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Dynamic traffic noise assessment tool: A comparative study between a roundabout and a signalised intersection

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ABSTRACT

Considering traffic flow as a steady noise source is common practice when studying traffic alternatives and its impact on the sound environment. However, vehicle dynamics have a strong influence on both transport behaviour and noise emission. One of the most relevant elements of traffic design is the intersection, where replacement of crossing intersections with roundabouts is common. In order to understand the features of these two traffic configurations, microscopic approaches are needed, making it possible to study time-pattern fluctuations relevant for the urban sound environment perception. A model based on individual-vehicle characteristics as function of time is developed and implemented in a real case study at a development stage. The model incorporates state-of-art microscopic traffic simulation software combined with the recent noise emission model, CNOSSOS-EU, applied through an in-house developed dynamic traffic noise tool, including both internal combustion engine and all-electric vehicles at different traffic flows. The tool is described in general terms incorporating the randomisation of source power. The propagation considers a flat-city configuration up to 100 m range. The tool enables study of different statistical indicators, including descriptors of probability density functions, calm periods through the novel indicator Centre of Mass Time (CMT) and noise events. The outcomes are presented through graphs and maps explaining traffic disruptions, acceleration effects, vehicle configurations and flows, source strengths, contribution and difference maps. Among the results, it is shown that, for the signalised crossing, the acceleration of the simulated traffic has a large effect on the source strength. It is however also shown that, for an unbalanced roundabout intersection leading to congestions, it can become noisier than the signalised crossing. It is furthermore shown that, when reducing the traffic flow, the two intersection types behave more similarly; however the roundabout having the best performance for the majority of the studied analysis. Further results are shown, e.g. for removing heavy vehicles, removing also medium heavy vehicles and assuming only all-electric light vehicles, including analysis from using various indicators. A discussion about the presented tool, the current results and ideas for future work concludes the paper.

The present paper goes along a series of studies with the overall intention to provide a more solid basis for justifying decisions in traffic planning regarding the outdoor sound environment.

1. Introduction

Being able to control the acoustic environment is a fundamental question in order to support liveable cities, especially at the current densification processes. The available means of transport and the spatial pattern characteristics are largely dictating the urban form. A careful planning is the key to avoid poor patches in the urban configuration and future economical burden.

Transport is not only the major noise source in cities [1]. It has been strongly linked to noise annoyance, sleep disturbance and numerous health effects [2]. Latest data on noise exposure in Europe [3] suggested that 42 million of European citizens are exposed to road traffic noise levels above the targets of the World Health Organisation (L_{den} = 55 dB). This high exposure is partly caused by the urban and traffic planning, as well as by the building design.

One of the common attempts to control the sound environment is to adopt Action Plans based upon strategic noise-mapping results according to the Environmental Noise Directive (END) [4]. Although several investigations have identified measures to reduce traffic noise [5–7], the traffic flow is normally considered as

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non-dynamic. This assumption is used as well to build the strategic noise maps using commercial noise mapping software. The resulting time-averaged A-weighted sound pressure levels and its derivations as L_{den}, L_n, L_d are the output of these maps intended to study large areas, e.g. a city.

For high traffic variations, as the ones present in (dense) urban environments, this analysis leads to miss-estimations [8–10]. Moreover, annoyance and certain aspects of sleep disturbance have been related to the identification of noise events resulting from variations in traffic flow [11,12]. The influence of noise events remains as an open question, pointing out the existence of a threshold and their effect on annoyance [13,14], or the inability of humans to distinguish between situations as vehicle flow increases and the noise is perceived as a continuum [15], suggesting that further studies need to be made to understand the detection mechanism of events. In this context, the study of traffic transformations requires a microscopic approach that includes traffic behaviour and vehicle kinematics, opening the study to the time-pattern fluctuations through the instantaneous sound pressure levels relevant to describe the urban sound environment and study the suitability of human activities [8,16].

Intersections have been considered as the main factor to assess the performance of the road network. In order to improve the traffic design, a common practice in recent decades has been the replacement of crossing intersections with roundabouts. This transformation, apart from political decisions, is based mainly on the increased safety for pedestrians [17], and has been argued as well to plausibly reduce the noise. The main difference among these intersection designs is based on the drivers' capacity to accept or deny gaps in the roundabout compared with the signalised crossing characterised by a stop-controlled situation. In the first one, the workload is mainly on the driver [18].

Vehicle kinematics have been pointed out as a characteristic with strong influence on the vehicles' noise emission and hence, on the sound environment [9,16,19–22]. As a consequence, several models have been developed. In order to mention some of the most relevant ones, three models are highlighted here. The model developed by EPFL called DRONE [23] uses AVENUE as traffic simulation model and the ASJ Model-1998 for the noise estimation. The lanes are divided into segments and the vehicles are located at the centre of each segment. The effect of buildings is included based on a statistical approach. The model developed by Ghent University [19] uses PARAMICS as micro-simulation model, where the noise emission values are only function of speed and vehicle type. Here, a beamtrace 2.5D propagation model is included, counting for multiple reflections. PARAMICS uses a space-discrete system, opposed to VISSIM, which is space-continuous. The acoustic model is based on the Nord2000 vehicle noise emission database. When the simulation is too large, the exact positions of vehicles is not accounted for and a grid is used instead. The third model mentioned is the one developed by INRETS/CSTB [24], using SYMUVIA as a component of the noise simulation package SYMUBRUIT, fed in studies as in [9] with the noise emission laws from the FHWA database, where the emission depends on the speed and the throttle states specified by two acceleration rates: full or cruising throttle. Other studies using SYMUVIA, such as the validation in [25], rely on NMPB-Routes-96 noise emission model, accounting as well for geometric sound attenuation. Another emission law followed is the one based on the outcomes of a previous work [26], using the propagation model NMPB-Routes-96 implemented in the Mithra software [16]. The SYMUVIA traffic modelling has been improved to account for several traffic conditions including e.g. lane-changing phenomena [21]. For example, different scenarios were tested where one of them replaces a traffic signal by a roundabout [16]. In those scenarios, the noise emission is estimated through noise cells defined by their sound power level, with sizes of 10 m between road sections and 5 m at intersections, and only the vehicles present in the cell contribute. Moreover, the model used assumes that all vehicles are equal in terms of sound power.

The model presented in the present paper does not rely on this assumption. The CNOSSOS-EU model [27], where the noise emission of a certain vehicle at a certain time-step depends on the current speed and acceleration, together with the vehicle type. In this sense, within the same vehicle type and same values of acceleration and speed, the noise emission will be the same. Once this is computed, a variability in the emission among the same vehicle type is inserted. This variability has been proven relevant in the assessment of peaks of noise estimation [28], and included within dynamic traffic noise models [28–45]. The variation in emissions are further explained in Section 2.1. Randomisation of source power.

The breakpoint of these models, including the present one, is the introduction of indicators to reflect urban traffic noise dynamics. Classical descriptors based on long-term measurements have been proven inefficient to reflect not only short-term, but as well long-term variations [20], being unable to describe the sound variations in the built environment. Specific indicators have been used to reflect traffic evolution over time. For example, noise fluctuations indicators have been proposed to distinguish between traffic cycles and the percentage of these when the maximum sound pressure level exceeds a certain value [20]. The indicators have also been influenced by those of room acoustics, e.g. the noise rating curves, suggested to highlight emergent frequencies [29]. Other indicators try to relate pleasantness in a musical context with the road traffic noise rhythm [19]. As previously mentioned, sound events have been highlighted as an opportunity to study nuisance [30], and indicators underlying noisy periods have been studied, either relative to a statistical value or to a fixed noise level value [31,32]. The present paper introduces indicators regarding noise events and calm periods, e.g. the novel indicator called Centre of Mass Time (CMT) attempting to study the weight of quiet periods clustering as explained in Section 2.2. Noise descriptors.

The methodology of study results in a time-pattern analysis tool capable to illustrate and explain the influence of the traffic dynamics and the effect of noise emission of each vehicle. The output power level is then computed each 0.1 s for all vehicle positions present during the calculation hour. The propagation modelling includes pressure doubling due to hard ground conditions and sound attenuation due to geometric spreading under a flat city configuration. This way, the modelling tool is used to make an initial study of a large variety of statistical indicators, including descriptors of probability density functions, calm periods and noise events, as well as visual outcomes such as contribution and difference maps.

The tool is tested on a real case scenario under development in the city of Gothenburg, with a high traffic stream. In the comparison of the two types of intersections, the traffic demands are the same, requiring adaptations in terms of road configurations, among other characteristics explained in the paper. The advantages of the model are that it uses state-of-art traffic simulation tool and incorporates a variation in the sound power level to adapt it to more realistic situations. Novel indicators to reflect the cluster and weighting of quiet periods are incorporated. The tool is tested with realistic complex cases holding the same demands regarding the origin-destination matrices, requiring adaptations in the traffic layout.

2. Dynamic traffic noise tool

The purpose of the tool is to study the resulting sound environment through the analysis of road traffic noise emission computed