inter.noise
HAMBURG 2016

Isolating key features in urban traffic dynamics and noise emission: a study on a signalized intersection and a roundabout

Laura ESTÉVEZ-MAURIZ[1]; Jens FORSSÉN[1]; Wolfgang KROPP[1]; Georgios ZACHOS[1]

[1] Division of Applied Acoustics. Department of Civil and Environmental Engineering. Chalmers University of Technology, Gothenburg, Sweden.

ABSTRACT

Urban planning and transport network are considered as major urban systems with great impact on the sound environment. Most of the work done in transport management and traffic design to improve the quality of both outdoor and indoor sound environment relies on conventional noise mapping software outcomes. This type of tool is based on macroscopic traffic modelling, considering traffic flow as a steady noise source. A commonly implemented practice intended to reduce noise in urban areas is the transformation of a signalised crossing into a roundabout. However, the individual vehicle behaviour becomes relevant in these decisions, where high time-pattern fluctuations are responsible for changes in the quality of the urban sound environment and of human activity. The present paper studies a set of indicators from isolated key features in these two road traffic configurations and their possible variations (acceleration, heavy vehicles, etc.). A VISSIM microscopic traffic simulation model combined with the CNOSSOS-EU noise emission model is used to test cases based on real situations, now in development stage. The approach presented aims to provide stronger basis in the reasoning behind why different road traffic configurations adopted in the urban planning practice give certain effects in relation to the urban sound environment.

Keywords: Road traffic noise, Traffic dynamics, Urban sound environment
I-INCE Classification of Subjects Number(s): 52.3, 68.2, 76.1.1

1. INTRODUCTION

Transport management has been acknowledged as one of the main systems in city development. However, the road traffic network is a fundamental part of the urban form, carrying sometimes with it a “locking” effect, having enormous consequences not only shaping the physical urban layout but moreover, stating a model of city. This practice is particularly important to guarantee the livability of spaces and hence, its environmental quality. In these situations, retrofitting is not only complex, but also expensive (1), limiting its capacity to adapt to current and future demands.

This paper is a continuation of the study attempting to look for answers about what is considered a good built environment (2), developing dynamic tools that may improve the urban planning process, assessing and understanding the transport system and its consequences in the acoustic environment.

1.1 Transport planning: an opportunity to control the acoustic environment

The importance of transport management and road traffic design is directly linked to noise exposure causing annoyance, sleep disturbance and other health effects. The European Environment Agency (3) pointed out that around 42 million of EU citizens are exposed to road traffic noise levels above the World Health Organization targets (Lden<55dB). The high exposure is, to a large extent, a consequence of the urban planning and building design, where traffic management plays a significant role in the characteristics of the sound environment. Controlling the acoustic environment by creating high quality urban spaces that support health and wellbeing is a priority in the unavoidable densification process of cities. However, the acoustic environment also includes the idea of the functionality of space, being an important part of the experience of a place and an indicator of the quality of life, including the concept of appropriateness of the urban sound environment.

[1] laura.estevez@chalmers.se

As a first attempt, the Environmental Noise Directive (END) requires to adopt action plans based upon noise-mapping results, preventing and reducing environmental noise in situations where exposure noise levels may affect human health. However, mainstream methods to assess noise impact are through noise mapping, based on simplified calculation methods where traffic flow is even and results mainly constructed on time-averaged A-weighted sound pressure levels and derivations (e.g. L_{den}, L_n). At high traffic variations, as the ones present in dense urban environments, this type of analysis leads to noise assessment underestimations, where noise annoyance has been suggested to be partly determined by the noise events resulting from traffic flow (4,5). With this methodology, the study of the city from a micro-scale level capable to attend to features from transport dynamics is neglected. These features have a large impact in the resulting sound environment, where one of the most important designs in cities' traffic network is the intersection.

A common practice in the latest decades has been the replacement of crossings with roundabouts as a safer alternative for pedestrians and vehicles (6), expanding the study of the consequences of such transformations. One of the main differences in these two intersection designs is that the roundabouts are based on the drivers accepting or denying of gaps, while the signalized crossing corresponds to a stop-controlled situation, making the workload on the driver generally less than in the roundabout case (7).

The inclusion of vehicle kinematics has been pointed out as a feature with strong influence on the vehicle noise emission (8-11). The focus in the present paper is to recognise some of those features that could explain traffic dynamics and noise emission of two equivalent road intersection designs in terms of traffic demand. For this, the analysis is made from using a microscopic traffic modelling capable to describe those dynamics, such as acceleration and other driving behaviour. The outcomes are combined with the CNOSSOS-EU model for noise emission (12) and analysed using in-house developed Matlab scripts. The scenarios are based on a real situation of an urban development process as plausible urban configurations with the same traffic demand and several vehicles types.

The aim is to improve the knowledge of the characteristics of the urban sound environment that these two intersections are describing, including for example, the acoustic performance, the time pattern behaviour and the difference maps assessing several urban sound environment indicators as percentiles and number of events.

2. METHODOLOGY

2.1 Case study on traffic strategies: signalized intersection and roundabout

The traffic situation is designed in accordance with the peak hour traffic forecast for an intersection in the Frihamnen (13) future urban development, located in Gothenburg, Sweden. The project will allocate around 15,000 inhabitants and the same number of working places. Its location and success is considered as a key project among the city government and the citizens, being a test-bed in the process of urban planning.

The traffic forecast follows the recommendations found in (14), where the situation corresponds to the peak hour in the afternoon and the peak month in an OD matrix simulating the worst possible scenario (see Fig. 1). The aim was to set the same parameters for the origin-destination (OD) matrix for both intersection types, holding the same number of vehicles and adapting their layout to the traffic capacity needs, e.g. adding a second lane if needed. In order to study the influence of vehicle types, the two scenarios where modelled with three different vehicle types, including light (LV), medium-heavy (MHV) and heavy vehicles (HV).

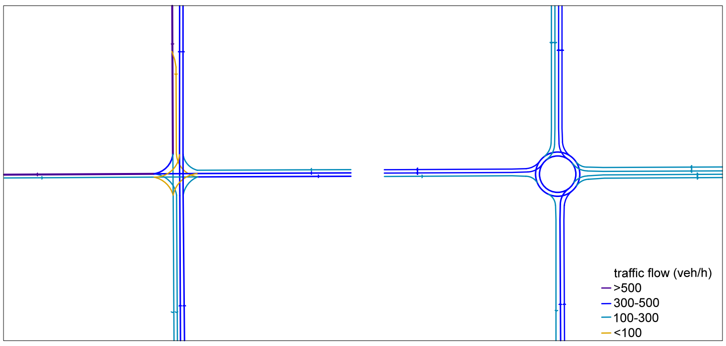

Figure 1 – Two scenarios and its traffic network demand. Roundabout (left) and signalized crossing (right).

2.1.1 **Transport management, traffic design and microscopic simulation**

To develop the microscopic traffic model, the software VISSIM was used. VISSIM is a microscopic, time and behaviour-based simulation where driver-vehicle-units are modelled as single objects. This type of modelling allows the study of the key features that characterize these two road traffic configurations and its variations due to the influence of e.g. acceleration and heavy vehicles.

The microscopic model includes the individual traffic behaviour, giving as output the position of each vehicle versus time, the vehicle category, its speed and acceleration. These parameters acknowledge a better understanding of the vehicle kinematics, being able to model all vehicles' noise emission during the simulated time. To capture the vehicle positions often enough, 1/15 s simulation resolution is performed, with simulation runs of 3600 s, and 300 s to allow traffic to stabilize at the beginning and 300 s at the end to complete the trips.

In order to model the two intersections, the design of number of lanes, its flow rate, the cycle length and phases (in the case of the crossing), the storage lanes' length, the number of through and turning lanes, as well as other transport network requirements were modelled according to (15). Since the future Frihamnen road traffic layout is under constant development, the length of lanes approaching and leaving the intersection was set to 200m as a representative distance between main intersections in urban situations (16), letting the vehicles flow towards the intersection with the possibility to reach the desired speed.

The traffic software used accounts for vehicles to maintain the desired speed until the traffic conditions or the geometric characteristics forces them to change it. For that reason, reduced speed areas were also included, as for example in the approaching lanes of the roundabout or in the crossing intersection. For all this, both a roundabout and a crossing with a similar behaviour from the city of Gothenburg (17) were used as a calibration to build the speed profile in both cases through a probability distribution, assuming that 85 % will drive at the signed speed, which was 50 km/h. The parameters set in the microscopic traffic modelling were based on (6,7,15,18,19) including the banning of lane change for heavy vehicles, the maximum entry and circulatory speed in the roundabout stop lines as well as conflict markers An example of its simulation is shown in Fig. 2.

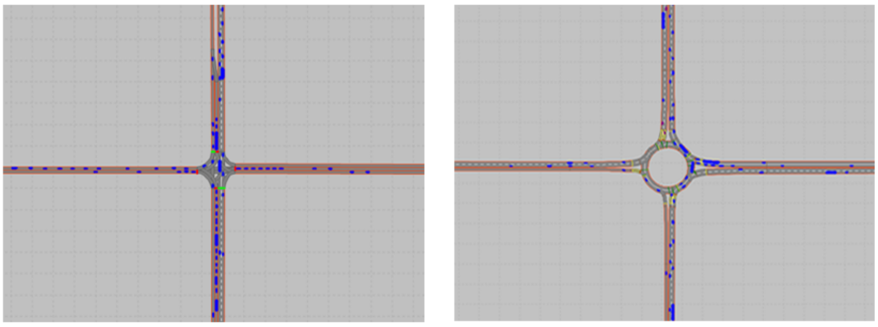

Figure 2 – Example of the signalized crossing and roundabout microscopic simulation in VISSIM

The modelling amounted to six situations, varying the vehicle types in the two intersection types according to Table 1. The vehicle type distribution corresponds to the categories presented in the CNOSSOS-EU noise emission modelling (12): light vehicles (LV), medium heavy vehicles (MHV) and heavy vehicles (HV). Those categories were equated to the vehicles types included in the microscopic traffic modelling.

Table 1 – Scenarios for signalized crossing and roundabout: vehicle distribution

Case	% Vehicles		
	Light (LV)	Medium-heavy (MHV)	Heavy vehicles (HV)
1) LV-MHV-HV	92	4	4
2) LV-MHV	96	4	-
3) LV	100	-	-

2.2 Noise emission model

To compute the source strength of the vehicles, the common approach to assess the environmental noise exposure proposed by the Environmental Noise Directive is implemented. This method, known as the CNOSSOS-EU method (12), has the intention to develop a common noise assessment framework. The assessment includes the road traffic noise source emission, which is computed including three different vehicle types (light, medium-heavy and heavy vehicles). The frequency range to define the noise source is in the octave bands from 65 Hz to 8 kHz. The noise model is divided in two main noise generators, the propulsion and rolling noise, displayed at a unique point source at height 0.05m.

In this method, the vehicle noise responds to the vehicle type, speed, environmental effect corrections and acceleration/deceleration. The latter operating condition was replaced by the engineering model Harmonoise (20), where acceleration/deceleration effect is included, correcting the propulsion noise. This was done since the CNOSSOS-EU is intended to model static traffic, adding a correction factor due to the proximity to the intersection. For comparison reasons of these traffic designs, the model includes geometric attenuation and energy doubling due to the ground.

3. RESULTS

In order to study the characteristics of previous traffic strategies and its acoustic performance, a series of results are shown as an attempt to get answers about the behaviour and suitability of these traffic intersections in city planning.

3.1 Sound pressure level at selected study points

To analyse the possible variations in the equivalent sound pressure level (L_{Aeq}), a series of study points were selected at equivalent distances in both intersections. The selection corresponds to possible locations for pedestrians, where four of them are located closer to the intersections (1-4), four more in the vicinity of the E-W lanes (9-12) and the last four (5-8) located further away, at about 100 m distance from the lanes.

In Fig. 3, a map of L_{Aeq} for 900 s is plotted for Case 1, i.e. all vehicle types included. Differences in the sound pressure level between the two intersection types can be identified. The lanes entering from the East give a higher sound pressure level in the roundabout than in the crossing, and the opposite is seen for the lanes coming from the south.

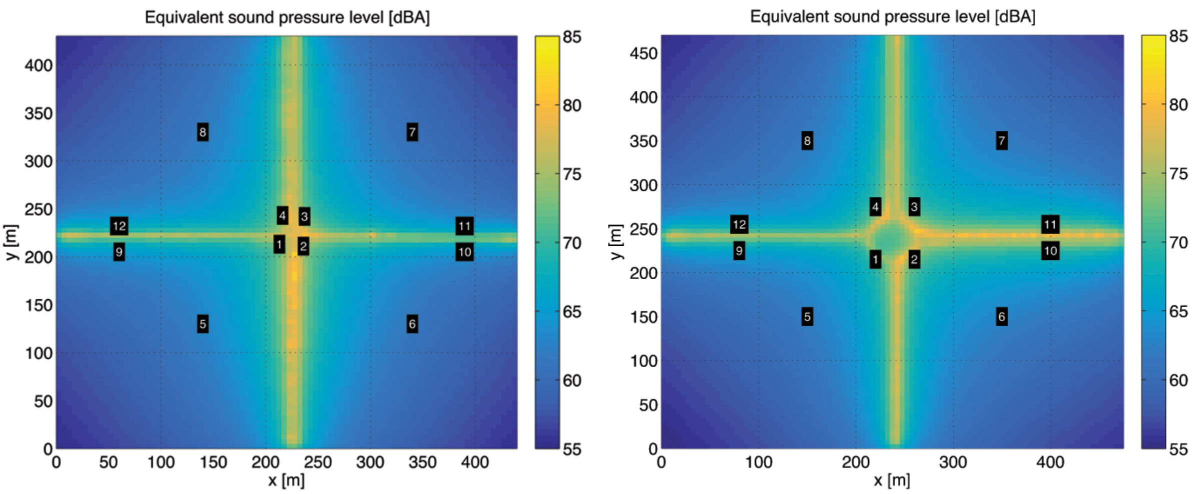

Figure 3 – $L_{Aeq,900s}$ for the signalized crossing (left) and the roundabout (right), 1[st] case study

To understand the effect of heavy vehicles, Fig. 4 shows all study points at both intersections. Removing heavy vehicles from the intersections gives a reduction of 1.5-2.5 dBA in the case of the roundabout, and 2-3 dBA for the signalized crossing, varying with study point location. If the decision includes as well the banning of medium-heavy vehicles, the reduction for the equivalent sound power level gives 1.5-2 dBA extra for both cases.

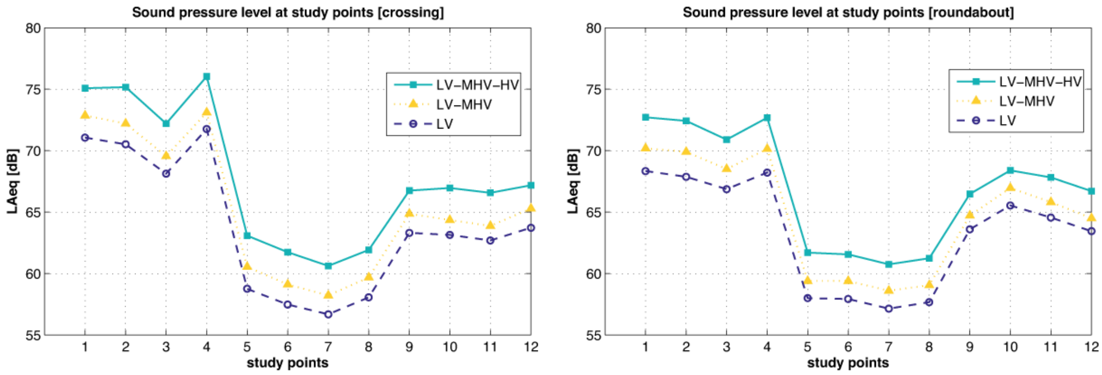

Figure 4 – L_{Aeq} at study points for crossing (left) and roundabout (right)

The next analysis compares both intersections for the three vehicle compositions by plotting the difference in L_{Aeq} as function of study point (Fig. 5). The points located at the intersection resulted in a higher sound pressure level for the crossing (stop-and-go driving behaviour) especially at the study point number 4. In the points positioned at the possible sidewalks at the E-W lanes (9-12), the results fluctuate depending on the traffic network, where the study points located at the East side of the intersection (10 and 11) have a higher sound pressure level for the roundabout. This is happening for example at the study point 11, where the vehicles are queuing because of the large amount of them coming from the south entry lanes. This situation is stopping the cars coming from the East to enter the roundabout, generating queues as instantaneous demand exceeds the instantaneous capacity of the road intersection, in this case the roundabout. Compared to these two points are the ones located at the west side of the intersection (9 and 12), holding a different behaviour. Here, the sound pressure level is practically the same in both intersections, probably due to the low traffic flow close to study point 9 (<150 veh/h) leading to a very similar flow for both types of intersections. For point 12, the amount of vehicles passing by is higher (~800 veh/h). This situation, along with the large number of vehicles traveling from south towards other directions, demanded two lanes in the case of the roundabout and one for the crossing intersection, resulting in a similar sound pressure level in both cases.

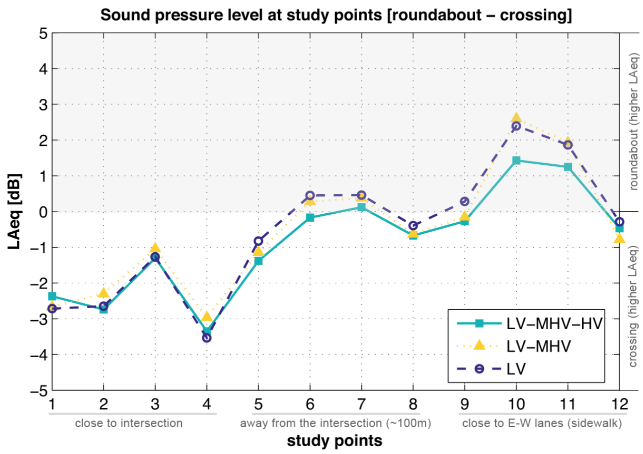

Figure 5 – L_{Aeq}(dB) difference at selected study points

3.2 Time patterns at equivalent sound pressure level at selected study points

Noise distributions over time are depicted in Figs. 6 and 7 for study points 4 (close to the intersection), 8 (far away from intersection) and 11 (at the sidewalk). In order to better visualize the traffic noise fluctuations, both figures represent the second simulation quarter as a representative one.

The are interesting effects observable related to the time patterns and their corresponding statistical distributions. In the case of study point number 4, the noise distribution tends to normal for the roundabout. The signalized crossing has a pulsed flow with higher sound pressure levels, where its time pattern reflects a high dynamic behaviour, typical for this kind of intersection. For study point 8, located in the same quadrant as study point number 4 but 100m away from the noise sources,

the roundabout intersection is the one giving the higher noise levels. However, longer distances make the time patterns more even, with narrow noise distributions in both scenarios. In study point number 11, the roundabout ends up to have a larger spread in noise levels (σ^2_{round}=13.2; σ^2_{cross}=11.4), also on average being higher than for the signalised intersection (μ_{round}=64.6; μ_{cross}=63.1), fluctuating in a different way.
From the equivalent sound power perspective, the crossing type is the one with the highest level among all study points. However, those differences are always less than 3.5 dBA between the two intersections (σ=1.6). However, annoyance has been seen to be more related to the noise time pattern of vehicles passing-by, being higher at signalized intersections (an overview can be found at 4). In order to study this effect, the number of noise events above a certain level is used as a descriptor to undertand the features of these intersection types (see 3.4 Noise descriptors and difference maps).

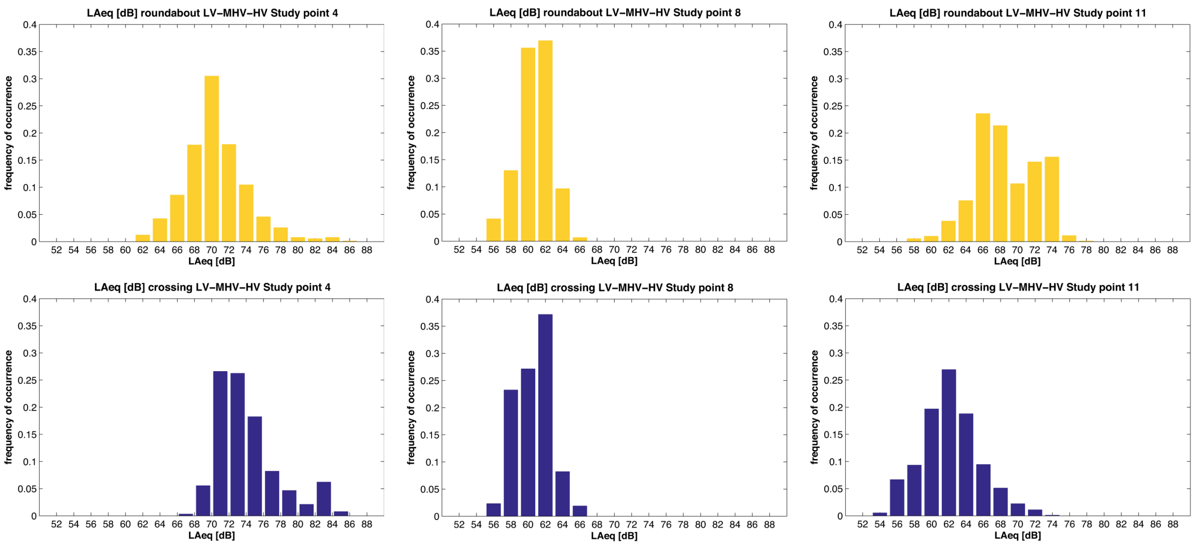

Figure 6 – L_{Aeq} (dB) distribution at the different scenarios

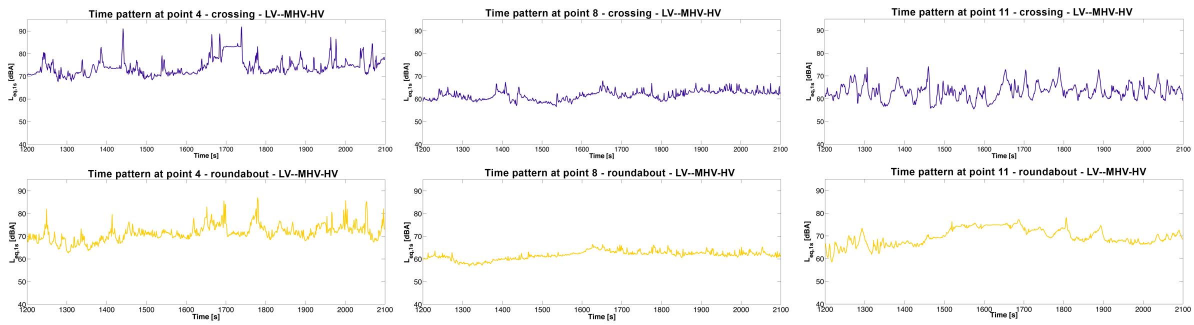

Figure 7 – Time patterns at selected study points for the first case

3.3 Sound power level

The following analysis is centred on the sound power level (LWA) as an attempt to further understand the source strength as determinant in the noise that reaches the receiver (21).

3.3.1 Sound power level at collection points

Several collection points were included in the road traffic networks. Collection point 1 is located just before the intersection at the South entry lanes (the inner lane for the roundabout and the middle lane for the crossing). Collection point number 4 is situated just after the intersection in the north exit lanes, as a continuation of traffic traveling in the S-N direction.

These cases are shown as an example in Fig. 8, in which a different behaviour is observed for both scenarios. In the case of Collection point 1 in the signalized intersection, the vehicles are accelerating once the traffic light is open, giving in general a higher LWA (dB) than for the roundabout. However, in the presence of heavy vehicles, the lower percentage within the 90-95 dBA range is counteracted by an increase within the 95-100 dBA range for the roundabout, indicating that those vehicles are probably accelerating while trying to join the roundabout. In the collection point number 4, vehicles are driving faster in the signalized crossing, since they already have passed the traffic light, resulting in higher noise levels. Meanwhile in the roundabout scenario, the vehicles just left the intersection and their speed is lower, where around 80 % of them are in the 85-90dBA sound power level range. However, this needs to be further studied since the road traffic sound power level distribution model is simplified in the CNOSSOS-EU noise emission method. Comparing the three traffic cases, in general, the sound power level is decreasing while the heavy vehicles are removed.

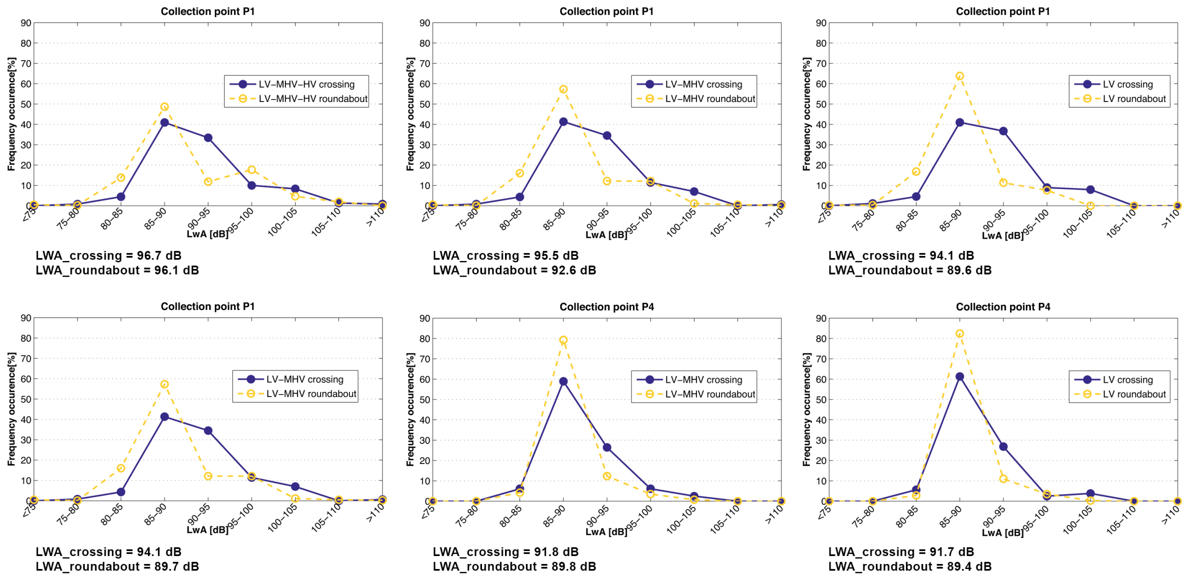

Figure 8 – LWA (dB) at collection points 1 and 4 for the signalized crossing and the roundabout in all cases. Average LWA is displayed in the plot for each case.

3.3.2 Sound power level at roads

The following assessments are integrating in one unique lane all the present lanes at each exiting or entry road, assuming a virtual composition. This way it is possible to study the differences in terms of the total sound power level.

In general, the vehicles in the roundabout are driving inside the intersection at a low speed, however, the moment they are leaving the intersection, they try to achieve the desired speed (see Fig. 9 right), leading to a higher sound power level just after the intersection. In the signalized crossing the behaviour is different, where vehicles are braking before entering the crossing and accelerating once the traffic light is open, having a more constant speed through the whole lane length. The sound power level along the entry roads is very different between the crossing types in the case of the north vehicle input (see Fig. 9 left), where the integrated road at the roundabout situation has an even sound power level, while the crossing has higher fluctuations along the whole lane length as a result of the stop and go behaviour. This is increasing the sound power level as they approach the traffic light. Fig. 9 can also be related to Fig. 14 at section 3.4, where the study point number four is located in the intersection between the entry and exit roads.

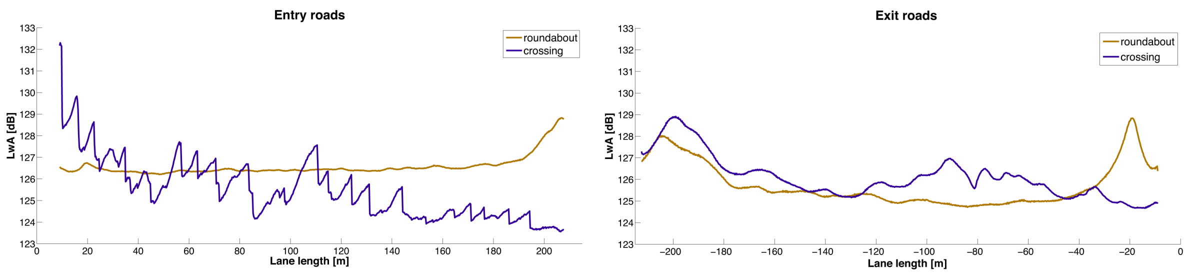

Figure 9 – Sound power level from entry (left) and exit (right) roads for crossing and roundabout in the first case. Intersection is located at (0,0) leading traffic flow in both cases to be read from right to left

3.3.3 Effect of acceleration and deceleration at the network

In congested urban streets, as traffic flow increases, the vehicle interactions increase as well, while speed tends to decrease. Nevertheless, those interactions are coupled with the periodicity of vehicle accelerations and decelerations, leading to an effect in the noise emission. Below, the first case is presented as an example of the influence of acceleration (Fig. 10), neglecting its impact in the sound power level calculations for the two modelled scenarios.

Comparing crossing and roundabout intersections, the sound power level distribution from the whole road traffic network is very similar in both situations, increasing its percentage in the lower ranges in the case of the roundabout. If acceleration and deceleration are removed, the range spread is reduced and condensed mainly in the range of 85 dBA (around 70% for signalized crossing and 73% for roundabout), where both higher and lower ranges are reduced. However, in this analysis the effect of tire noise due to the braking is not taken into account, due to the Harmonoise model implementation.

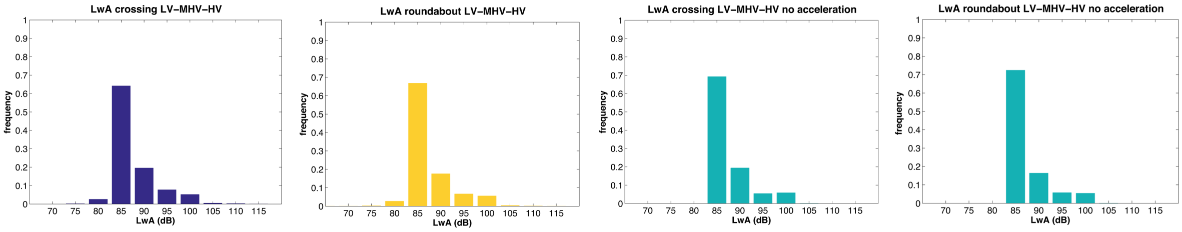

Figure 10 – Sound power level (dBA) at crossing and roundabout network and removing the acceleration effect in both intersections

3.4 Noise descriptors and difference maps

As a final analysis, noise descriptors are represented mainly through difference maps between both scenarios, giving a visual input of their behaviour. The equivalent sound pressure level differences (Fig. 11) between the two intersection types reflect the dominance of the crossing for all vehicle compositions.

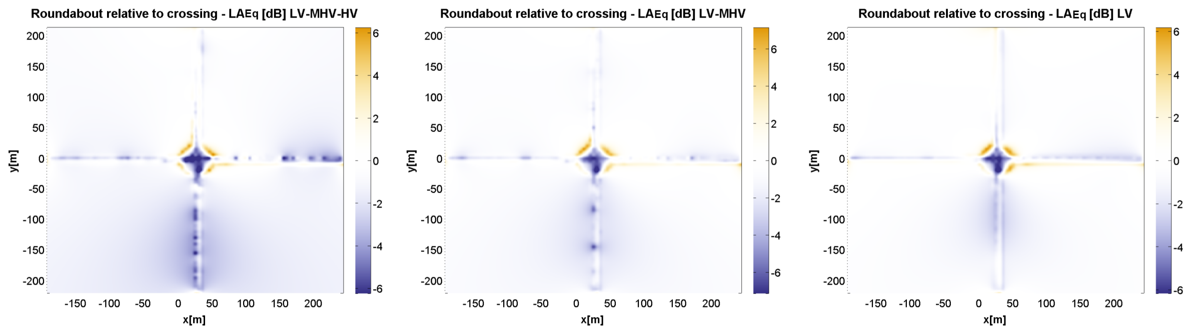

Figure 11 – Difference maps for L_{Aeq} (dB) in the three cases

The temporal distribution is represented by the maps of percentiles L_{A10} (peak) and L_{A90} (background), as the level for roundabout minus that of crossing, as a measure of the noise level variation (Fig. 12). In terms of the background noise, L_{A90}, the crossing intersection has overall higher background noise levels, especially in the presence of heavy vehicles. The higher background levels are observed at the congested lanes (south and east), with larger queues. These queues are reduced in the case heavier vehicles are removed, where background noise levels are still higher for the signalized crossing, however, these are only found in positions close to the intersection. The nodes do not differ much between the two types. In the peak noise levels, represented by LA10, again the signalized crossing intersection has overall higher values than the roundabout, meaning it has higher peak levels. The presence of heavy vehicles is resulting in a clustering of noise peaks among the congested lanes, smeared out in case heavy vehicles are removed. In this case, Case 3, differences between the two intersection types in the case of peak noise levels are smaller, however the signalized crossing still keeps the highest number.

The crossing scenario fosters a driving behaviour regulated by the signals where vehicles are clustered in flow groups, allowing them to travel longer distances in a short period of time, achieving a greater speed while contributing to higher accelerations and decelerations, and therefore, higher levels of sound power, as well as higher values of LA10 and LA90.

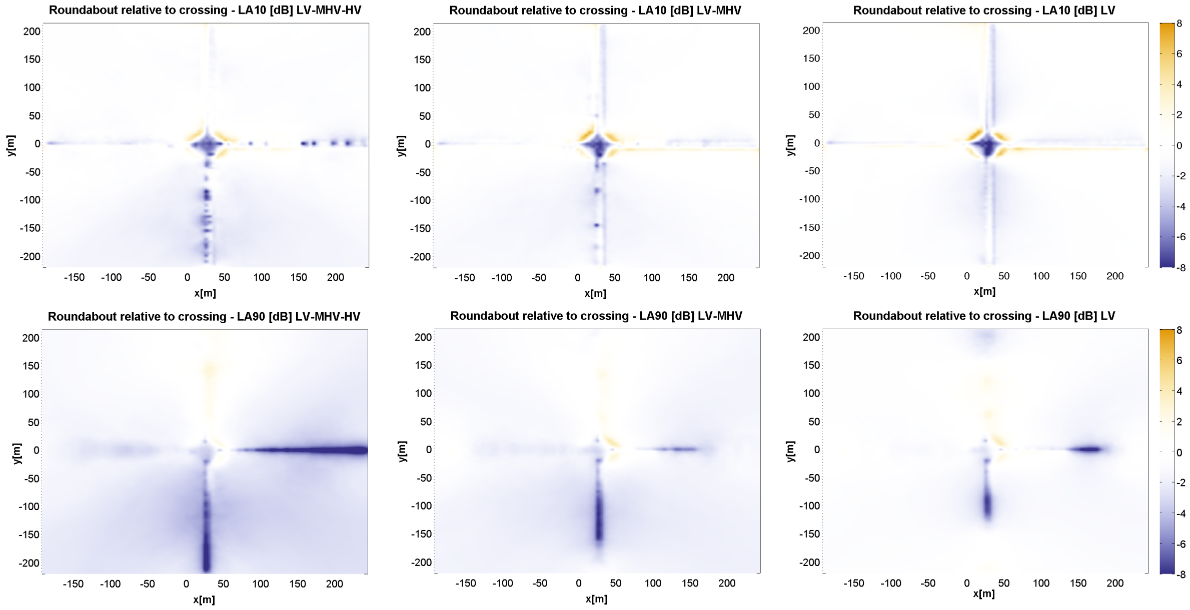

Figure 12 –Maps for L_{A10} and L_{A90} (dB) in the three cases, plotted as roundabout relative to crossing.

As previously mentioned, annoyance has been related to the noise events caused by road traffic noise. In the present study, an *event* is defined to occur when a chosen noise level threshold is exceeded, lasting for at least 3 seconds, and then is finished when the level has decreased 3 dBA from the threshold. This is based on studies presented in (4). The difference maps in terms of number of events above 60 dBA reflect the influence of heavy vehicles, resulting in a larger number of events. As soon as the heavy vehicles are removed, the differences start to smear out, being the largest ones in the entrance of the East lanes, where the roundabout has a higher number of events, probably due to the large queue as a consequence of the great amount of vehicles traveling S-N.

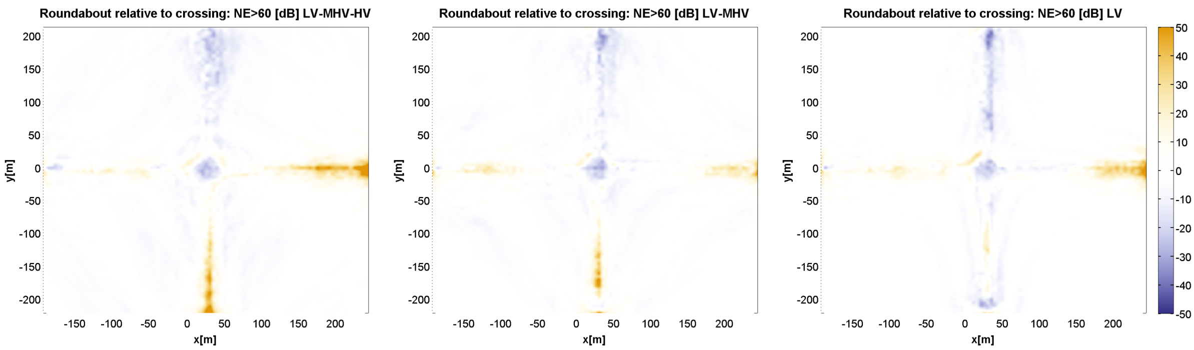

Figure 13 – Difference maps for the number of events above 60dBA in the three cases

Finally, Fig. 14 includes the study of Case 1 for both intersection types, highlighting several study points (see Fig. 3) and their number of noise events above 60 dBA. This number is specially large for all cases in study point 12, where different behaviours may lead to these higher values, e.g. vehicles coming from the signalized crossing are grouped, while in the roundabout their appearance is more random, leading to higher number of events. Contrary, in study point number two, located close to the intersections, the number of events is higher for the signalized crossing due to the existence of a traffic light in the surroundings. In this case, the indicators related to the number of events might also be sensitive to how large in time the peak of the event gets.

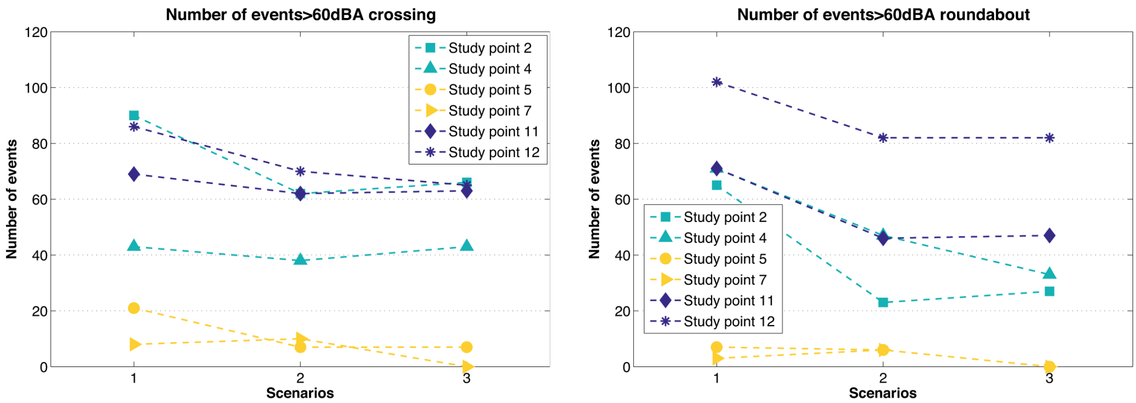

Figure 14 –Number of events above 60 dBA at crossing (left) and roundabout (right) for selected study points

4. CONCLUSIONS

The aim of the present paper is to study the transport management and traffic design and its consequential sound environment through a micro-scale perspective, combining microscopic traffic simulation with noise calculations (both emission end exposure) as function of time. The model incorporates vehicle kinematics, obtaining single-vehicle output in terms of position, vehicle type, speed and acceleration over time. This output is used as input to estimate the noise emission of each vehicle through a series of in-house developed Matlab scripts. With these data, dynamic noise maps are generated and time pattern analysis is made for all scenarios.

The focus is placed on the intersections as one of the most relevant designs in cities' traffic network, attempting to improve the knowledge about the key features in urban traffic dynamics and noise emission. To do this, the tool under development can be seen as a dynamic one, which may bring further knowledge in the urban and traffic planning decision-making process. Selected outcomes are presented in this section.

From the analysis performed in the selected study points, in case of banning heavy vehicles that are mainly seem as the loudest ones, the equivalent sound pressure level is reduced by 1.5-3 dBA. This reduction is slightly higher for the signalized crossing. Smaller differences are shown in the case of removing medium-heavy vehicles (1.5-2 dBA).

However, for the number of events above 60dBA, its reduction due to the banning of heavy vehicles is larger in the case of the roundabout, at least for the selected study points. The smaller effect for the signalized crossing makes it more relevant to suppress heavy vehicles in the case of the roundabout. This is probably due to the larger number of vehicle stops realized in the roundabout scenario (large queues at certain lanes as a consequence of high flow rate traffic on previous input lanes). These statistics have been studied, however they are not shown in the paper. The crossing is normally characterized as a stop-controlled situation, while the roundabout depends largely on the ability of drivers to admit or deny gaps (7).

Moreover, this example demonstrates that in the presence of heavy vehicles, the implicit rule to yield to vehicles in the roundabout results in a higher congestion of certain parts of the network, as these vehicles need a larger gap to enter the roundabout, turning it into a complex situation in the case of a higher traffic flow from the previous entry lanes. However, if the heavy vehicles are removed, the number of loud events in the roundabout (>60 dBA) is dramatically reduced. This means that for Cases 2 and 3 the number of loud events (>60 dBA) for the studied points is, in general, smaller for the roundabout. This may attempt to answer to the findings in (5), since the presence of heavy vehicles led to higher unpleasantness scores in the roundabout cases. These types of results are interesting in the study beyond the energy equivalent measures, accounting for noise events caused by traffic, which has been suggested to have an impact in noise annoyance (22). With this, we want to go further in the understanding of traffic scenarios and its relation to traffic density and traffic flow, where for example, a continuous flow has been rated as less unpleasant.

The temporal distribution is represented by the variances between the two scenarios through L_{A10} (peak) and L_{A90} (background) noise levels. For both, the noise levels are higher in the signalized crossing intersection cases. In this type of intersection, vehicles are clustered in groups and higher speeds are reached in a short period of time. This, together with greater variations in acceleration, gives higher dynamics in the temporal distribution along the roads. However, larger effects are noticeable in the presence of heavy vehicles. The highest background levels are mainly seen at the congested lanes. These levels are reduced as heavy vehicles are removed and the difference between intersection types becomes smaller. For the peak noise level difference maps (LA10), the presence of heavy vehicles is resulting in a clustering of noisy peaks among the congested lanes, smeared out if the heavy vehicles are removed.

In the case of acoustically clustering the lanes for both the roundabout and the signalized crossing, the resulting sound power level distribution from the case including the three vehicle categories is very similar for both intersection types, however, the percentage of levels in the lower ranks has increased in the case of the roundabout, reducing overall sound power levels.

A good solution to improve the sound environment resulting from the roundabout scenario will be to have a traffic light in the south entry. This way, the vehicles coming from the east will be able to incorporate to the roundabout with a certain flow, since now, the large amount of cars traveling form the south is precluding them to enter the intersection and reach their destination within a reasonable time, increasing the sound power level along the whole road.

The tool presented is under development and further development is needed. Future work will look towards the improvement of the road traffic sound power level distribution model (23), bringing the results closer to real urban environments. Also, measurement data to calibrate average deceleration and acceleration emission will also improve the traffic model. Finally, the inclusion of pedestrian crossings is of interest since it will affect the driving behaviour and hence, the sound environment, especially in the case of the roundabout scenario. Furthermore, a more advanced propagation model including the effect of buildings will enhance the realism of the model and its outcomes.

With this type of study, we attempt to answer to different demands in urban sound qualities by studying and controlling the road traffic and its dynamics, as it is the major noise source in cities.

ACKNOWLEDGEMENTS

This research received funding through the People Programme (Marie Curie Actions) of the European Union's 7th Framework Programme FP7/2007-2013 under REA grant agreement n°290110, SONORUS "Urban Sound Planner".

This research has made use of software Vissim provided by PTV Group. The authors thank Lars Hansson for his support and valuable advice.

REFERENCES

1. Salat S, Chen M, Liu F. Planning energy efficient and livable cities: energy efficient cities. [Internet]. Energy Sector Management Assist. Program, Washington: The World Bank Group; 2014. Available from: http://documents.worldbank.org/curated/en/2014/11/23795273/planning-energy-efficient-livable-cities-energy-efficient-cities
2. Estévez-Mauriz L, Forssén J, Kropp W, Zachos G. Traffic dynamics, road design and noise emission: a case study. In: Proc. the 10th European congress and exposition on noise control engineering (Euronoise 2015), Maastricht, The Netherlands, May 31-June 3, 2015
3. European Environment Agency. Exposure to and annoyance by traffic noise. TERM 05. Copenhagen: EEA; 2014.
4. Brown AL. An overview of concepts and past findings on noise events and human response to surface transport noise. Proc. 43rd International Congress on Noise Control Engineering November (Internoise 2014), Melbourne, Australia, November 16-19, 2014
5. Sato T, Yano T, Björkman M, Rylander R. Road traffic noise annoyance in relation to average noise level, number of events and maximum noise level. Journal of Sound and Vibration. 1999; 223(5):775-7784
6. Rodegerdts, L, Bansen J, Tiesler C, Knudsen J, Myers E, Johnson M, et al., NCHRP Report 672: Roundabouts: An Informational Guide [Internet]. Transportation Research Board of the National Academies, Washington, D.C.: Transportation Research Board; 2010. Available from: onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf
7. Trueblood M, Dale J. Simulating roundabouts with VISSIM. In: Proc. of the 2nd Urban Street Symposium, Anaheim, California, July 28-30, 2003
8. Can A, Leclerq L, Lelong J, Defrance J. Capturing urban traffic noise dynamics through relevant descriptors. Applied Acoustics. 2008 Dec; 69(12):1270-1280

9. Chevalier E, Can A, Nadji M, Leclercq L. Improving noise assessment at intersections by modelling traffic dynamics. Transportation Research Part D: Transport and Environment. 2009; 4(2):100-110
10. Can A, Chevalier E, Nadji M, Leclercq L. Dynamic traffic modelling for noise impact assessment of traffic strategies. Acta Acust united Ac. 2010; 96:482-493
11. De Coensel B, Can A, Degraeuwe B, De Vliege I, Botteldooren D. Effects of traffic signal coordination on noise and air pollutant emissions. Environmental Modelling & Software. 2012; 35:74-83
12. Kephalopoulos S, Paviotti M, Anfosso-Lédée F. JRC Reference report on Common Noise Assessment Methods in EU (CNOSSOS-EU). EUR 25379 EN. Luxembourg: Publications Office of the EU. 2012
13. Göteborg Stad. Älvstaden. Frihamnen district. [Internet]. Available from: http://alvstaden.goteborg.se/vara-delomraden/frihamnen/
14. Trafikverket. Utformning av vägar och gator [Design of roads and streets]. [Internet]. Available from: http://www.trafikverket.se/for-dig-i-branschen/vag/Utformning-av-vagar-och-gator/
15. Mannering FL, Washburn SS. Principles of Highway Engineering and Traffic Analysis. 5th ed. New York: Wiley; 1998
16. De Coensel B, Botteldooren D. Traffic signal coordination: a measure to reduce the environmental impact of urban road traffic? In: Proc. 40th International Congress and Exposition on Noise Control Engineering 2011 (Internoise 2011), Osaka, Japan, September 4-7, 2015
17. Göteborg Stad, Trafikkontoret. [Internet] Trafikmängder på olika gator. Available from: http://goteborg.se
18. National Research Council. Transportation Research Board. HCM 2010: highway capacity manual. Washington, D.C.: Transportation Research Board; 2010
19. PTV Vissim 6 User Manual. Karlsruhe, Germany: PTV AG; 2013
20. Nota R, Barelds R, van Maercke D. Technical Report Harmonoise WP3 Engineering method for road traffic and railway noise after validation and fine-tuning. Deliverable of WP3 of the Harmonoise project. Technical Report HAR32TR-040922-DGMR20. 2005
21. Forssén J, Kropp W, Khilman T. Introduction to traffic noise abatement. In: Nilsson ME, Bengtsson J, Klæbe R, editors. Environmental methods for transport noise reduction. Florida: CRC Press; 2015. p. 1-18
22. Trollé A, Terroir J, Lavandier C, Marquis-Favre C, Lavandier M. Impact of urban road traffic on sound unpleasantness: A comparison of traffic scenarios at crossroads. Applied Acoustics. 2015; 94:46-52
23. De Coensel B, Brown AL, Tomerini D. A road traffic noise pattern simulation model that includes distributions of vehicle sound power levels. Applied Acoustics. 2016; 111:170-178