Iran. J. Environ. Health. Sci. Eng., 2005, Vol. 2, No. 3, pp. 145-152

AIR QUALITY DETERIORATION IN TEHRAN DUE TO MOTORCYCLES

***[1]M. Shafiepour and [2]H. Kamalan**

*****[1]Faculty of Environment, University of Tehran, Iran

[2]K. N. Toosi University of Technology, Tehran, Iran

Received 13 January 2005; revised 13 March 2005; accepted 5 May 2005

ABSTRACT

Since there is a rise of motorcycles population as well as other motor vehicles, it seems that air Pollution deterioration should be studied as one of its environmental impacts. The main objective of this study was to develop a number of scenarios in order to determine the amount of Tehran's air pollution attributable to motorcycles and select the best and the most probable case to be recommended for implementation. The first step was to collect data such as the number of active motorcycles, daily traffic volume, average traveling speed and actual emission factors. For this purpose, a detailed questionnaire was designed to be completed by field surveys and measurements. The collected data were compared with traffic volume data, manufacturing statistics and the latest production capacity forecast in this field. Finally, with this data and emission factors for each type of motorcycle, an emissions inventory model was chosen to provide annual emissions from motorcycles in Tehran in different scenarios. The results showed that in 2002, there has been about 450'000 active motorcycles (4-stroke 58%, 2-stroke 28%, and moped 14%) with average speed of 40 km/h and average mileage of 110 km/d. Five scenarios were developed. The best scenario was "Changing all motorcycles to 4-strokes under EU-97 standard" which would result in reduction of NMVOC by 75%, CO by 35% and PM_{10} by 88%.

Key words: Air pollution, emission, modeling, motorcycle, Tehran

INTRODUTION

The air quality in Tehran is mainly deteriorated mainly because of mobile sources. In fact, in excess of 70% of daily discharge of air pollutant in 1996 is contributed to motor vehicles. Air pollution of mobile sources and in particular, those of motorcycles, (under standard conditions), are considered to at least be four times greater than light duty passenger cars in each kilometer traveled while the motorcycles engine capacity is much less than cars (Jahanro, 1995). On the other hand, the demand for owning a motorcycle is on a soaring path. This is of course due to a number of social and economic reasons, but convenience of avoiding heavy traffic congestions, appear most favorable in Tehran. It is clearly observed that the population of all types of motorcycles is growing fast to the extent that besides goods and parcels, passengers are also moved by such mode of transportation in the central part of Tehran. Attempts have been made by traffic planers to manage the modal split favorably so that besides traffic, the environmental circumstances may also be improved. This research focuses to the effects of using motorcycles extensively in Tehran on its air quality which is still considered to be among the top-10 capitals in the world experiencing detoriated air quality. Hence, measures for reduction of motorcycles air pollution are imperative and indispensable.

MATERIALS AND METHODS

Since the existing statistics are out dated, a questionnaire was designed for collection of some vital data such as the number of active motorcycles, daily traffic volume, average traveling speed and actual emission factors. The

*Corresponding author: Tel: +98 912 1056189,
Email: *m_shafiepour@yahoo.com*

collected data were compared with traffic volume data, manufacturing statistics and the latest production capacity forecast in this field. Finally, with this data and emission factors for each type of motorcycle, an emissions inventory model was chosen to determine annual emissions from motorcycles in Tehran, capital of Iran, in different scenarios.

Motorcycles population and respective traffic and environmental data

The main unknown factor in this study was to identify the exact quantity and the respective environmental quality of the newly produced and used motorcycles. Thus, a number of approaches were made to update the existing data of produced motorcycles until 1996. There have been 255'490 active motorcycles in Tehran in 1996 which consist of 4-stroke; 42%, 2-stroke; 37% and moped; 21% (Anonymous, 1995). Tehran's Transportation Emission Reduction Project (TERP) conducted in 1994, estimated the emissions inventory with the help of some data such as the road network, population of vehicles, EMME2 as a traffic planning software, emission factors for pollutants and AIRVIRO as an air pollution simulation software. Table 1 shows the emission factors in a glance. NMVOC , NO_x, CO, PM_{10} factor for Tehran's motorcycles fleet in 1996 are 9628, 82, 38350, and 309 mg/km, respectively (Anonymous *et al.*, 1997).

Updating data for 2002

There are several approaches to updating Tehran's active motorcycles population as follows:

- Statistics of registered motorcycles from police
- Statistics of motorcycle manufacturing from ministry of industry and mines
- Trip statistical data

None is the exact statistics for motorcycles population, because: (i) Police statistics for registered motorcycles are less than expected population; mainly because there are lots of motorcycles in Tehran which are unregistered. As it has been mentioned in the statistics, there were 43% unregistered motorcycles in Tehran in 1996 (TTSC, 1995), (ii) Statistics of manufactured motorcycles are much more than Tehran's active motorcycles; because, the market for them is whole Iran, not only Tehran, and (iii) Traffic data include number of trips are an approximate statistics and do not provide a good estimation for motorcycles population because. The population of Tehran's active motorcycles has been updated with the help of a logical assumption in this study, and then controlled in deferent ways.

Table 1: Motorcycles emission factors in 1996 (mg/km)*

Velocity (km/h)	Motorcycle	NMVOC	NOx	CO	PM_{10}
ECE (18.7)	2-stroke	15840	63	30750	759
	4-stroke	8125	91	50000	36
	moped	9750	75	11600	433
40	2-stroke	12240	55	28274	570
	4-stroke	7471	79	45973	27
	moped	7650	66	11000	335
60	2-stroke	11326	61	15744	523
	4-stroke	4160	88	25600	25
	moped	9250	73	13667	410
80	2-stroke	12566	88	14476	561
	4-stroke	3825	127	23538	25
	moped	10950	106	16167	485

*(SWECO *et al.*, 1997)

Updating Motorcycles' Traffic Data

Since the traffic data like average speed, daily mileage and also distribution of motorcycles by their types is unknown, a field survey was done on 140 motorcycles through a questionnaire to prepare some necessary data. Statistical society was selected through the chance method and analyzed through Guttmann approach (Gheranmaye, 2001). Table 2 shows the results of field survey briefly.

According to Fig. 1, the number of manufactured motorcycles from 1996 till 2002 is 1128807. It is assumed that "willingness of owning motorcycles in rural communities are two times more than urban communities", and as a matter of fact, Iran consists of 65% urban communities and 35% rural communities (Anonymous, 2001). The demand for Iran with the population of 65 million is calculating as $(2*35\%+65\%)*65*10^6=87.75*10^6$. On this basis, the demand for having motorcycle for Tehran with the day population of 10.5 million is calculating as 12% out of whole Iran. The attraction of motorcycles in Tehran has been calculated by another method to control the abovementioned assumption. 2151511 motorcycles were manufactured

till 1996 (Shafiepour and Kamalan, 2004), and there were 255490 active motorcycles in Tehran (Anonymous, 1995). It means that 12% of whole manufactured motorcycles is attracted to Tehran. On this basis 1607197 × 12% = 192864 motorcycles have been attracted to Tehran in the period of 1996 to 2002. Thus, there were 448354 active motorcycles in Tehran in 2002.

There were 390947 active motorcycles in 2001 by using this approach and 11500000 motorcycle's trips in Tehran in the same year. Motorcycle trips have been calculated as 1035000 by considering the contribution of 9% for them in urban trips (Anonymous, 2002). Number of trips are estimated about 517500 because each trip consists of two sub-trip (go and back), which confirms existence of 390947 active motorcycles in Tehran in 2001.

As part of this research methodology, 1996 data is used as the baseline platform for sincerity analysis of abovementioned data. Since, motorcycles were seldom used as courier or delivery, and it was mainly used as private mode of transportation vehicle at that time, therefore, motorcycles average mileage is estimated to be about 3730×10^6 km/year in 1996 which has less than 3% variation with TERP report (Anonymous,1997). Average velocity of Equivalent Private Passenger Car (EPPC) is 29 km/hr in morning peak of traffic in 2002 (Anonymous, 2002). It is obvious that daily average speed of EPPC is more than 29 km/hr and motorcycles average speed is determined to be more than daily average speed of EPPC. Hence, 40 km/hr as the average speed of motorcycles yielded from the field survey in this research is reliable.

Table 2: Motorcycles daily mileage in Tehran*

Usage of Motorcycle	Mileage in Working Days (km)	Mileage in Holidays (km)	Average Mileage (km)
Courier, Human Delivery	180	40	160
Food Delivery	130	130	130
Private	40	40	40
Result	-	-	110

*(Field survey)

Table 3: Population and distribution of motorcycles type in different years*

Motorcycle	Up to 1996	From 1996 to 2002	2001	2002	2003
4-stroke (%)	42	80	52	55	58
2-stroke (%)	37	15	31	29	28
Moped (%)	21	5	17	15	14
Population	255490	192864	348010	390755	448354

*(Shafiepour and Kamalan, 2004)

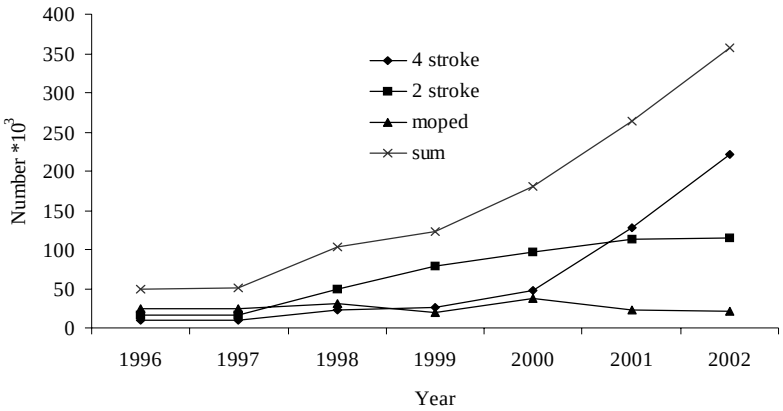

Fig. 1: Manufactured motorcycles statistics in Iran from 1996 to 2003

With regards to the manufacturing statistics (Fig. 1) and results of field survey, distribution of motorcycles' type is 4 stroke 80%, 2 stroke15%, and moped 5% for the period of 1996 to 2003. Table 3 shows distribution of motorcycles type in 2001, 2002 and 2003.

Motorcycles emission estimation model

The result of any emissions inventory model depends on following three portions (Zheng, 2001; Valerie, 1994):

- Transportation data from transportation model
- Emissions rates from emissions rates models,
- Coordination of transportation data and emissions rates in emissions inventory models.

On the other hand, there are three types of emissions from vehicles as follows (Power, 1998):

- Hot start emission,
- Cold start emission,
- Evaporation of hydrocarbons which consist of three categories of a, b and c:
  a) Running losses emission
  b) Hot soak emission and
  c) Diurnal emission

The most suitable emissions inventory model for Tehran's motorcycles for NMVOC is (Shafiepour and Kamalan, 2004) :

$$E_i = 10^{-9} \times (M \times L_i + N \times 365 \times (d_i + h_i) \qquad (1)$$

Where:

E_i = total emitted pollutant i (ton/year)
M = motorcycles annual mileage (km)
L_i = emission rate of pollutant i (mg/km)
N = population of motorcycles
d_i = diurnal emission (mg/km)
h_i = Hot soak emission(mg/km)
m = average mileage of each motorcycle (km)

The most suitable emissions inventory model for Tehran's motorcycles for other pollutants is (Shafiepour and Kamalan, 2004):

$$E_i = 10^{-9} \times (M \times L_i) \qquad (2)$$

It is important to know that macroscopic traffic simulation model, speed-based emissions rates model and ECE driving cycle have been used to develop above mentioned model (Shafiepour and Kamalan, 2004).

RESULTS

Current situation of motorcycles emissions

Emission rates of different types of motorcycles in 2003 are presented in Table 4. Utilizing the above mentioned model and emission rates from Table 4: total NMVOC , NOx , CO, PM_{10} emitted from Tehran's motorcycles fleet in this scenario are 161118, 650232, and 3999 ton , respectively in year 2003. Fuel consumption is obtained by multiplying the mileage to fuel consumption factor, which is 702 million liters in the same year.

Five scenarios for motorcycles emission reduction

Five scenarios have been developed to make the best decision which will reduce motorcycles emission more efficiently. Emission factors have been obtained from TERP report in all scenarios, and then used as input for the model. The outputs of the model are emissions inventory which are shown in the following tables.

Baseline scenario,"business as usual"

This scenario is based on the current situation considering that no changes will happen. Tables 5 and 6 show the result of implementing this scenario.

Table 4: Motorcycles emission rate in velocity of 40 km/hr in 2003

Motorcycle	Distribution	Fuel Consumption (l/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
4-stroke	58	0.045	7471	79	45973	27
2-stroke	28	0.036	12240	55	28274	570
Moped	14	0.022	7650	66	11000	335
Total	100	0.039	8831	71	36121	222

*(Shafiepour and Kamalan, 2004)

Table 5: Motorcycles emission rate in scenario one

Motorcycle	Distribution	Fuel Consumption (l/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
4-stroke	58	0.045	13868	63	30750	486
2-stroke	28	0.034	10575	55	28274	365
moped	14	0.032	9785	61	15744	334
Total	100	0.034	10857	88	14476	359

Table 6: Motorcycles emission rate in scenario two*

Motorcycle	Distribution	Fuel Consumption (l/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
4-stroke	58	0.045	2253	317	22987	27
2-stroke	28	0.034	4010	113	11493	173
moped	14	0.032	2791	66	6286	108
Total	100	0.034	2735	217	16856	77

*(Shafiepour and Kamalan, 2004)

Table 7: Motorcycles emission rate in scenario three

Motorcycle	Distribution	Fuel Consumption (l/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
4-stroke	100	0.045	7471	79	45973	27
2-stroke	0	0.036	12240	55	28274	570
moped	0	0.022	7650	66	11000	335
Total	100	0.045	7471	79	45973	27

Scenario one, "using better gasoline and catalyst for 2-stroke motorcycles"

Transportation data is the same as base line scenario. Motorcycles population is 448,354 with distribution of 4-stroke; 58%, 2-stroke; 28%, and moped; 14%. Emission factors which are different from pervious scenario, are shown in Table 5.Utilizing the above mentioned model and emission rates from Table 5; total NMVOC, NOx , CO, PM_{10} emitted from Tehran's motorcycles fleet in this scenario are 90811, 1445, 397034, and 2617 ton, respectively in year 2003. Fuel consumption is assumed as 661 million liters.

Scenario two,"using all motorcycles with EU-97 standards"

Transportation data is the same as pervious scenarios. Emission factors which are different from pervious scenario are shown in Table 6. Utilizing the abovementioned model and emission rates from Table 6; total NMVOC, NOx , CO, PM_{10} emitted from Tehran's motorcycles fleet in this scenario are 49258, 3909, 303555 and 1383 ton, respectively in 2003. Fuel consumption is assumed as 650 million liters.

Scenario three,"changing all motorcycles to 4-stroke

Transportation data is the same as pervious scenarios. Distribution of Motorcycles is changed to four stroke 100%, in this scenario. Emission factors are shown in Table 7. Utilizing the abovementioned model and emission rates from Table 7; total NMVOC, NOx , CO, PM_{10} emitted from Tehran's motorcycles fleet in this scenario are 49258, 3909, 303555 and 1383 tons, respectively in 2003. Fuel consumption is assumed as 650 million liters.

Scenario four, "changing all motorcycles to 4-stroke under EU-97 standard"

Transportation data and distribution of motorcycles are the same as pervious scenarios. Emissions factors are shown in Table 8. Utilizing the abovementioned model and emission rates from

Table 8; total NMVOC, NOx , CO, PM_{10} emitted from Tehran's motorcycles fleet in this scenario are 40580, 5703, 413967 and 480 ton respectively in year 2003. Fuel consumption is assumed as 786 million liters.

DISCUSSION

According to what has been presented in this paper, it is noted that there were 448354 motorcycles with average daily mileage of 110 km and average daily speed of 40 km/hr and the type distribution of 4 stroke 58%, 2 stroke 28%, and moped 14%, in 2003. Comparing such findings with those of 1996 reported by SWECO, it looks that there has been a shift of approximately 16% to 4 stroke motorcycles from mopeds and 2 stroke motorcycles. Also, due to the rise of motorcycle population as well as other motor vehicles, the average commuters speed has reduced from 50 km/hr to 40 km/hr. Approximately, 3' 999 tons of PM_{10}, around 650' 232 tons of CO, in excess of 1272 tons of NOx, and 161118 tons of NMVOC have been emitted by motorcycles in Tehran in that time. Also, Motorcycles consumed over 702 million litters of gasoline during the same period.

As it is clear in Fig. 2 and Table 9, NMVOC, CO and PM_{10} would be decreased by about 40% in scenario one. NMVOC and PM_{10} would be decreased by about 60% and CO increase by about 10% in scenario two. Scenario three has a reduction of PM_{10} by about 85% and NMVOC by about 15% and an increase of CO by about 30%. Scenario four would reduce NMVOC by 75%, CO by 35% and PM_{10} by 88%. It is natural that NOx emissions will increase if engine is working in a better situation (Jiun, 2002). In fact, four stroke motorcycles have higher fuel consumption than two stroke ones (Dietrich, 1999). On this basis fuel consumption will be more in scenarios three and four.

"Changing all motorcycles to four stroke under EU-97 standard" is the best scenario to reduce emitted pollutants by motorcycle in Tehran among four other scenarios which are "business as usual", "using better gasoline and catalyst for two-stroke motorcycles", "using all motorcycles with EU-97 standards", and "changing all motorcycles to 4-stroke". This scenario is the best applicable one. NMVOC will be deceased by 75%, CO by 35% and PM_{10} by 88% by selecting the best scenario and fuel consumption will be increased by 12% and NOx by 350%. Motorcycles emissions (total of NOx, CO, NMVOC, PM_{10}) was about 816621 tons in Tehran in 2002, which was 22.2% of whole emissions by mobile sources in Tehran (Shafiepour and Kamalan, 2004). Applying the best scenario will decrease motorcycles emission to 460730 ton which cause reduction of motorcycles role in emissions to 11.1%. If the proposed scenario is adopted for implementation, emissions contributed by mobile sources in Tehran would be reduced by 9.7% which is considered to be significantly attractive for air quality improvement within greater Tehran area.

Table 8: Motorcycles emission rate in scenario four*

Motorcycle	Distribution	Fuel Consumption (L/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
4-stroke	100	0.045	2253	317	22987	27
2-stroke	0	0.034	4010	113	11493	173
moped	0	0.032	2791	66	6286	108
Total	100	0.045	2253	317	22987	27

* (Shafiepour and Kamalan, 2004)

Table 9: Changes in emission inventory (%)

Scenario	Fuel Consumption (L/km)	NMVOC (mg/km)	NOx (mg/km)	CO (mg/km)	PM_{10} (mg/km)
Base Line	0	0	0	0	0
One	-5.84	-43.64	13.60	-38.94	-34.56
Two	-7.41	-69.43	207.31	-53.32	-65.42
Three	14.53	-16.50	12.34	27.33	-87.85
Four	11.97	-74.81	348.35	-36.34	-88.00

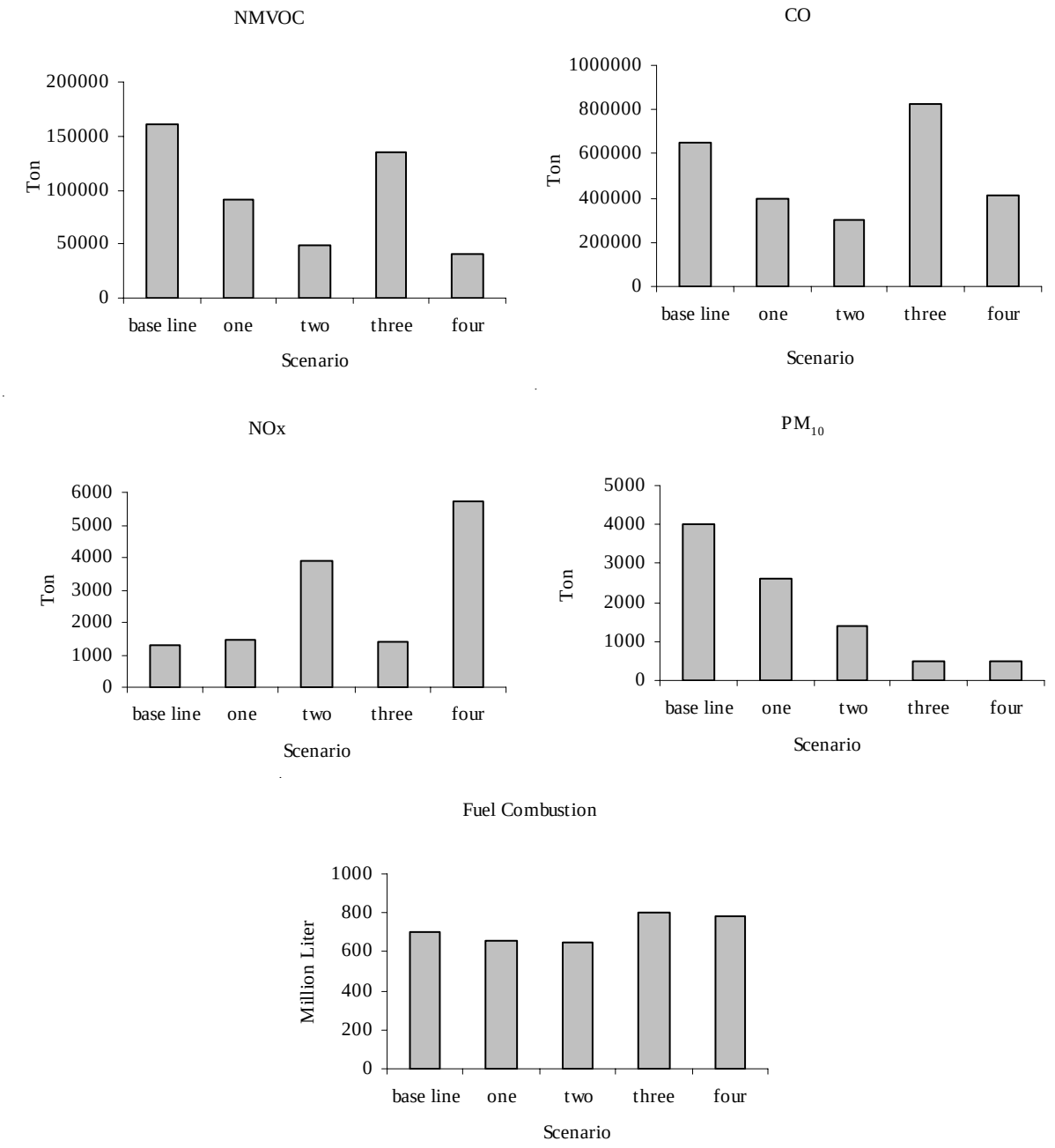

Fig. 2: Comparison of emissions and fuel consumption in five different scenarios

REFERENCES

Anonymous, (1995), Statistics report on Tehran motorcycles, Air Quality Control Co., TTSC, Municipality of Tehran, Iran.

Anonymous, (1995), International gas emission standards from two and four stroke motorcycles, Jahanro Engineering Unit, Iran.

Anonymous, (1997), Tehran Transport Emission Reduction Project, Air Quality Control Co., SWECO, MTC, and SMHI., Municipality of Tehran, Iran

Anonymous, (2001). Annual statistics of 2000, Iran Statistics Center Publications.

Anonymous, (2002), Statistics on transportation, , Air Quality Control Co., TTSC, Municipality of Tehran, Iran.

Broadwell V., (1994), methodologies for estimating emission and travel activity effects of TCMS, System Applications International, UK.

Ghranmaye Pour, M., (2001). Research methods, Islamic Azad University Publications, Iran.

Horng J., (2002), Volatile organic profiles and photochemical potentials from motorcycle engine exhaust, Air and Waste Management Association, USA.

Power H., (1998), Air pollution emissions inventory, Computational Mechanics Publications, UK

Schwela, D., (1999). Urban traffic pollution. World Health Organization, USA.

Shafiepour M. and Kamalan H., (2004), A model for estimating of Tehran's motorcycles emission, J. Environ. Sci. Tech., **20**, 23-33.

Yi, Z., (2001), A grid-based mobile sources emissions inventory model, Available from: http://www.aqp.engr.ucdavis.edu/SCF%20Study/newgridmodel