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ANALYSING STREET TRAFFIC NOISE POLLUTION IN THE CITY OF YAZD

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ABSTRACT
A model is demonstrated that describes street traffic-induced noise pollution in 2008 in Yazd, Iran. Sound levels were measured using a Bruel and Kjaer-2260 sound level meter on 10 streets across the city over this period during the morning rush hour and different vehicle types were counted simultaneously at various sampling points. Geographical Information System was used to generate, store and retrieve the spatial data and map the sound levels using an interpolation technique. The minimum and maximum sound levels appeared to be 70.9 dBA and 80.7 dBA, respectively and these values were above the national legislated norm. Cars and motorcycles were the most commonly used vehicle type in the city, comprising 61.2% and 23.7 % of the total traffic volume, respectively. These data were followed by trucks, buses and bicycles. A number of parameters which were assumed to impact on noise pollution were collected and considered, including geographical position, elevation, the distance to the nearest intersection, street geometry and the numbers of vehicles according to class. The modelling demonstrated that there is a significant relationship between the average sound level and traffic flow (R^2 = 0.5). The results showed that although street traffichas increased between 2002 and 2008, the sound levels in the city decreased slightly and this has been attributed to advances in vehicle design.

Key words: Street traffic, Noise pollution, Sound level, Modelling, Yazd

INTRODUCTION
The main urban transport problems include street injuries and fatalities, congestion, inadequate public transport and pollution. Air and noise pollution are the two undesirable impacts of the vehicular traffic and these are especially important in urban areas. The impacts and sources of air pollution are generally well documented (Lipfert *et al*., 2006), although noise has received considerably less attention.

The effects of noise has been studied on humans (Lipfert *et al*., 2006; Belojevic *et al*., 2008; Briggs *et al*., 2008; Zaheeruddin and Jain, 2008; Fyhri and Klaeboe, 2009; Jakovljevic *et al*., 2009), animals (Jaeger *et al*., 2008; Moura *et al*., 2008; Zhang *et al*., 2008), plants (Watts *et al*., 1999) and buildings (Akdag, 2004; Naticchia and Carbonari, 2007). Noise is a major factor that should be considered in the design and construction of new transport systems, as well as when improvements are made to existing systems (Abo-Qudais and Alhiary, 2007). In addition, local authorities and environmentalists recognise the importance of monitoring trends in noise pollution when developing mitigating plans. As such, there is an obvious need to measure and model noise pollution.

Due to cost and time restrictions, the modelling of noise is often preferred to its measurement over regional areas (Gündoğdua *et al*., 2005) and such modelling takes into account various traffic parameters. Abo-Qudais and Alhiary (2007) modelled noise levels at signalized intersections using parameters including traffic volume, speed, British Pendulum Number (BPN - a measure of surface roughness), heavy vehicle number, slope (%), number of a street lanes, and lane width (m). An analysis of the parameters indicated that the

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noise levels were mainly dependent on traffic volume. Calixto *et al*. (2003) conducted a study to estimate street traffic noise using vehicle flow data considering different streets surfaces and slopes, and vehicle speeds. They found that there was a significant relationship between noise level and traffic flow.

The objectives of this study are to: (1) model sound levels based upon street traffic characteristics; (2) compare measured noise levels and those predicted by mathematical models; (3) assess measured levels with the allowed levels according to the national permissible limits; (4) and investigate the change of sound levels over the time.

MATERIALS AND METHODS

Study area

The city of Yazd has a population of 430,000 (The office of National Statistics, 2007) and is located in central part of Iran. It has an area of 97 km^2 and a traffic network length of about 240 km. The city is expanding and new streets are being built and added to the existing network. Noise pollution was studied in the city in 2002 (Oveissi, 2003; Oveissi *et al*., 2007), during which sound levels were measured on 10 selected streets within residential-commercial zones, as these were thought to be the most representative of streets across the city. The selected streets were far from the airport and the rail station to include only the vehicular noise. Oveissi *et al*. concluded that all streets had a sound level greater than the national limit of 60 dBA.

Sound level measurements and fleet composition

In the current study, the 10 streets studied by Oveissi *et al*. were chosen as measurement sites. The aim was to obtain two directly comparable databases and to identify how noise levels had changed between 2002 and 2008. Similar to the study of Oveissi, sampling positions were in the central point of streets to decrease impacts of the intersections (e.g. low speed). Sampling was planned only for weekdays and holidays and weekend days were excluded.

Four parameters were measured at each location: (1) A-weighed continuous equivalent sound level (LAeq); (2) traffic activity (cars, buses, motorcycles, bicycle and trucks); (3) street geometry (longitude, latitude, elevation and slope); and (4) distance to the nearest intersection.

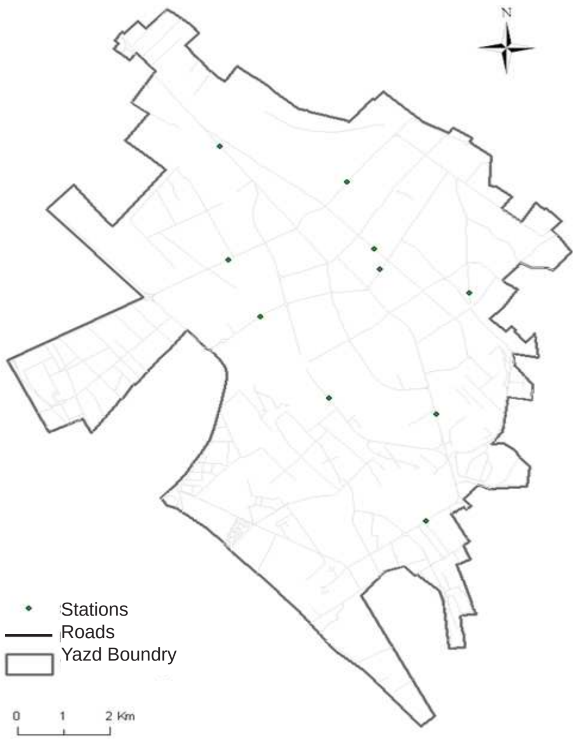

Fig. 1: Sampling stations and road traffic network in the city of Yazd, Iran

The measurement stations are shown in Fig. 1.

Noise levels were measured using a class 2260 Bruel and Kjaer sound level meter (manufactured by Bruel & Kjaer). For each measurement, the instrument was first installed on the pavement adjacent to each street and 1.5 m above ground. The instrument was calibrated prior to taking measurements using a 4231 Bruel and Kjaer calibrator. A wind screen was also used on the microphone, though there was no significant wind during the study period. Finally sound levels were measured during the morning peak period (07:30-09:30) on weekdays (Saturday to Thursday) in spring 2008 (21th April -5th May). The levels of noise generated depend on vehicle type and it is necessary therefore to take fleet composition into account when modelling the measurements and for assessing the possible success of mitigating actions by encouraging alternative modes of transport. Consequently, traffic flow was determined for 5 vehicle types (i.e. cars, motorcycles, buses, trucks and bicycles) alongside the noise measurements. The street geometry and distance to the nearest intersection for each station was obtained using a Global Positioning System (GPS) and a Geographical Information System (GIS).

Fig. 2 shows the fleet composition in terms of different vehicle types. Cars were found to be the predominant vehicle type (61.2%) followed by motorcycles (23.7%) and trucks (10.5%). Buses (4.2 %) and bicycles (0.4 %) were the least common vehicle types in the city. These figures show that cars and motorcycles are a popular means for commuters. Cycling, which is a more environmentally friendly mode of transport, is used much less. In addition, public transport is probably under-utilised because of its limited efficiency and lack of infrastructures (e.g. connecting stations, etc.).

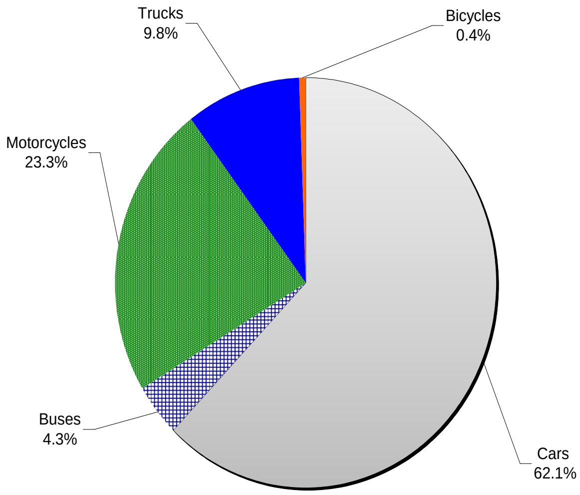

Fig. 2: Fleet composition in terms of different vehicle types

Geographical Information System (GIS) support

GIS has been used to map noise pollution previously (Murphy *et al*., 2009). Such an approach was adopted in the current study (using ArcGIS as a tool) with the objective of assembling a database that incorporated noise levels and positional factors that included the street network (i.e. polyline layer) and the monitoring stations (i.e. point layer). For each monitoring station the X coordinate (latitude), Y coordinate (longitude), and elevation (m) (each determined by GPS) were included. Street network data was provided by the Yazd County Council to determine the nearest intersections from each measurement station and they were also entered into ArcGIS (version 9.2) also. In order to achieve street slope (%), the measured elevation values of the sampling stations were used and surfaced using the 3D Analyst tool in ArcGIS. Finally, the traffic counts and sound levels were linked to each sampling station. Therefore a GIS-based database consisting the up mentioned factors was created and used for more analysing.

ArcGIS was then used to interpolate the measured sound levels between the 10 sampling stations and to predict levels at intermediate points. Interpolation has been used in different fields and most recently to interpolate air pollution data (Kanaroglou *et al*., 2005; Matejıcek *et al*., 2006; Marshall *et al*., 2008). Such techniques are either deterministic or geostatistical. Deterministic techniques use mathematical functions to interpolate intermediate levels, while geostatistical techniques assess the uncertainty of predictions (Matejıcek *et al*., 2006). Both techniques rely on the similarity of nearby sample points to create the spatial interpolation in our study; the Regularized Spline which is moderately quick deterministic interpolator has been used. This is a preliminary technique for a quick look at interpolated data in the form of two-dimensional horizontal layer of sound distribution, without assessing prediction errors. The Spline Interpolation imposes two conditions on the interplant, the surface must pass exactly through the data points and have minimum curvature (Environmental Systems Research Institute, 2006).

It is important to illustrate noise levels to facilitate a better interpretation of the results and so that responsible authorities.can better appreciate the extent of any problem or the potential impact of any mitigating countermeasures. The most frequently used approach to display spatial variations of pollution is via a contour map (SEN *et al*., 2006). Consequently, it was decided to apply a similar approach to create sound level contour maps. Therefore the regularized Spline technique was used to find out sound levels beyond the sampling stations.

Modelling noise pollution

In order to model sound levels based upon traffic characteristics and street geometry, a number of independent variables were assumed to have an impact on the street traffic induced sound levels (see Table 1). Statistical relationships between the variables were examined using the linear regression (i.e. stepwise method) in SPSS (version11.5).

Results showed that there are autocorrelation between some of the independent variables (e.g. cars and trucks). Therefore in order to omit colineariity, the most relevant variables were selected and the rest excluded.

L_{Aeq} in (dBA) was then regressed against the independent variables using linear regression. The results showed that the sound levels are mainly controlled by the number of cars and the most significant equation is shown in Table 2.

Table 1: Correlation between variables

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
X1:Longtitude (UTM)	1	0.127	0.211	0.338	0.213	0.191	0.367	0.780	0.724	0.325	0.346
X2:Latitude (UTM)		1	0.000 (**)	0.342	0.504	0.618	0.917	0.548	0.089	0.026 (*)	0.688
X3:Elevation(m)			1	0.547	0.580	0.545	0.893	0.496	0.270	0.008 (**)	0.545
X4:Cars				1	0.338	0.097	0.003 (**)	0.294	0.016 (*)	0.699	0.298
X5:Buses					1	0.114	0.146	0.275	0.827	0.103	0.101
X6:Motorcycles						1	0.052	0.853	0.547	0.284	0.159
X7:Trucks							1	0.090	0.109	0.746	0.059
X8:Bicycles								1	0.420	0.837	0.066
X9:LAeq									1	0.375	0.827
X10:Distance to the nearest intersection (m)										1	0.099
X11: Slope (%)											1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 2: Statistical results of predicting the dependent variables

	Constant	Cars	F	R^2_a
LAeq	70.776(0.000)*	0.001	9.286	0.479(0.016)

LAeq = 70.776+ 0.001cars
* p values are in brackets

RESULTS

One of the main objectives of the study was to investigate the change of sound levels in Yazd over the last six years. Fig. 3 depicts the number of cars (Y axis) for the city's streets (X axis) in 2002 and 2008. Moreover, Fig. 4 shows sound levels (LAeq) in Y axis for individual streets (X axis) in the same years. Looking at these figures, the obvious result is that the number of cars has increased on all streets over this period, but with the exception of two streets, levels of sounds have decreased slightly. Since 2002, the average sound levels on the city's streets have decreased by almost 2.3 dBA.

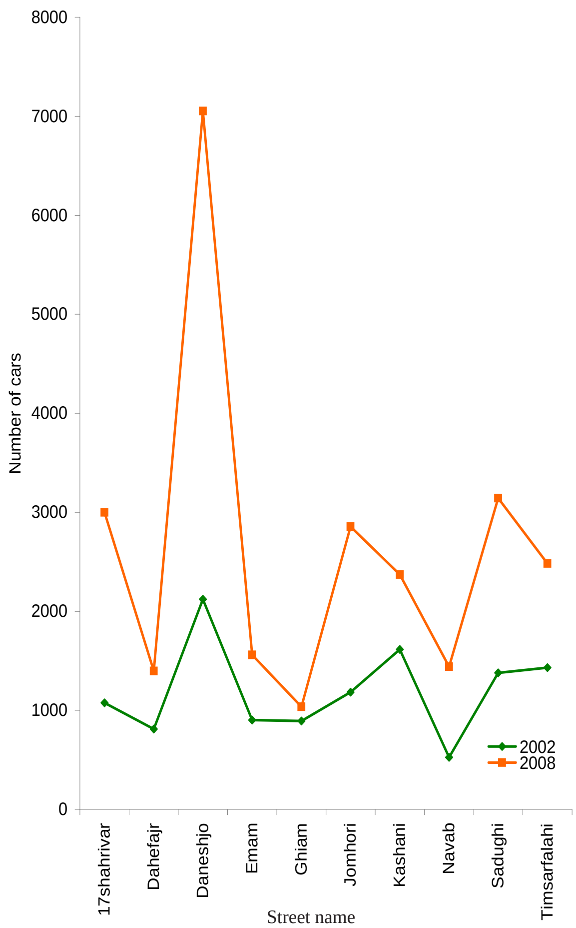

Fig. 3: Variations of number of cars in different streets of Yazd

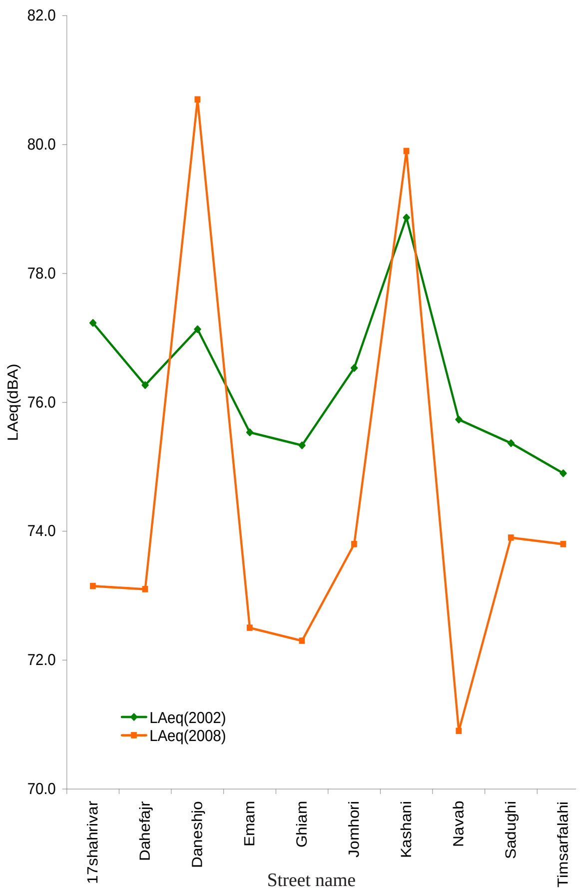

Fig. 4: Sound levels for individual streets

In Iran, the permissible noise level for residential-commercial areas has been legislated to be less than 60 dBA in urban areas (Department of Environment, 2001) and Table 3 shows the noise levels to be above this. In different streets measurements made at the ten monitoring sites showed that the city's streets have a sound level between typically 70.9 dBA and 80.7 dBA. As a result dwellings near these streets are likely to be exposed to unacceptable levels of noise pollution. In such cases, local authorities should implement ways to reduce human exposure (Murphy *et al.*, 2009).

Variations in noise levels are illustrated in Fig.5 which demonstrates that the city suffers from noise pollution at its center. Furthermore, it suggests that the sound levels decrease from the city centre towards north and south and this might be an important consideration when planning new buildings such as hospitals and schools.

Fig. 6 shows comparison between the measured and modelled values. It can be seen that the modelled values are relatively closer to the measured ones at low values of LAeq than at higher ones.

In order to assess the accuracy of the modelling, a relative error (SEN *et al*., 2006) was calculated. The relative error is defined as the difference between observation and prediction divided by the observation value and multiplied by 100. It

Table 3: Noise levels at the sampling stations

Station	Longitude (UTM)	Latitude (UTM)	Measured LAeq (dBA)
Timsarfalahi	251959	3525465	73.8
Sadughi	248375	3530417	73.9
Navab	250254	3533653	70.9
Kashani	252225	3527902	79.9
Jomhori	247493	3534504	73.8
Ghiam	250845	3532026	72.3
Emam	250969	3531534	72.5
Daneshjo	249860	3528439	80.7
Dahefajr	252903	3530970	73.1
Hefdehshahrivar	247674	3531755	73.2

UTM: Universal Transverse Mercator

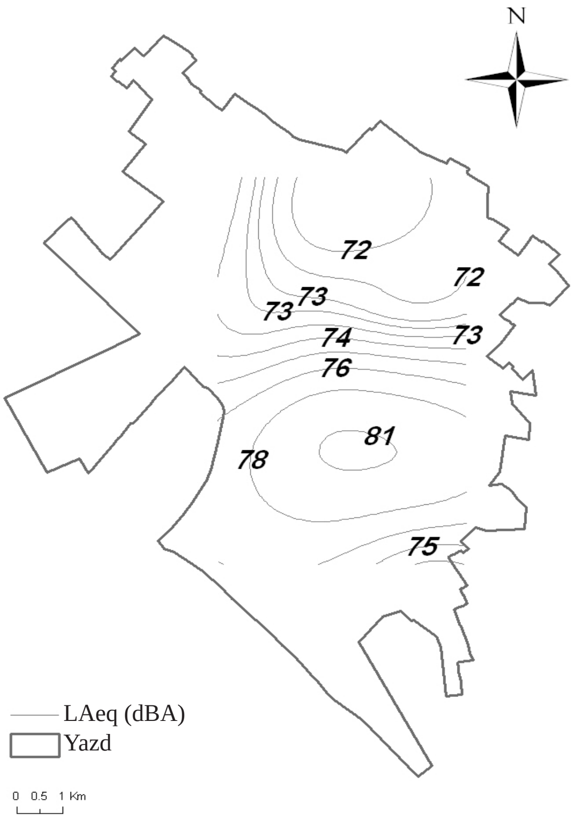

Fig. 5: Noise pollution contour map

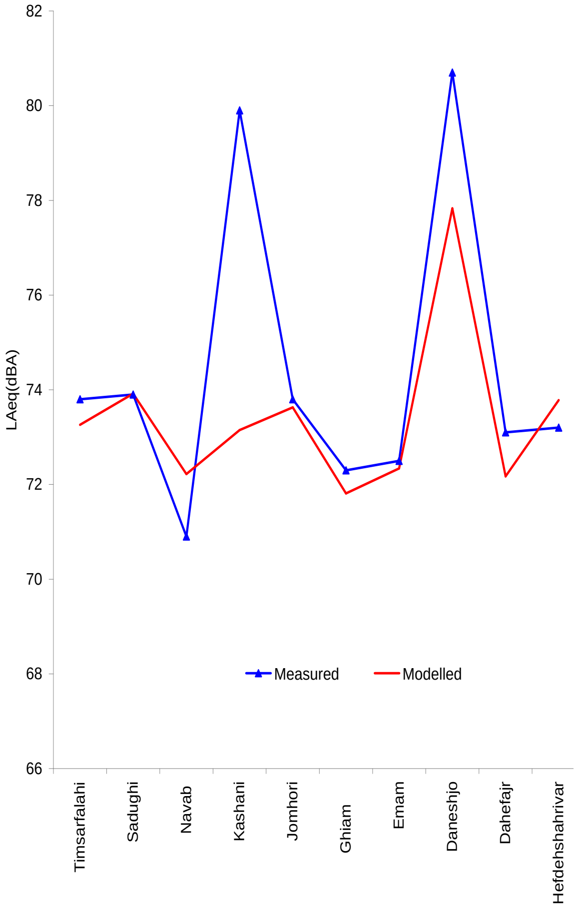

Fig. 6:Comparision between measured and modelled values LAeq

was found that the average relative error was 1.8%. The results are shown in Table 4.

Table 4: Assessing the modelling through relative error

Station	Measured LAeq (dBA)	Modelled LAeq (dBA)	Relative error
Timsarfalahi	73.8	73.26	0.73
Sadughi	73.9	73.92	0.03
Navab	70.9	72.22	1.86
Kashani	79.9	73.15	8.45
Jomhori	73.8	73.63	0.23
Ghiam	72.3	71.81	0.68
Emam	72.5	72.34	0.22
Daneshjo	80.7	77.83	3.56
Dahefajr	73.1	72.17	1.27
Hefdehshahrivar	73.2	73.78	0.79

DISCUSSION

Results of this study revealed that the city's average sound levels (LAeq) reached to 74.4 dBA which is significant. Similar studies in other Iranian cities have reported that noise pollution is greater than the national permissible level of 60 dBA. Golmohammadi *et al*. (2009) conducted a study in Hamadan and concluded that the average sound level was 69.04. A 72.5 dBA was measured for Kerman (Mohammadi, 2009). It was also found that despite increasing number of cars sound levels have been decreased between 2002 and 2008.

One reason for the decline in noise might be due to technological improvements in the manufacture of cars over the last six years. For example, the production of Paykan (based on British Hillman), Iran's most popular car came to an end in 2005 after nearly 40 years production, because the Iranian government regarded it to be environmentally inferior to new models and encouraged its phasing out. A poor fuel economy (12 miles per gallon) as well as being a noisy light vehicle (Alimohammadi *et al*., 2005) meant the car did not meet modern international emissions standards and an old design precluded any radical modification (Atash, 2007). Furthermore, green spaces as natural barriers have an impact on noise and air pollution and noise reduction strategies using green elements are characterized by the amount of dBA decrease they induce (De Ridder *et al*., 2004). Since 2002, the city has witnessed more development and an expansion of green spaces especially those in streets and boulevards. As a consequence part of noise decrease in 2008 can be because of green spaces barriers.

It can be argued that the street width can control the traffic flows. For instance because of narrow width, Ghiam Street, in the city center, has not provided further room between 2002 and 2008 for more cars. Therefore there has been a negligible increase on this street over the last six years. In contrary, Daneshjo Avenue, as an inner ring, which can link south, southern west and western part of the city to the city center, has had enough room for more vehicles. Consequently, commuters may have chosen this path to reach their destinations in the city which has led to a significant flow increase during this period (3.3 times).

It was found that overally a decrease in sound level is obvious, nevertheless there are exceptions on two streets. Due to considerable increase in number of cars on Daneshjo Avenue; sound level has been increased from 77.1 dBA in 2002 to 80.7 dBA in 2008. However, on Kashani Street there is a notable increase in sound levels (Fig. 4) but less increase in number of cars (Fig. 3) compared to the Daneshjo Avenue. This can be because of fleet composition, street geometry and cultural reasons on the two streets. Fig.7 depicts fleet composition for the 10 streets. Kashani Street has more motorcycles and trucks than Daneshjo Avenue. Consequently the motorcycles and trucks can compensate the car contribution in sound level on this street compared to the Daneshjo Avenue. The car contribution in Kashani Street is as a result of the street width which is much less than the Avenue. Therefore commuters switch on motorcycles as this street is the central street in the city. The other reason could be due to congestion on this street and with respect to the cultural background of individual drivers may lead to more hooting.

In summary, the following conclusions can be drawn from the current study:

(1) The results demonstrate that the levels of noise in the study area (Yazd, Iran) are greater than the national standard for urban areas.

(2) Predicted Equivalent Average Sound Levels were mainly determined by traffic volume.
(3) There is a need to control the noise pollution by suitable abatement techniques (which might include reducing the speed limit or encouraging the use of non-motorised transport, for example).
(4) There was an apparent decrease in sound levels between 2002 and 2008 which might be due to better vehicle design.
(5) The adopted model can be used to successfully predict noise pollution and could be useful in assessing the efficiency of any abatement techniques.
(6) In order to achieve a sustainable transport, a fleet composition change is required. Yazd dwellers have driven bicycles for many years. However, during recent years, number of cars has been increased. As a consequence raising awareness on the environmental benefits of non-motorized vehicles can encourage people to reduce noise pollution as well. This is especially practicable as the city is flat and with no considerable gradient.

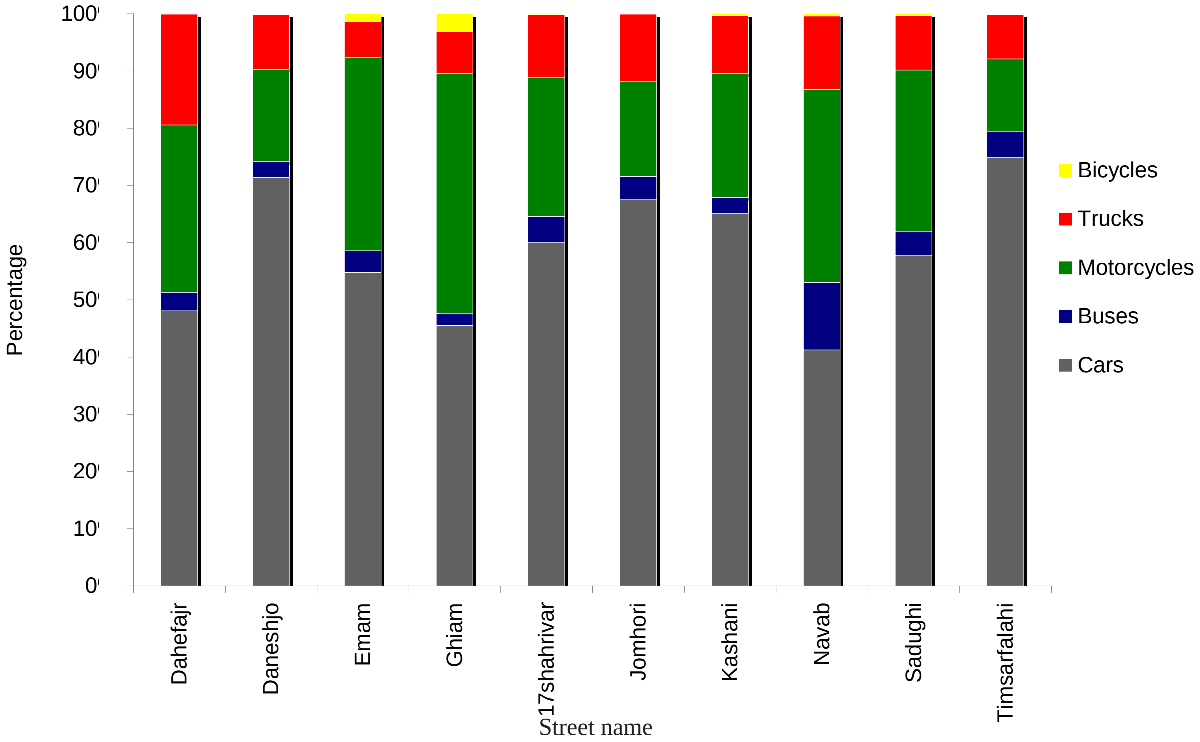

Fig.7 : Fleet composition for the different streets

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