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A methodology to assess the impact of driving noise from individual vehicles in an urban environment

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Road traffic is a major source of environmental noise pollution in urban areas, while the intra-day distribution of road traffic is often leading to sub-optimal use of infrastructure and ressources. In order to evaluate and enable improved distribution of traffic, taking into consideration its impact in terms of noise emissions and other externalities, the present contribution focuses on a methodology designed to assess the impact of the noise generated by individual vehicles on a city's population using NoiseModelling, an open-source library implementing the CNOSSOS-EU model, capable of producing environmental noise maps. The method was applied to delivery trucks in the city of Stockholm, comparing the population's exposure in a variety of scenarios.

The initial step consists in processing microscopic traffic data (simulated in the present contribution), where the traffic intensity is dependent on the time of day that is targeted. The micro-traffic data is subsequently used to generate background noise maps by simulating the propagation of traffic noise using NoiseModelling. Then, the impact of the noise from the vehicle of interest is simulated, based on several parameters (route followed, type of motorization: diesel or hybrid, etc.). Finally, the data is post-processed to calculate the "exceedance" (increase in ambient noise) caused by the vehicle, taking the previously calculated background noise maps as reference. The complete methodology, its underlying assumptions, and the associated criteria proposed in order to assess the impact of noise emissions from individual vehicles will be presented and demonstrated on realistic scenarios.

1. Introduction

The increasing prevalence as well as better understanding of noise exposure as a cause of health problems has motivated major developments in the estimation and assessment of noise pollution, of which road traffic noise is found to be a leading contributor. Traditional noise mapping allows for taking reactive measures to abate existing levels of noise pollution such as testing action plans using strategic noise maps [1]. In order to address further challenges associated with noise pollution at a more detailed level than that offered by the generation of strategic noise maps, more refined approaches are necessary. The present paper proposes such a methodology which is intended to allow for preemptive decision making when planning urban mobility strategies.

The methodology described in this contribution processes the output of a noise emission and propagation module which takes traffic flow as input, in order to extract the driving noise impact of individual vehicles within the flow. Time-dependent noise mapping, which is a variant of the

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static noise mapping approach, currently in its developing stage [2, 3], is considered in the proposed approach due to the need to assess noise emissions under varying configurations of traffic flow. In that sense, the methodology also allows to overcome the limitations associated with time-averaged noise indicators during sparse nighttime traffic [4] by offering the possibility to introduce appropriate noise indicators [5].

After introducing an overview of the proposed methodology, its modelling steps and necessary input data in Section 2, case studies and the associated discussion are presented in Section 3 before drawing general conclusions.

2. Methodological Proposal

The proposed methodology aims at comparing how driving noise emissions from single vehicles impact a city's population in multiple scenarios. Establishing those scenarios consists in varying the values of one or more of the parameters introduced in our approach, whose general workflow is described in Fig. 1. These influential parameters include for example:

– time of day, *e.g.* peak hour, night time, specific time;
– vehicle route, including speed;
– vehicle noise emission model, depending on the type of vehicle, the type of propulsion system, etc.

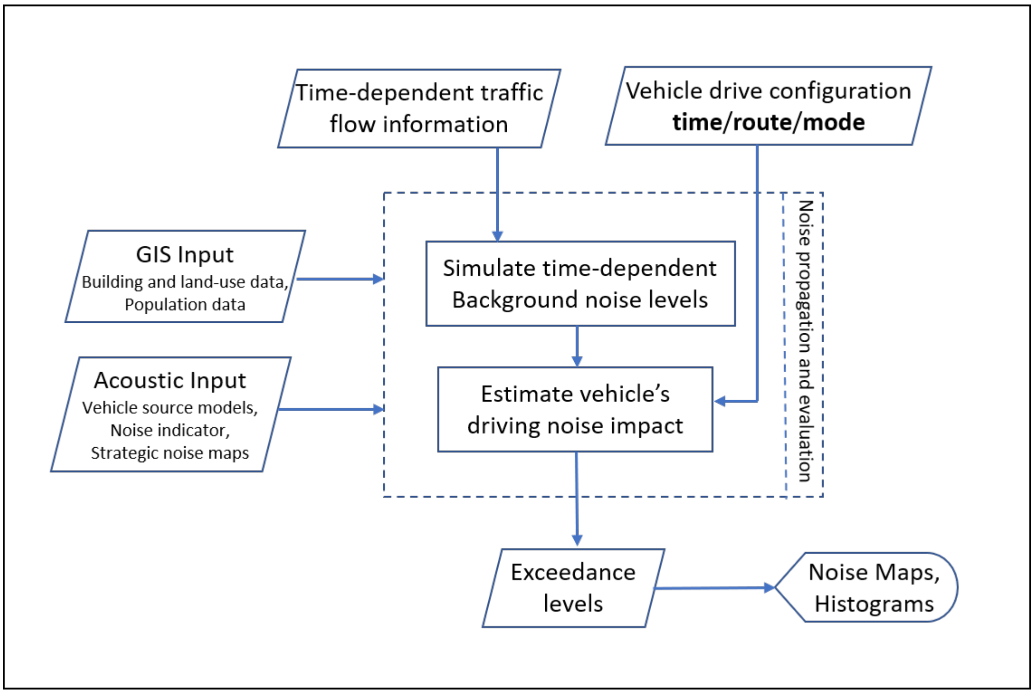


Figure 1: Flowchart of the methodology

2.1 General methodology steps

The methodology itself may be described following three main steps:

1. the first step consists in establishing an average background noise map for the area of study, which will serve as a noise level baseline;
2. the second step consists in simulating the propagation of the sound emitted by the individual vehicle of interest;
3. the final step consists in evaluating the impact of the individual vehicle with an indicator which reflects the increase in noise levels that citizens are exposed to, compared to the otherwise established baseline level.

2.1.1 Baseline: background noise maps

As previously mentioned, the first step consists in generating a reference noise map for each of the targeted time segments of the day.

To generate such a map, the initial choice made in this contribution is to aggregate micro-traffic data into average traffic per each road segment. NoiseModelling, an open source tool designed to produce environmental noise maps [6], is then used to generate sound sources from those road segments according to the harmonized noise modelling standards CNOSSOS-EU [7] and to subsequently calculate the sound level at each receiver. This sound level is converted to and stored as A-weighted, equivalent level, LA_{eq}.

2.1.2 Vehicle noise simulation

On the basis of a specific noise emission model associated with the studied vehicle and its speed, each position of the vehicle is assigned an emitted sound power level in each octave. NoiseModelling is subsequently used to simulate the propagation of the sound from the positions of the vehicle to the receivers. The outcome is stored as LA_{eq} levels for each receiver, and for each time step.

2.1.3 Noise impact evaluation via an exceedance indicator

The noise impact of an individual vehicle varies depending on the time of day or the neighbourhood in consideration, given that ambient noise can play an important role in the discomfort caused by a vehicle.

In order to evaluate that impact in connection with a baseline level associated with ambient noise, an *exceedance* indicator exc_i (in dB) is calculated at receiver i and defined as

$$exc_i = 10 * log_{10}\left(10^{LA_{eq,i}/10} + 10^{bg_i/10}\right) - bg_i \tag{1}$$

where $LA_{eq,i}$ is the sound level generated by the vehicle (without background noise) at receiver i, and bg_i is the average background noise level at receiver i at the given time of day.

This indicator therefore reflects an increase in sound power received due to the passing of the vehicle. It is calculated for each receiver, for each time step, from the previously generated background maps and vehicle noise emission and propagation simulation.

Subsequently, a local indicator associated with the *impact* of the vehicle on the population may be derived from the exceedance measure. For instance, when defining the impact in the case study of this contribution, a choice is made to evaluate the impact in terms of the quantity $exc * pop$ for each receiver and for each time step, where pop refers to the aggregated number of citizens to each receiver.

Finally, a global impact indicator may be evaluated from this local indicator, in order to compare multiple scenarios easily, using a single metric. In the present contribution, the impact values of all time steps are summed, for each receiver, to calculate the vehicle's impact over the duration of the trip for each receiver. The impact values of all receivers may later be summed into a single metric to compare the global impact of multiple scenarios. Apart from the global indicator considered here, more specific indicators may be derived from the data, which is in itself a topic of interest beyond the scope of the present contribution [8].

2.2 Modelling and input data

Traffic noise modelling consists in the simulation of traffic sound emission and propagation in an area of study. The two main steps of such modelling are the prediction of the sound emission levels of sound sources (cars, trucks...), and the propagation of that sound in the area of study depending on the layout of the area (buildings, forests...).

In the present contribution, the CNOSSOS-EU framework is used for both noise emission and propagation models, though the methodology is not limited to these. As previously mentioned, NoiseModelling, being almost compliant with the CNOSSOS-EU standard method [6], is used here for the simulation of road traffic sound emission and propagation. The following inputs are necessary for this purpose: sound sources (*e.g.* vehicles), the layout of the area of interest (buildings, parks...) and receivers, *i.e.* locations where the sound level is calculated. Those receivers may be defined in several ways, commonly as a regular grid of points, or as points around buildings, at a given distance from the facades. For the proposed methodology, the latter method is chosen, as it simplifies the aggregation of citizens to each receiver.

In the following, the key input data to the proposed methodology are detailed.

2.2.1 Geographical data

Multiple categories of geographical data describing the area of interest are necessary to model the impact of noise. This data is stored as shapefiles, which can be opened and processed using a GIS (Geographic Information System) application, unless specified otherwise.

The first category of geographical data of interest is the physical layout of the area, which includes:
– the road network;
– buildings, as two-dimensional shapes with the height of each building as an attribute;
– green areas, including parks and forests, *i.e.* highly sound absorbent spaces.

The second category of necessary geographical data is population data. It should be as spatially detailed as possible, ideally distributed at the level of each building. In this contribution, population is added as an attribute of each building. The population of a building is then spread equally among all of the receivers which are placed around it. This population distribution serves as a basis for the estimation of noise exposure.

2.2.2 Traffic data for reference background noise evaluation

Microscopic traffic data or *micro-traffic data* designates the position and speed of individual vehicles at short time intervals ($\sim$ 1 second) for different times of the day. It may either be measured data or simulated data. For instance, open-source software *Eclipse SUMO* can generate micro-traffic data based on measured traffic data for given streets. This data is then aggregated to the chosen time interval (*e.g.* 15 minutes, 1 hour...) as average traffic per road segment.

If micro-traffic data is not available for the area, then existing strategic noise maps or traffic flow data may be used instead as a starting point. These may either be used as is if the time granularity is fine enough, or post-processed with interpolation (*e.g.* based on complementary measurements) for coarser granularity.

2.2.3 Vehicle route

The routes followed by the vehicle whose impact is studied must be available for each scenario, including a specific timestamp, position, and associated speed of the vehicle. This data may be either retrieved from measurements (*e.g.* GPS receiver) or simulated (*e.g.* with Eclipse SUMO). If this data is measured data from a GPS receiver, it needs to be pre-processed to correct positioning errors so that every position is placed on the road. To refine the granularity of the data retrieved from the simulations, it is here interpolated (with an equal time interval between each position) such that the distance between 2 successive positions of the vehicle is short enough, *e.g.* less than the typical distance between buildings on the two sides of a road.

2.2.4 Vehicle-specific noise emission model

In the present contribution, noise emission models part of the CNOSSOS-EU framework are used. These imply a dependency of the sound power level on the vehicle category (car, truck, etc.), its driving speed, and a distinction between rolling noise and engine noise, see [7].

3. Case Study and Discussion

The previously described methodology was applied to evaluate the impact of a delivery truck on the island of Södermalm, in the city of Stockholm, Sweden. The following provides further details on the associated steps.

3.1 Baseline: background noise maps

Ideally, the reference noise maps may be established from measured data, or, as introduced in the introduction of the methodology, following an aggregation associated with micro-traffic simulations. The second approach is the one intended by the authors in their methodology, where an averaged traffic per road segment is to be introduced as a sound source in a tool such as NoiseModelling in order to generate baseline noise maps.

Unfortunately, measured micro-traffic data is usually not available for entire cities. When it is available for some roads, it may be extrapolated to other roads, but the resulting data could be inaccurate.

However, some strategic background noise maps exist for the city of Stockholm (L_{day}, L_{night}). These may be used, in an initial approximation, as a baseline, particularly if a time-dependent interpolation can be introduced on the basis of measured data, such that a more realistic set of noise maps may be derived as a reference. This is the approach chosen to be followed in the case study considered.

In order to obtain these maps for specific times of the day, those background noise maps were interpolated to the hour, using time series of sound levels measured by a microphone placed on the island. Figure 2 shows two examples of background noise maps resulting from this interpolation. It

(a) 5.00 a.m. (b) 8.00 a.m.

Figure 2: Interpolated background noise maps for two times of the day on Södermalm. The colour scale is continuous, from purple (low noise levels) to yellow (high noise levels); white is for "no data".

should be noted that the results of those interpolations, while valid in the vicinity of that microphone, might be inaccurate in other parts of the city, if traffic dynamics depending on the time of day are different there.

3.2 Vehicle noise simulation

The truck's positions for this case study are based on GPS measurements carried out aboard a delivery truck. The data points were corrected, *i.e.* they were properly re-positioned on the road when meeting GPS inaccuracies, and subsequently interpolated such as to ensure one position per second. All positions of the truck are plotted in Fig. 3. It should be noted that the interpolation method chosen

(a) Measured truck positions

(b) Corrected truck positions

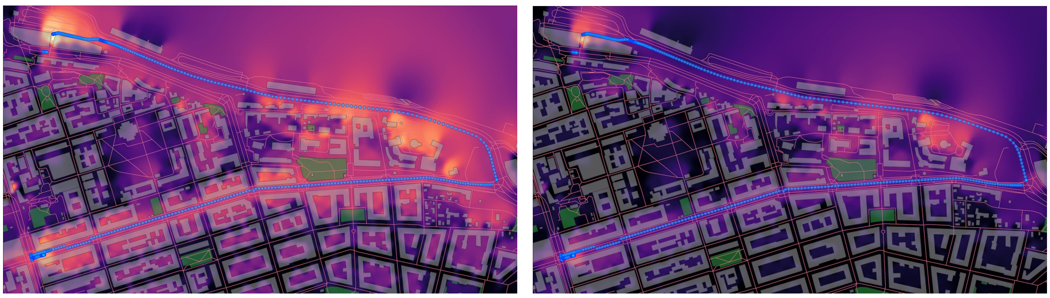
Figure 3: Positions of the truck (a) before and (b) after correction and interpolation.

here for the GPS positions doesn't take acceleration into account. The positions and attributes (speed, timestamp) of the data points are interpolated linearly.

Those truck positions are each associated with emission sound levels using the CNOSSOS-EU emission model for diesel trucks, and defined into NoiseModelling as sound sources. The acceleration of the vehicle is not taken into account in the emission model that we used, but another emission model could allow for this possibility, provided that the necessary input data is available. The result is a table containing, for each time step, LA_{eq} for each receiver at that time step.

3.3 Impact evaluation and discussion

The exceedance for each receiver and each time step is subsequently evaluated according to Eq. (1). Exceedance values are then summed for all time steps, for each receiver, and the resulting map is spatially interpolated into a continuous exceedance map. The resulting map is presented in Fig. 4. As shown on this map, exceedance levels – and thus the impact of the truck on population exposure – are higher when average traffic is lower, and spotting the areas of the neighbourhood which are most impacted by the noise emissions of the truck is straightforward.



(a) 5.00 a.m.

(b) 8.00 a.m.

Figure 4: Map visualisation of the exceedance caused by the truck at two times of the day: (a) 5.00 a.m., (b) 8.00 a.m.; the colour scale is continuous, from black (low exceedance) to yellow (high exceedance).

This visualisation method doesn't show population data, even though this may provide valuable insight in areas where population is not spread homogeneously. Both population and exceedance may be visualised on a map where the size of the receivers is modulated by the number of citizens while the colour of the receivers depends on the exceedance level (see Fig. 5). This approach makes it possible to determine the areas where high exceedance levels have the highest impact on the population. Used in conjunction with Fig. 4, Fig. 5 illustrates how some areas are exposed to high exceedance levels but are very sparsely populated (*e.g.* towards the North of the island).

Figure 5: Population weighted exceedance map. Each circle is a noise receiver. Their colour represents noise levels, from black (low) to yellow (high); their size increases with the number of citizens affected.

However, this visualisation method also highlights some limitations associated with this case study: *i)* the dynamics of population density are not taken into account, implying that the citizens are always expected to be home, and *ii)* only permanent residents are taken into account, which overlooks the impact on sensitive zones such as schools, hospitals, etc. These considerations are however a problem of input data, which does not affect the potential of the approach proposed in itself.

It is also worth noting that the approach in the version detailed herein should only be applied at times and in places where traffic is not too sparse, *i.e.* places where *average* noise levels are meaningful. If traffic is very sparse, then analysing the noise level fluctuations caused by each vehicle makes more sense than having average noise levels as a baseline (as is the case in this methodology) to better characterize the exposure to sound. Moreover, sleep sensitivity models might be used to better assess the impact of the vehicle.

4. Conclusion

The present contribution describes a method which enables the assessment of the impact of an individual vehicle in an urban environment without the need for field measurements of the vehicle's sound emissions in the area of interest. It may be used as a way to qualitatively compare different scenarios, seeking to minimize the impact of a vehicle on the citizens in urban environments. In particular, it places a high focus on the choice of timing for routing, as well as taking into consideration an estimated number of citizens impacted. This later is highlighted to be a static input data in the case study introduced, which should ideally also be considered as time-dependent in a way similar to the fluctuating background reference noise levels. Finally, the sharp difference in properties of daytime vs. nighttime traffic implies that adjustments to the proposed methodology should be included, particularly in the context of sparse traffic.

Future developments and variants of the method will further allow for the assessment of the sensitivity of each road segment for sound emission and other applications.

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