idle condition and accelerated pass-by are dominated by emission from the engine and the intake. The exhaust is the main noise source for the drive away at the traffic lights situation. Of course this is due to the geometry of this situation, but nevertheless a fact worth considering

No significant tendencies could be found comparing current and not current models or classes of passenger cars.

Table 2: Main noise sources of vehicles at considered driving situations ((*) hybrid car, tram: engine shuts off during standing)

vehicle class	stop-start approach	deceleration	idle	drive away	const30	const50	med_acc30
mini 01	tires	tires/intake	intake	engine	tires	tires	tires/engine
mini 02	tires/engine	tires	exhaust	engine/exhaust	intake/tires	tires/intake	exhaust/intake
mini 03	tires	tires/engine	engine	intake/engine/exhaust	intake/engine	tires/intake/engine	intake/engine
sub_compact 01	tires	tires/intake/engine	intake	exhaust	tires	tires	tires
sub_compact 02	tires	tires	intake	exhaust	tires	tires	tires
compact 01	tires	tires/engine	engine	exhaust	tires	tires/exhaust	no data
compact 02	tires	tires	- (*)	intake/exhaust	tires	tires	tires/intake
compact 03	intake/tires	intake/tires	engine	engine	intake/engine	tires	intake/engine
medium 01	tires	tires	engine	exhaust	tires	tires	tires/engine
medium 02	tires	tires	intake	exhaust	tires	tires	tires/engine
medium 03	engine	engine	engine/intake	intake/exhaust	engine	engine/tires	engine/tires
upper_medium 01	tires	tires	engine	exhaust	tires	tires	no data
upper_medium 02	tires	tires	intake/exhaust	exhaust	tires	tires	tires
luxury 01	tires	tires/engine	engine	engine/exhaust	tires/engine	tires	tires/engine
cabriolet 01	tires/engine/intake	tires/engine/intake	engine	exhaust	engine/tires	tires/exhaust	tires/exhaust
cabriolet 02	tires	tires/engine	engine/exhaust	intake/engine/exhaust	intake/engine/exhaust	tires	intake/engine/exhaust
van 01	intake	intake	intake/engine	engine/exhaust	engine	engine	no data
van 02	tires	tires	engine	exhaust	tires	tires	engine
SUV 01	tires/engine	tires/engine	engine	engine/exhaust	tires/engine	tires	tires/engine
comm_van 01 nl	tires	tires	engine	engine/exhaust	intake/tires	tires/intake	intake/exhaust
comm_van 01 wl	tires	tires	intake	intake/exhaust	intake/tires	intake/tires	intake/engine
comm_van 02	intake	intake	engine	engine/exhaust	intake/engine	engine/tires	engine/intake
truck 01	tires/engine	tires/intake/engine	intake/engine/exhaust	intake/engine/exhaust	intake/engine/exhaust	intake/engine/exhaust	intake/engine
bus 01 (38 km/h)			engine/exhaust/intake		engine/intake		engine/intake
bus 02 (38 km/h)			engine/exhaust/intake		engine/intake		engine/exhaust
tram	tires	tires	- (*)	tires	tires	tires	tires/engine
tires	21	21	0	1	16	22	11
intake	4	7	11	7	11	6	11
engine	5	9	17	11	12	6	16
exhaust	0	0	6	21	2	3	5

The maximum SPL for the idle condition and the four pass-by situations with constant 30 km/h, constant 50 km/h, medium acceleration from 30 km/h, and rolling from 50 km/h are listed in Table 3.

Table 3: L_{max} in dB(A) for considered situations

vehicle	idle	const30	const50	med_acc30	roll50
mini 01	50	66	71	71	69
mini 02	47	68	74	69	73
mini 03	55	68	75	73	74
sub_compact 01	43	66	74	68	72
sub_compact 02	44	64	71	68	71
compact 01	59	63	69	no data	no data
compact 02	-	62	65	68	65
compact 03	58	67	72	70	72
medium 01	43	64	72	71	70
medium 02	44	64	68	67	67
medium 03	55	68	73	73	71
upper_medium 01	59	63	70	no data	no data
upper_medium 02	44	66	72	66	72
luxury 01	49	67	74	72	73
cabriolet 01	47	68	75	73	73
cabriolet 02	47	65	71	69	70
van 01	59	65	68	no data	no data
van 02	51	60	67	71	69
SUV 01	52	68	73	72	72
comm_van 01 nl	58	71	74	74	70
comm_van 01 wl	58	69	73	73	70
comm_van 02	57	67	72	70	69
truck 01	62	72	76	76	73
bus 01	70	75		81	69
bus 02	70	80		81	69
tram 01	-	70	78	73	78
mean	53,4	67,2	72,0	71,7	70,9
deviation	6,6	2,9	2,3	2,8	2,0
min	43	60	65	66	65
max	70	80	78	81	78

The mean values of the situations *const50* and *roll50* differ by 1.1 dB(A) supporting the conclusion of the former paragraph, that rolling noise gives the main contribution to the overall level of the constant pass-by with 50 km/h.

Also the importance of the combustion noise for the commercial vans, truck and public transport busses is proved, since these vehicle classes often show the highest values except for *roll50*.

Given this fact, it is not surprising that the highest levels for these situations are reached by vehicles with diesel engines. Considering only the passenger cars this effect turns out to be only a tendency, meaning that there are more parameters to it than just the diesel engine.

For instance, a slight correspondence exists between the noise level at idle mode and the age of the vehicle. Here the three vehicles measured for the SVEN project provide the highest levels. In this context it has to be pointed out that the hybrid car (compact 02) has the lowest idle levels, because it shuts off its engine while standing.

In general the deviations between the L_{max} of the passenger cars are rather low to gain significant distinctions between vehicle classes or types.

The procedure and the results of the psychoacoustic analysis are described in D2.8. Shortly, listening test are conducted to get annoyance evaluations for the compiled pass-by sounds and a evaluation index EI – a calculations method using psychoacoustic parameters – is developed that represents these subjective evaluations. There also a comparison between subjective evaluations and dB(A) weighting can be found. It points out, that the correlation between dB(A) and the annoyance effect of pass-by noise is rather weak.

According to the **subjective evaluation**, the engine noise of the vehicles is the main factor influencing the perception. If different vehicles at the same driving condition are compared, the vehicles with strong engine – and especially diesel engine – noise are rated more annoying then the others (see Table 4).

Table 4: Annoyance ratings for two sound sets showing the importance engine / diesel noise

const30

vehicle	rating
upper_medium 02	2.90
sub_compact 01	4.60
cabriolet 02	5.60
medium 03 (diesel)	6.20
comm_van 02 (diesel)	7.40
compact 03 (diesel)	8.30

med_acc30

vehicle	rating
upper_medium 02	3.83
medium 02	4.42
sub_compact 01	4.83
mini 01	6.08
mini 02	6.17
medium 03 (diesel)	6.67
compact 03 (diesel)	8.17
comm_van 02 (diesel)	8.25

The dB(A) values differ not much between the driving situation const50 and roll50 – the influence of the power train noise is small. But the subjective evaluations show that in a direct comparison the roll50 situation is rated much better – scores between 2 and 5 – than the const50 situation rated almost always with 5 and higher (see Table 5).

Table 5: Annoyance ratings for the big_mix sound set showing the high influence of engine noise on the subjective perception

big_mix

vehicle	condition	rating
mini 01	roll50	2,29
upper_medium 02	const30	3,00
van 02	const50	3,00
mini 02	roll50	3,14
comm_van 02	roll50	3,21
medium 03	roll50	3,36
sub_compact 01	roll50	3,79
cabriolet 02	roll50	3,79
upper_medium 02	med_acc30	4,07
sub_compact 01	const30	4,14
cabriolet 01	roll50	4,50
mini 01	const50	4,93
upper_medium 02	const50	5,00
mini 01	med_acc30	5,14
medium 02	med_acc30	5,21
medium 03	const30	5,29
cabriolet 02	const30	5,29
sub_compact 01	med_acc30	5,57
comm_van 02	const30	5,64
medium 03	const50	6,14
compact 03	const30	6,14
mini 02	med_acc30	6,14
compact 03	const50	6,21
medium 03	med_acc30	6,29
comm_van 02	const50	6,50
sub_compact 01	const50	6,57
cabriolet 02	const50	6,64
comm_van 02	med_acc30	6,86
cabriolet 02	med_acc30	6,86
compact 03	med_acc30	6,93

This is proved also by the weighting of the psychoacoustic parameters forming the evaluation index EI. The RA(f)[2], that represents mainly frequency patterns and tonal components of the power train noise, gets the highest weighting. Further listening tests with the near field signals of the engine and the tires show the same effect. As long as the tire noise is free of very annoying characteristics, e.g. a stone in the tread pattern, its ratings are always better compared to engine noise.

[2] RA(f) … Relative Approach for frequency pattern: a psychoacoustic analysis that simulates the adaptivity of the human hearing and thereby is able to identify and evaluate patterns (here in the frequency domain) which are attracting the listeners attention.

Table 6: Annoyance ratings for the source comparison sound set showing that engine noise characteristics cause higher annoyance ratings; driving situation: const50

source comparison

vehicle	source	rating
suv 01	tire_rear	3,17
upper_medium 02	tire_front	3,42
upper_medium 02	tire_rear	3,42
luxury 01	tire_rear	4,08
luxury 01	tire_front	4,67
mini 01	tire_rear	4,75
suv 01	tire_front	5,17
upper_medium 02	engine	5,50
van 02	engine	5,50
medium 02	engine	5,83
mini 01	engine	6,33
suv 01	engine	6,42
truck 01	engine	6,58
medium 02	tire_rear	6,83
comm_van 02	engine	7,42
compact 03	engine	7,67

So the power train noise has only small influence on the dB(A) but high influence on the annoyance. The relative high level of rolling noise at 50 km/h does not relate to its annoyance effect.

Generally speaking, the power train noise is most important regarding the subjective perception. Presence or differences in intensity of the power train noise can lead to essential changes in the subjective evaluation. Which component of the power train is the most important for the exterior noise depends on the geometry of the vehicles as well the driving situation.

Nevertheless, the rolling noise cannot be neglected. The evaluation index EI considers also the 5 % percentile of the psychoacoustic parameter sharpness which represents the influence of the tire noise in the high frequency range, e.g. as annoying hissing noise. This parameter is the parameter with the second highest weighting within the EI. Especially for deceleration and constant pass-by at higher speeds it can be substantial.

The conclusion that with rising speeds the importance of the tire noise will increase (see above) leads to the assumption that the subjective perception of vehicles with constant speeds at approximately 70 km/h will mainly be influenced by the emitted rolling noise. This kind of driving condition occurs on urban motorways managing the traffic flow into and out of cities. For residents near these motorways the rolling noise will be important.

The results of the psychoacoustic test show no real preference for certain classes of passenger cars (the vehicles with the best ratings are a mini, a sub_compact and a upper medium class car). In fact, the type of engine (diesel / gasoline) or type of tires (e.g. summer / winter) and the driving situation are the decisive factors.

Regarding measures for the improvement of noise emission and immission these results lead to different conclusions. The traffic situation of inner city centres is characterized by low speeds as well as frequent stops and accelerations. Here the power train noise is the most important noise source and has the highest potential for improvement. Measures could include the support of vehicles with a quiet driving system like electric powered vehicles.

The traffic noise on city arterials is essentially formed by rolling noise. The mitigation measures applied here should account to that, e.g. by reducing rolling noise with an adequate road surface.

5 CONCLUSION AND OUTLOOK

Further measurements complete the data acquisition started during the first twelve months of QCITY (see D2.1).

The first step of the data evaluation uses standard parameters like spectra and dB(A). It is shown that a distinction between passenger cars and heavier vehicles like commercial vans or busses is necessary to avoid misinterpretations.

The overall noise of the heavier vehicles is dominated by their combustion noise. Regarding the passenger cars this accounts only for acceleration situations. Primarily rolling noise is emitted at approach and deceleration of a passenger car and during the pass-by with a constant speed above 50 km/h.

The dB(A) values differ not much between the driving situation const50 and roll50 – the influence of the power train noise is small. The subjective evaluations of the pass-by noise in WP2.2.2[3] change this picture. They show that the roll50 situation is rated much better than the const50 situation – here the presence of combustion noise influences essentially the perception. Generally it shows that the combustion noise is the most dominant source for the subjective evaluation. Improvements of the traffic noise level can be gained by introduction and support of new and quieter driving systems and traffic control measures.

Rolling noise becomes important for constant pass-by at speeds above 50 km/h. Here the ratio of combustions and rolling changes in comparison to acceleration at a traffic light. The perceptive share of rolling noise rises from the second important factor to a dominant one. Here quiet road surfaces and tire designs can improve the noise situation.

So, the most important factor for noise generation is the driving condition which determines the approximate weighting of combustion and tire noise. For accelerations and low speeds the combustions noise is dominant. Further it had to be differentiated between strong engine noise – especially diesel engine noise – and moderate / low engine noise for these driving situations. Regarding constant pass-by at speeds above 50 km/h the type of tire and road surface will be decisive for the perception.

The achieved data and conclusions are input to the further work within QCITY. The database is integrated into the sound library of the TrafficNoiseSynthesizer software created within WP2.2.3. By this, the time signals will be available to all project partners, who can auralize and filter them. The filters can be calculated in respect to various

[3] In WP 2.2.2 the pass-by noise is subject to listening tests and the analysis of annoyance evaluations of the test individuals. D2.8 presents the procedures and results of this analysis. It describes the development of a calculation method that represents the subjective perception of pass-by noise. This will be further enhanced and improved in WP5.12 regarding traffic flow noise and filtering. The listening tests and the so called evaluation index EI is used for a perceptive ranking of noise sources.

mitigation conditions defined within ISO 9613 or imported from other measurements or calculations of mitigation measures.

The database and the gained results from it are strongly related to WP5.12. In SP2 insights into the characteristics of vehicles at certain driving situations are achieved. This has resulted into to conclusions about the “acoustic classes” of vehicles (e.g. strong diesel engine – moderate engine) and situations (e.g. constant at high speed – constant at low speed), which again will be combined for the auralization of traffic flow at a specific road section with a specific vehicle fleet composition in WP5.12.