Analysis of Traffic Noise in a Road Intersection Configuration

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Abstract: - Acoustical noise produced by vehicular traffic depends on many parameters, including the geometry and the general features of the road. The presence of a conflicting point, i.e. an intersection, strongly affects and modifies the simulation strategy of noise in urban environments, that is usually performed with statistical models tuned on experimental data related to standard condition (free flow traffic, intermediate vehicular volumes, etc.). In this paper, the author presents the analysis of an intersection case study in proximity of Salerno University, performed by means of experimental measurements and software simulations. The chosen area presents interesting features because of the priority rights on the principal road and because of the relevant amount of vehicles and buses, mainly due to the University students and personnel that transit in the intersection, especially during rush hours. The aid of a predictive software is highlighted, together with the shortcomings of a simulation strategy that does not take into account traffic dynamics.

The analogy between electrical current and vehicular flow is sketched and used in the roads vehicles volume definition.

Key-Words: - Acoustical Noise Control, Traffic Noise, Road Intersections, Modelling.

1 Introduction

In the framework of environmental acoustical noise control, many sources should be considered in an urban area. In the scientific literature one can find both theoretical and experimental studies concerning the control of noise coming from different infrastructures (see for example [1-9]). The Harmonoise and IMAGINE projects (*Improved Methods for the Assessment of the Generic Impact of Noise in the Environment*) [10, 11], funded by the European Community, constitute an attempt to furnish an exhaustive description of the noise calculation, measurement and mapping problems. Moreover, in the Harmonoise project, there is the final and ambitious aim of producing an European common standard criterion for the characterization of noise sources and for the evaluation of their impact on the human being life. This issue is very important because of the possible damages induced by a long exposition to acoustical noise.

Actually, the noise problem is not felt very important for human health by people, with respect, for example, to air pollution or electromagnetic fields. This is probably due to a low perception of the risk and of the possible damages of noise, especially before the problem occurs, i.e. before the noise source is operating. More on this topic can be found in [12], where the authors proposed the definition of an overall Health Quality Index, based on the evaluation and on the monitoring of some physical polluting agents, such as noise, electromagnetic fields, fine dust and other air components, temperature and humidity. This considerations lead to the need of an accurate prediction of noise impact in urban area, both in proximity of operating sources and in the design of a new infrastructure.

In general, literature and law regulation consider vehicular traffic as one of the main noise source in an urban framework, together with railways, industrial areas and airports. Road traffic noise, thus, is a very important element in environmental impact studies, since car is one of the most used transportation mean in Europe. The prediction of noise coming from vehicular traffic is strongly influenced by some "intrinsic" parameters (due to both noise production and propagation processes), such as traffic volume, traffic flow, velocity, road features, etc., and other "specific" parameters (dependent on the particular area of interest), such as kind of vehicles, speed limits, vehicles maintenance duties, law emission thresholds, driving skills, amount and typologies of road intersections, etc.. In last years, many Traffic Noise Models (TNMs) have been developed (for a review see [13]) and the most used ones use an empirical and approximated approach, tuning the model parameters on a particular set of data and neglecting many of the elements listed above. Thus, even if the prediction is quite unstable, these models result to be enough efficient and precise in most of the practical applications. These models, in fact, furnish a good approximation of the equivalent acoustical level (L_{eq}) when the condition of the traffic flow is standard, i.e. continuous flow, regular traffic volume, absence of conflicting points, etc.. This prediction is performed by means of a formula which generally depends on the vehicular flow, usually classified in light vehicles, heavy ones and motorcycles, plus other additive corrections. The general expression of a TNM can be written in a three parameters formula as follow:

$$L_{eq} = A \cdot LogQ\left[1 + \frac{P}{100}(n-1)\right] + b \cdot Log(d) + C \quad (1)$$

where L_{eq} is the acoustic equivalent level (defined later), Q is traffic volume in vehicles per hour, P is the percentage of heavy vehicles, n is the acoustical equivalent and d is the distance from observation point to center of the traffic lane. The A, b and C coefficients may be derived, for a fixed investigated area, by linear regression methods on many L_{eq} data taken at different traffic flows (Q, P) and distances (d). The acoustical equivalent, n, (defined as the number of light vehicle that generate the same acoustic energy of a heavy one) can be estimated both by regression method or by single vehicle emission measurements.

In this paper, the main idea is to focus the noise control problem on the road intersection configurations, where the prediction cannot be performed in simple way. The prediction of noise level is calculated in the CadnaA software framework and then compared to the results of an experimental activity of noise measurements in a case study, by means of noise maps and contour lines. Moreover, the software can be used to model an engineering intervention on the case study, such as the design of a new intersection. In the last section, the introduction of a roundabout is presented as a noise mitigation action.

A more detailed analysis could take into account driver behaviour, for instance by means of neural network approach or self-learning neurons, such as in [14].

2 Intersections and flow features

2.1 Intersection typologies

In [15] the authors gave a quite complete description of different road intersections and choice criteria. In this section, the main ideas related to intersection issues will be resumed, in order to introduce the simulation procedure and choices.

"Road intersection" is defined as the area obtained by the convergence in the same point of three or more road branches. The intersections, wherever they are localized, constitute a critical point for a road network because of the crossing of different traffic flows. They are divided into three main categories:

- *Planar Intersection*, subdivided in *linear intersections* (see for example Fig. 1) and *roundabouts*, where the converging roads are coplanar, with consequent interferences between transiting and curving currents.
- *Traffic Light Controlled Intersections*, which are still coplanar crossings, but there is a periodic and alternate stop of the traffic currents. They are used quite exclusively in urban and suburban ambits.
- *Not Planar Intersections*, in which the separation of the different transit currents is obtained through overpasses, while the connection between the two streets is given by one or more exchanging ramps.

The typology of intersection has to be chosen according to specific and regulated choice criteria, resumed in [16, 17, 18]. In particular, the acoustical noise impact on the surrounding environment should be considered in the design phase.

2.2 Flow typologies

Another important feature of the road that have to be considered in the simulation phase is the flow typology. Not always, in fact, vehicles travel at a constant speed (as it is assumed in the principal TNMs). Thus, according to International Standards, one can define four typologies of vehicular flow as follow:

Fluid continuous flow, when all the vehicles travel at an almost steady velocity, with a very narrow variance in the speed distribution.

Pulsed continuous flow: when many vehicles are in a transitory state (i.e. increasing or decreasing their speed) but it is possible to define an average overall velocity, which is stable and repetitive for a sufficiently long period of time.

Pulsed accelerated flow: when a significant portion of vehicles is in accelerating state.

Pulsed decelerated flow: when a significant portion of vehicles is in decelerating state.

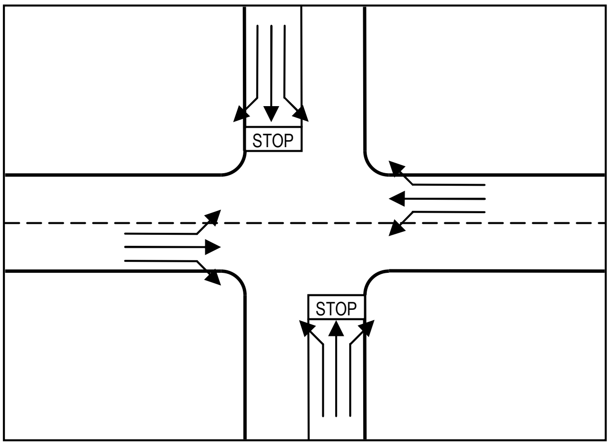

Fig. 1: Example of simple cross intersection with possible directions for each lane.

3 Intersections noise impact

In this section a brief review of studies on the acoustical impact of intersections is reported, with a particular emphasis on the noise reduction corresponding to some useful interventions [19].

In general, the presence of an intersections leads to a growth of the noise level in that point, proportional to the traffic flow, since there will always be many conflicting actions, such as turning, breaking, acceleration, etc.. In literature several studies tried to give an estimation, both on an experimental and on a theoretical basis, of the noise impact of different typologies of intersections.

For example, on the experimental point of view, an American study [20] affirms that roundabouts decrease noise level compared to traffic light controlled intersections. On the other hand, due to the high rate of accelerations at the exit of the roundabout, noise equivalent level could be increased from 1 to 2 dBA with respect to continuous traffic (without intersections).

Another paper [21] reports that, in the Japan case study, the installation of traffic lights brings to different noise impacts, depending on various traffic conditions. In average, the noise level close to signalized intersection is reported to be 2.4 dBA higher than a fluid continuous traffic flow.

On the other hand, in the past, many theoretical Traffic Noise Models (TNMs) have been developed [13]. Many of them do not consider the presence of intersections, except, in some cases, for a constant corrective element. A deeper description can be found in [22], where three different typologies of traffic noise prediction models are presented and applied to an intersection case study, with the simulation of a roundabout or of a traffic light controlled junction. The result is that in a under-saturated traffic flow regime, the roundabout induces to a 2.5 dBA noise reduction compared to signalized intersection, while in over-saturated regime, i.e. in presence of traffic congestion, the noise impact is quite balanced.

Despite of these considerations about noise increase due to traffic lights, very often one cannot replace signal-controlled intersections with roundabouts because of geometrical issues or high pedestrian flows (see previous sections). In these cases, the optimization of traffic fluidity close to traffic light controlled intersections, can result in a lowering of the noise equivalent level.

In fact, a study in Geneva [23] demonstrates that the active adaption of traffic lights cycles to the vehicles speed, so that a vehicle should not decelerate or accelerate in correspondence of the intersection, can lead to a decrease up to 2 dBA in the noise equivalent level.

4 Electric current and vehicular flow analogy

The theoretical model that can be used for studying vehicular flow balance in an intersection has been developed starting from the Kirchhoff's circuit laws in Electrical Engineering. In particular, if one considers the Kirchhoff Current Law (KCL), the analogy between electrical current and vehicles flow can be highlighted. Vehicles entering or exiting the intersection can be considered respectively as entering or exiting currents, where the intersection play the role of the circuit node[1] (junction). Of course, one can easily notice that, in the intersections, vehicles are not allowed to park or to stop, and, consequently no vehicle can enter the intersection without exiting or vice versa. This means that in the intersection a kind of continuity equation related to vehicles density stays, in absence of sources and/or wells.

[1] More in general, the KCL is valid for any closed surface in which the node is placed, since it is related to flux concept.

Standing this analogy, one can affirm that "*the sum of the number of vehicles that enters a given intersection from any road converging in that point, is equal to the sum of the number of vehicles that exits that intersection from any branch*", that is:

$$\sum_n Q_n^{IN} = \sum_n Q_n^{OUT} \quad (2)$$

For example, if one considers a standard 4 branches intersection as in Fig. 2, where the x_i represents the vehicle flow related to the *i*-esim lane, it can be affirmed that:

$$x_2 + x_4 + x_6 + x_8 = x_1 + x_3 + x_5 + x_7 \quad (3a)$$

that is:

$$\sum_{n=1}^{4} x_{2n} = \sum_{n=1}^{4} x_{2n-1} \quad (3b)$$

These considerations do not depend on the kind of intersection chosen, since these equation stays for roundabouts, cross intersections, signal controlled junctions, etc..

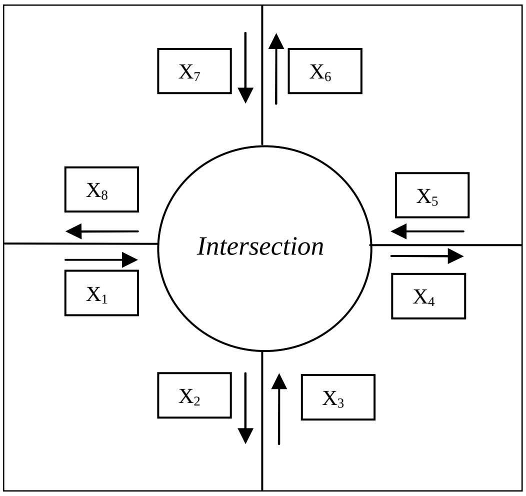

Fig. 2 Generic intersection configuration.

The analogy between circuits and road networks can be helpful in the study of some intersections, such as roundabouts. In this case, in fact, the equation (2) can be used in order to evaluate the flow charge on each sector of the roundabout (see Fig. 3).

If one considers that a vehicle coming from the *i*-esim lane, will not come back on the same direction, i.e. the U-turn is neglected, it can be stated that the *i*-esim sector of the roundabout is covered by all the vehicles coming from the adjacent converging lane, plus a given percentage of vehicles coming from other two converging lanes. These percentages are related to the number of vehicles that converge in the intersection from the other lanes and do not exit before. For example, if one considers the flow y_1 of Fig. 3, the relation is:

$$y_1 = x_1 + \alpha x_7 + \beta x_5 \quad (4)$$

Of course, no percentage of x_3 flow is considered, since the U-turn is neglected. Moreover, it is not considered that a vehicle could miss the right exit and could make more than one round. The α and β coefficients can be even measured by operators or induced by statistical considerations and/or historical data.

Starting from this assumption and standing the KCL statement for vehicular flows, one can build the linear system for y_i variables:

$$\begin{cases} y_1 = x_1 + \alpha x_7 + \beta x_5 \\ y_2 = x_3 + (y_1 - x_2) = x_3 - x_2 + x_1 + \alpha x_7 + \beta x_5 \\ y_3 = x_5 + (y_2 - x_4) = x_5 - x_4 + x_3 - x_2 + x_1 + \alpha x_7 + \beta x_5 \\ y_4 = x_7 + (y_3 - x_6) = \\ \quad = x_7 - x_6 + x_5 - x_4 + + x_3 - x_2 + x_1 + \alpha x_7 + \beta x_5 \end{cases} \quad (5)$$

$$y_1 = x_1 + (y_4 - x_8) = \\ = x_1 - x_8 + x_7 - x_6 + x_5 - x_4 + x_3 - x_2 + x_1 + \alpha x_7 + \beta x_5$$

From this system, the vehicles volume on each sector of the roundabout can be easily evaluated, once x_i flows and α and β coefficients have been measured or assumed.

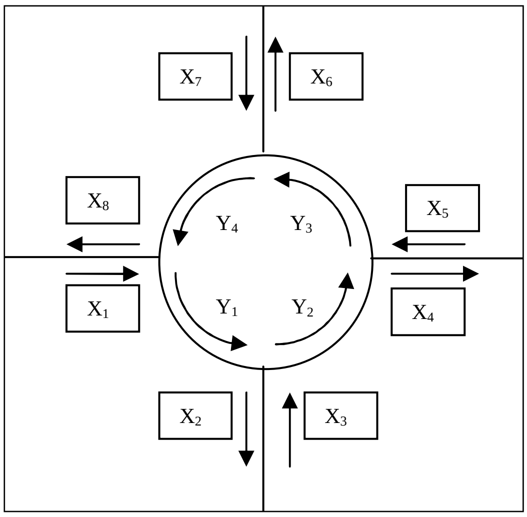

Fig. 3: Roundabout configuration and vehicular flows.

5 Case study analysis and results

In this section, the author presents the noise analysis of a road intersection in Fisciano, Italy, where some peculiarities can be underlined.

The case study here considered is the intersection in Fig. 4, placed at one of the exits of the Salerno University Campus. This intersection is very often congested, especially during lunch time and rush hours, because of the high number of people, in particular workers and students, that live, work or study in that area. The traffic is made both of light (principally cars) and heavy vehicles (buses and trucks), with a moderate number of motorcycles, even in winter time.

Looking at Fig. 4, one can easily notice that vehicles exiting from University have not the priority and, in congested situation, this results very often in a long queue. These vehicles can be considered as a “not continuous” flow.

A measurement campaign has been performed, in order to collect data to be compared with the simulation. The sound data acquisition has been performed by a two channel SINUS Analyzer, SOUNDBOOK (SN 0614), equipped with a pre-amplifier Larson Davis PRM902 (SN 3217), a microphone Larson Davis 2451 (SN 8183) and an acoustical calibrator Larson Davis CAL200 (SN 4874). In addition, a compact digital sound level meter PeakTech 8005 has been used in Point 1 (see Fig. 4c).

The measurement procedure has been carried out in fulfilment to the International regulation, ISO 9613. Once the measurement has been started, the acquisition software is able to detect and record the sound pressure level for each frequency. The experimental activity has been carried out by three operators, in charge of counting the number of vehicles on the roads in proximity of their position (see Fig. 4c), i.e. X_1, X_6, X_7 and X_8, with the nearby turning lanes. In this way, one can evaluate the α and β coefficients and apply the linear system (5) in order to obtain X_2 and X_3. These flows data are fundamental in order to evaluate the noise level with a TNM.

The measured hourly equivalent noise levels can be then compared with the results of a simulation performed by a noise predictive software, i.e., in our case, CadnaA, licensed by DataKustik.

Fig. 4: Case study: a) Salerno University Campus with; b) Zoom on considered intersection; c) Implementation of the intersection in CadnaA, with measurement points and operators position.

This software is based both on “Angle Scanning” and on the inverse “ray-tracing” principle: area under analysis is divided in many small surfaces in which a receiver is placed at a variable height, in order to build a determined calculation grid. Each receiver releases many rays with a full angle coverage (omni directive) and these rays, eventually after many reflections, intercept the different noise sources. The path length of the single ray describes the attenuation of the sound wave coming from a certain noise emitter. Moreover, it is possible to insert different kind of sources, such as roads, railways, parking lots, geometrical sources, etc.. Noise coming from each source is simulated according to International Standards and to specific predictive model. In [4-7, 15, 17] the simulation performances of this software have been exploited and applied in different cases, with different kind of sources. The results have been also compared with experimental data, showing a quite good agreement in almost all the standard situations.

In the case under study, the simulation is performed according to the French road traffic noise model, recommended by European Community as a standard reference model [24], the *Nouvelle Méthode de Prevision du Bruit* – NMPB. The simulation needs as input many parameters, such as geometry of roads and intersection, traffic flow data together with accelerating or decelerating features (where necessary), heavy vehicles percentage, road pavement, speed limits, road gradient, etc.. Once these parameters have been fixed according to the real case study and the configuration is implemented in CadnaA, the simulation is performed and the calculation is made inside a suitable grid formed by cells. The spatial resolution of the prediction, of course, depends on the size of the cells. Moreover, the height of the receiver is fixed at 1.5 m from the ground, which is the height of the measurement instruments.

In Table 1, the results of measurements and simulation corresponding to one of the measurement sessions are shown, while in Fig. 5, the noise map obtained in CadnaA is reported.

Table 1: Results of measurements and simulation, in Point 1 and Point 2

	L_{eq} exp	L_{eq} sim	L_{90} (background noise)
Point 1	70.3	71.5	50.3
Point 2	70.9	72.5	64.3

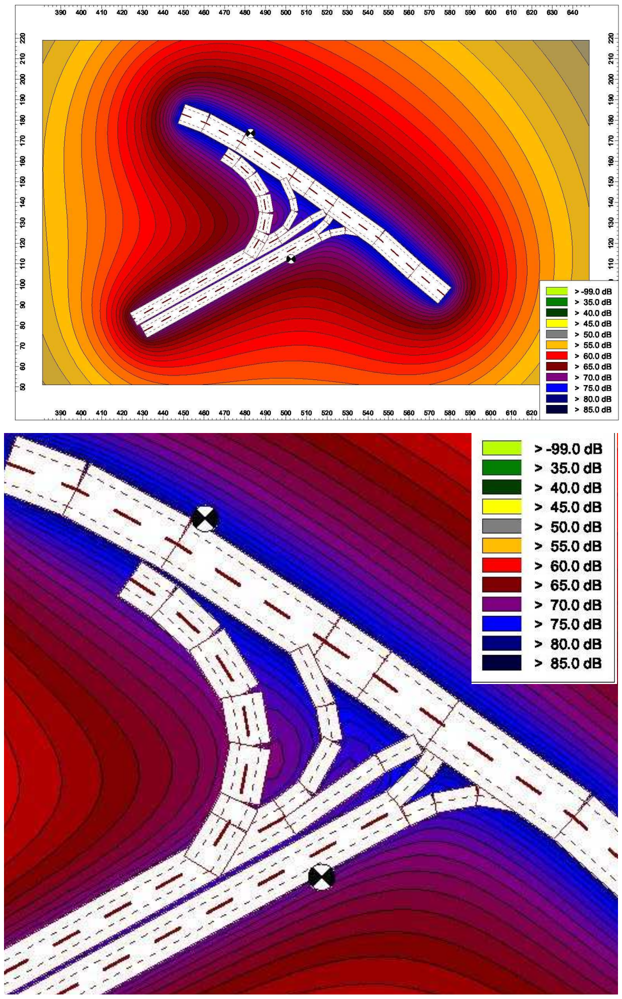

Fig. 5: Actual intersection simulated noise maps

It is interesting to notice that this measurement session is related to a traffic jam on the principal road and, if one compares values in Table 1, the measured values are lower than the simulated ones. This is due to the fact that the predictive model, and consequently the software, works in standard conditions, that are fluid continuous, pulsed or accelerated/decelerated flows and average speed. Thus, if the vehicular volume input is given, the software will make these vehicles run with an average speed, resulting in a higher L_w, and thus L_{eq}, with respect to a traffic jam situation where the vehicles are often stopped or run with a very low speed. Moreover, this consideration is confirmed by the fact that L_{90}, which gives an estimation of the background noise, is quite high with respect to normal conditions, being 64.3 dBA.

In Point 1, for example, in order to achieve a better agreement between simulations and experimental data, it was necessary to specify, in the simulation, the typology of traffic flow, because the presence of "not continuous" flows results in different equivalent levels with respect to standard conditions. The measurement in Point 1 related to the experimental session reported in Table 1 gave an hourly equivalent level of 70.3 dBA, while the simulation in CadnaA gave 71.5 dBA. This discrepancy is probably due both to the previous consideration (related to the traffic jam situation) and to the intrinsic error in the predictive model, and it was much higher when the traffic flow of X_1 was not set properly ("decelerating" flow because of stop signal and priority).

Besides this comparison, the introduction of a new intersection configuration can be implemented in the CadnaA framework, in order to evaluate the best solution in terms of noise equivalent level impact. In literature, for example in [19], [25], [26], the roundabout configuration is suggested as one of the best solution to be adopted, provided that flows and geometry of the intersection are suitable with this solution.

In Fig. 6, the design of a roundabout is proposed, while in Fig. 7, the noise map produced by the simulation in CadnaA of the roundabout instead of the actual intersection is presented. The flows have been chosen according to the previous simulation and the roundabout geometry has been designed according to the legislative requirements [27], [28]. In Point 1, the introduction of the roundabout leads to a lowering of the L_{eq} of about 1 dBA, which is consistent with values found in literature and briefly reported in Section 3.

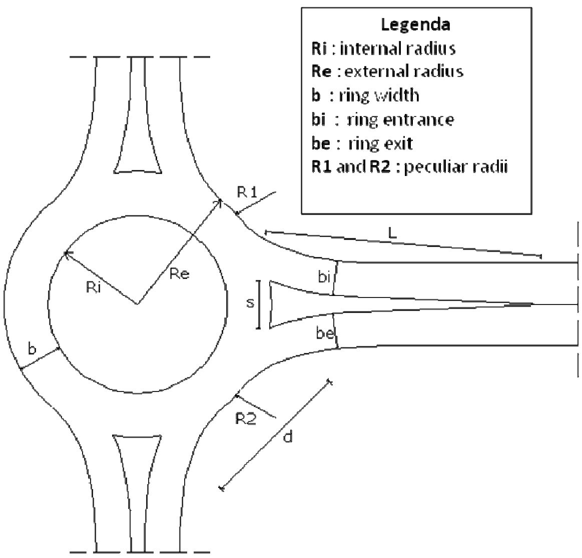

Fig. 6: Roundabout design

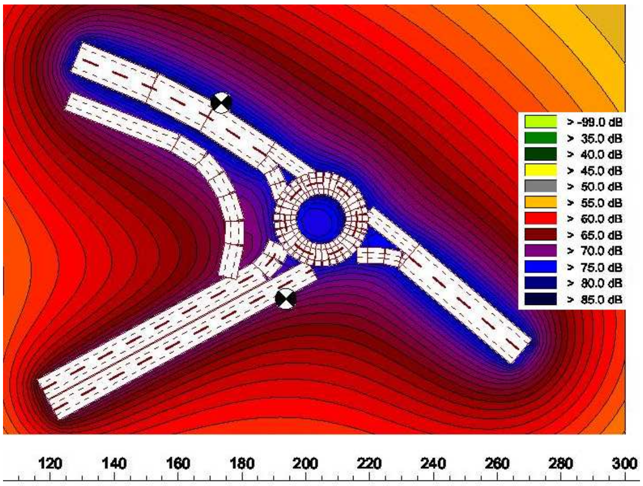

Fig. 7: Roundabout configuration noise map

6 Conclusions

In this paper, the noise control problem in intersections has been exploited in the case study of one of the exits of Salerno University. The analogy between electric current and vehicular flow has been sketched and applied to the case study. The experimental results of a measurement session have been compared with software simulations, in the CadnaA framework, showing that the predictive models, and consequently the software, works in standard conditions and cannot be easily compared with, for instance, a traffic jam measurement results. Let us remark that this software has been employed both on the predictive and on the graphical point of view. In fact, a clear and "easy to read" representation of the simulation results can provide a direct feedback of the expected noise coming from a particular configuration.

The CadnaA software has been used also to predict the noise impact of a possible new intersection configuration, i.e. a roundabout, verifying the lowering of noise equivalent level, consistent with literature values.

The possible evolution of this work is the development of a traffic noise model able to evaluate and include the presence and the typology of road intersections. A global approach, in fact, cannot neglect the modifications due to a conflicting point. Thus, in a more detailed analysis, other elements could be taken into account, such as driver behaviour, for instance by means of neural network approach or self-learning neurons (see for example [14]), trajectory estimation with Fuzzy systems [29], etc..

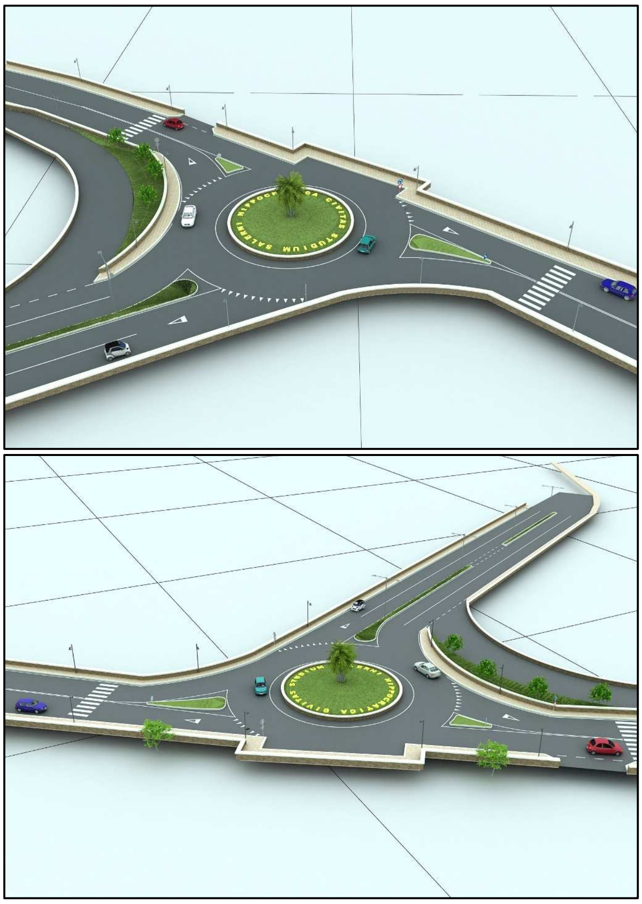

Fig. 8: 3D render of roundabout configuration insertion

Acknowledgements

The author is grateful to E. Zappia and D. Barbato for their help in the measurement campaign and in the software data processing.

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