Traffic dynamics, road design and noise emission: a study case

Laura Estévez-Mauriz, Jens Forssén, Wolfgang Kropp, Georgios Zachos
Division of Applied Acoustics, Department of Civil and Environmental Engineering, Chalmers University of Technology, Göteborg, Sweden.

Summary

Traffic management and traffic design have been issued as the main solutions to reduced problems related to mobility. In relation with noise mapping, traffic simulation is usually based on macroscopic modelling, with e.g. mean speed and flow as output. However, dynamics in terms of acceleration have a strong influence on noise emission. In the current paper, road traffic noise emission is calculated with dynamic traffic as input. A real case, now in planning stage, is used as a setting containing several traffic design alternatives. The resulting total noise emission is calculated for the different traffic and road design solutions by using a microscopic traffic simulation model (VISSIM) combined with a model for noise emission (CNOSSOS-EU). The qualities of the resulting traffic and noise situations are discussed.

PACS no. 43.50.Lj, 43.50.Rq

1. Introduction

There is an increasing awareness on the environmental impact that entails a discussion about the need for new urbanization configurations. These patterns are seen as the key to a sustainable built environment [1]. However, balance between performance optimization, sustainability and quality of life have become the main concern. It is essential to establish the framework enabling greater environmental benefits to ensure livability of spaces.

The current paper is presented with the question in mind about what is considered a good built environment. We attempt to look for a dynamic tool that helps in the urban planning process to understand the underlying systems (e.g. transport) and the effects they have on noise pollution and by end, in the wellbeing of inhabitants.

1.1. City as a complex system

Most of the urban planning practice is based on one main system (i.e. urban form) as the project leader. This one-dimensional approach leads to a problem-solving scenario. The multi-perspective methodology has normally been rejected, considered as too costly and difficult to achieve, only beneficial in the long-term.

In recent decades the study approach has shifted from physical characteristics of a built-up area to a multifaceted approach [2]. However, new complex insights on functional and response scenarios are needed, where interaction between systems [3] guides the urban planning processes.

1.2. Urban transport, city planning and environmental quality

One of the main underlying systems in cities is related to transport and traffic management, considered as a source to collateral problems generating a cascade effect. All around Europe, chronic traffic congestion has become a problem. The European Environment Agency points out the impact of urban transport in the quality of life for three quarters of Europeans living in cities [4]. Urban traffic is responsible for 40% of CO_2 emissions and 70% of other pollutants [5].

Related to environmental pollution, Urban Environment Stress (UES) is increasing in urban areas [6]. This causes physical and psychological illnesses, indicating the inability to adapt to surrounding situations due to unacceptable environmental conditions.

1.3. Traffic dynamics and noise pollution

Although investigations have identified measures to reduce noise in traffic compositions [7,8,9], the problem is normally attacked with static traffic flow analysis, dismissing the vehicle kinematics with a strong influence in terms of noise emission [10,11]. In this sense, higher fluctuations in traffic noise assessment can be underestimated by noise prediction software. Literature reflects the importance of its inclusion by modelling synchronized traffic lights [12], assessing driving conditions [13] or the effects of intersections [11]. In order to analyse different traffic strategies that may bring an opportunity to improve the environmental acoustic quality, a dynamic traffic model based on a microscopic analysis under a real case scenario is now under development. This will allow performing a more realistic study and consequently, assessing a more reliable noise emission performance. High acceleration and deceleration rates, driving behaviour and obstacles cause disruptions in traffic, increasing the risk of higher noise emission due to traffic.

2. Methodology

2.1. Case study: Frihamnen area, Gothenburg, Sweden

In order to represent and study a real case, simulations are performed at Frihamnen area in Gothenburg, Sweden. It is subjected to an enormous transformation, reinventing itself from a port area into a dense/mixed-used neighborhood with 15,000-20,000 inhabitants and the same number of jobs [14].

Figure 1. Preliminary traffic distribution. Frihamnen.

Frihamnen is seen as a testbed of urban form and planning processes. One of the first concerns relates to mobility, where bicycles, pedestrians and public transport are encouraged and private transport is partially limited. For it, a preliminary traffic planning (Fig. 1) has been established by the Traffic Office of Gothenburg, Trafikkontoret (TK). Their proposal is to segregate public and private transport, creating two public transport corridors (N-S and E-W direction). The two southern piers will have traffic restrictions, allowing only residents. However, one can find uncertainties regarding disposition details, which have been adjusted to hold the demanded traffic capacity.

2.2. Traffic strategies: analysis of plausible scenarios

Plausible variations in traffic strategies under the base scenario were made while holding the same traffic (Table 1). Fig. 2 is the correspondance to the modelled layout.

Table 1. List of studied scenarios.

Scenario	Description	Model layout
1	Base scenario with adaptations	A
2	Remove parallel road to highway E155	B
3	Remove roads close to piers	C
4	Transform intersection with lights into roundabout	D
5	Reduce speed on E155 to 50km/h	A
6	Reduce speed on bridge to 50km/h	A
7	Reduce speed on road close to piers to 30 km/h	A
8	Remove medium-heavy and heavy vehicles	A
9	Acceleration set to 0	A

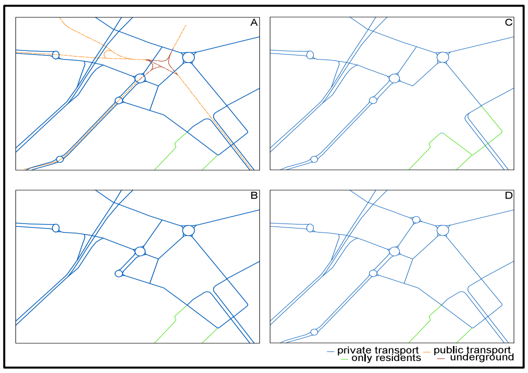

Figure 2. Traffic strategies.

2.3. Microscopic simulation and traffic situation

A microscopic simulation was performed to analyze road transport noise emission under various strategies and optimize traffic with high dynamic fluctuations. This was done through the software VISSIM which represents individual traffic behavior and gives dynamic outputs such as position versus time, speed and acceleration.

As mentioned before, assumptions had been done since the project is in a development phase. In this sense, input data for traffic came from demand adaptation based on traffic counts from previous years in the area [15, 16], together with the maximum state of traffic proposed from TK. Simulation is performed based on a forecast of the daily peak hour within an OD matrix following the recommendations in [17]. This way, the worst plausible scenario is always represented. Static routes for private vehicles, freight transport and buses through the area are taken into account; at this stage new N-S and E-W public transport corridors were not included.

2.4. Noise emission model

The European Noise Directive (END) demands to establish a common approach to assess exposure to environmental noise. In this sense, EC and EU member states developed a common framework for noise assessment methods [18]. At the current stage, this method is valid for determining road traffic noise in the octave bands 125 to 4 kHz.

Generators of vehicle noise are grouped under rolling and propulsion noise labels, modelling noise emission as a point source at 0.05 m height. Here, 3 vehicle categories are included: light, medium-heavy and heavy vehicles. Since the amount of heavy vehicles counted in previous years in the area was 6-10% and, to adapt vehicle categories to the ones in CNOSSOS-EU [18], the amount of light vehicles was set to 92%, while medium-heavy and heavy vehicles was 4% each.

The noise produced by a vehicle is described by parameters as the vehicle category and the speed. Attached to these, corrections for environmental effects are performed as well as acceleration or deceleration with a significant effect on the noise emission. The adjustment due to the latter was determined through the Harmonoise model [19], which included a correction term for driving conditions multiplied by the actual acceleration or deceleration of the vehicle. This substitution was done since the term in CNOSSOS model only depends on the existence of a junction close enough to have an effect on the noise emission (crossing/roundabout).

The traffic analysis modeling gives data about vehicles position, speed, acceleration, type, link in which they are positioned every 0.1 second. This is the input for the analysis through a series of scripts developed in Matlab with the CNOSSOS source emission model. The procedure makes possible to obtain acoustic characteristics of each scenario described later on. The output power level is computed for the emissions of all vehicle positions present during the calculation hour, which is divided into quarters (900 s). For this paper, geometric attenuation and energy doubling due to the ground are considered. This simplification will be improved in future work, however it enables a comparison of traffic strategies.

Eleven analysis points where chosen for the study with the intention to represent different situations, from points close to traffic to others located in the piers. Noise maps (Fig. 3 & 4) reflect differences in terms of sound pressure level. All traffic was handled, meaning that it was re-allocated (see highlighted road in Fig. 4).

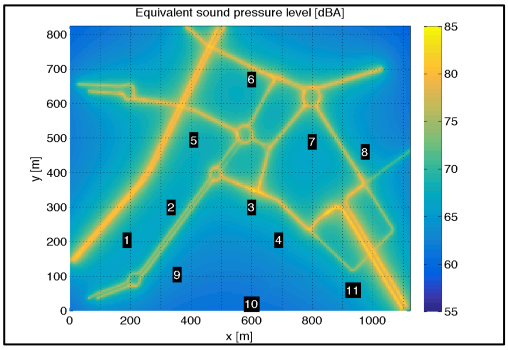

Figure 3. Eleven points of analysis for the $L_{AEq,900s}$ of the first scenario.

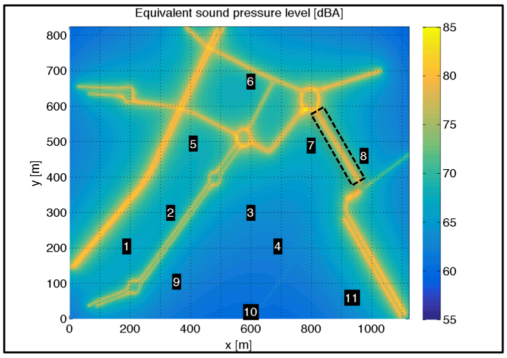

Figure 4. Eleven points of analysis for the $L_{AEq,900s}$ of the third scenario.

2.5. Noise descriptors

The use of dynamic model allows to represent $L_{Aeq,1s}$ with traffic evolution over time, in this case, one hour. Different indicators can help to assess qualities of a good environment. Due to the relation of road traffic with noise annoyance and interference in human activities [21], the study introduced a set of indicators related to calm periods and noise events.

Centre of mass time (CMT). Periods of time with noise level below a limiting level are given a weight that increases linearly with the length of the time period, e.g. a single 5-second "quiet" period is given five times higher value compared to five 1-second "quiet" periods, i.e. penalizing fragmentization of “quieter periods” and valueing clustering of them. This way of measuring time variances along a period aims to a better understanding of the chances to recover from high noise levels due to larger less noise time periods.

Number of events. Research in recent decades have pointed to the relation of noise events caused by road traffic with noise annoyance and other health effects [20, 21]. However, even if this kind of analysis is particularly important during night time where sleep disturbances is more evident, we like to include it as part of the methodology. The indicators are function of noise level (e.g. 50<Leq<55 dBA, meaning equivalent noise level between 50 and 55 dBA) or of a certain indicator (e.g. L50 meaning the level exceeded 50% of time). Based on studies summarized in [20] and in the convenience for the presented scenarios, we qualify as an event when the level/indicator is exceeded by 3 dBA and lasting for at least 3 seconds. The event is over when the level has decreased by 3 dBA from the level on which it starts to count.

3. Results: Traffic strategies and acoustic performance

In the sections bellow, analyzes are shown as examples of the possibilites the tool may offer.

3.1. Sound pressure level and peak sound pressure level. Segment analysis

To study data through maps, roads are grouped into segments (ca 150). They show the equivalent sound pressure level $L_{Aeq,900s}$ that each segment contributes to a certain point, i.e. a kind of contribution noise map. The same way, the largest $L_{Aeq,1s}$ value during the period, here denoted L_{peak}, is analyzed. This in order to reflect on the differences between the two indicators and on the possibilities that dynamic traffic assessment gives. For it, contribution maps of the first 15 minutes of analysis in study point 6 are shown for two scenarios where a crossing with traffic lights is replaced by a roundabout. $L_{Aeq,900s}$ between strategies (Fig. 5 & 6) show already an improvement by reduced contribution from the nearest traffic segment. Differences in L_{peak} are around 2.5 dBA (Fig. 7 & 8).

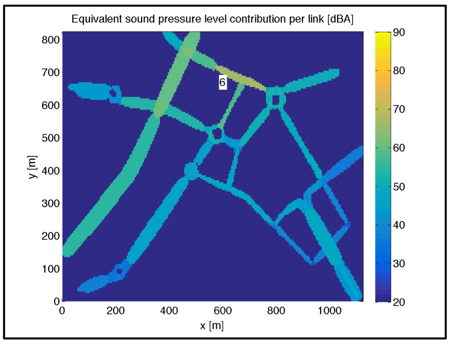

Figure 5. $L_{AEq,900s}$ contribution per link. Base scenario, study point 6.

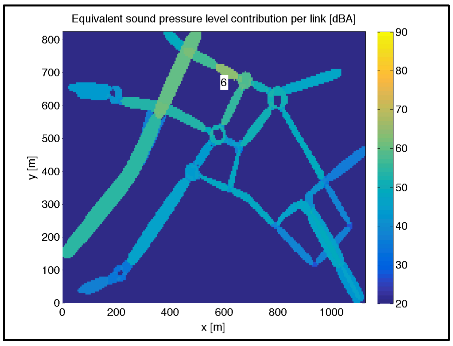

Figure 6. $L_{AEq,900s}$ contribution per link. Scenario 4, study point 6.

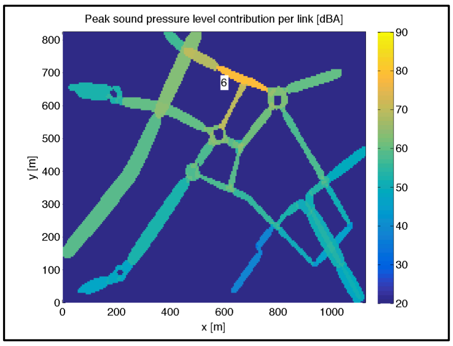

Figure 7. L_{peak} contribution per link. Base scenario, study point 6.

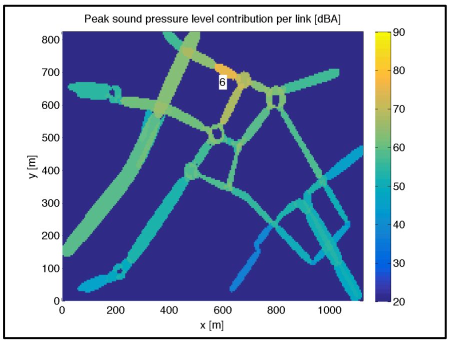

Figure 8. L_{peak} contribution per link. Scenario 4, study point 6.

3.2. Acoustic performance

The purpose here is to get an overview of the global improvement of each scenario.

In Fig. 9 L_{Aeq} and L50 for 1 hour are presented for all scenarios and all study points. In general, when assessing $L_{Aeq,1h}$ the most favourable scenarios are 3, 5, 8 and 9. Speed reduction in the highway (scenario 5) might be a good solution to reduce noise levels in the majority of the study points. Keeping only light vehicles (scenario 8) reduces levels up to 2.5 dBA. Since the fluctuation in time is changing between scenarios, the figure addresses differences between mean ($L_{Aeq,1h}$) and median level (L50).

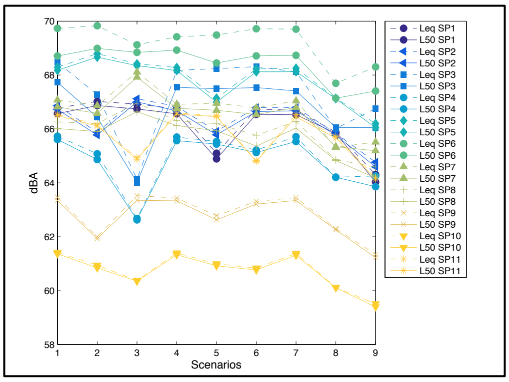

Figure 9. Sound pressure level (dBA) and L50 (dBA) in all scenarios for all study points.

3.3. Sound pressure level, calm periods and events

Now the focus is on finding relations between scenarios and receiver positions and between mean-energy-based descriptors and time-pattern-based indicators, describing events and calmness periods (Fig. 10). Relatively large variations in CMT L50 (+7/-11 s compared to baseline 33 s) as well as in the number of events above L10 and L50 (ca +/- 40% compared to base scenario).

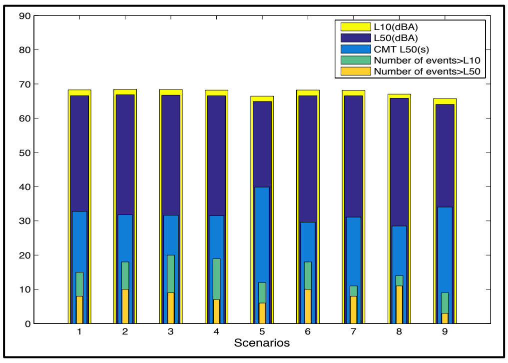

Figure 10. Statistical indicators, events and calm period descriptors. Study point 1.

3.4. Time ratio under a certain noise level and number of events

Analysis of study point 3 (Fig. 11) shows no events in the range of 70-75 dBA for scenarios 3 and 8, while scenario 1 has 59. However, differences are found in relation with time under certain noise levels; in scenario 1, time ratio between 65-70 dBA is significant (83%) while in 3, it is reduced (14%), shifting the majority of time (86%) to the lower range 60-65 dBA.

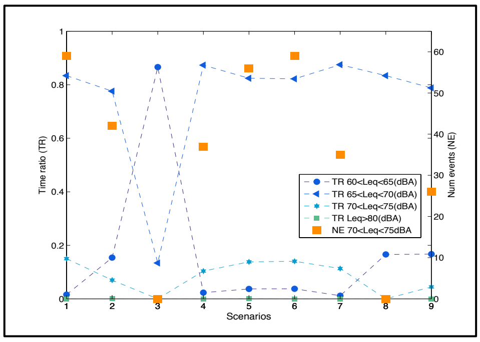

Figure 11. Time ratio noise levels and number of evernts. Study point 3.

4. Discussion

The present tool is seen as a dynamic map that can be adapted to assess different possibilities in real scenarios. The output can be in the form of noise contribution maps and time patterns.

We present here a summary of specific outcomes. Sound pressure level is reduced for most of the study points in scenarios 3, 5, 8 and 9. Scenario 3 with a more radical change (road removal) has higher effects on a larger area. However, special attention needs to be paid to consequential effects, where careful decisions in traffic strategies have to align to qualities and usage needs. Examples showed that within the same layout, removing acceleration reduced 60% of the events above L10, while banning heavy vehicles reduced 7%. Also, absence of events in some points can respond to different causes. In scenario 3 noise levels are lower compared to scenario 1, but level in scenario 8 is even due to the ban of heavy vehicles, reducing possibilites for events.

This type of assessment is still under development. Future work will look towards the inclusion of a more advanced propagation model and the influence urban development planning has on the acoustic quality, like the shape of buildings. Related to road traffic strategies, the work will pursue the effects of introducing electric vehicles as well as dynamic routes and changes in data networks. As part of the connection with other environmental factors, CO_2 emissions are of interest to explore.

5. Conclusion

We have here attempted to take initial steps for a dynamic noise mapping tool in a real case scenario. It is conceived as a development tool composed by noise contribution maps and time patterns that helps to minimize the gap between urban planning practice and current situations in cities. The inclusion of a real case allows us to test plausible traffic strategies to raise opportunities to improve acoustic quality. In this sense, when studying static noise models, as in noise prediction software, traffic flow is even [12]. This leads to noise assessment underestimations, especially in cities with high traffic fluctuations in e.g. acceleration.

In the present paper we want to highlight the impact that decisions in traffic management may have in the built environment. When negative impacts are to be reduced, global and local actions are needed at every level of society, having a greater consideration for the environment from the beginning of the urban planning processes [9].

With this type of study we also want to point out that there is no single solution for all built environments. However, this can be seen as a starting point to combine strategies depending on uses and qualities that want to be assessed and to help define differences in sound capacity.

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 Jonas Andersson from Göteborg Stad Trafikkontoret, as well as Mani Fakhar and Hengameh Fattahi.

References

[1] T. Wilbanks, S. Fernández. Climate Change and Infrastructure, Urban Systems, and Vulnerabilities: Technical Report for the U.S. Dep. of Energy in Support of the Nal. Climate Assessment. Washington DC:Island Press, 2013.

[2] Larkham, P.J. Understanding urban form? Urban Design 93 (2004) 22-24.

[3] J.M. Gurr, C. Walloth. Towards a Transdisciplinary Understanding of Complex Urban Systems. In: C. Walloth, J.M. Gurr, J.A. Schmidt. Understanding Complex Urban Systems: Multidisciplinary Approaches to Modelling. Springer, 2014.

[4] European Environment Agency EEA. A closer look at urban transport. TERM 2013: transport indicators tracking progress towards environmental targets in Europe. Luxembourg:Pub. Office of the EU, 2013.

[5] Commission of the EC. Green Paper. Towards a new culture for urban mobility. Brussels, 2007.

[6] D.A. Stanners, P. Bourdeau. Europe’s Environment. The Dobris Assessment. Copenhaguen:EEA,1995.

[7] Novel solutions for Quieter and Greener Cities. HOSANNA workshop summary brochure. Available: www.greenercities.eu

[8] J. Forssén, W. Kropp, T. Kihlman. Introduction to traffic noise abatement. In: M. Nilsson, J. Bengtsson, R. Klaeboe (eds). Environmental Methods for Transport Noise Reduction. CRC Press:Florida, 2014.

[9] T. Kihlman, W.Kropp, W. Lang. Quieter Cities of the Future. Chalmers Univ. of Technology:Gothenburg, 2014.

[10] A. Can, L. Leclerq, J. Lelong, J. Defrance. Capturing urban traffic noise dynamics through relevant descriptors. Applied Acoustics 69 (2008) 1270-1280.

[11] E. Chevalier, A. Can, M. Nadji, L. Leclercq. Improving noise assessment at intersections by modeling traffic dynamics. Transportation Research Part D: Transport and Environment 4(2) (2009) 100-110.

[12] B. De Coensel, A. Can, B. Degraeuwe, I. De Vliege, D. Botteldooren. Effects of traffic signal coordination on noise and air pollutant emissions. Environmental Modelling & Software 35 (2012) 74-83.

[13] A. Can, D. Botteldoren. Towards traffic situation noise emission models. Acta Acust united Ac. 97 (2011) 900-903.

[14] Göteborg Stad. Älvstaden. Available: http://alvstaden.goteborg.se

[15] Göteborg Stad, Trafikkontoret. Trafikmängder på olika gator .Available: http://goteborg.se

[16] National Väg databas. TrafikVerket. Available: https://nvdb2012.trafikverket.se/SeTransportnatverket

[17] Kontoret för vägutformning Vägutforming 94 Version S-2 Trafikteknisk standard. Stockholm, 2002:114.

[18] S. Kephalopoulos, M. Paviotti, F. Anfosso-Lédée. JRC Reference report on Common Noise Assessment Methods in EU (CNOSSOS-EU). Luxembourg: Pub. Office of the EU, 2012

[19] R. Nota, R. Barelds, D. van Maercke, Technical Report Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine-tuning, 2005.

[20] A.L. Brown. An overview of concepts and past findings on noise events and human response to surface transport noise. Proc. Internoise 2014.

[21] B. De Coensel, A.L. Brown, Botteldooren, D. Modeling road traffic noise using distribution for vehicle sound power level. Proc. Internoise 2012.