# A methodology for evaluating urban traffic plan scenarios from the point of view of traffic noise

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*Abstract:* - In recent decades, given the growing importance of sustainable mobility in all its various aspects, reducing traffic noise has become one of the main objectives of transportation planning in urban areas. 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. The proposed method is tested on a real study case, comparing the initial and final scenarios of a UTP, adopting three different traffic noise models. Numerical results show that the proposed method is able to evaluate the scenarios in terms of traffic noise reduction.

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

## 1 Introduction

Transportation plans are important tools for programming and managing transportation systems in urban and regional areas. Most can be classified as either strategic plans that consider long time horizons (10-20 years) and involve decisions on significant capital investments (construction of new roads, railway lines, airports, etc.), or tactical plans that consider short or medium time horizons (2-5 years) and limited capital resources, assuming no significant interventions on existing facilities. In both cases, the planning process can be very complex, especially as sustainability aspects now assume a key role for decision makers and society.

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].

Provision for noise reduction under future traffic scenarios is often neglected or overlooked in urban traffic plans because consolidated procedures and/or resources for noise measurements are not always available. Whilst there may be tools and procedures for measuring current traffic noise at some points of an urban area, estimation of the future effects of a new scenario are less consolidated for the following reasons: (i) resources for calibrating a specific model for a specific urban area are not usually available; (ii) although some models (and software) proposed in the literature are able to estimate noise levels in specific cases, their transferability to other cases is not ensured; (iii) more accurate models usually require extensive data on pavement textures, lateral buildings, road slopes, etc. that are not always available and that need time and money to be surveyed; (iv) assuming transferability, if a scenario produces (as commonly occurs) a decrease in traffic noise on some roads and an increase on others compared with the previous scenario, no procedures are available to evaluate which is better.

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 Lden (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.

The research community have studied the traffic noise problem from several angles. Recent European research projects comprise CNOSSOS [4], which proposed a model for estimating noise produced by road traffic, ENNAH [5], which focused on the impacts of noise on human health, HOSANNA [6], which studied the barriers for abating the noise, and CITYHUSH [7], focusing on transport noise in urban areas.

Several other models for estimating the equivalent noise level have been proposed. 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 [8] reviewed the models proposed before 2001. Numerous papers deal with road traffic noise; some models and methods can be found in [9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 4]. Peng and Mayorga [20] studied the impact of traffic noise with probabilistic and fuzzy approaches. Some models for traffic noise at signalised intersections were proposed by Abo-Qudais and Alhiary [21] and Quartieri et al. [22].

Specific cases have been extensively studied, as found in [23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41]. Simulation methods were proposed by Bhaskar et al. [42]. Road traffic noise management strategies were studied by Naish [43], Geographical Information Systems (GIS) for traffic noise analysis by Pamanikabud and Tansatcha [44], and life cycle assessment (LCA) studies were proposed in Althaus et al. [45, 46].

The impacts of traffic noise on human health, annoyance or sleep disturbance have also received extensive attention; in this review we refer to [47, 48, 49, 50, 51, 52, 53, 5, 6]. The effects of traffic noise on land prices were studied by Kim et al. [54] while the impacts on house prices by Theebe [55].

## 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. Implementation of such a model requires that transportation demand (usually represented by OD matrices) be estimated in different hours of the day and that a mathematical supply model representing the road network be constructed, adopting graph theory [56]. The basic principles of transportation models and the methods for estimating transportation demand and implementing the supply model can be found at length elsewhere (see for instance [57]).

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. Obviously, on each oriented link the flow, mean speed and other characteristics may differ.

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.);

...

$A^m_J$ 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 $\Delta L_{den,J}$.

The models proposed in the literature for estimating $L_{eq}$ can be classified into two main groups: specific models and general models. Specific models are specified and calibrated in certain case studies (for instance a town, some roads, etc.) and usually require as input data only traffic flows, speeds and (sometimes) some features of the road (slope, pavement, etc.) and/or the distance of the receptor. The applicability of these models to other case studies can be acceptable in similar situations and are simpler to use. General models, instead, can be applied to different case studies but require more input data and are more complex to use. Eqn. (3) can be adopted whatever the model adopted for estimating $L_{eq}$, but if we use a specific model some simplifications can be made. Indeed, examining the literature, we can formulate a specific model as:

$$L^h_{eq,J} = \beta_0 + \beta_1 \cdot \log_{10} f_J^h + \beta_2 \cdot \sigma(s_J^h) + \beta_3 \cdot \alpha^1(A^1_J) + ... + \beta_{2+m} \cdot \alpha^m(A^m_J) \quad (4)$$

where:

$\beta_0, \beta_1$ ... are the coefficients of the model;

$f_J^h = f_j^h + f_{j'}^h$

$s_J^h = (f_j^h \cdot s_j^h + f_{j'}^h \cdot s_{j'}^h)/(f_j^h + f_{j'}^h)$

Therefore, the before and after corresponding values can be calculated as:

$$L^{A,h}_{eq,J} = \beta_0 + \beta_1 \cdot \log_{10} f^A{}_J^h + \beta_2 \cdot \sigma(s^A{}_J^h) + \beta_3 \cdot \alpha^1(A^1_J) + ... + \beta_{2+m} \cdot \alpha^m(A^m_J) \quad (5)$$

$$L^{B,h}_{eq,J} = \beta_0 + \beta_1 \cdot \log_{10} f^B{}_J^h + \beta_2 \cdot \sigma(s^B{}_J^h) + \beta_3 \cdot \alpha^1(A^1_J) + ... + \beta_{2+m} \cdot \alpha^m(A^m_J) \quad (6)$$

Note that the only differences between equivalent noise levels $A$ and $B$ can be produced by flows and speed. Indeed, none of the other road segment characteristics will change, since the UTP makes no provision for infrastructure interventions (for instance on the road pavements). So, for each road segment we can calculate the difference between the $L^{h}_{eq,J}$ as:

$$\Delta L^{h}_{eq,J} = L^{B,h}_{eq,J} - L^{A,h}_{eq,J} = \beta_1 \cdot \log_{10} (f^{B}{}_{J}{}^{h}/f^{A}{}_{J}{}^{h}) + \beta_2 \cdot [\sigma(s^{B}{}_{J}{}^{h}) - \sigma(s^{A}{}_{J}{}^{h})] \quad (7)$$

and, if we use a model that does not consider the speed as variable, as:

$$\Delta L^{h}_{eq,J} = \beta_1 \cdot \log_{10} (f^{B}{}_{J}{}^{h}/f^{A}{}_{J}{}^{h}) \quad (8)$$

Note that this approach allows a significant reduction in the coefficients of the model to calibrate. The results are independent of the coefficient $\beta_0$, which depends on the background noise that can differ greatly between the areas of a city. Moreover, calibration of models (7) and (8) is very simple, since we have to measure only traffic flows and (for the first case) mean speeds jointly with the corresponding values of $L_{eq}$ in two different traffic conditions, without the need to measure other road characteristics.

The corresponding $\Delta L_{den,J}$ can be calculated modifying eqn. (2) as follows:

$$\Delta L_{den,J} = 10 \cdot \log_{10} \frac{1}{24} \cdot \left[ \sum_{h \in H_d} \left( n_h \cdot 10^{\frac{\Delta L^{h}_{eq,J}}{10}} \right) + \sum_{h \in H_e} \left( n_h \cdot 10^{\frac{\psi_e \cdot \Delta L^{h}_{eq,J}}{10}} \right) + \sum_{h \in H_n} \left( n_h \cdot 10^{\frac{\psi_n \cdot \Delta L^{h}_{eq,J}}{10}} \right) \right] \quad (9)$$

where $\psi_e$ and $\psi_n$ are coefficients greater than 1 that represent the greater importance of reducing noise in the evening and at night; we propose to use the value $\psi_e$ = 1.1 and $\psi_n$ = 1.2. Indeed, since we use the differences between $L_{eq}$, adopting the $\psi$ coefficients is a way to consider the different importance of a noise reduction in the evening or at night with respect to the day.

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) or eqn. (9). 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 intersections; it was estimated that this scenario should reduce: (i) the total travel time in a weekday (–9.44%), (ii) the fuel consumption (–862,000 gasoline litres and –562,000 diesel litres) and (iii) the emissions (–8.0% of greenhouse gases and –7.7% of PM10). In this paper we verify whether a benefit on traffic noise is also produced by the final scenario.

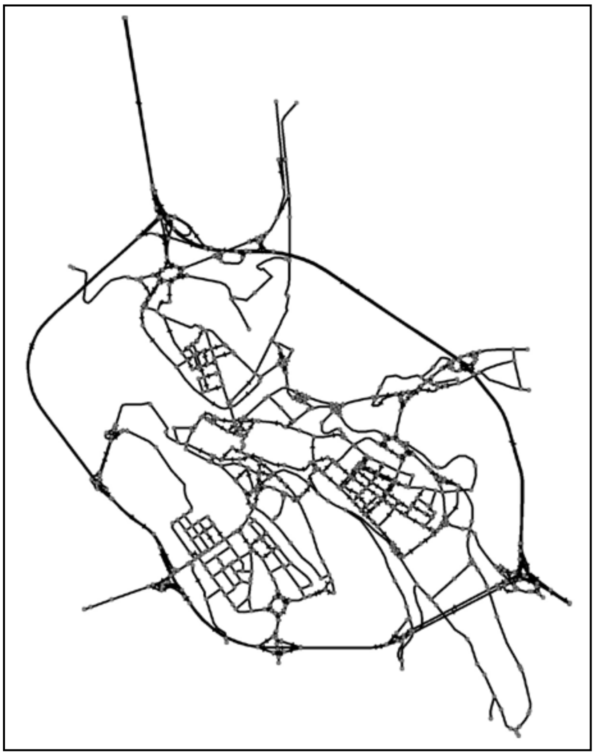

Fig. 1 - The road network model.

## 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, eqns. (2) and (9) become respectively:

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

$$\Delta L_{den,J} = 10 \cdot \log_{10} \frac{1}{24} \cdot \left[ 1 \cdot 10^{\frac{\Delta L^{MP}{}_{eq,J}}{10}} + 2 \cdot 10^{\frac{\Delta L^{AP}{}_{eq,J}}{10}} + 9 \cdot 10^{\frac{\Delta L^{DOP}{}_{eq,J}}{10}} + 3 \cdot 10^{\frac{\psi_e \cdot \Delta L^{DOP}{}_{eq,J}}{10}} + 1 \cdot 10^{\frac{\psi_e \cdot \Delta L^{NOP}{}_{eq,J}}{10}} + 1 \cdot 10^{\frac{\psi_n \cdot \Delta L^{DOP}{}_{eq,J}}{10}} + 7 \cdot 10^{\frac{\psi_n \cdot \Delta L^{NOP}{}_{eq,J}}{10}} \right] \quad (11)$$

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, $s_J^h$.

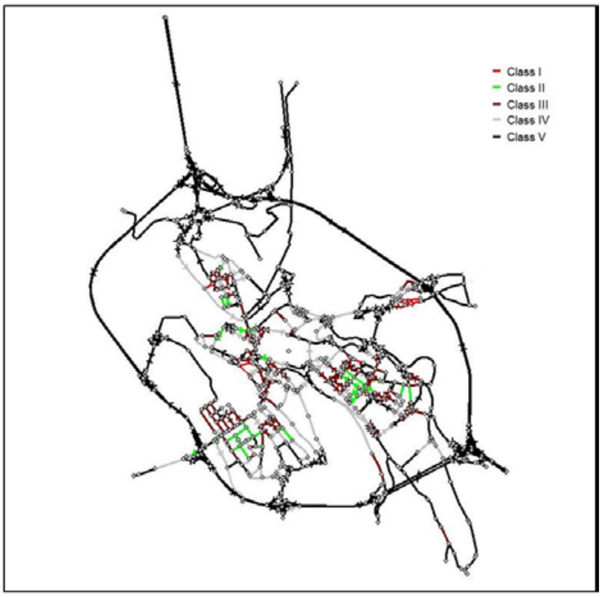


Fig. 2 - Weight classes of road segments.

## 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.

## 4.3 Traffic noise models

In this paper we tested the proposed method by adopting as traffic noise models one general model and two specific models.

### 4.3.1 General model

The general model adopted in the test is the one developed in the EU project CNOSSOS [4], 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 [4].

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

$$L_{eq,tot} = 10 \cdot \log_{10} \sum_i 10^{(L_{W',i,m} + A_i)/10} \qquad (12)$$

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. In this case, eqns. (3) and (10) were adopted for estimating the values of $\Delta L_{den,J}$.

#### 4.3.2 Specific models

As specific models, we tested two models proposed in Italy. The first was proposed by the National Research Centre [58]:

$$L_{eq} = 35.5 + 10 \cdot \log_{10}(f_c + 8 \cdot f_{hv}) + 10 \cdot \log_{10}(25/d) + \Delta L_s + \Delta L_{w1} + \Delta L_{w2} + \Delta L_p + \Delta L_g + \Delta L_{ls}$$

where:
$f_c$ is the hourly traffic flow (veh/h) of cars;
$f_{hv}$ is the hourly traffic flow (veh/h) of heavy vehicles (buses and trucks);
$d$ is the distance of the receptor from the road (m);
$\Delta L_s$ is a correction parameter that considers the mean speed (0 until 50 km/h, +1 for 60 km/h, +2 for 70 km/h, +3 for 80 km/h, +4 for 100 km/h);
$\Delta L_{w1}$ is a correction parameter that considers the possible presence of a rear wall (+2.5);
$\Delta L_{w2}$ is a correction parameter that considers the possible presence of a wall on the opposite side (+1.5);
$\Delta L_p$ is a correction parameter that considers the kind of pavement (–0.5 for smooth asphalt, –0.1 for rough asphalt, +1.5 for concrete);
$\Delta L_g$ is a correction parameter that considers the slope of the road (0 until 5%, +0.6 for 6%, +1.2 for 7%, +1.8 for 8%, +2.4 for 9%, +3.0 for 10%);
$\Delta L_{ls}$ is a correction parameter that considers the presence of traffic lights or very low speed (+1.0 near traffic lights, –1.5 for mean speed < 30 km/h).

Adopting the methodology proposed in Section 3, given that on almost all the roads of the network model the mean speed is between 30 and 50 km/h, except for some roads where the mean speed exceeds 50 km/h (ring roads) for which the before and after speeds are almost the same, we can use eqn. (8) for calculating on each road segment, $J$, the value of $\Delta L^h_{eq,J}$ as follows:

$$\Delta L^h_{eq,J} = 10 \cdot \log_{10} (f^{B\ h}_J / f^{A\ h}_J) \quad (13)$$

where $f^{B\ h}_J$ and $f^{A\ h}_J$ are the homogenised flows assuming the coefficient 8 for heavy vehicles.

The other model is the one proposed by Cirianni and Leonardi [10]:

$$L_{eq} = 4.42 \cdot \log_{10} f - 0.03 \cdot \log_{10} (15/d) - 0.178 \cdot s + + 0.07 \cdot g + 61.40$$

Using this model, the variation in the equivalent noise level is calculated as:

$$\Delta L^h_{eq,J} = 4.42 \cdot \log_{10} (f^{B\ h}_J / f^{A\ h}_J) + - 0.178 \cdot (s^{B\ h}_J - s^{A\ h}_J) \quad (14)$$

Using these models, eqn. (11) was adopted for estimating the value of $\Delta L_{den,J}$.

### 4.4 Indicators

The proposed methodology was applied by adopting the general model and the specific models described in subsections 4.3.1) and 4.3.2) 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. Since the equilibrium traffic flows are affected by the adopted zoning (partition of the study area into traffic zones), if the traffic flows on a link were less than 1 veh/h this flow was assumed equal to 1 veh/h. Indeed, all models for predicting traffic noise are valid only if the flow is higher than 1. Moreover, a link traffic flow equal to 0 veh/h on a road open to traffic is due only to the approximations adopted for building the model that is unable to simulate very low local traffic.

Table 2 reports the results obtained by the proposed method for all tested road traffic noise models. 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. The average values (ATNV and WATNV) have the same magnitude for all models while the standard deviation (SD) is very different (significantly lower for the Cirianni and Leonardi model).

| Indicator | CNOSSOS | CNR | Cirianni and Leonardi |
|---|---|---|---|
| *TTNV* | 41.681 | 28.605 | 27.931 |
| *WTTNV* | 21.455 | 20.288 | 17.638 |
| *ATNV* | 0.032 | 0.022 | 0.021 |
| *WATNV* | 0.016 | 0.016 | 0.014 |
| *MV* | -19.637 | -19.107 | -8.547 |
| *MWV* | -19.637 | -9.147 | -4.067 |
| *SD* | 2.286 | 0.861 | 0.105 |

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

Importantly, adopting the proposed method with three different traffic noise models, the result is the same for the purposes of UTP assessment: the final solution reduces traffic noise with respect to the initial network configuration.

## 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 additional computational effort; the main variables required (traffic flows and average speeds) are usually calculated to evaluate other UTP indicators; only the application of the CNOSSOS model requires to know other features of the roads. The method also appeared robust, giving the same results (in terms of improving traffic noise conditions) with different noise models. Future research will aim to test the proposed procedure in other real cases and for other kinds of transportation plans. Moreover, the use of the procedure within multi-criteria analysis will be studied, since the objective to reduce traffic noise may conflict with other objectives, such as travel time and consumption reduction.

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