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Improving noise assessment at intersections by modeling traffic dynamics

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ABSTRACT

Three families of road noise prediction models can be distinguished. Static noise models only consider free-flow constant-speed traffic with uniformly distributed vehicles. Analytic noise models assume that all vehicles are isolated from one another but account for their mean kinematic profile over the network. Micro-simulation noise models relax the hypothesis of no interaction between vehicles and fully capture traffic flow dynamic effects such as queue evolution. This study compares the noise levels obtained by these three methodologies at signalized intersections and roundabouts. It reveals that micro-simulation noise models outperform the other approaches. Particularly, they are able to capture the effects of stochastic transient queues in under-saturated conditions as well as stop-and-go behaviors in oversaturated regime. Accounting for traffic dynamics is also shown to improve predictions of noise variations due to different junction layouts. In this paper, a roundabout is found to induce a 2.5 dB(A) noise reduction compared to a signalized intersection in under-saturated conditions while the acoustic contributions of both kinds of junctions balance in oversaturated regime.

1. Introduction

Temporal and spatial variations in vehicle speeds have a substantial impact on traffic noise emissions. At intersections, vehicle kinematics is strongly influenced by single vehicle dynamics in the absence of other traffic and traffic dynamics induced by vehicle interactions and queue length evolution. Depending on the way noise prediction models account for traffic flow, these dynamic effects are more or less accurately captured.

In static noise models, roads are divided into sections where traffic flow is considered smooth and homogeneous. Since this assumption does not hold in the vicinity of intersections, some models, like the German RLS90 model (RLS, 1990), include a propagation correction term. Others, such as the Nordic model (Jonasson and Storeheier, 2001) or the ASJ RTN Model (Yoshihisa et al., 2004), modify the emission law to represent the effects of transient driving conditions. Yet, the dynamic effects are just accounted for by ad-hoc empirical or statistical formula.

Other engineering, national standards, such as the US Federal Highway Administration's TNN model (Menge et al., 1998) or the French noise estimation model (Certu, 1980), attempt to capture the impact of interrupted traffic on the average vehicle speed profile. They split each road section into sub-segments where vehicles are assumed to have a constant average velocity and homogeneous running conditions. Each sub-segment is then considered as a line source whose sound power level is calculated from the average flow rate and the sound power level of a single isolated vehicle (varying with its velocity). Engineering standards can be refined by considering average vehicle kinematic patterns continuously; this is the purpose of analytic noise models. Mean vehicle kinematic patterns are combined in a noise emission law to compute instantaneous sound power levels due to the bypass of a single vehicle. The traffic flow only consists of vehicles driving over the

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road section with constant time-headways. Instantaneous sound pressure levels at a given reception point are obtained by considering each vehicle as a mobile line source. Based on this approach, some studies have attempted to derive equivalent sound pressure formula in terms of the number of freely-moving and stopping vehicles (Makarewicz et al., 1999), or the number of queuing vehicles at traffic signals (Stoilova and Stoilov, 1998). Contrary to static noise procedures, analytic models account for single vehicle dynamics. Thus, they are partly able to assess the noise contribution of different kind of intersections (Makarewicz and Golebiewski, 2007; Picaut et al., 2005). They disregard, however, traffic dynamics induced by vehicle interactions or saturation.

At intersections, the only way to capture the noise impacts of both single vehicle dynamics and traffic dynamics is to use a micro-simulation noise model such as M+P JARI (Suzuki et al., 2003), MOBILEE (De Coensel et al., 2005), TUNE (Goodman, 2001), ROTRANOMO (Volkmar, 2005) or SYMUBRUIT (Leclercq and Lelong, 2001). These models are based on different microscopic traffic simulation tools that give position, speed and acceleration of each vehicle, at each instant. Those outputs are fed into a noise emission law to assign an instantaneous sound power level to each vehicle. Then, instantaneous sound pressure levels at a given reception point can be calculated with a sound propagation model.

This paper demonstrates that micro-simulation noise models outperform other approaches at intersections where the influence of traffic on vehicle kinematics is expected to prevail. A comparison between a micro-simulation noise model and the static STAMINIA-NCHRPR model was performed in Wayson et al. (1997) at signalized intersections. Based on experimental data, it reveals that the static model underestimates the noise levels compared to the simulation model. De Coensel et al. (2006) derived analytical correction formula for engineering national standards to catch-up the noise deviation compared to a micro-simulation model at different kind of intersections. In the same spirit, this study will highlight the need to capture traffic dynamics to improve noise estimates, especially in oversaturated conditions. For this, emission levels produced by: a static noise emission procedure; a well-established analytic noise model and a micro-simulation noise package will be compared. Both signalized intersections and roundabouts will be studied in under-saturated and oversaturated conditions.

The first part of this paper describes the geometric layout of the studied site when it is transformed into a signalized intersection or a roundabout. Demand rates representative of a 2 h-commuting period as well as kinematic parameters will also be presented. Then, a detailed description of the static, analytic and micro-simulation noise models will be performed. The second section will highlight the results of the comparison between the three models.

2. Methodology

2.1. Case study

2.1.1. Geometric design

The case study consists of a major road crossing a minor road with traffic levels of Δ_1 and Δ_2 (Fig. 1a).

The four approaching and the four departure arms are one-lane sections of 3 m-width. Their length is equal to 250 m because noise impacts of road crossings are negligible farther out. The signalized intersection and roundabout layouts are represented in Fig. 1c and d. They were chosen so that the stop-lines of the signalized intersection correspond to the yield-lines of the roundabout entries. The inscribed circle diameter of the roundabout is 24 m and the circulatory roadway is 3 m-width. At the signalized intersection, the distance between the stop line and the line extended from the edge of the intersection road is 9 m. The green period G is set to 27 s (respectively 16 s) for the major (respectively the minor) road. The signal cycle c is equal to 55 s to account for lost-times during both signal phases.

2.1.2. Demand flow scenario

The chosen demand scenario is representative of a morning commuting period. On the major (respectively the minor) road, the traffic demand pattern is a step function (see Fig. 1b) with three thresholds Δ_{1a}, Δ_{1b} and Δ_{1c} (respectively Δ_{1a}, Δ_{2b} and Δ_{2c}). Four different periods are separately studied in the sequel. The first 30 min-period is a free-flow period (under-saturated regime) with medium demand thresholds on both roads. The next 30 min-period is a peak period (oversaturated regime) with high demand thresholds which trigger a queue on the major road. Traffic conditions become fluid again during the next 30 min-period when the demand rates drop to low levels. Only a few minutes are required to discharge the queue before recovering free-flow conditions. Finally, the fourth 30 min-period is also a free-flow period with low demand thresholds. With this demand profile, the Highway Capacity Manual (Transportation Research Board, 2000) predicts the same average delay and 95th-percentile queue for both intersection types at the end of the peak period: 62 s and 36 queuing vehicles on approaching arms 1 and 3; 19 s and 5 queuing vehicles on approaching arms 2 and 4. This study only focuses on one category of vehicles (light-duty vehicles) to ease comparison. The origin-destination matrix is the same for each arm: 20% of traffic turns left or right; 60% goes straight ahead. In the sequel Δ_{ij} denotes the demand rate between approach i and exit j.

2.1.3. Vehicle kinematics

Vehicle kinematic parameters are chosen to match the speed profiles commonly observed at signalized intersections or roundabouts and recommended by the US Federal Highway Administration (FHWA) (Robinson, 2000; Rodegerdts, 2004). The