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Dynamic noise modeling at roundabouts

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ABSTRACT

Modeling spatial and temporal noise variations at roundabouts is a tedious task. Indeed, noise levels are strongly influenced by the complex vehicle interactions taking place at the entries. An accurate modeling of the merging process and its impact on vehicle kinematics, waiting time at the yield signs and queue length dynamics is therefore required. Analytical noise prediction models disregard those impacts since they are based on average flow demand patterns and pre-defined kinematic profiles. The only way to capture all traffic dynamics impacts on noise levels is to combine a traffic simulation tool with noise emission laws and a sound propagation model. Yet, such existing dynamic noise prediction packages fail in representing vehicle interactions when the roundabout is congested and are difficult to calibrate due to their numerous parameters. A new traffic simulation tool, specifically developed for roundabouts, is therefore proposed in this paper. It has few easy-to-calibrate parameters and can be readily combined with noise emission and propagation laws. The obtained noise package is able to produce relevant dynamic noise contour maps which can support noise emission assessment of local traffic management policies. Results are validated against empirical data collected on a French suburban roundabout on two different peak periods.

1. Introduction

Space–time variations in vehicle kinematics due to intersections were shown to greatly influence noise levels in urban areas [1,2]. Although several noise estimation procedures have been developed to catch these effects, few of them are suitable for improving noise mapping at roundabouts.

In most existing prediction tools, like the FHWA Traffic Noise Model [3] or the German RLS-90 Model [4], noise impacts of interrupted traffic flows are roughly taken into account through empirical correction factors. More sophisticated statistical models have been proposed to improve noise appraisal at signalized intersections in terms of traffic volumes, traffic speeds, traffic composition, geometry or pavement surface textures [5]. Derivation of similar regression formula at roundabouts is possible, yet unfruitful since spatial variations in noise levels cannot be captured.

To circumvent this deficiency, advanced analytical methodologies based on the computation of average noise signatures for each vehicle class have been introduced [6,7]. They combine a mean vehicle kinematic pattern per class with a noise emission law depending on vehicle speed and running conditions. A single class-specific vehicle is assumed to cross the junction. At each instant, the resulting sound power level and vehicle position are input into a propagation model to calculate the instantaneous sound pressure level at a given receptor point. The sound pressure exposure of the class-specific vehicle is then obtained by integrating the instantaneous sound pressure levels over the time needed to cross the junction. Repeating this process for a set of receivers along the infrastructure gives the average noise signature for the corresponding vehicle class. Influence of traffic flow can then be accounted for by multiplying the noise signature by the number of vehicles passing during a given interval and so, for each class. Such a method has already been applied to roundabouts [8]. It has also been implemented in the Harmonoise traffic source model to draw noise difference contour maps at road crossings between situations where all vehicles maintain constant speed without stopping and situations where they all have to decelerate, stop and then accelerate away from the junction [9]. Spatial kinematic variations appeared to either increase or decrease average noise levels depending on the traffic volumes. The major drawback of this analytical procedure is to neglect the noise impacts of vehicle interactions. Particularly, it cannot catch noise variations due to: (i) random occurrence of stopping or freely-entering vehicles into the roundabout; (ii) fluctuating waiting times on the roundabout approaching links; (iii) fluctuating queue lengths; and (iv) potential hindrance effect due to a congestion spilling back from downstream. As a result, the output noise contour maps are not completely satisfactory.

The only way to catch the noise impacts of vehicle interaction consists in coupling a traffic flow simulation tool with vehicle noise emission laws and a sound propagation model. As underlined

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within the Imagine project [10] this technique allows for evaluating how short-term transient queue events as well as spatial and temporal variations in vehicle kinematics influence noise estimates. It has already been implemented into softwares like DRONE [11], MOBILEE [12], TUNE [13] or ROTRANOMO [14]. However, to the authors' knowledge, no model calibration or validation study was specifically conducted to assess noise estimates at roundabouts. This is troublesome since the corresponding traffic simulation tools included into these softwares (respectively AVENUE or M+P, PARAMICS, DRACULA, VISSIM) have a large number of parameters that are often difficult to calibrate and may affect noise outputs to a large extent. Moreover, these tools were recently shown to badly represent vehicle interactions and kinematics in highly congested situations [15,16]. By predicting unrealistic queue length and delay values, they may, therefore, lead to irrelevant noise estimates at roundabouts.

The goal of this paper is to propose another dynamic noise emission model based on a new microscopic traffic simulation tool, specifically devoted to roundabouts. This tool solves the major drawbacks of classical micro-simulation packages underlined within the IMAGINE project: (i) it has few parameters; (ii) it is easy-to-calibrate with a limited set of data; (iii) it is able to model the number of stopped vehicles, the vehicle delays and the queue length dynamics on each approaching links accurately whatever the traffic conditions on the roundabout. Consequently, realistic vehicle kinematics can be obtained and fed into appropriate noise emission laws. Then, a sound propagation calculation is performed with respect to geometry and urban landscape. This paper will highlight that accurate dynamic noise contour maps can be simulated. They can be used to assess the noise impacts of traffic flow at roundabouts in both free-flow and saturated conditions.

The first part of this paper will outline the three key components of the proposed framework: the microscopic traffic simulation tool, the noise emission laws and the sound propagation model. For the study purpose, we will only focus on: (i) a single mean emission law for light duty vehicles; (ii) a very basic propagation model. However, it should be highlighted that the framework can handle with any class-specific emission laws and very complex propagation models. In the second part of the paper, the overall framework will be validated against empirical sound pressure levels collected at four receptor points close to the road axis of a single-lane roundabout. Results in terms of equivalent sound pressure levels, statistical descriptors as well as noise levels distributions are really convincing.

2. Basic components of the roundabout noise emission model

2.1. Overview of the model

The purpose of the roundabout noise emission model is to accurately account for traffic dynamics in order to reproduce spatial and short-term variations in noise levels in the vicinity of the infrastructure. As mentioned in the introduction, this can be done by coupling a traffic flow simulation tool with noise emission laws and a sound propagation model. The modeling chain is depicted in Fig. 1. The traffic flow simulation needs some input data to fix the traffic demand scenario (traffic volumes, destination proportions, traffic composition) as well as some parameters which has to be calibrated beforehand. Outputs of the traffic model are position x^t, speed v^t, acceleration a^t and vehicle type of each vehicle, at each time t. Those outputs are fed into noise emission laws to assign an instantaneous sound power level L_w^t to each vehicle. Then, individual contributions of each vehicle at a given receptor point can be calculated according to a sound propagation model. The instantaneous sound pressure levels at the receiver are obtained by summing all the contributions at each time. Finally, those levels can be used to calculate a large array of noise descriptors.

2.2. Microscopic traffic simulation tool

Microscopic traffic simulation tools aim at modeling the progression of individual vehicles through a road network. The overall simulation period is usually broken down into a number of discrete time-steps Δt. Positions of all vehicles are updated at each time-step by specific algorithms. Speed and acceleration can then be deduced from positions at successive time-steps. Two algorithms are commonly used in order to model a roundabout: (i) a *car-following algorithm* which simulates vehicle trajectories on the approaching/departure links and inside the roundabout (the position of any vehicle in the network is given in terms of the one of its leader); (ii) an *insertion decision algorithm* which specifies whether vehicles arriving at the yield sign can enter or not the roundabout.

Most of the existing microscopic simulation tools for roundabouts were shown to have the following drawbacks:

- profusion of parameters that may be troublesome or data consuming to calibrate [17];
- sensitivity of the simulated vehicle trajectories to parameters [18];
- failure in modeling insertion rates, vehicle delays and queue length dynamics when a congestion spills back on the roundabout [15,16].

As a result, reliability of noise level estimates cannot be guaranteed when these traffic flow models are used in combination with a noise estimation process.

This has motivated the development of a new parsimonious, easy-to-calibrate microscopic traffic model for roundabouts able to capture two kinds of observed merging behaviours depending on traffic conditions on the roundabout:

- in free-flow conditions, approaching vehicles respect the yield rule and insert into the roundabout only if the time-interval before the arrival of the next circulating vehicle is sufficient [19];
- in congested conditions, approaching vehicles do not respect the yield rule anymore and alternatively insert between circulating vehicles following a ratio γ [20,21].

To model these merging behaviours, two distinct insertion decision algorithms are used:

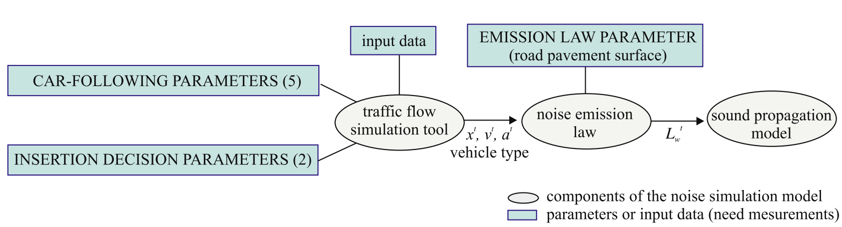

Fig. 1. Overview of the dynamic roundabout noise emission model.