Petrol and Diesel Vehicles in Delhi: Nitrogen Oxide Emission

Dr. Debabrata Das
Indus Business Academy
Plot No. 44, Knowledge Park-III
Greater Noida-201308
Utter Pradesh, India

Abstract

In the age of motorization vehicular pollution is the greatest evils to the health of humans, animals, and plants. Nitrogen dioxide is one of the major air pollutant produced by automobiles. Direct exposure to nitrogen dioxide leads to increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function. Therefore, this paper projects the growth of vehicles and to estimate the subsequent level of nitrogen dioxide emission in different scenarios in Delhi. Based on the data from 1965-66 to 2009-10, a long-term trend in the growth of petrol, diesel and compressed natural gases vehicles is projected up to the year 2020-21 by using S-curve growth model. It is found that the total number of vehicles will increase from 80 thousand in 2005-06 to nearly 147 lakhs in 2020-21, with increasing share of compressed natural gases vehicles; however, the share of petrol vehicle will be decreased marginally. If the present trend will continue the concentration of nitrogen dioxide will be decreased 9 per cent to the present level (50.9 $\mu g/m^3$, 2008). The further conversion of petrol vehicles into compressed natural gases vehicles will reduce the nitrogen dioxide emission level significantly i.e. 40 $\mu g/m^3$ by 2021. Therefore, government should encourage use of cleaner technology and alternate fuel for personal vehicles, which in turn will reduce the Nitrogen dioxide emission in future.

1. Introduction

A striking feature of all kinds of mechanized road transport is the total domination of the internal combustion engine. At present, every type of vehicle running on roads today, from the fragile moped to the heavy duty bulldozer, uses three kinds of internal combustion engines i.e. petrol, diesel and CNG (compressed natural gases). A petrol engine is a specialized form of an internal combustion engine in which power is obtained by burning a mixture of petrol vapour and air, which is ignited electrically by a spark plug. The petrol engine was originally selected for automobiles because it could operate in a more flexible and over a wide range of speeds and is used as a readily available, moderately priced fuel, petrol. A diesel engine differs from a petrol engine, principally, in that it relies on heat generated by compressing air in the cylinder to ignite the fuel. To generate the required heat, the diesel engine must produce higher compression than the petrol engine, making it heavier, bulkier, more expensive and capable of being operated only at slower speeds. But it can operate on cheaper, less highly refined fuel, which gives it an advantage in many heavy transportation and construction equipment, such as trucks, buses, trailers, bulldozers etc. [1]. To overcome some known disadvantages of the petrol and diesel engine basically due to expensive fuel and pollution, the government of Delhi substituted CNG for petrol or diesel fuel as mandatory for the public transport system in Delhi. The order was directed towards replacement of all pre-1990 autos and taxis with new vehicles using clean fuels and the entire city bus fleet to be steadily converted to single fuel mode on CNG by March 31, 2001 [2]. It is considered to be an environmentally "clean" alternative to those fuels. It is made by compressing methane (CH_4) extracted from natural gas.

Vehicular pollution has become a growing problem in mega cities and large urban areas throughout the globe. The major vehicular pollutants are sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), lead and other toxic matter such as suspended particulate matter (SPM) [3]. The different types of vehicle consume different types of fuels such as petrol, diesel, etc. and emit different types of pollutants. Pollutants are released when fuel is burnt in the internal combustion engine and the air/fuel residuals are emitted through the tailpipe. Heat generated by hot day-time temperature, engine warming and refueling at the service station, causes fuel to evaporate into the atmosphere [4]. These pollutants in the atmosphere are one of the greatest evils to the health of humans, animals, and plants [5].

Therefore the objective of the paper is to project the long-term growth of motor vehicles, and subsequently based on the projected growth of motor vehicles; estimate the level of nitrogen dioxide emission in Delhi. The S-curve growth model will be fit for projection of three different types of fuel consuming vehicles viz. petrol, diesel and CNG using annual data from 1965-66 to 2009-10. The level of nitrogen dioxide emission will be estimated by ordinary least square method under different scenarios e.g. as usual growth scenario and promotion for use of CNG vehicles scenario.

2. Motor Vehicle Growth

2.1. Vehicle with Fuel Specification

The increasing dependence on road transportation has been the prime contributing factor to the phenomenal growth in motor vehicles especially the private vehicles in India. In contrast to Mumbai, Chennai and Kolkata, the travel demand in Delhi has been predominantly dependent on road transport system. The highest number of vehicles with largest road network compels this city to consume more petroleum energy and emit more pollutants in the atmosphere. Only with the commencement of metro rail, public transport in Delhi has witnessed a changing scenario. At present, buses are the primary mode of transport, which constitute only about 1 per cent of the total motor vehicles whereas, private vehicles account for 94 per cent, out of which two-wheelers are 63 per cent and four-wheelers are 31 per cent. The other mode of transport includes taxis, auto rickshaws and goods vehicles which are 5 per cent of the total motor vehicles [6].

Table 1. Vehicle With Fuel Specification

Years	Population	Petrol Vehicle	Diesel Vehicle	CNG Vehicle	Total Vehicles
1965-66	3140214	68942	11478	0	80420
	(4.08)	(23.13)	(14.90)		(21.94)
1970-71	4065698	181445	22633	0	204078
	(4.25)	(14.07)	(10.84)		(13.72)
1975-76	5006283	341950	36968		378918
	(4.25)	(8.37)	(7.80)		(8.32)
1980-81	6220406	508585	53183	0	561768
	(4.15)	(13.49)	(11.26)		(13.28)
1985-86	7622810	990237	85249	0	1075486
	(4.15)	(13.41)	(10.65)		(13.19)
1990-91	9420644	1787638	136149	0	1923787
	(3.85)	(7.68)	(6.14)		(7.57)
1995-96	11379236	2610529	183076	0	2793605
	(3.85)	(4.75)	(3.70)		(4.68)
2000-01	13782976	3238242	218337	0	3456579
	(3.09)	(7.24)	-(7.99)	(39.53)	(6.91)
2005-06	16021000	4523439	169823	115748	4809010
	(2.86)	(6.84)	(3.69)	(33.92)	(7.63)

Source: Transport Department, Govt. of N.C.T of Delhi
Delhi Statistical Hand Book, From 1970 to 2010

Till March 2010, total number of vehicle registered in Delhi was 64.5 lakh, out of which 91 per cent are petrol vehicles, 3 per cent are diesel vehicles and the rest 6 per cent are CNG vehicles. In 2001-02, Delhi has only 26 thousand CNG vehicles, but at present, the entire public transport vehicle such as bus, taxi, auto rickshaw and few private cars are run by CNG fuel. From 1965-66 to 2005-06, the number of registered motor vehicles has increased more than 80 folds, while population rose about 6 folds. In the same period, the petrol vehicle increased from 69 thousand to 45 lakhs, while diesel vehicles increased from 11 thousand to 1.7 lakhs. However, CNG vehicles increased exponentially from 26 thousand to 36 lakhs in the last decade (Table 1). The high growth in CNG vehicle is basically due to the implementation of several directives issued by the Supreme Court of India for the control of vehicular pollution in the years 1998, 2000 and 2001. These directives are such as the phasing out or ban on plying of old commercial passenger vehicles and conversion of commercial passenger vehicles into single fuel mode i.e. CNG [2]. Therefore, the period between 2000-01 and 2005-06 shows an average negative growth rate in diesel vehicles. Although large proportion of mobility need is still catered by public transport vehicles, there is a rapid increase in reliance on private vehicles such as car, jeep, motorcycle, scooter and moped in the recent years. This may be primarily due to increase in household income, increase in commercial and industrial activities, availability of motor vehicle product and improvement in road infrastructure. Beside these, there have been significant changes in motor vehicle sector during the last two decades. After liberalization of Indian economy during late 1980s and early 1990s, many new firms entered motor vehicle market to produce variety of cars and two-wheelers. Availability of motor vehicle and its financing at low interest rate increased the sale of petrol vehicles substantially after 1990. Though all these have contributed in the increase of the share of petrol vehicles, equally important reasons are to be found in public transport system itself. Speed, service quality, convenience, flexibility and availability favour adoption of petrol vehicles as the main mode of transport at present in Delhi [7]. Finally, using the trend of motor vehicles growth per 1000 persons, the forecasting model will be developed in the next section.

2.2. Model Formulation for Projection

The growth of vehicles per 1000 persons over time typically follows a sigmoid or S-shaped curve. There are a number of different functional forms that can describe S-shaped curves, for example, logistic, Gompertz, Von Bertalanffy, etc. These curves are to forecast how and when a given growth system will reach its saturation limit [8]. Originally these functions were developed to describe the self-limiting growth of population. First use of these functions to analyze the economic growth is attributed to the French sociologist Gabriel Tarde [9]. Tarde's idea is followed by other scholars like Prescott, who obtained demand forecasts for automobile using a Gompertz function [10]. Although the path of these growth functions can be represented in general S-shape fashion, different types of entities can grow different patterns. For example, the slope may be very steep during early phases, including rapid growth, or it may be gradual suggesting a slow and hesitant start, but all of them will level into saturation limit. The properties of the S-curve growth model is such that if the growth is quite rapid at an early phase and relatively slow when approaching the saturation level, then the Gompertz function is the best, on the other hand, if the growth is initially slow and relatively rapid during the maturing phases, then the logistic function is superior then Gompertz [11] [7]. The major problem that has to be solved first in these functions is the saturation level. A few studies have estimated the saturation level of the S-curve growth function internally [12], but many provide the saturation level externally by applying rule of thumb, e.g. one car per family [13], one driving member per family [14], per capita vehicle ownership [15] [16]. Therefore, this paper assumed the saturation level based on 1000 population per vehicle.

Let V_t be the vehicle growth per 1000 persons at time t and S be the saturation level of the growth. The logistic function states that the changes in vehicle growth with respect to time i.e. $\frac{dV_t}{dt}$ is proportional to the product of the level of vehicle growth at time t i.e. V_t and the fraction of market untapped i.e. $\left(\frac{S-V_t}{S}\right)$. Therefore, the corresponding equation is $\frac{dV_t}{dt}=\frac{bV_t(S-V_t)}{S}$ (1)

where b > 0 is the proportionality constant i.e. the growth rate.

Integrating equation (1) over the interval 0 to t, we get that the logistic function i.e. $V_t=\frac{S}{1+ae^{-bt}}$ (2)

Parameters a and b model the location and shape of the curve. For t = 0, $V_0=\frac{S}{1+a}$ is the starting level of the vehicle growth and for t = ∞, V_∞ = S is the saturation limit.

Similarly, the Gompertz distribution states that the change in vehicle growth with respect to time i.e. $\frac{dV_t}{dt}$ is proportional to the product of present level of vehicle growth at time t i.e. V_t and the logarithm of vehicle density level i.e.ln(S/V_t). The corresponding equation is

$$\frac{dV_t}{dt}=bV_t\ln\left(\frac{S}{V_t}\right) \quad (3)$$

where b > 0 is the proportionality constant i.e. the growth rate.

Integrating equation (3) over the interval 0 to t, we get that the Gompertz function i.e. $V_t=Se^{-ae^{-bt}}$ (4)

Parameters a and b model the location and shape of the curve. For t = 0, $V_0 = Se^{-a}$ is the starting level of vehicle growth and for t = ∞, V_∞ = S, is the saturation limit. Unlike logistic curve, it is not symmetrical about its point of inflection.

2.3. Model Output Analysis

Parameters are estimated by ordinary least square methods and values of these parameters are reported in Table 2.

Table 2. Estimated results of logistic and Gompertz models

Type of Vehicle	Type of Model	Parameter		R^2	MSE
		B	*Lna*		
Petrol Vehicle	Logistic	-0.06 (-30.6)	3.41 (60.8)	0.96	595.95
	Gompertz	-0.03 (-48.5)	1.3 (88.1)	0.98	190.62
Diesel Vehicle	*Logistic*	-0.02 (-7.2)	5.16 (59.9)	0.55	9.03
	Gompertz	-0.01 (-7.1)	1.64 (89.9)	0.54	9.14
CNG Vehicle	Logistic	-0.29 (-14.9)	6.32 (58.2)	0.97	1.37
	Gompertz	-0.06 (-30.6)	1.87 (60.8)	0.98	0.46

Note: Figures in the parenthesis are values of t-statistics

Based on the R^2 and mean square error (MSE) value, the better models are selected. According to R^2 value, the models fit the data very well. All the parameters have the expected sign and most are highly significant as observed from t statistic. The petrol and CNG vehicle growth provides higher R^2 and lower MSE values in Gompartz model, whereas, the growth of diesel vehicle is fit well in Logistic model. Substituting the value of saturation level and the selected parameters a and b (Table 2) in equations (2) and (4), the forecasting models for the petrol, diesel and CNG vehicles per 1000 persons as given below.

$$PV_t = 1000e^{-3.66e^{-0.03t}} \quad (5)$$

$$DV_t = \frac{1000}{1+174.76e^{-0.02t}} \quad (6)$$

$$CNGV_t = 1000e^{-6.47e^{-0.06t}} \quad (7)$$

Equations (5), (6) and (7) project the growth of petrol, diesel and CNG vehicles per 1000 persons for the years 1010-11, 2015-16 and 2020-21, by substituting t = 46, 51 and 56 respectively. Projected population and types of fuel consuming vehicles are reported in Table 3.

Table 3. Projected growth of population and vehicle with fuel types in Delhi

Year	Population #	Petrol Vehicle	Diesel Vehicle	CNG Vehicle
2010-11	18451000	6432082	307550	494725
2015-16	21285000	8478927	398411	1421119
2020-21	24485000	10958951	514526	3234337

Note: # Population figures are estimated by Registrar General of India
Note: The figures in the parenthesis are percentage to personal vehicle

The total number of vehicles in Delhi will rose to 147 lakhs in the year 2020-21, which is marginally less than half of the projected population at that time. In the projection period, the number of petrol and diesel vehicle will be 5 times more than what we had in 2010-11, while that of CNG vehicle it will be 21 times. On the other hand, the share of petrol and diesel vehicles will be decreasing with a significant increasing in the share of CNG vehicle. These projected growth of different types of vehicle help in estimating the level of nitrogen dioxide emission in Delhi in the next session.

3. Nitrogen Dioxide Emission

3.1. Concentration of Nitrogen Dioxide

Nitrogen oxides are colorless and odourless gas [1]. The concentration of nitrogen oxide in exhaust gas is found to depend mainly on the peak temperature and pressure and the supplied air-fuel mixture composition [4]. Nitrogen oxides react chemically with hydrocarbons to form ozone and other highly toxic pollutants. It is the most prominent pollutant contributing to acidic deposition. The common pollutant nitrogen dioxide (NO_2) can often seen combined with particles in the air as a reddish-brown layer over many urban areas. It is formed when the oxygen and nitrogen in the air react with each other during combustion [1]. Nitrogen oxide emissions from vehicles produce a variety of adverse health effects such as the direct exposure to nitrogen dioxide leads to increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function [17] [18].

In the past, several times Delhi has been listed amongst the ten most polluted cities of the world. This is not only due to an exponential growth of motor vehicles, but also due to the rise in the consumption of major auto fuels such as petrol and diesel. Then up to 1995, a rapid increase in the level of NO_2 was seen and after that there are many ups and down in the level of NO_2. In twenty years, the absolute increase is found to be two and half times, whereas the increase of motor vehicles is more than three times in the same period. First ten years the average growth rate of NO_2 level is 8 per cent annually and next ten years is 2 per cent (Table 4).

Table.4 Mean concentrations of NO_2 in Delhi (in µg/m3)

Year	NO_2	Year	NO_2	Year	NO_2	Year	NO_2
1989	19.0	1994	33.5	1999	40.0	2004	57.0
1990	23.0	1995	35.0	2000	42.0	2005	49.0
1991	26.5	1996	33.0	2001	42.0	2006	55.9
1992	31.0	1997	45.0	2002	46.0	2007	40.2
1993	33.5	1998	42.0	2003	56.0	2008	50.9

Source: Economic Survey of Delhi, 2008-09

Now, Delhi has been showing signs of improvement in the pollution level for the past one decade [19] [20]. This could be attributed to the stringent implementation of vehicular emission norms, fuel quality up-gradation, mandatory fitting of catalytic converters in April 1995 and better maintenance of engines through all possible measures. This achievement could be linked to conversion of all buses/taxis/autos into CNG engines. Introduction of CNG buses in Delhi was initiated after April 1998. In September 1999, an amendment to Motor Vehicle Act brought CNG vehicles under permit and tariff jurisdiction of government. Finally, by 31st March, 2000 all pre-1990 autos and taxis were replaced with new vehicles using clean fuel CNG. Subsequently, the conversion of entire bus fleets into CNG fuel mode was completed in November 2002. The conversion of all auto rickshaws to CNG engine took place in the year 2002-03, while that of taxis and buses in 2003-04 [21]. On the other hand, the conversion of private cars to CNG engine was very low. The problem being faced in the mega cities is how to reduce the adverse environmental impacts from vehicle growth without giving up the benefits of mobility. This dilemma becomes more pressing under conditions of rapid growth of petrol vehicles [22].

3.2. Scenarios for Nitrogen Dioxide Emission

In scenario approach, the nitrogen dioxide (NO_2) emission is assumed to be a function of petrol and diesel vehicles (PDV), and CNG vehicles (CNGV) under different scenarios. This relationship is generally established by regression technique [23]. The regression technique is rather common in establishing a functional relationship between air pollution and its factor [24] [25]. Starting from 1989, twenty annual mean NO_2 level are gathered from Economic Survey of Delhi, 2008-09. The responsibility of data collection rests on Central Pollution Control Board, Govt. of India, which has been monitoring the air quality regularly at various locations in Delhi. The growth of petrol plus diesel and CNG consumption vehicles are taken from the previous section (section 2). The general form of the above model is

$$NO_2 = f\,(PDV, CNGV) \qquad (8)$$

The parameters and significance level of these functions are estimated by ordinary least square method. In general, in the models of the above form, there are some fundamental assumptions that must be fulfilled so that the ordinary least square estimates the parameter that have optimal statistical properties. The assumption should be that no multicollinearity and autocorrelation in the model are tested by Durbin Watson (DW) statistic [26] and Klein's rule of thumb [27]. From equation (9), it is observed that the estimated DW of NO_2 model is found to be 2.05, indicates that the data are not autocorrelated. Klien's rule of thumb, free the NO_2 model from multicolinearity problem.

$$NO_2 = -3.76 + 0.00002\ PDV - 0.00009\ CNGV \qquad (9)$$
$$(7.32) \qquad\qquad -(3.84)$$
$$R^2 = 84 \quad DW = 2.05$$

Figures in the parentheses are values of t statistic of PDV and CNGV. From t values, it is observed that both PDV and CNGV of NO_2 models are significant at 95 per cent confidence level. The coefficient of the growth of petrol and diesel vehicles is expected to have the positive value in accordance with the fact that it is highly correlated with NO_2 concentration. On the contrary, the coefficient of CNG vehicle has a negative sign, which indicates that conversion of vehicle from petrol and diesel into CNG engine stating it's preventing to NO_2 concentration. R^2, the coefficient of determination of NO_2 model is equal to 0.84, indicates that 84 per cent of the variation in concentration of NO_2 is due to the growth of petrol plus diesel and CNG vehicles, while the rest 16 per cent may be due to some other reason, which is not taken into account here.

Finally, using the future growth of petrol, diesel and CNG vehicles, the NO_2 model projects the level of NO_2 pollutant for the years 2015 and 2020 under different scenarios as shown in Figure 1. S1 is the as usual growth scenario that estimate the concentration of NO_2 under usual growth of petrol diesel and CNG vehicles. In this scenario, the NO_2 concentration will be decreased in 9 per cent by the year 2020 as compared to what it was in 2010. On the other hand, the scenario S2 estimates the level of NO_2 concentration under conversion of 1per cent of additional petrol vehicle into CNG engine yearly up to 2020. The above conversion of petrol vehicles will reduce the concentration of NO_2 level from 51 mg/m^3 to 40 mg/m^3 i.e. 20 per cent reductions in future. Thus, it is inferred that the higher conversion of petrol vehicles into CNG will lower the concentration of NO_2 level.

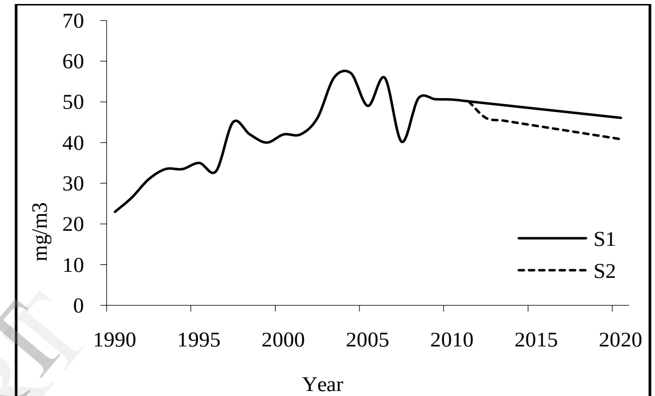

Figure 1: Projected Level of Nitrogen Dioxide

4. Strategies for Reduction in Nitrogen Dioxide Emission

Nitrogen dioxide is one of the major vehicular pollutants in Delhi [28]. Therefore, a strategy for use of cleaner fuel, reduction in fuel consumption, efficient maintenance of engines and installation of pollution control devices should be adopted. In Delhi, the growth of personal petrol and diesel vehicles is exorbitantly higher than public transport CNG vehicles, which may be the cause of higher NO_2 emission in last few years. NO_2 emissions depend heavily on flame temperature. By altering the composition of the air charge to increase its specific heat and the concentration of inert gases, it is possible to decrease the flame temperature significantly. The exhaust re-circulation systems utilize certain percent of exhaust stream to recycle into the intake manifold with the fresh air fuel mixture. The exhaust gas dilutes the fresh charge and thus lowers the flame temperature. The water injection is also lowering the flame temperature and consequently nitrogen dioxide. Installing the copper-cobalt-aluminum catalyst or a modified recycling system on a vehicle couple with various exhaust manifold reactors will result in substantially reduced emission [1]. Similarly, transport planning of the cities should specially emphasize on public transport system [29]. Although rail based transport services in Delhi are available for intra-city transportation, they hardly play any role in meeting the travel demand. At present, Delhi has also added 65.05 kilometers route of mass rapid transit system [30] and the expansion of this rail based public transport system may reduce the use of personalized petrol and diesel vehicles, subsequently reducing the nitrogen dioxide emission. Considering the financial health of the government and the investment required to expand the mass rapid transit system, it is also evident that the bus transport services in Delhi will have to play major role in providing passenger transport services in future. Therefore, there is an urgent need for restructuring this system to enhance both quantity as well as quality of services. There is a need for an integrated transport system, which will integrate rail, road as well as intermediate public transport. They should offer an attractive and easier way to use public transport system, leading to use of existing resources and improvement in the efficiency of service delivery and comfort for commuters. This integrated system has potential to attract people away from using personal petrol and diesel vehicles which in turn will reduce NO_2 emission in future. On the other hand, the government should promote use of cleaner technology and alternate fuel (CNG) for personal petrol and diesel vehicles. This will again reduce the NO_2 emission in future.

5. Conclusion

This study estimates the future growth of petrol, diesel and CNG vehicles and the corresponding NO_2 emission in Delhi. The trends over the past forty five years helps in projecting the growth of petrol, diesel and CNG vehicles up to the years 2020-21 in Delhi. The Gompertz and logistic growth model fits well in all these three types of fuel consuming vehicles. The projection states that the total number of vehicles in Delhi will rose to 147 lakhs in the year 2020-21, which is marginally less than half of the projected population at that time. The share of CNG vehicles is gradually increasing with marginally decreasing share of petrol and diesel vehicles in coming years. The level of NO_2 emission is estimated by regression technique with respect to the growth of petrol plus diesel vehicles and CNG vehicles under different scenarios. The growth of different types of vehicles under usual scenario estimates the level of concentration of NO_2 will be declined by 9 per cent in future. However, the further conversion of petrol vehicles into CNG vehicles will be reduced the NO_2 emission level significantly. Therefore, the government should encourage use of cleaner technology and alternate fuel such as CNG for petrol and diesel vehicle users, which in turn will reduce the NO_2 emission. This study is limited to the city of Delhi only. The severe constraints on availability of data with respect to two strokes and four strokes engine of petrol vehicle constituted a major stumbling block for better analysis.

6. References

[1]. M.N. Rao and H. V. N. Rao, “Air Pollution”, *Tata McGraw Hill Publishing Company limited*, New Delhi, 2001

[2]. Transport Department Government of NCT of Delhi, India, “Directions of Hon’ble Supreme Court for control of pollution in Delhi”, http://transport.delhigovt.nic.in/pc/pc.html, 2000

[3]. Delhi Pollution Control Committee, “Towards Cleaner Air: A case study of Delhi”, Government of NCT of Delhi, 2003

[4]. S. Kush, Automobile Pollution, *IVY Publishing House*, New Delhi, 2001

[5]. V. Kathuria, “Vehicular pollution controls in Delhi, India-Are the efforts enough?” *Transport Research: Part D.* Vol. 7, No. 5, pp373-387, 2002

[6]. Planning Department Government of NCT of Delhi, India, “Economic Survey of Delhi 2008-09”, 2009

[7]. S. K. Singh, “The demand for road-based passenger mobility in India: 1950-2030 and relevance for developing and developed countries”, *European Journal of Transport and Infrastructure Research*, Vol. 6, No. 3, pp247-274, 2006

[8]. N. R. Draper and H. Smith, “Applied Regression Analysis”, *John Wiley & Sons Inc.*, Singapore, 1998

[9]. G. Tarde, “The Laws of Imitation”, Henry Holt (Translation into English of Le Iois de I’ imitation, 1890), 1903

[10]. R. B. Prescott, “Law of growth in forecasting demand”, *Journal of American Statistical Association*, pp 471-479, 1922

[11]. K. S. Ogut, “S-curve models to determine the car ownership in Turkey”, ARI, Vol. 54, No. 2, pp 65-69, 2004

[12]. S. K. Singh, “Estimating the level of rail and road based passenger mobility in India”, *Indian Journal of Transport Management*, Vol. 24, No. 12, pp 771-781, 2000.

[13]. J. Palelink, “Projection du parc Automobile en Belgique”, *Cashiess Economiques de Bruxellers*, Vol. 3, pp407-418, 1960.

[14]. J. C. Tanner, “Long term forecasting of vehicle ownership and road traffic”, *Journal of the Royal Statistical Society*, Vol. 141, No. A, pp14-63, 1978

[15]. K. Button, N. Ngoe, and J. L. Hine, “Modeling vehicle ownership and use in low income countries”,

Journal of Transport Economics and Policy, Vol.27, No.1, pp51-67, 1993

[16]. H. K. Peter, D. E. Jon and E. D. Thomas, "Scenario analysis of Chinese passenger vehicle growth", *Contemporary Economic Policy*, Vol. 21, No. 2, pp200-217, 2003

[17]. S. Dietrich, Z. Olivier and S. Philipp, "Motor Vehicle Air Pollution: Public Health Impact and Control Measures", *World Health Organization and ECOTOX*, www.bvsde.paho.org/comun/airefile/mvr.pdf, 1997

[18]. Asian Development Bank, "Adverse Health and Environmental Effects from Vehicle Emissions", www.adb.org/documents/guidelines/vehicle_emissions/appendix.pdf, 2003

[19]. A. Mittal, A. Arora and A. Mandal, "Vehicular pollution by introduction of CNG in Delhi-A case study", www.cleanairnet.org/bag2004/1527/printer-59170.html, 2004

[20]. A. Singh, N. Sharma, K. Sharma and C. Bhan, "Emission characteristics of in-use CNG vehicles in Delhi", www.deas.harvard.edu/TransportAsia/workshoppapers/Singhetal.pdf, 2005

[21]. Directorate of Economic and Statistics, "Delhi Statistical Hand Book", Government of NCT of Delhi, India, (Various issues)

[22]. D. Das, "Transportation System in Delhi: A Modeling Approach", Unpublished Thesis, *Jamia Millia Islamia (A Central University)*, New Delhi, 2008

[23]. M. Khare and P. Sharma, "Modeling Urban Vehicle Emissions", *WIT PRESS*, Southampton, Boston, 2002

[24]. Briggs, J. David, C. Hoogh, J. Gulliver, J. Wills, E. Paul, K. Simon and S. Kirsty, "A regression-based method for mapping traffic-related air pollution: application and testing in four contrasting urban environments", *Science of The Total Environment*, Vol. 253, No. 1-3, pp 151-167, 2000

[25]. R. Zev, E. B. Paul, S. Rusty, G. Robert, S. Svetlana, W. Steve and J. Michael, "Nitrogen dioxide prediction in Southern California using land use regression modeling: potential for environmental health analyses", *Journal of Exposure Science and Environmental Epidemiology*, Vol.16, pp106–114, 2006

[26]. S. Makridakis, S. C. Wheelwright and R. J. Hyndman, "Forecasting Methods and Application", *John Wiley & Sons Inc.* Singapore, 1998

[27]. L. R. Klein, An Introduction to Econometrics, *Prentice-Hall Englewood Cliffs*, New Jursey, 1962

[28]. R. Khaiwal, W. Eric, S. K. Tyagi, S. Mor and R. V. Grieken, "Assessment of air quality after the implementation of compressed natural gas as fuel in public transport in Delhi, India". www.cleanairnet.org/caiasial1412/articles-60204cng.pdf, 2005

[29]. D. Das, A. Sharfuddin and S. Datta, "Importance of Metro Rail in Public Transport Network: A Case Study of Delhi", *Indian Journal of Transport Management*, Vol. 31, No. 3, pp 223-236, 2007

[30]. A. Dayal, "A dream revisited: an archival journey into the making of the Delhi metro rail", *Delhi Metro Rail Corporation Ltd*, 2003