EFFETTI DI DIVERSE AZIONI DI MITIGAZIONE DEL TRAFFICO URBANO SUI LIVELLI DI RUMORE AMBIENTALE.

EFFECTS OF DIFFERENT URBAN TRAFFIC MITIGATION ACTIONS ON CITIES' NOISE LEVELS

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RIASSUNTO

Negli ultimi anni molte città hanno adottato o pianificato strategie volte alla riduzione del traffico veicolare. Quasi tutte le strategie di mitigazione intendono affrontare principalmente i problemi connessi alla qualità dell’aria ed alla sicurezza stradale. Tuttavia, l’implementazione di tali azioni può influire positivamente sui livelli di rumore nelle aree urbane, che risultano fortemente influenzati dal trasporto su gomma. Il presente articolo intende analizzare gli effetti di diverse azioni di mitigazione del traffico urbano sui livelli di rumore ambientale. A tal fine, è stata effettuata una rassegna delle differenti strategie di gestione del traffico, dopodiché è stata condotta una campagna di misure in due diversi siti, nel Regno Unito ed in Italia, al fine di esaminare i relativi livelli di rumorosità.

ABSTRACT

Recently several cities have implemented or planned policies to reduce vehicles’ traffic. Most of the mitigation strategies mainly aimed to tackle the problems of the air quality and the safety. Nevertheless, the implementation of these actions may positively affect the urban noise levels, strongly influenced by road transports. This paper aims to investigate the effects of different urban traffic mitigation actions on environmental noise levels. To this purpose, a literature review of different traffic management strategies was carried out, while an on-site measurements campaign through two test sites in UK and Italy was performed in order to investigate the related urban noise levels.

Parole chiave: Rumore da traffico stradale, gestione del traffico, zone a bassa velocità.
Keywords: Road traffic noise; traffic management; low speed zones.
1. Introduction

The last century was characterized by an overwhelming increase of traffic volumes in urban areas for both developed and developing countries. This urged local authorities to deal with emerging issues related to vehicles’ circulation. Air pollution and road safety in the cities are probably the two most well-known problems of modern urban areas. Air pollution represents surely one of the main dangers for public health. According to the European Air quality Report [1], in the period 2009-2011 almost one third of Europe’s city dwellers are exposed to excessive organic compounds. Considering the WHO Air Quality reference values, the number of exposed subjects even exceeds the 85% of the European urban population. Reducing accidents and increasing safety for pedestrians and cyclists are other two important challenges for the modern cities. A statistical data analysis in ten European Countries has shown that the number of pedestrian fatalities in 2005 varied between 4.6 and 15.7 per 1 million populations; moreover, fatalities occur more frequently within built-up areas than outside built-up areas [2]. According to NHTSA [3], in Unites States during 2012 almost three-fourths (73%) of pedestrian fatalities occurred in urban or suburban areas instead of 27% occurred in rural settings.

Besides these themes, the problem of road traffic noise for the citizens must not be neglected. The extent of the community noise problem is large. According to the WHO Guidelines for Community Noise [4], in the European Union about 40% of the population is exposed to road traffic noise with an $L_{eq}$ exceeding 55 dB(A) during the day, whilst 20% is exposed to levels exceeding 65 dB(A). Considering all transportation noise, about half of all European Union citizens live in zones acoustically uncomfortable. At night, it is estimated that more than 30% is exposed to $L_{eq}$ exceeding 55 dB(A), with consequent sleep disturbances. In cities of developing countries, the noise pollution problem is equally serious, mainly because of traffic. Data collected alongside busy roads were found to have a 24 hour $L_{eq}$ of 75-80 dB(A). As far as the health concerns, the noise pollution produced by traffic presents several health impacts: noise-induced hearing impairment; interference with speech communication; disturbance of rest and sleep; psycho-physiological, mental-health and performance effects; effects on residential behaviour and annoyance; as well as interference with intended activities.

In the last two decades a growing number of cities has implemented or planned policies to reduce vehicles’ traffic. Most of the mitigation actions taken in the different countries have mainly moved tackling the delicate problems of the air quality and the safety. The design and the implementation of traffic management strategies are based mostly upon the concept of ‘controlled accesses’ or ‘limited speed’. The first one involves the reduction of vehicle traffic volume by means of a more or less gradual interdiction of vehicles to traffic in urban areas. Limited Traffic Zones (LTZs), Low Emission Zones (LEZs) or Pedestrians Zones are just some examples of mitigation actions applied in several cities. On the other hand, the ‘limited speed’ schemes aims to limit the vehicle speeds, producing a decrease in the accident risk for pedestrians and in the air pollution. These actions are represented by traffic calming measures and Low Speed Zones (LSZs).

Although the strategies previously described were not meant to explicitly tackle the noise pollution issue in urban areas, the implementation of these types of actions may positively affect the urban noise levels, strongly influenced by road transports. Nevertheless, in some European cities actions mainly centred on reduction of noise traffic levels have been already proposed. “Quiet Zones” (Q-Zones) are actions proposed in the CityHush project [5,6]. They consist in areas where a significantly
lower level of traffic noise is maintained by allowing only low noise vehicles to enter. In this project five different noise classes have been developed, from the class A, which represents the quietest class, to the class E, corresponding to the noisiest one, with the purpose of granting free access to a Q-zone just to the vehicles fulfilling the noise class A ($L_{\text{urban}} < 64 \text{ dB(A)}$). This value is about 8-10 dB lower than the actual noise levels of typical vehicles driven on urban roads with speed limit 50 km/h.

In this study, an overview about the different traffic management strategies, and on the noise effects that they can provide to the urban environment, was carried out. In order to better investigate the assortment of these actions, the measures have been classified in two broad categories, according to the parting in traffic volume limitation measures and speed limitation measures. A further section reporting other traffic management measures has been included to complete the strategies framework.

Beside to the preliminary review, a measurements campaign in areas characterized by the same implemented action has been carried out as case of study. In particular, the attention has been focused on the LSZs: among the analysed traffic schemes, these areas seemed to show the best effects in terms of noise reduction. The monitoring has been carried out in six different LSZs of Sheffield (UK) and Naples (Italy).

2. Urban traffic management strategies

Regarding the traffic management in urban areas, the measures dealing with restrictions of the traffic itself will plausibly have more immediate effects. These kinds of policies are likely to be sorted into two main groups: limitations to vehicles’ number or type and limitations to vehicles’ speed.

It is worth pointing out that the traffic volume within an urban area may vary because of many other different reasons. The development of a public transportation system based on rail infrastructure with high capacity and frequency (i.e. metros, trams) may discourage people from driving, but it represents an expensive and long term solution. A different strategy consists in applying access restrictions in some areas. The Access Restriction Schemes (ARSs) can be considered as a powerful policy tool and their potential in addressing the major challenges of urban sustainability is recognized as considerable [7]. The restrictions can involve different criteria: vehicle category, type of engine, owner’ residence, time slots, number of license plates.

The traffic volume changes may affect the noise levels. Considering unchanged traffic composition and speed, a 50% reduction of the traffic volume results in a 3 dB reduction in noise levels due to the logarithmic nature of the dB scale, independently by the number of vehicles (Tab. 1). Moreover, when the traffic flows more freely, a change in driving pattern can be found; decreasing the number of accelerations and decelerations, lower noise levels on the roads are more likely to happen. But a reduction in the traffic volumes on a road does not always lead to a reduction in noise levels. Indeed, the remaining vehicles can often drive unhindered and increase their speeds or accelerations, working against the reductions in noise emissions caused by the reduced traffic level.

On the other hand, another large number of traffic flow measures is led by reduction in vehicle speeds. Reducing speed and thereby improving traffic safety represent often the main reasons for the implementation of most of actions. A systematic review of child and adolescent injury prevention conducted in 200 small areas of England, Wales and Scotland has concluded that speed reduction contributes to a 70% decrease in child pedestrian injuries [9]. The traffic management strategies which tend to reduce speeds sometimes produce also traffic volume reductions, owing to the fact that the drivers are
discouraged from using vehicles for local moves or persuaded to choose less busy roads to reach their destinations.

The reduction in vehicle speeds obviously represents a valid way to reduce the traffic noise. Nevertheless, it occurs providing that the required measures do not lead to an increase in accelerations and decelerations. The effect strongly depends on the traffic composition, but for both light and heavy vehicles at low speeds the largest reductions are achieved. At speeds below 50 km/h, noise reductions of 2-3 dB(A) are realistic as a result of 10 km/h reductions in actual speeds (Tab. 2).

Tab. 2 - The effect of speed reductions on noise [10]

<table>
<thead>
<tr>
<th>Reduction in speed</th>
<th>Noise reduction (L_{AE}, dB) from light vehicles</th>
<th>Noise reduction (L_{AE}, dB) from heavy vehicles</th>
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<tr>
<td>From 130 to 120 km/h</td>
<td>1.0</td>
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<td>From 120 to 110 km/h</td>
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<td>From 110 to 100 km/h</td>
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<td>From 100 to 90 km/h</td>
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<td>From 90 to 80 km/h</td>
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<td>From 80 to 70 km/h</td>
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<td>From 70 to 60 km/h</td>
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<td>From 60 to 50 km/h</td>
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<td>From 50 to 40 km/h</td>
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<td>From 40 to 30 km/h</td>
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2.1 Reduction in traffic volumes

Using ARSs represents a traffic management measure centred upon the idea of reducing traffic volume. The ARSs can be applied in different manners. Below two different strategies are discussed: Low Emission Zones (LEZs) and Limited Traffic Zones (LTZs). Considering LEZs and LTZs in 13 European countries, in 2011 there were 215 ARSs and most of them worked for 365 days/24 hour per day, with restrictions headed mainly towards heavy vehicles [11]. As shown in Figure 1, Italy and Germany represent the countries with the major number of cities with ARSs.
2.1.1 Limited traffic zones (LTZs)

The LTZs are areas of the city centre where the traffic is limited to just some vehicles. In the most of the cases the LTZs are closed to some categories of vehicles (as lorries or freight vehicles), or specified vehicles meeting certain emissions criteria or standards (e.g. certain Euro standards). Quite often the restriction criteria can involve non-residential traffic, except for the city buses, taxis and other authorized vehicles. Moreover, there are some ARSs led by hourly, daily or weekly slots, and many more where the daily traffic is regulated by the odd or even number of license plates. Hence, to drive in all these areas the vehicles must show a valid permit; otherwise, the vehicles’ identification can occur by an automatic license plate recognition system.

In Italy in the last decade an important increase of LTZs as strategies to reduce air and noise emissions in the big and medium cities was observed. About one hundred cities adopted this mitigation traffic action in some areas of the city centre. Maffei et al. [12, 13] have studied the effects of the LTZ’s implementation in Naples (Italy) in terms of possible variations of acoustics and non-acoustics aspects influencing the perception of environmental quality. Since March 2012 an LTZ has been implemented in the historic centre in Naples. The adopted LTZ bans the traffic of some vehicles’ categories (minimum standard Euro 4) [11] or non-residents’ vehicles. Surveys by soundwalks and interviews were conducted in three different periods (2012A before the LTZ implementation, 2012P and 2013P after LTZ implementation). The results showed that after a short period in which a reduction of the environmental sound level was experienced, the noise increased newly, probably due to more concessive access policies authorized by the Municipality, such as freight traffic at any time of the day.

2.1.2 Low Emission Zones (LEZs)

The LEZs are areas more restrictive than the LTZs, because in these defined areas the limitation regards only vehicle emissions criteria. An LEZ prohibits older vehicles (with low Euro standards) from operating in that area. In this way it is observed a traffic volume reduction, and above all the exclusion of the most polluting vehicles from the roads, with a direct impact on the urban air quality.

In Stockholm, since 1996 LEZs for freight vehicles have already been successfully implemented and they have led to improvements in air quality levels: the emissions of
nitrogen oxides have been reduced of 3-4%, VOC of 16-21% and particles of 13-19% [14]. In 2008, an advanced plan of LEZ was also implemented in London, with the aim to improve the air quality within the London district. In measurements performed within the LEZ a decrease of 5% in NO\textsubscript{X} and an increase of 2.1% NO\textsubscript{2} and 5.6% for PM\textsubscript{10} were found [15]. In Berlin the LEZ was introduced in 2008 and since 2010 only vehicles with Euro 4 or retrofitted Euro 3 vehicles are allowed to enter in. Significant effects in terms of transport emissions reduction have been observed: in 2010 the emissions from exhaust pipes decreased by 40% and NOx by 19%. A change in the overall composition of the vehicles fleet in Berlin has also been observed. In 2009, 88% of the cars driving in Berlin both inside and outside the LEZ had a minimum of Euro 4 Standard [16].

In terms of noise pollution, the LEZs should have noise benefits. However, traffic noise is the combination of engine, exhaust system and transmission noise, and noise generated from the interaction of the tires with the road surface: only the first of these is affected by an LEZ. The London study modelled the noise benefits of an LEZ with a minimum of Euro 2/3 Standard. It found that traffic noise levels should not be significantly altered after the implementation, with noise reductions lower than 0.5 dB(A). However, a reduction in the maximum noise level of some pass-by events of the oldest and noisiest vehicles could be noticed [17]. Likewise, no indications about the usefulness of Berlin LEZ as a tool to reduce road traffic noise, if not accompanied by other noise mitigation measures, came out from the first impact assessment [16].

2.2 Reduction in speed

Very often traffic management schemes aimed to reduce the traffic speed are introduced to tackle congestion jam and low urban quality of life of the cities. One of the main goals of these actions is to improve traffic safety. Collecting data from different Countries, mainly Scandinavia, Finch et al. [18] suggest that the absolute change in speed limit is directly proportional to the percentage change in accidents. A link between changes in mean vehicle speeds and changes in accident frequencies could be also observed; a 1 mph reduction in mean speed giving a 5% reduction in accident frequency (Fig. 2).

![Fig. 2 - Relationship between speed and accidents][18]
The speed limitation can be achieved basically through two different ways: imposing low speed limits, or implementing traffic calming measures forcing the drivers to drive slowly. Below these two different strategies are described.

2.2.1 Low Speed Zones

The implementation of Low Speed Zones (LSZs) in urban and residential areas represents a widely used measure to reduce traffic congestion. In several European cities 30 km/h zones are nowadays consolidated strategies, also valid to reduce the risk of accidents between different vehicles and in particular between vehicles and people. In UK from 2007 the “20’s plenty for us” campaign aims to introduce 20 mph limit areas within urban centres and residential neighbourhoods in several cities. Today nearly 13 millions people live in local authorities which are adopting or have adopted this policy [19].

LSZs can significantly reduce the number of car accidents and improve road safety, especially for weak users like pedestrians and cyclists. In Denmark, a study on 679 streets with 30 km/h speed limit showed that in the areas regulated by speed limit signs the crashes have been reduced by almost 25%, whilst the number of casualties fell by nearly 56% [20]. In Graz (Austria), 30 km/h zones on roads with previous 50 km/h speed limits were implemented around the cities in 1994, after two years trial period. Mackie [21] has shown that the average speed was reduced of 1.9 km/h. Although this speed reduction may seem very small, it shows that even small changes in speed can have important results: indeed, the number of severe injured dropped by 24%, while the number of pedestrian casualties fell by 17%.

Moreover, LSZs can produce environmental benefits, in terms of fuel consumption and air pollution. A research carried out in Germany as part of the evaluation of the Buxtehude traffic calming project has shown that slower and calmer style of driving can reduce polluting emissions [22].

Furthermore, the implementation of this type of actions can positively affect the urban traffic noise levels, provided that increases of accelerations and decelerations are avoided. The first link between traffic noise benefits and vehicle speed limitation has been observed in 30 km/h zones of Buxtehude: due to the vehicle speed reduction and the decrease of road traffic, the LSZ established an acoustic benefit with a reduction of up to 7 dB(A) [22]. In the Graz 30 km/h zones, measurements taken before-and-after transformation has shown noise level reductions of 1-2 dB(A) compared to previous 50 km/h level [23]. In 2000 in the city of Modena (Italy), a residential area characterized by excessive through-traffic, was transformed in a 30 km/h zone. Before-and-after measurements were carried out: a 50% traffic flow reduction as well as a massive speed decrease was observed. Comparing the road noise levels before and after the implementation, a reduction from 3 to 5 dB(A) was recorded. [24]. A Swedish LSZ’s experience showed that whether the speed is reduced from 50 to 30 km/h, a reduction of the equivalent noise level ($L_{Aeq}$) of 3-4 dB(A) can be achieved, while as far as the maximum noise level, reduction up to 7 dB(A) could be observed [8]. In Berlin, when several 30 km/h zones were introduced in both residential areas and main roads, simultaneous reductions of noise level (3 dB(A)) and air pollution (10% of PM$_{10}$) were observed [16]. Also according to a recent UKNA report, in urban areas with speed limit between 20 and 35 mph, a 6 mph speed reduction decrease noise levels by up to 40% [25].
2.2.2 Traffic Calming

According to the definition of the Institute of Transportation Engineers [26] “Traffic calming involves changes in street alignment, installation of barriers, and other physical measures to reduce traffic speeds and/or cut-through volumes, in the interest of street safety, liveability, and other public purposes.”

The physical devices used in traffic calming can be divided into three broad categories: vertical deflections, horizontal deflections and roundabouts. Vertical deflections are raised devices that force drivers to lower their speeds, in order to avoid violent bumping and vibrations. Examples are represented by speed humps, speed cushions and raised intersections. Horizontal deflections consist in deviations from the linear driving path or constriction in the roadway that encourage slow speeds and safe driving patterns. They include road narrowing and chicanes. Also the roundabouts create path shifts, by means of a central island on the roadway. Roundabouts represent traffic measures that reduce the speed and the number of acceleration and deceleration events at the junction approaches.

In Gothenburg (Sweden) in 2005 more than 2000 different traffic calming measures had already been implemented. To assess the effects of these actions, a program of scheme evaluation was conducted. The survey showed that as a consequence of traffic calming measures implementation, a significant reduction in the number of people killed or seriously injured was observed: the number of accidents involving pedestrians fell by 41% [27].

In Havant (UK) after the implementation of traffic calming scheme in 1997, a reduction of vehicle speeds was observed. The measure had the effect of reducing speeds by up to 12 mph, depending on the type of measure and location. Speed cushions and raised junctions showed high speed reductions at the measure (11-12 mph), as well as mini-roundabouts (about 11mph). Slightly lower speed reductions were observed between the sets of cushions (9-12 mph), while the speed reduction at the road narrowing (traffic island) was about 5 mph [28].

The design of a traffic calming scheme can strongly influence the good-working of the implemented measure. A defectively designed scheme may result in small speed reductions, or in drivers braking and accelerating at the individual measures in the scheme. The second event represents a negative condition in terms of both air quality and noise.

Vertical Deflections

Vertical deflections are humps, speed cushions and raised junctions. Road humps are typically 3-4 m long and rise to a maximum of 100 mm. Speed cushions are similar to the humps, but their shape presents gaps on the sides in order to allow heavy vehicles crossing without vertically wheels’ deflections. Vehicles with smaller width cannot avoid these cushions, so at least one set of wheels are deflected. Raised junctions are flat raised areas which cover the whole junction zone. The access ramps can be up to 100 mm high on the junction approaches.

The overall effect on noise of a traffic calming scheme with vertical deflections is highly dependent on the design of the scheme. A distance between devices in excess of 100 meters is not advised, because the drivers could be encouraged to accelerate and decelerate between humps, increasing the likelihood of noise variations [29].

In Denmark, a study upon the effects of a series of road humps implemented on 8 urban roads has shown that the introduction of humps reduced the speed by 5 to 14 km/h. Noise measurements detected that after the humps implementation also the noise
levels showed a decrease: reductions of 2 to 4 dB(A) by the humps was found, while between the sets of humps the reduction was around 1 dB(A) [30].

In UK, in 1993 and 1994 series of measurements were carried out in Slough and York to assess the effects of the implementation of traffic calming measures [31]. In Slough, round-top humps (75 mm high) were installed on a residential road, while in York wide speed cushions (60-80 mm high) were constructed on a wider area. The study has shown that day-time traffic noise levels were reduced by about 3 dB(A) alongside the humps in Slough and by about 4 dB(A) alongside the speed cushions in York. The reduction in noise levels at these sites resulted due to changes in vehicle speeds (19 km/h in Slough and 23 km/h in York). These effects, especially road humps noise reduction, are valid whether the predominant vehicle flow consists of light vehicles. Abbott et al. [32] focused on the effects of traffic calming measures when commercial vehicles and buses represent a considerable rate in traffic flow. A scheme model considering a 10% of commercial vehicles in the traffic flow showed noise levels increase respectively of 6.4 dB(A) and 7 dB(A) for flat-top road humps and wide speed cushions. Despite the low speeds, the vertical deflections cause vehicle body noise (e.g. body rattle and suspension noise) which leads to noise increase.

Also in the city of Gloucester (UK) noise surveys upon traffic calming schemes in 7 different sites were carried out [33]. After the scheme’s implementation the noise from light vehicles decreased at each of the monitoring sites. The average noise reduction along the cushion was 5.2 dB(A), while alongside the road hump and the junction table was respectively 5.3 dB(A) and 6.6 dB(A). For heavy vehicles a slight and statistically not significant increase in noise was registered at the hump and the raised junction, and a slight, statistically not significant decrease at the cushions.

Finally, the results of studies upon the effects of vehicle and traffic noise on different traffic calming schemes carried out by Transport Research Laboratory (TRL) in 1996 [29] are reported. The investigation concerned large commercial vehicles. At low speeds, ramps and trench were the noisier measures. Wide cushions and flat top road humps showed substantial increases in maximum noise levels over a level surface, while for round-top humps and narrow cushion (up to 1700 mm wide) slight reductions were observed. When the speeds exceeded 20 km/h, at round-top humps vehicle noise levels increased significantly. In the study the change in traffic noise levels according to the type of installation was estimated too, considering a range of traffic scenarios with increasing proportion of large commercial vehicles in the unchanged total traffic flow. For proportion of large commercial vehicles lower than 20%, the noise reduction performance of round-top humps was notable. The study concluded that in residential areas, providing the flow of large commercial vehicles is generally confined to the normal working day, round-top humps seem to be the best technique for keeping noise levels to a minimum.

**Horizontal Deflections**

Horizontal deflections can be divided into road narrowing and chicanes. Road narrowing consists in roadway constrictions which force traffic from one direction to give way to the opposite flow. On the other hand, chicanes vary for characteristics and dimensions, but generally they can be used as two-way working or single-lane working. On two-way working scheme, the chicane deflections is provided using build-outs and the two lanes are separated by a central island or road markings. On single-lane working scheme, the chicane is combined with a road narrowing. The shift is still provided by build-outs, and the narrowing forces drivers to proceed slowly.
Likewise, the horizontal deflections are strongly influenced by the design of the scheme. A correct design allows speed reductions of up to 20 mph for cars and up to 10 mph for buses and coaches [34]. These chicanes are however too tight for articulate lorries passing. Increasing the dimensions to allow buses, coaches and articulated lorries to pass through them at 20 mph would allow cars to adopt a relatively straight line, with little or no speed reduction.

As far as noise, chicanes generate less vehicle body rattle than vertical deflections. Nevertheless, chicanes may encourage more stopping, starting, acceleration and braking noise, increasing the noise levels. French studies have assessed the acoustic impact of different traffic calming actions in urban and suburban areas, and particularly by single lane chicanes [35, 36]. In suburban areas the results showed that in terms of day and night \( L_{Aeq} \), reductions of up to 4 dB(A) were obtained in the centre of the site, whereas increases of up to 5 dB(A) were measured both at the input and exit of the site. The noise increase depended on the braking and accelerating effects at both extremities of the chicanes. In the urban areas results consistent with the previous ones were observed. In spite of the lower vehicle speeds in urban areas, the chicanes effect was significant (above 3 dB(A)). To avoid the noise increases due to acceleration and deceleration, successive chicanes could be built. In this way, higher speed decrease, as well as steady speed with less decelerations and accelerations, could be found.

**Roundabouts**

Roundabouts represent useful strategies able to reduce traffic speeds at junctions. Moreover, the elimination of forced stop at the intersection can reduce the number of acceleration and deceleration, providing a reduction in the air pollution and noise levels with unchanged traffic volumes. When the space does not permit the construction of a roundabout, mini-roundabout could be implemented with lower, but still significant, effects.

The design variables of a roundabout are the radius, the number of lanes and the number of entry/exit roads. The parameters should be rightly optimized in order to avoid the creation of congestion zones along the various roads leading to the roundabout and to reduce the braking and acceleration periods, influencing the noise reduction effects.

In 1991, 21 mini-roundabouts were constructed at intersections on arterial roads in Växjö in Sweden as part of a project to reduce traffic speed, thereby increasing traffic safety. The results of a study have shown that the mini-roundabouts reduced the speed considerably at the junctions (11-18 km/h), and almost all speeding was eliminated. Also noise measurements were carried out at three junctions before and after the implementation. The noise level reductions at the roundabouts were 3.9 dB(A), 4.2 dB(A) and 1.6 dB(A) [37]. In the study upon the effects of traffic calming measures in Havant, noise effects of the implementation of a mini-roundabout were also observed [28]. The mini-roundabout installation reduced the speed by 5.8 mph, and a reduction in the maximum noise level from light vehicles of 1.2 dB(A) was found. Speed reductions of about 12 mph and light vehicle noise reductions of 3.2-3.4 dB(A) were observed at the approaching and exit points, where speed cushions were also implemented. For heavy vehicles, the study showed that although the mean speeds were reduced after the mini-roundabout installation, the maximum noise levels increased. Speed reductions of 4.4-8.6 mph and maximum noise level of 4.5-6.2 dB(A) were recorded. As far as reduction in daytime traffic noise levels, the mini-roundabout provided a reduction of 2.7 dB(A), which is in close agreement with the reduction in maximum noise level of
light vehicles. In France, the noise effects of roundabouts implementation in three different cities have been assessed. Comparing the equivalent noise levels before and after the roundabouts introduction, reductions of the $L_{Aeq}$ of 1 to 4 dB(A) during the day and of 1 to 3 dB(A) during the night have been observed [38]. In Modena (Italy), a study about the replacement of a traffic light junction with a roundabout was carried out. Noise measurements taken before and after the implementation showed a noise level reduction of 1 dB(A) during the day [24].

2.3 Other measures

This last section has been dedicated to traffic management measures that cannot be included in the previous broad categories. In particular, the measures described are Congestion Charging Zones and Calming Green Waves.

2.3.1 Congestion Charging Zones

The Congestion Charging Zone (CCZ) represents an area where the vehicles can enter paying a pollution charge. The main objectives of the CCZs are the reduction of the vehicles number passing in and out the congestion area during the morning and afternoon peak periods, and the flow traffic improvement on the busiest roads. The first CCZ has been implemented in London in 2006, and after few months, in 2007 it was also implemented in Stockholm.

Such as for the LEZ, the reduction of traffic volume due to the CCZ implementation can lead also to improve environmental aspects. In London it was estimated that congestion charging had been directly responsible for reductions of 8 percent in Oxides of Nitrogen ($\text{NO}_x$), 7 percent in fine particulate matter ($\text{PM}_{10}$) and 16 percent for Carbon Dioxide ($\text{CO}_2$) [39]. In Stockholm, before the CCZ implementation a seven month trial period was performed. During those months, a variation assessment of most important air pollutants has been studied. Focusing on inhalable particles ($\text{PM}_{10}$) and nitrogen oxides ($\text{NO}_x$ and $\text{NO}_2$), it was calculated that the percentage reductions in emissions were approximately 8-14% [40].

The positive effects of a CCZ shown in the air quality improvement are not observable on the urban noise environment. Even if in London the sample surveys of ambient noise in and around the CCZ do not allow statistically-robust conclusions, the results for five years with congestion charging indicate any significant effect on noise levels [39]. In Stockholm, to assess whether the traffic reduction would lead to a reduction in the problems of road traffic noise, a measurement survey has been carried out during the trial period. In total, traffic noise levels from 152 monitoring sites were analyzed. The results showed a reduction in traffic noise by 1-4 dB(A) at 18 sites, whilst in six locations an increase in noise levels of 1-4 dB(A) was observed. At the remaining 128 locations changes in noise levels were less than 1 dB(A). The results showed that the CCZ does not lead to any remarkable improvements in the road traffic noise pollution [40].

2.3.2 Calming green waves

Traffic lights and green waves are usually optimized in order to improve the capacity of a road network. As further goal, this kind of measure could be useful in order to reduce speed and, at the same time, to lead to a better driving pattern, with a lower number of stops, accelerations and decelerations, causing increases on noise levels. A French study has assessed the effects of a traffic calming scheme called “Calming Green Waves” and tested in four towns [41]. The implementing calming
green waves were optimized for speeds of 40–45 km/h on roads with speed limits of 50 km/h. The results showed that the average speeds were reduced by 15 km/h, and the number of cars exceeding the speed limit was reduced. Setting green wave speed higher than 35 km/h are recommended, because lower speeds can increase braking and acceleration instead of having a constant speed. The study concluded that “Calming Green Waves” could reduce traffic noise emissions: if driving patterns are unchanged, a reduction in average speeds of 10 to 15 km/h would result in a noise reduction of 2.5 to 3.0 dB(A), depending on the traffic composition.

### 2.4 Outline of traffic management strategies

The rationale for reviewing the main traffic management strategies was identifying those having the better outcomes in terms of consequent noise reduction. Table 3 summarises the reviewed traffic mitigation actions according to the proposed categorisation (i.e. reduction in traffic volume, reduction in speed, and other measures), reporting the corresponding noise reduction observed in the different sites.

<table>
<thead>
<tr>
<th>TRAFFIC MITIGATION ACTIONS</th>
<th>EXPERIENCE SITE</th>
<th>NOISE EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REDUCTION IN TRAFFIC VOLUME</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIMITED TRAFFIC ZONE (LTZ)</td>
<td>Naples (ITALY)</td>
<td>About 3dB L$_{Aeq}$ reduction just after the implementation, No reduction effects after 1 year from the implementation [12,13]</td>
</tr>
<tr>
<td>LOW EMISSION ZONE (LEZ)</td>
<td>London (UK)</td>
<td>Less than 0,5dB L$_{Aeq}$ reduction [17]</td>
</tr>
<tr>
<td>Berlin (GERMANY)</td>
<td>No reduction effects [16]</td>
<td></td>
</tr>
<tr>
<td><strong>LOW SPEED ZONES (LSZ)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buxtehude (GERMANY)</td>
<td>Up to 7dB L$_{Aeq}$ reduction [22]</td>
<td></td>
</tr>
<tr>
<td>Graz (AUSTRIA)</td>
<td>1-2dB L$_{Aeq}$ reduction [23]</td>
<td></td>
</tr>
<tr>
<td>Modena (ITALY)</td>
<td>3-5dB L$_{Aeq}$ reduction [24]</td>
<td></td>
</tr>
<tr>
<td>Berlin (GERMANY)</td>
<td>3dB L$_{Aeq}$ reduction [16]</td>
<td></td>
</tr>
<tr>
<td>SWEDEN</td>
<td>3-4dB L$<em>{Aeq}$ reduction, up to 7dB maximum L$</em>{Aeq}$ reduction [8]</td>
<td></td>
</tr>
<tr>
<td><strong>REDUCTION IN SPEED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROAD HUMPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DENMARK</td>
<td>Light vehicles: 2-4dB L$_{Aeq}$ reduction at the devices, 1dB between devices [30]</td>
<td></td>
</tr>
<tr>
<td>Slough (UK)</td>
<td>Light vehicles: 3dB L$_{Aeq}$ reduction at the devices [31]</td>
<td></td>
</tr>
<tr>
<td>Gloucester (UK)</td>
<td>Light vehicles: 5,6dB L$_{Aeq}$ reduction at the devices, Heavy vehicles: Non-significant increase [33]</td>
<td></td>
</tr>
<tr>
<td>Track Trial (UK)</td>
<td>10% heavy vehicles in traffic flow: 6,4dB L$_{Aeq}$ increase at the devices [29]</td>
<td></td>
</tr>
<tr>
<td>York (UK)</td>
<td>Light vehicles: 4dB L$_{Aeq}$ reduction at the devices [31]</td>
<td></td>
</tr>
<tr>
<td>Track Trial (UK)</td>
<td>10% heavy vehicles in traffic flow: 7dB increase at the devices [29]</td>
<td></td>
</tr>
<tr>
<td>Gloucester (UK)</td>
<td>Light vehicles: 5,3dB L$_{Aeq}$ reduction at the devices, Heavy vehicles: Non-significant reduction [33]</td>
<td></td>
</tr>
<tr>
<td>RAISED JUNCTIONS</td>
<td>Gloucester (UK)</td>
<td>Light vehicles: 6,6dB L$_{Aeq}$ reduction at the devices, Heavy vehicles: Non-significant reduction [33]</td>
</tr>
</tbody>
</table>
### Effects of Different Urban Traffic Mitigation Actions on Cities' Noise Levels

<table>
<thead>
<tr>
<th>Reduction in Speed</th>
<th>Traffic Calming Measures</th>
<th>Horizontal Deflections</th>
<th>Locations</th>
<th>Noise Reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicanes with Road Narrow-Wing</td>
<td>FRANCE</td>
<td>Suburban areas: up to 4dB $L_{Aeq}$ reduction at the site, up to 5dB $L_{Aeq}$ increase at input and exit of the site [35,36]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Calming Measures</td>
<td>Horizontally Deflected</td>
<td>Roundabouts</td>
<td>Växjö (SWEDEN)</td>
<td>1.6-4.2dB $L_{Aeq}$ reduction at the devices [37]</td>
</tr>
<tr>
<td>Traffic Calming Measures</td>
<td>Horizontally Deflected</td>
<td>Roundabouts</td>
<td>Havant (UK)</td>
<td>Light vehicles: 1.2dB maximum $L_{Aeq}$ reduction at the site, 3.2-3.4dB maximum $L_{Aeq}$ reduction at input and exit of the site, Heavy vehicles: 4.5-6.2dB maximum $L_{Aeq}$ reduction [28]</td>
</tr>
<tr>
<td>Other Measures</td>
<td>Congestion Charging Zone (CCZ)</td>
<td>London (UK)</td>
<td>No reduction effects [39]</td>
<td></td>
</tr>
<tr>
<td>Other Measures</td>
<td>Calming Green Waves</td>
<td>FRANCE</td>
<td>1-4dB $L_{Aeq}$ reduction at the devices during the day, 1-3dB $L_{Aeq}$ reduction at the devices during the night [38]</td>
<td></td>
</tr>
<tr>
<td>Other Measures</td>
<td>Calming Green Waves</td>
<td>Modena (ITALY)</td>
<td>1dB $L_{Aeq}$ reduction at the devices during the day [24]</td>
<td></td>
</tr>
<tr>
<td>Other Measures</td>
<td>Calming Green Waves</td>
<td>Stockholm (SWEDEN)</td>
<td>No reduction effects [40]</td>
<td></td>
</tr>
<tr>
<td>Other Measures</td>
<td>Calming Green Waves</td>
<td>FRANCE</td>
<td>2.5-3.0dB $L_{Aeq}$ reduction [41]</td>
<td></td>
</tr>
</tbody>
</table>

### 3. Case Study

The outline of traffic management strategies reported in Section 2.4 pointed out that speed reduction measures are likely to be the better approach in terms of noise reduction. More specifically, the review of the literature showed that Low Speed Zones (LSZs) achieved overall noise reductions up to 7 dB. Indeed, a speed mitigation action implemented without the introduction of physics traffic calming devices allows a noise reduction related to the decrease of vehicle speed and at the same time it avoids an increase of acceleration and deceleration phases, which can result in an increase of the vehicle noise emissions.

In order to investigate more in the detail this type of mitigation action, a measurement survey has been carried out in six different LSZs. In particular, for the campaign the areas have been chosen in two different countries, in order to take into account the variability potentially associated to external parameters, e.g. cultural background, vehicle fleet age and so on. Two areas have been chosen in Sheffield (UK), namely Taplin Rd and Hillsborough Pl; while the remaining four have been individuated in Naples (Italy), namely Via Preti, Via Catullo, Via Nevio, and Via Dalbono.

The six LSZs were similar among them in terms of geometric characteristics of the street section and they were characterized by a one-way road with buildings on both sides. An additional criterion for the spot selection was also presenting low traffic flows.

This investigation aimed to assess the environmental noise levels under different traffic flow conditions and to analyse whether it is possible to identify, a correlation between these two factors for the analysed areas.
4. Methodology

The measurements have been carried out by means of a Solo 01dB Sound level meter (SLM), and a four channel audio recorder has been used to record the tracks. The SLM was positioned on the road side at the height of 1.60 m above the ground, while the distance from the road axis was about 3.50 m (Fig. 3). Every 125 ms the sound-pressure levels, as well as the corresponding third octave band spectrum, were logged. Each measurement lasted 10 minutes long. All recording sessions were carried out on weekday mornings, when typical events of urban environment are supposed to happen. During the audio recording, a second operator took pictures of the sites and made notes about the number of vehicles/pedestrians coming across the recording section. Information about the characteristics of the road (i.e. width, number and height of buildings, type of pavement) was collected too. For each LSZ, two different monitoring sessions in different days were carried out, for a total of twelve 10-minute measurements. Table 4 reports the main acoustic parameters, namely: $L_{Aeq}$, $L_{Amax}$, $L_{Amin}$ and the statistical $L_{A10}$, $L_{A50}$, $L_{A90}$ values for each monitoring session.

![Fig. 3 - a), b) Measurements in Sheffield; c), d) Measurements in Naples](image)

5. Results

In order to investigate the possible correlation between sound pressure levels and vehicle flows, a preliminary study has been carried out plotting the $L_{Aeq}$ and the statistical $L_{A10}$ vs the number of vehicles passing in front of the receiver point during the measurements.

The outcome of a preliminary data analysis showed that the most of data monitored during the on-site survey had a logarithmic relation between sound-pressure levels and vehicle flow (this occurs, with different slope, both for $L_{A10}$ and $L_{Aeq}$), as suggested by
the current literature [42-44]. However, two points of the dataset, corresponding to the data recorded in Via Preti, seemed to deviate significantly from such a trend. In order to verify this preliminary assumption, an investigation on the correlation between $L_{A10}$ and vehicle flow, as well as between $L_{Aeq}$ and vehicle flow for the whole data was performed excluding Via Preti. The data were logarithmically interpolated, showing a good correlation, coherently with the low vehicle flow condition, as reported in Fig. 4.

Tab. 4 - Sound-pressure levels for each measurement point

<table>
<thead>
<tr>
<th>Location</th>
<th>Round</th>
<th>No. max</th>
<th>$L_{10}$</th>
<th>$L_{eq}$</th>
<th>$L_{50}$</th>
<th>$L_{90}$</th>
<th>$L_{min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taplin Rd</td>
<td>1</td>
<td>78.4</td>
<td>64.7</td>
<td>61.0</td>
<td>53.5</td>
<td>47.1</td>
<td>42.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>83.8</td>
<td>66.5</td>
<td>63.2</td>
<td>55.1</td>
<td>49.3</td>
<td>45.9</td>
</tr>
<tr>
<td>Hillsborough Pl</td>
<td>1</td>
<td>71.7</td>
<td>62.2</td>
<td>57.9</td>
<td>52.8</td>
<td>48.2</td>
<td>44.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>74.1</td>
<td>62.8</td>
<td>58.9</td>
<td>52.2</td>
<td>46.4</td>
<td>42.1</td>
</tr>
<tr>
<td>Via Preti</td>
<td>1</td>
<td>92.1</td>
<td>64.8</td>
<td>64.1</td>
<td>56.9</td>
<td>53.3</td>
<td>48.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>93.9</td>
<td>62.3</td>
<td>61.3</td>
<td>56.6</td>
<td>52.7</td>
<td>49.1</td>
</tr>
<tr>
<td>Via Catullo</td>
<td>1</td>
<td>81.7</td>
<td>64.2</td>
<td>60.7</td>
<td>53.4</td>
<td>40.4</td>
<td>35.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>79.1</td>
<td>65.3</td>
<td>60.9</td>
<td>53.0</td>
<td>40.9</td>
<td>34.1</td>
</tr>
<tr>
<td>Via Nevio</td>
<td>1</td>
<td>83.3</td>
<td>64.3</td>
<td>62.3</td>
<td>57.2</td>
<td>48.5</td>
<td>41.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>80.0</td>
<td>63.9</td>
<td>61.2</td>
<td>53.9</td>
<td>47.5</td>
<td>35.7</td>
</tr>
<tr>
<td>Via Dalbono</td>
<td>1</td>
<td>83.2</td>
<td>65.7</td>
<td>63.1</td>
<td>54.5</td>
<td>48.5</td>
<td>39.3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>81.5</td>
<td>67.7</td>
<td>64.2</td>
<td>54.2</td>
<td>47.5</td>
<td>43.1</td>
</tr>
</tbody>
</table>

Fig. 4 - Sound-pressure levels ($L_{Aeq}$ and $L_{A10}$) vs vehicle number for each measurement point

Starting from the fit line equation, the predicted noise level related to the vehicle flow monitored in each measurement has been calculated and compared with the real noise level. The shift between the two values has been assessed.
In order to test whether the absolute shifts between sound-pressure levels and fit line for via Preti differed significantly from the other locations' values, a set of one-sample t-tests was performed for both the $L_{A10}$ and $L_{Aeq}$ variables, considering the values of the two rounds of measurements separately and comparing them to the mean value of all other measurements. For both variables and rounds of measurement, the Via Preti values resulted to be statistically different with respect to all other measurements ($p < 0.001$), as reported in Table 5.

**Tab. 5 - One-sample t-tests for the via Preti values (see Table 4), compared to all other values**

<table>
<thead>
<tr>
<th>Test Variable</th>
<th>Test Value</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{A10}$</td>
<td>3.38</td>
<td>-21.115</td>
<td>9</td>
<td>0.000</td>
<td>-2.70800</td>
<td>-2.9981 -2.4179</td>
</tr>
<tr>
<td></td>
<td>22.79</td>
<td>-172.458</td>
<td>9</td>
<td>0.000</td>
<td>-22.11800</td>
<td>-22.4081 -21.8279</td>
</tr>
<tr>
<td>$L_{Aeq}$</td>
<td>5.67</td>
<td>-28.089</td>
<td>9</td>
<td>0.000</td>
<td>-4.98600</td>
<td>-5.3876 -4.5844</td>
</tr>
<tr>
<td></td>
<td>12.34</td>
<td>-65.664</td>
<td>9</td>
<td>0.000</td>
<td>-11.65600</td>
<td>-12.0576 -11.2544</td>
</tr>
</tbody>
</table>

Therefore, the statistical analysis confirms that Via Preti shows a different behaviour than the other selected locations. Moreover, it is observed that, for this measurement point, $L_{A10}$ and $L_{Aeq}$ have very similar values, while for the other measurement points the differences in levels for these two parameters are higher.

A possible explanation for these findings can be the higher background noise levels, as well as a different composition of the sound sources recorded in via Preti during the measurements. In fact, although the vehicle flow was not high, the surrounding environment was characterized by the presence of other sound sources that increased the overall levels (e.g. pedestrians, sounds coming from commercial activities).

In general, for the selected locations, it was observed that the higher the vehicle flow, the higher the sound-pressure levels, and that this trend was linear. Nevertheless, in situation where the surrounding environment is characterized by the presence of other sound sources, more attention should be given to other factors, possibly adopting a broader strategy for the management of the urban acoustic environment (e.g. the soundscape approach, which is focused on the perception of the sonic environment rather than the sound levels only).

**Conclusions**

This paper investigated the effects of different urban traffic mitigation actions on environmental noise levels. To this purpose, a literature review was carried out in order to analyse potential noise reduction benefits deriving from different traffic management strategies. Moreover, an on-site measurements campaign was carried out in six locations across two test sites (Sheffield and Naples), in order to further analyse the urban noise levels in areas characterized by a specific traffic mitigation action (i.e. Low Speed Zones). Overall, the main findings of this study are:

- Low Speed Zones (LSZs) are among the most effective traffic mitigation actions at reducing road traffic noise (up to 7 dB);
- in the investigated LSZs, both $L_{Aeq}$ and $L_{A10}$ resulted to be positively correlated with traffic flows and that relationships were logarithmic;
when more sound sources come into play apart from road traffic, larger deviations from the above mentioned linear trend.

In general, this study aimed at providing new insights on how even urban planning and traffic management strategies that are not explicitly conceived for noise control purposes are likely to have a significant impact on noise levels in cities. However, this study also suggests that when dealing with complex urban scenarios where different activities and sound sources occur, a broader approach to the management of the acoustic environment should be used.

References


[19] www.20splentyforus.org.uk/index.htm (last access: 10/10/2015).


