A COMPARATIVE EMPIRICAL ASSESSMENT OF ROUNDABOUTS OPERATIONS IN RURAL AREAS: IMPACT ON CONGESTION-SPECIFIC VEHICLE SPEED PROFILES, POLLUTANT AND NOISE EMISSIONS

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Keywords: Roundabouts, Speed Profiles, Discrete Models, On-road Emissions, Noise

Subject area: Sustainable cities

1. INTRODUCTION

Roundabouts are replacing intersections previously controlled by traffic lights to improve operational performance, at least in certain flow ranges (Rodegerdts et al., 2010). Their design forces drivers to slow down in the approaching, steer laterally around the central island and accelerate at the exiting (Fernandes et al., 2016). Despite the demonstrated safety benefits and traffic flow improvements (Park et al., 2018), some roundabout layouts present doubts in terms of emissions and noise (Fernandes et al., 2018; Vasconcelos et al., 2014). Roundabouts in suburban areas combine features of both urban and rural environments (Rodegerdts et al., 2010). On the one hand, they can include pedestrian and bicycle features and small inscribed circle diameters. On the other, they can present high approaching speeds and thus may require special attention to visibility and cross-sectional details (Rodegerdts et al., 2010).

A good body of research has focused on the impacts of roundabouts on pollutants and noise emissions. One of the most largely-used method to study exhaust emissions is the Vehicle Specific Power (VSP) that uses on-road emission data from portable emissions measurement system (PEMS); VSP is a function of vehicle speed, road grade, and acceleration on second-by-second basis. Prior research has documented the use of the VSP methodology to compute vehicular emissions at single-lane (SL) (Coelho et al., 2006; Vasconcelos et al., 2014), compact-two lane (CTL) (Fernandes & Coelho, 2019), Multi-lane (ML) and turbo-roundabouts (Fernandes et al., 2016; Vasconcelos et al., 2014). The above-mentioned studies showed vehicles at any roundabout can follow one of three possible trajectories: i) vehicle travels through the roundabout without stopping; ii) vehicle stops completely at yield line to negotiate a gap in the circulating area; and iii) vehicle faces multiple-stop at the approach until passing the yield line. They also found that the occurrence of these profiles depended on the entry and the conflicting traffic flows (Coelho et al., 2006; Fernandes et al., 2016). Even though research has been performed in light duty cars using PEMS under a wide range of operating conditions, few studies using PEMS can be found in different roundabout layouts. Existing research in this field has been dealt with the comparison of roundabouts and traffic lights (Gastaldi et al., 2017; Liu et al., 2017) and stop-controlled intersections (Hallmark et al., 2011).

Research on traffic noise prediction near roundabouts using steady-state and dynamic approaches. While the first one uses aggregated kinematic information such as road traffic volumes and average speeds (Garg & Maji, 2014), dynamic relies on microscopic information of vehicle activity data, i.e. the relative position of vehicle/receiver, speed and acceleration (Guarnaccia, 2013). Among these, many authors put accent on the comparison of traffic noise between signalized intersections and roundabouts (Chevallier et al., 2009; Guarnaccia, 2010; Li et al., 2017) finding that the latter ones present less noise levels that the first ones. Although pollutants and noise emissions in roundabouts has been well explored, little attention has been paid to: i) environmental and noise performance of roundabouts installed in rural and suburban environments; ii) comparison of pollutants and noise emissions impact on roundabouts with different layouts; and iii) assessment of entry lanes and speed trajectories profiles in terms of capacity, global and local pollutant emissions and noise in an integrate way.

Therefore, this work quantifies and contrasts on-road emissions and noise levels produced by road traffic in three different suburban roundabouts (SL, CTL and ML) located in Aveiro, Portugal. This research tested the hypothesis that both carbon dioxide (CO_2) and nitrogen oxides (NOx) emissions and equivalent continuous A-weighted sound level (L_{Aeq}) levels are influenced by differences in: i) traffic volumes in the approaching, conflicting and exiting; ii) the volume-to-capacity (V/C) ratio; and iii) the roundabout layout. This research was accepted to be presented in a podium session of the 99th Transportation Research Board Annual Meeting.

2. METHODOLOGY

The research team collected vehicle emissions, noise, dynamic, engine, and traffic data at the studied locations. The methodology used is summarized in Fig.1. Traffic data such as approaching (Q_{in}), conflicting (Q_{conf}) and exiting (Q_{out}) volumes were collected using cameras installed at the approach and circulating areas of roundabouts. The occurrence of speed trajectory profiles – no stop (SPI), one-stop (SPII) and multiple stops (SPIII) was estimated from the videotapes. Simultaneously, a sound level meter was installed at the approach area of roundabouts and then an appropriate filtering was applied to the acoustic signal and L_{Aeq} was computed. On-road emissions, namely volumetric fractions of CO_2 and NO_X from a light duty diesel vehicle were measured using an integrated PEMS, while the vehicle activity and the engine data were collected with an On-Board Diagnostic system. The relationship between congestion level of roundabouts and occurrence of each speed profile was established using a multinomial logistic regression model that use as input the collected traffic data. Finally, the emissions, noise and V/C ratio for the three roundabouts were compared in different scenarios and, in particular for the noise estimation, Quartieri et al. model (2010) was used. Data included 200 travel runs for each through movement (more than 140 km of road coverage) and more than 27 hours of video and noise data (9 hours at each location), which corresponded to 106 data slots of 15-min.

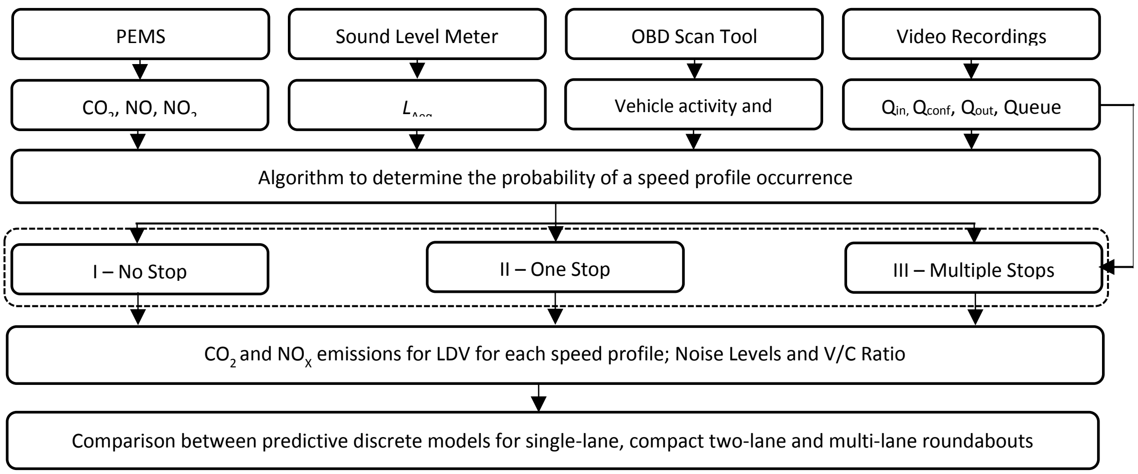

Figure 1: Methodology used

3. PRELIMINARY RESULTS / DISCUSSION

Results show that SL has on average lower travel (15% and 13%) and idle (40% and 60%) times, and CO_2 per kilometer (20% and 5%) than CTL and ML, respectively. However, NO_X emissions in SL are 7% more than ML, which is mostly due to a more aggressive driving behavior. Another explanation for these results is that the acceleration rate of vehicles tends to increase as Q_{conf} decreases (Coelho et al., 2006). This is the case of SL where conflicting traffic is low (Q_{conf} < 150 vehicles per hour – vph) in several periods of the day. Although CTL achieves similar performance levels to ML, it yields the highest emission levels. This could be due to the fact that CTL has low inscribed circle diameter together with moderate Q_{conf}.

The MLRM was then applied to the selected case studies to predict the occurrence of each speed profile at different congestion levels (Q_{total}, = Q_{in} + Q_{conf}), as shown in Fig.2.

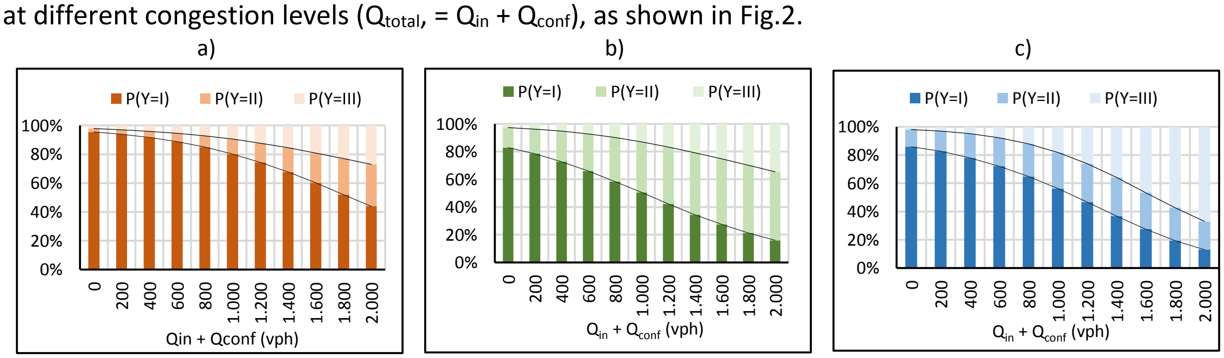

Figure 2: Predictive models for the relative occurrence of speed profiles by roundabout layout: a) SL; b) CTL; c) ML

Intuitively, the probability of the driver to enter the roundabout without stopping (PI) decreases as the traffic flow increases. It can be observed that more than 50% of vehicles enters in the SL without stopping for Q_{total} lower than 1,800 vph while at CTL and ML this occurs for lower values. Since SL has lower conflicting traffic (9% of Q_{total}) compared to the other layouts (>13% of Q_{total}), it handles more traffic. For traffic flows higher than 1,800 vph, 30% of vehicles at SL and CTL, and 70% at ML, will face multiple stops. Thus, five traffic demand scenarios were tested for each roundabout (see Fig.3), as follows: S1: Q_{total} = 400 vph and Q_{out} = 350 vph; S2: Q_{total} = 800 vph and Q_{out} = 700 vph; S3: Q_{total} = 1,200 vph and Q_{out} = 1,000 vph; S4: Q_{total} = 1,600 vph and Q_{out} = 1,350 vph; and S5: Q_{total} = 2,000 vph and Q_{out} = 1,700 vph.
CTL generates the highest amount of pollutant emissions per vehicle, in every tested scenario: in average 33% and 21% more CO_2 and, 66% and 73% more NO_X than SL and ML respectively. Although SL shows to be as the best option in terms of CO_2 (may be explained by lower travel time), it yields more NO_X than ML in S1-S3. This could be due to accelerations at high speeds to which NO_X emissions in LDDV are sensitive. Regarding the noise, SL achieves high L_{Aeq} values (> 67 dBA) under low and moderate traffic conditions (S1-S3) since vehicles maintain higher approaching speeds than vehicles in CTL and ML. Because the activity of motorcycles is high, CTL records higher L_{Aeq} than ML in almost scenarios. Noted that the studied SL and CTL approach reaches saturation at S3 while ML saturated at S4. This could explain the high L_{Aeq} values obtained in ML at this latter scenario, i.e. vehicles drive at higher speeds with same traffic volume.

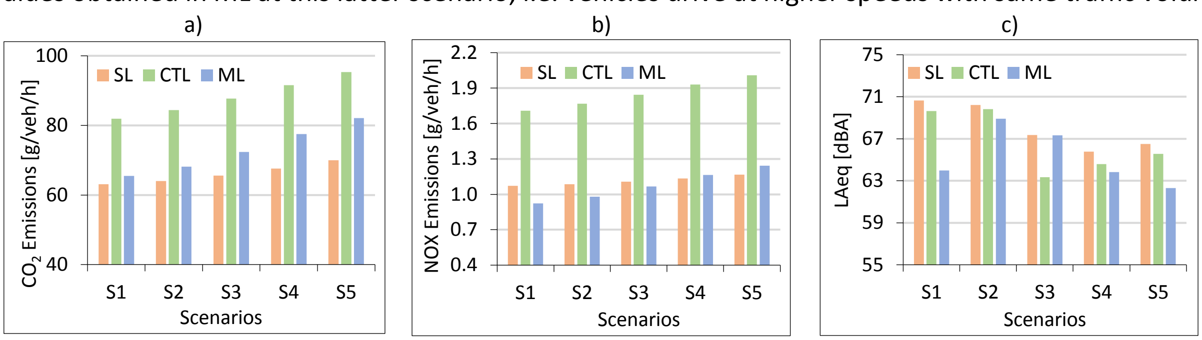

Figure 3: Variation of the measured parameters (hourly basis) by vehicle and scenario: a) CO_2; b) NO_x; and c) L_{Aeq}.

4. CONCLUSIONS

This work explores the impact of roundabout layouts on pollutants emissions and noise using field measurements. In addition, discrete choice models were applied to predict the occurrence of speed profiles in different traffic conditions. The methodology illustrated can be also tailored to other SL, CTL and ML, by simply identifying their traffic volumes and occurrence of speed profiles. This could support and help traffic planners and local authorities to avoid traffic congestion at roundabouts that result negative impacts on global warming (CO_2) and air pollution (NO_X and noise). As result of attributes of these roundabouts (high approaching speeds, negligible pedestrian and cyclist activity), this research can provide relevant information pertaining pollutant and noise emissions comparison between roundabouts and other traffic control treatments, such as traffic lights and stop-controlled intersections.
Future work should be focus on additional real driving emissions of gasoline and hybrid car and on the development of a noise model that include more kinetic variables such as acceleration and jerk (i.e. first derivate of acceleration).

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the following projects: TEMA – CENTRO 01-0145-FEDER-022083; Strategic Project UID/EMS/00481/2019 (FCT-Portuguese Science and Technology Foundation); MobiWise (P2020 SAICTPAC/0011/2015), co-funded by COMPETE2020, Portugal2020 - Operational Program for Competitiveness and Internationalization (POCI), European Union's ERDF (European Regional

Development Fund), and FCT; DICA-VE (POCI-01-0145-FEDER-029463), funded by FEDER through COMPETE2020, and by National funds (OE), through FCT/MCTES.

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