Evaluation of urban traffic plan scenarios in terms of traffic noise abatement

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Abstract: Urban traffic plans (UTPs) are tactical planning tools for managing urban areas and traffic noise abatement is one of their objectives, explicitly provided for under Italian law. To date, the various models and methods for estimating traffic noise have concerned its estimation in a point (or on a road segment). In this paper we propose a method that is able to evaluate the effects of UTPs on noise abatement on the whole network, hence that can be used for comparing different planning scenarios.

Key-Words: - Traffic noise, urban traffic plan, noise models, transportation plan, sustainable mobility

1 Introduction

The main aspects related to sustainable mobility are greenhouse gas emissions, air pollution, safety and noise. All these aspects can be seen as transport externalities. In particular, traffic noise can be a major disbenefit in both urban and rural areas, since it significantly reduces the quality of life, produces health damage, annoyance and sleep disturbance and of course it reduces property values. Hence noise reduction is a common objective of transportation planning. In Italy, noise abatement is identified as one of the main objectives of urban traffic plans (UTPs), together with (a) improvement in traffic circulation and (b) road safety, (c) reduction in air pollution and (d) energy saving.

A UTP is an administrative and technical tool for managing urban transport in the short term; it has to be updated every two years. In Italy it is mandatory for every town over 30,000 inhabitants to draw up a UTP. Such a plan does not provide for the construction or widening of roads, but only manages existing facilities (road directions, junction management, parking, etc.). It is governed by the Highway Code [1] and by specific guidelines prepared by the Italian Ministry of Public Works [2].

The aim of this paper is to propose a comprehensive procedure to compare different scenarios in terms of noise so as to verify whether a UTP scenario is able to reduce traffic noise globally on an urban network, and among several alternative scenarios, to identify the one(s) that is(are) most effective in terms of noise abatement.

This paper is organised as follows: section 2 examines the background; section 3 proposes the methodology and section 4 tests it on a real case study; section 5 concludes and identifies prospects for future research.

2 Background

The European Directive 2002/49/EC [3] defines the acoustic parameter L_{den} (Level day-evening-night), that is adopted to standardise noise measurements for European Countries, as follows:

$$L_{den} = 10 \cdot \log_{10} \frac{1}{24} \cdot \left[12 \cdot 10^{\frac{L_d}{10}} + 4 \cdot 10^{\frac{L_e+5}{10}} + 8 \cdot 10^{\frac{L_n+10}{10}} \right] \quad [dB(A)] \tag{1}$$

where:

- L_d is the equivalent noise level during the day (7:00-19:00);
- L_e is the equivalent noise level during the evening (19:00-23:00);
- L_n is the equivalent noise level during the night (23:00-7:00).

The evening period can be reduced by one or two hours, increasing the other time periods.

Several models for estimating the equivalent noise level have been proposed in the literature.

These models usually estimate the equivalent noise level according to variables such as traffic flow, road surface, average vehicle speed, distance of the receptor from the traffic lane, percentage of heavy trucks, and kind of pavement. Steele [4] reviewed the models proposed before 2001. Numerous papers deal with road traffic noise; some models and methods can be found in [5], [6], [7], [8], [9], [10], [11], [12] and [13]. Some models for traffic noise at signalised intersections were proposed in [14] and [15].

3 Models and methods

For a city, we assume the availability of a transportation model that is able to estimate, in different hours of the day, the traffic flows on all links of the road network.

In the transportation model, a road segment, J, is represented by only one oriented link, j, if it is one-way, while it is represented by two oriented links, j and j', if it is two-way.

Let:

J be a road segment;

j an oriented link that represents one direction of the road segment J;

j' an oriented link that represents the other direction of the road segment J;

h the generic hour of the day;

l_J the length of the road segment J (m);

f_j^h [$f_{j'}^h$] the homogenised hourly traffic flow on the oriented link j [j'] at hour h (veh/h);

s_j^h [$s_{j'}^h$] the mean speed on the oriented link j [j'] at hour h (km/h);

A^1_J a generic other characteristic of the road segment J (for instance width, pavement, etc.);

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A^m_J a generic other characteristic of the road segment J (such as width, pavement type, etc.).

In the following, we assume that we know the current configuration of the road network of a city where an urban traffic plan is going to designed and we have a transportation simulation model that is able to estimate all features of traffic flows on the road network in different hours of the day; moreover, all features of road infrastructures are known. We refer to the current configuration of the network as before (B). We consider that a new scenario is proposed during or at the end of the UTP design; this scenario, that we call after (A), will present several differences in the network configuration (e.g. link way directions) with respect to scenario B.

We assume that we are able to estimate, by means of a model, the road traffic noise on a road segment J in terms of equivalent noise level, L_{eq}. We indicate with $L^h_{eq,J}$ the equivalent noise level produced by road traffic on a road segment J at hour h and the corresponding $L_{den,J}$ modifying eqn. (1) as follows:

$$L_{den,J} = 10 \cdot \log_{10} \frac{1}{24} \cdot \left[\sum_{h \in H_d} \left(n_h \cdot 10^{\frac{L^h_{eq,J}}{10}} \right) + \sum_{h \in H_e} \left(n_h \cdot 10^{\frac{L^h_{eq,J}+5}{10}} \right) + \sum_{h \in H_n} \left(n_h \cdot 10^{\frac{L^h_{eq,J}+10}{10}} \right) \right] \quad (2)$$

where:

H_d is the set of hours that belong to the day (7:00-19:00);

H_e is the set of hours that belong to the evening (19:00-23:00);

H_n is the set of hours that belong to the night (23:00-7:00);

n_h is the number of hours for which the equivalent noise level can be assumed equal.

For each link, we can define the before and after values as $L^B_{den,J}$ and $L^A_{den,J}$ and introduce the before-after difference as:

$$\Delta L_{den,J} = L^B_{den,J} - L^A_{den,J} \quad (3)$$

This difference, measured in dB(A), can be positive or negative if there is a reduction or an increase in road traffic noise: the more the UTP scenario reduces the noise on road segment J, the higher the value of $\Delta L_{den,J}$.

In order to develop the proposed methodology, we assume that on each road segment, J, every 100 m there is a virtual receptor. At each receptor, we calculate the corresponding value of $\Delta L_{den,J}$ with eqns. (2-3). The number of virtual receptors on a road segment J is given by:

$$NVR_J = l_J/100$$

Since the receptors are only virtual, it can also be a non-integer number and will be used for generating some indicators that can be defined for evaluating the impacts of a network configuration (scenario) on traffic noise. We propose five indicators for comparing scenarios and/or for evaluating the goodness of a plan configuration in regards to traffic noise; these indicators are described in the following.

Total traffic noise variation

This indicator is representative of the total traffic noise variation produced by the UTP scenario and is very simple to calculate. It assumes that all roads are equivalent (with no differences among noise zones) and is able to give an initial indication of the global impact of the UTP scenario on traffic noise. The indicator is calculated as follows:

$$TTNV = \Sigma_J\, \Delta L_{den,J} \cdot NVR_J$$

The higher the indicator, the more the network configuration complies with the aim of reducing noise.

Weighted total traffic noise variation

This indicator is similar to the previous one but it weights the $\Delta L_{den,J}$ term for each road segment. More precisely, at each road segment, J, a weight, W_J, is attributed which is representative of the importance of reducing the noise on the road. The indicator is calculated as follows:

$$WTTNV = \Sigma_J\, W_J \cdot \Delta L_{den,J} \cdot NVR_J$$

The weights to assign to each road segment can be obtained in several ways. We suggest assigning the weights as a function of the population density of the urban area that is crossed by road segment J. In this way, greater importance is given to reducing traffic noise where more people live, since the number of virtual receptors on each road segment multiplied by the weight is a good proxy of the number of people exposed to the noise produced in the same segment. To use this indicator instead of directly considering the people exposed is suggested by the fact that the census data are aggregated by zones and more detailed data are very difficult to obtain, especially if operating not on a single road but on a whole city.

Average traffic noise variation

This indicator is the average traffic noise variation on the network:

$$ATNV = TTNV/(\Sigma_J\, NVR_J)$$

Weighted average traffic noise variation

This indicator is the weighted average of traffic noise variations on the network:

$$WATNV = WTTNV/(\Sigma_J\, NVR_J)$$

Minimum variation

This indicator is the minimum value on the network of the term $\Delta L_{den,J}$:

$$MV = min_J\, \Delta L_{den,J}$$

This value will almost always be negative and should be determined in order to verify the negative effects (increase in equivalent sound level) on some links.

Minimum weighted variation

Similar to the previous variation but also considers the weights assigned to each link:

$$MWV = min_J\, (W_J \cdot \Delta L_{den,J})$$

Standard deviation

This indicator is the average distance of all $\Delta L_{den,J}$ from their average:

$$SD = \sqrt{\frac{\sum_J \left(\Delta L_{den,J} - ATNV\right)^2}{N_J - 1}}$$

where N_J represents the number of road segments. This indicator shows that the UTP scenario is able to modify the noise with the same impact on the whole network: assuming that we have a positive value of $ATNV$, if SD is low it means that noise reduction is well distributed on the whole network; vice versa if the value of SD is high.

4 Case study

We tested the proposed methodology on the urban traffic plan of Benevento. Benevento is a town in the south of Italy with about 62,000 inhabitants. The supply model (see Fig. 1) represents the road network (216 km of roads) and is composed by 949 road segments (1,577 oriented links), 678 nodes and 80 centroids. The UTP of Benevento was designed by adopting a “what if” approach that compared over 80 scenarios defined with the main objective of reducing the daily total travel time on the network. The final scenario provided interventions regarding the direction of some road segments and the configuration and/or control of some intersection. In this paper we verify whether a benefit on traffic noise is produced by the final scenario.

4.1 Demand and traffic flows

The origin-destination matrices, representing the transportation demand, were estimated by using a mathematical model and traffic surveys. Four different matrices were generated, corresponding to four time periods: MPH (morning peak-hour); APH (afternoon peak-hour); DOPH (daily off-peak hour); NOPH (nightly off-peak hour). Each matrix can be used to simulate traffic flows in some hours of the day. According to the distinction between day, evening and night, we assumed the following scheme:

- day (7:00-19:00): 1 MPH, 2 APHs and 9 DOPHs;
- evening (19:00-23:00): 3 DOPHs and 1 NOPH;
- night (23:00-7:00): 1 DOPH and 7 NOPHs.

Therefore, eqn. (2) becomes:

$$L_{den,J} = 10 \cdot \log_{10} \frac{1}{24} \cdot \left[1 \cdot 10^{\frac{L^{MP}{}_{eq,J}}{10}} + 2 \cdot 10^{\frac{L^{AP}{}_{eq,J}}{10}} + 9 \cdot 10^{\frac{L^{DOP}{}_{eq,J}}{10}} + 3 \cdot 10^{\frac{L^{DOP}{}_{eq,J}+5}{10}} + 1 \cdot 10^{\frac{L^{NOP}{}_{eq,J}+5}{10}} + 1 \cdot 10^{\frac{L^{DOP}{}_{eq,J}+10}{10}} + 7 \cdot 10^{\frac{L^{NOP}{}_{eq,J}+10}{10}} \right] \quad (4)$$

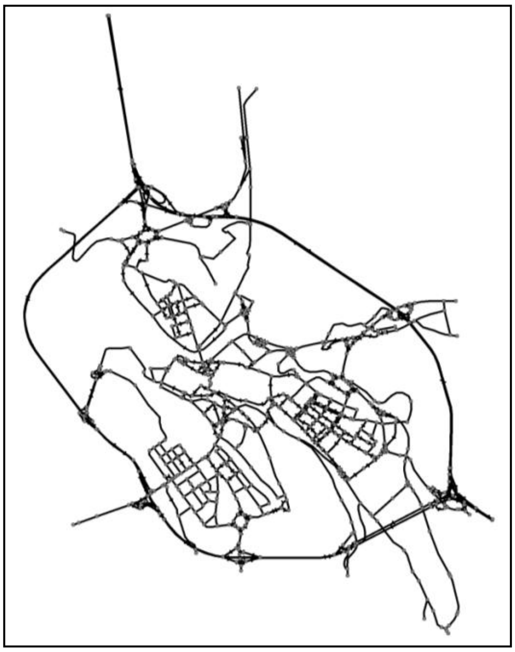

Fig. 1 - The road network model.

For both scenarios (B and A), each of the four OD matrices is assigned to the road network so as to estimate corresponding link traffic flows, f_J^h, and speeds, s_J^h.

4.2 Weights

We assign to each road segment of the Benevento network a weight as a function of the population density, according to Table 1 and Fig. 2.

Population density	Class	W_J
0.8-1.0 max density	I	1.0
0.6-0.8 max density	II	0.8
0.4-0.6 max density	III	0.6
0.2-0.4 max density	IV	0.4
0.0-0.2 max density	V	0.2

Table 1 - Weights for different population densities.

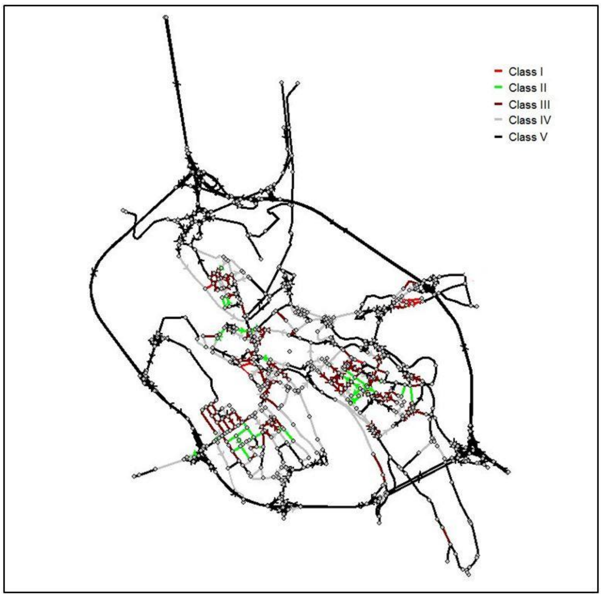

Fig. 2 - Weight classes of road segments.

4.3 Traffic noise model

The general model adopted in the test is the one developed in the EU project CNOSSOS [13], which calculates the sound power emission (in dB) as follows:

$$L_{W',eq,line,\,i,\,m} = L_{W,i,m} + 10 \cdot \log_{10}(f_m / (1000 \cdot s_m))$$

where:

$L_{W',eq,line,\,i,\,m}$ is the directional sound power per metre per hour per frequency band resulting from the vehicle flow;

$L_{W,\,i,\,m}$ is the instantaneous directional sound power in “semi free-field” of a single vehicle;

i represents the octave band of frequency from 125 Hz to 4 kHz;

m represents the category of vehicles;
f_m is the steady traffic flow of vehicles of category *m* (veh/h);
s_m is the average speed of traffic flows (km/h).

In order to estimate the sound power emission of a single vehicle, two main noise sources are considered: (a) rolling noise due to the tyre/road interaction and (b) propulsion noise. Moreover, four vehicle categories are considered: 1) cars and light duty vehicles ≤ 3.5 t (light); 2) duty vehicles and buses with two axles and twin tyres on the rear axle (medium); 3) heavy duty vehicles and buses with three or more axles (heavy); and 4) two-wheelers. The general form of the sound power emitted by one of the sources is a function of the average speed s_m as follows:

$$L_{W,i,m}(s_m) = A_{i,m} + B_{i,m} \cdot \varphi(s_m)$$

where $\varphi(s_m)$ is a logarithmic function in the case of rolling noise (*WR*) and a linear function in the case of propulsion noise (*WP*). For vehicles belonging to categories 1, 2 and 3 the sound power level is the sum of both contributions (a) and (b):

$$L_{W,i,m}(s_m) = 10 \cdot \log_{10}\left(10^{L_{WR,i,m}(s_m)/10} + \right. \\ \left. + 10^{L_{WP,i,m}(s_m)/10}\right)$$

For vehicles belonging to category 4 only propulsion noise (b) is considered. The sound power level of the rolling noise is expressed by:

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} \cdot \log_{10}(s_m / s_{ref}) + \\ + \Delta L_{WR,i,m}(s_m)$$

where:
$A_{R,i,m}$ and $B_{R,i,m}$ are coefficients;
s_{ref} is the reference speed (70 km/h);
$\Delta L_{WR,i,m}$ is a correction term.

The correction term takes account of the road surface, the vehicles that are equipped with studded tyres, the acceleration of vehicles crossing a signalised junction or a roundabout and the average temperature. The sound power level of the propulsion noise is given by:

$$L_{WP,i,m}(s_m) = A_{P,i,m} + B_{P,i,m} \cdot \frac{(s_m - s_{ref})}{s_{ref}} + \\ + \Delta L_{WP,i,m}(s_m)$$

where:
$A_{P,i,m}$ and $B_{P,i,m}$ are coefficients;
v_{ref} is the reference speed (70 km/h);
$\Delta L_{WP,i,m}$ is a correction term.

The correction term takes account of the road surface, the acceleration of vehicles crossing a signalised junction or a roundabout and the road gradient. The methods for estimating the correction terms are reported in the CNOSSOS research report [13].

The sound power level has to be calculated for each frequency band; the A-weighted sound pressure level is calculated by summing all frequencies:

$$L_{eq,tot} = 10 \cdot \log_{10} \sum_i 10^{(L_{W',i,m} + A_i)/10} \tag{5}$$

where:
A_i indicates the A-weighting correction according to IEC 61672-1;
i is the frequency band index.

The use of this model in our procedure requires the calculation of $L_{eq,tot}$ for each link of the network as a function of flows, speed and other features of the link; all necessary data for the application of the CNOSSOS model within our procedure are available.

4.4 Indicators

The proposed methodology was applied to assess the impact of the UTP final scenario on noise reduction. Transportation demand was the same for both before and after scenarios, and the traffic flows and average speeds were calculated by means of a stochastic assignment procedure.

Table 2 reports the results obtained by the proposed method. The results show that, even if the UTP was not designed to reduce traffic noise, it reduces road traffic noise (TTNV and WTTNV are positive) whatever the traffic noise model used inside the procedure.

Indicator	Value
TTNV	41.681
WTTNV	21.455
ATNV	0.032
WATNV	0.016
MV	-19.637
MWV	-19.637
SD	2.286

Table 2 - Results of the procedure applied to the Benevento UTP.

5 Conclusions and research prospects

In this paper a method for comparing the scenarios of an Urban Traffic Plan (UTP) *vis-à-vis* traffic noise was proposed and tested on a real case. The method, albeit unable to quantify the absolute traffic noise level of the area, gives useful information about the relative variation in traffic noise between two different UTP scenarios. It can be applied during the phase of UTP design to evaluate, together with other indicators (total travel time, emissions, consumption, etc.), the goodness of one scenario over another.

Tested on a real case, the method in question showed its applicability with limited additional computational effort; the main variables required (traffic flows and average speeds) are usually calculated to evaluate other UTP indicators. Future research will aim to test the proposed procedure with other traffic noise model and in other real-scale cases.

References:

[1] Highway Code, *D. L. 30 April 1992, no. 285, Nuovo codice della strada*. Suppl. ordinario Gazzetta Ufficiale della Repubblica Italiana, 18 May 1992, n. 114, 1992.

[2] Italian Minister of Public Works, *Direttive per la redazione, adozione ed attuazione dei Piani Urbani del Traffico*, Gazzetta Ufficiale della Repubblica Italiana, 24 June 1995, n. 146, 1995.

[3] European Commission, *Directive 2002/49/EC of the European Parliament and of Council of 25 June 2002 relating to the assessment and management of environmental noise* Official Journal of the European Communities, L 189/12, 18.7.2002, 2002.

[4] Steele C., A critical review of some traffic noise prediction models, *Applied Acoustics*, Vol. 62, 2001, pp. 271-287.

[5] Bendtsen H., The Nordic prediction method for road traffic noise, *The Science of the Total Environment*, Vol. 235, 1999, pp. 331-338.

[6] Cirianni F., Leonardi G., The application of a neural network on a study of noise pollution in urban transport: a case in Villa S. Giovanni, In *Air Pollution XII*, WIT press, Southampton, UK, 2004, pp. 559-570.

[7] Tansatcha M., Pamanikabud P., Brown A.L., Affum J.K., Motorway noise modelling based on perpendicular propagation analysis of traffic noise, *Applied Acoustics*, Vol. 66, 2005, pp. 1135-1150.

[8] Can A., Leclercq L., Lelong J., Dynamic estimation of urban traffic noise: Influence of traffic and noise source representations, *Applied Acoustics*, Vol. 69, 2008, pp. 858-867.

[9] Pamanikabud P., Tansatcha M., Brown A.L., Development of a highway noise prediction model using an Leq20 s measure of basic vehicular noise, *Journal of Sound and Vibration*, Vol. 316, 2008, pp. 317-330.

[10] Rajakumara H.N., Gowda R.M.M., Road Traffic Noise Prediction Model under Interrupted Traffic Flow Condition, *Environ Model Assess*, Vol. 14, 2009, pp.251-257.

[11] Hamet J.F., Besnard F., Doisy S., Lelong J., le Duc E., New vehicle noise emission for French traffic noise prediction, 2010, *Applied Acoustics*, Vol. 71, pp. 861-869.

[12] Makarewicz R., Gałuszka M., Road traffic noise prediction based on speed-flow diagram, *Applied Acoustics*, Vol. 72, 2011, pp. 190-195.

[13] Kephalopoulos S., Paviotti M., Anfosso-Lédée F., *Common Noise Assessment Methods in Europe (CNOSSOS-EU)*, EUR 25379 EN, Luxembourg: Publications Office of the European Union, (2012.

[14] Abo-Qudais S., Alhiary A., Statistical models for traffic noise at signalized intersections, *Building and Environment*, Vol. 42, 2007, pp. 2939-2948.

[15] Quartieri J., Mastorakis N.E., Guarnaccia C., Trois, A., D'Ambrosio S., Iannone G. Traffic Noise Impact in Road Intersections, *International Journal of Energy and Environment*, Vol. 1, 2010, pp. 1-8.