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Traffic Operating Characteristics and its Impacts on Air Pollution in an Urban Area - A Case Study of Chennai, India

Velmurugan.S.,
Scientist, Traffic Engineering and Transportation Planning *(TTP)*,
Central Road Research Institute,
New Delhi - 110 020 India
Ph: ++91 (0) 11 2631 2268
Fax: ++91 (0) 11 2684 5943
E-mail: vms@crridom.org

Madhu. E.,
Scientist, TTP
Central Road Research Institute,
New Delhi - 110 020 India
Ph: ++91 (0) 11 2631 2268
Fax: ++91 (0) 11 2684 5943
E-mail: madhue2002@yahoo.com

Reddy. T. S.,
Area Coordinator (TTP),
Central Road Research Institute,
New Delhi - 110 020 India
Ph: ++91 (0) 11 2631 2268
Fax: ++91 (0) 11 2684 5943
E-mail: tsreddy@crridom.org

Prasad Rao. I.,
Scientist
Road Development and Planning,
Central Road Research Institute,
New Delhi - 110 020 India
Ph: ++91 (0) 11 2631 2268
Fax: ++91 (0) 11 2684 5943
E-mail: prasad@crridom.org

Abstract
The traffic is growing at rapid rate in urban areas of India and the management of traffic operations on the limited road network of the cities has become a gigantic task to the concerned authorities. Despite the concerted efforts of concerned authorities aimed at augmenting road infrastructure, traffic congestion is continuing to increase leading to environmental degradation. Eventually, a major study was commissioned by the Government of India to quantify urban travel by road and associated air pollutants coming from automobile exhausts in eight cities namely, Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Kanpur and Agra. The main objective was to make an accurate assessment of total number of vehicles and develop database and techniques to estimate road traffic and pollution loads in each city. This paper describes operating characteristics of traffic and quantification of traffic and air pollution loads *(base and horizon year)* on major road network of Chennai city.
Key Words: Traffic Growth, Vehicle Vintage, Air Pollution Load Estimation, Auto Fuel Policy

1. INTRODUCTION

Comparatively urbanisation is moderate in India. This is because the major contributor to the Indian economy is agriculture and it is rural based. As per the Census of India 2001, the urban population of India is around 28 percent of the total population. This proportion of urban population has grown from ten percent in 1901 to twenty eight percent in 2001. The disturbing aspect of the urbanization trends in India is the skewed distribution of the urban population. Nearly seventy percent of the urban population is located in Class-I cities *(i.e. population of 100 thousand and above)*. Further, 38 percent of the total urban population is located in metropolitan cities *(i.e. population of 1 million and above)* numbering about thirty-five. This heavy concentration of population in a few centres has resulted in the expansion of cities in density as well as area. Consequently congestion, accidents and increasing levels of emissions from vehicles are contributing to the deteriorating environment in most of the cities. The situation in metropolitan cities of India has reached a stage where the ambient air quality has perceivably deteriorated establishing the need for taking certain stringent actions to control the pollution levels. The city of Chennai is a typical one falling under this category being ranked as the fourth largest metropolitan city in India with a population of 6.23 million *(Census 2001)*.

This paper highlights on the quantification of present and future traffic and air pollution loads [CRRI, (2002)] on the entire city road network of Chennai. This exercise is based on traffic

surveys carried out at strategically identified mid blocks and intersections. Further, this paper presents the operating characteristics of the traffic plying on major road network of the city of Chennai. This has helped to evolve immediate and intermediate steps, which are expected to help in providing relief to the existing and growing congestion problems on the city road network.

2. STUDY DESIGN

The main objective was to make a realistic assessment of total number of vehicles and develop database and techniques to estimate road traffic and pollution loads in the city. Keeping this in mind, the traffic counting stations were chosen in such a way that the survey points cover most appropriately the entire length of the city road network and the traffic interaction between the city and the outside world. Systematically planned classified traffic volume counts were carried out at selected mid blocks and intersections *(i.e. traffic count stations)* for 12-hour, 16-hour and 24-hour periods. To understand the level of service and operating characteristics, spot speeds were measured at mid blocks whereas journey speed and associated delays were also measured along the major road network of Chennai city. On the basis of classified traffic volumes, the quantity of criteria pollutants like Carbon Monoxide *(CO)*, Oxides of Nitrogen *(NO_x)*, Hydro Carbons *(HC)* and Particulate Matter *(PM)* have been estimated as per the category *(inter-city and intra-city)* of travel in the city of Chennai. This is accomplished by using the emission factors and appropriate deterioration factors *(refer Appendix - I)* of different types of vehicles used in India. Further, to assess what is likely to be the contribution of the external traffic to air pollution, the travel made by external traffic on city roads of Chennai and corresponding pollution loads have been estimated. Thereafter, an attempt has been made to estimate the future classified traffic volumes *(2010)* and corresponding pollution loads for different options of automobile technology and fuel quality options.

3. STUDY AREA CHARACTERISTICS

Chennai is the capital city of the State of Tamil Nadu located on the southeastern coast of the country. Chennai Metropolitan Development Authority *(CMDA)* is vested with the responsibility of regulating the developments and accomplishing the planning in the desired direction. The economic base of the Chennai city is a mixed one with small-scale industries and commercial activities distributed over the space of the city. The economic activities are mainly concentrated in and around port area with residences located in the areas connected by circular and radial roads. The city has now emerged as one of the most important magnets for job seeking and attracts migration from rural areas. With the establishment of major businesses including information technology, the metropolitan area of the city has witnessed rapid growth in population over the last two decades. Consequently, the city road network is experiencing severe problems with arterial roads leading to the CBD reeling under congestion with heavy volume of traffic. This could be mainly attributed to the concentration of commercial, industrial and other employment generators around the CBD area and the emergence of growth centers along the major arterials. The city network also faces problems due to poor riding quality, inadequate pedestrian facilities, traffic control and regulatory measures.

The road network system of Chennai is in the form of radial and circular / orbital pattern. There are basically six radial arterial roads namely NH-45 *(i.e. G.S.T. Road to Tindivanam and Villupuram)*, NH-4 *(i.e. Poonamallee Road to Bangalore)*, NH-5 *(G.N.T. Road to Vijayawada and Kolkata)*, NH-205 *(C.T.H. Road to Thiruvallur and Tiruttani)* Tiruvotriyur Main Road *(to Ponneri and Panchetty)* and East Coast Road *(i.e. E.C.R. to Pondicherry)*. Apart from this, the major orbital corridors that exist in the Chennai Metropolitan Area *(CMA)* network are the Inner Ring Road connecting Kathipara Junction on NH-45 to Madras Fertilizers Limited *(MFL)* Junction on NH-5 and Intermediate Ring Road *(i.e. Chennai Bypass: Phase - I)* which connects Tambaram on NH-45 to Maduravoyal on NH-4. The section between NH-4 and NH-5 *(i.e. Chennai Bypass: Phase - II)* is being implemented by National Highways Authority of India *(NHAI)*, Government of India. The development of the city is mainly oriented along these radial and circular roads. A total of about 2200 km *(all categories included)* of roads are considered to

be forming the lifeline of Chennai Metropolitan Area *(CMA)*. The road network map is shown in Figure 1. Chennai is reasonably well served by the public transport system comprising of bus transit and suburban rail system. Besides this, private vehicles like cars and two-wheelers and para-transit systems like autorickshaws also support the transport needs to a great extent. To augment the capacity of the public transport system, Mass Rapid Transport System *(MRTS)* is being built in the city. A part of this system from Beach to Mylapore is already in operation and the extension of the above link from Mylapore to Taramani is expected to be functional in the near future. However, the present ridership levels on MRTS are observed to be much lower than the carrying capacity. As of today, about 55 percent of the commuter trips are estimatedly made by public transport. A number of efforts have been made to move the traffic efficiently using the available road network by providing appropriate junction designs as well as grade separators wherever feasible along with suitable traffic control measures.

4. TRAFFIC STUDIES

In the foregoing section, study area characteristics have been described. To estimate the loads of pollutants it is necessary to estimate the vehicle kilometres travelled on road network of the city. In order to accomplish these estimates, traffic studies have been carried out extensively on the road network of Chennai. The traffic studies were designed and conducted not only to quantify the traffic load by vehicle type and fuel type on the road network of Chennai but also to assess the vintage and other characteristics of the vehicles and their pollution levels. The appropriate studies and their methodology are briefly described in the succeeding sections.

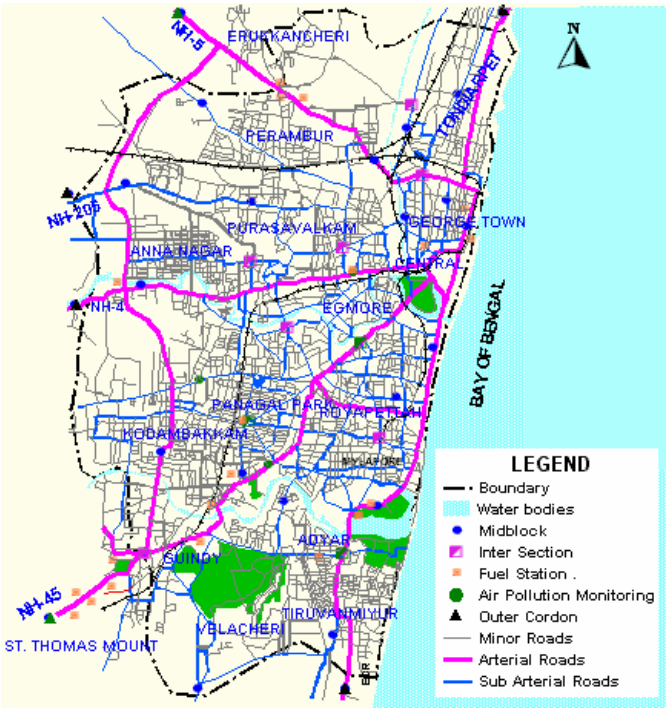

Figure 1: Road Network of Chennai Metropolitan Area

4.1. Mid Block Traffic Counts

A total of twenty-one mid block sections and six outer cordons points were selected *(as indicated in Figure 1)* to conduct classified traffic volume counts. Appropriate proformae were designed to record the number of vehicles moving across the count point during a given time. From these traffic counts, quantum of traffic volume during different hours of the day was obtained and the data was further analyzed to understand the composition of traffic by vehicle type. The traffic volume counts were conducted at all the selected locations for a minimum of 16-hour period *(6.00 am to 10.00 pm)* and a few locations were strategically selected to make 24-hour counts to assess the traffic flow characteristics during night hours. A summary of daily traffic volume on the surveyed locations is presented in Table 1. While expanding the 16-hour volume to 24-hour

volume, due care has been exercised to avoid any errors with respect to the composition of traffic. This is because the night time traffic composition is generally different from that of the day. The results presented in Table 1 show that the traffic on some of the major roads *(i.e. four road sections*) in Chennai exceeds even 100 thousand vehicles per day. Two wheelers and cars contribute to major share of traffic and this is followed by autorickshaws. Slow moving vehicles *(SMVs)* are predominant in a few locations in the northern part of the city. From this table it could be further inferred that the most of the road sections are carrying traffic volumes more than the capacity.

Table 1. Summary of Daily Traffic Volume at Different Mid Blocks in Chennai

S. No.	Road Name	Traffic Lanes*	Proportion *(in %)*									Grand Total
			Cars	Taxis	Autos	Two Wheelers	Buses	Trucks	LCVs[1]	Total FMVs[2]	SMVs[3]	
1	L.B. Road	2	13.1	2.4	10.0	47.7	0.9	1.5	4.1	79.6	20.4	30272
2	C.I.T. Nagar	3	15.5	1.7	10.9	52.1	5.9	1.9	3.5	91.5	8.5	53709
3	Arcot Road	4	13.8	2.1	13.7	51.5	3.1	1.0	1.9	87.3	12.7	111224
4	Inner Ring Road	4	15.3	3.5	10.1	47.4	3.2	4.8	4.5	88.9	11.1	58842
5	EVR Periyar Road	4	15.4	1.6	10.5	44.4	4.0	5.0	5.7	86.7	13.3	56245
6	Poonamallee High Road	4	16.5	1.3	14.1	53.4	2.2	2.6	2.3	92.4	7.6	107658
7	M.T.H. Road	4	7.1	0.1	6.0	62.9	2.5	3.2	3.7	85.5	14.5	55608
8	Paper Mills Road	2	2.9	1.0	8.6	48.5	1.5	1.5	1.5	65.6	34.4	30515
9	Erukencheri High Road	3	3.8	1.3	15.7	40.1	4.0	7.1	2.4	74.5	25.5	60851
10	Kodambakkam High Road	4	1.9	0.4	13.2	24.4	1.1	5.4	1.9	48.3	51.7	21081
11	Thruvotriyur High Road	4	6.3	0.4	15.2	39.6	6.1	5.7	3.8	77.0	23.0	56660
12	Prakasam Salai	2	2.0	0.2	14.7	36.6	1.4	1.4	1.8	58.1	41.9	43905
13	Rajaji Salai	4	11.5	1.6	17.2	54.5	3.3	1.9	2.6	92.5	7.5	110350
14	Kamaraj Salai	6	30.1	1.0	10.2	46.6	4.5	0.8	1.8	95.0	5.0	67049
15	Santhome High Road	2	26.5	1.4	9.7	44.8	3.5	3.1	4.6	93.7	6.3	54240
16	Dr. R.K. Salai	4	25.2	2.5	12.0	51.1	0.8	0.6	1.0	93.0	7.0	86504
17	Kotturpuram Main Road	2	22.3	2.5	11.1	48.9	1.3	1.2	1.7	88.9	11.1	80333
18	Velachery Main Road	2	9.0	1.0	6.6	62.8	3.3	4.1	3.1	89.8	10.2	39216
19	Konnur High Road	2	7.1	2.0	13.8	48.3	4.6	3.0	2.4	81.3	18.7	51218
20	Wall Tax Road	4	4.4	0.4	21.9	40.7	3.6	1.3	3.4	75.8	24.2	71841
21	Anna Salai	6	20.4	4.1	12.2	42.7	6.3	3.0	3.5	92.3	7.7	116603

*Note: * - Approximate Number of Effective Traffic Lanes; 1 - Light Commercial Vehicles; 2 - Fast Moving Vehicles; 3 - Slow Moving Vehicles*

4.2. Intersection Turning Volume Counts

A total number of ten intersections *(as indicated in Figure 1)* were selected for conducting traffic counts. Out of this, 12-hour *(i.e. 8.00 am to 8.00 pm)* turning volume count was done at seven intersections and at the remaining three intersections; survey was conducted for 24 hours. On the basis of the factors evolved for mid-blocks, the intersection traffic flows have been expanded to 24 hours. A summary of daily traffic volume at selected intersections is presented in Table 2. The composition of traffic by different vehicle types shown in this table illustrates that the two wheelers contributes the major share of about 50 percent followed by cars which amounts to about 15 percent.

4.3. Outer Cordon Surveys

A total of six outer cordon points were selected *(as already shown in Figure 1)* around the city for conducting 24-hour classified traffic volume counts along with roadside Origin - Destination *(O-D)* studies. The main purpose of this study was to assess the quantum of the vehicles entering and leaving the city on normal working days. The results of the traffic counts conducted at outer cordons are presented in Table 3. The roadside interviews were carried out on sampling basis for 24 hours at each of the locations covering all types of vehicles. Figure 2 indicates the overall pattern of external traffic entering / leaving the city on a normal working day along with their composition. The above figure reveals that a total of about 92,000 vehicles enter and about 88,000 vehicles leave Chennai on an average working day. It can also be noticed from the above figure

that the goods traffic forms about 23 percent of the total traffic with another 9 percent of traffic is composed of slow moving vehicles like cycles and animal carts etc. Of these vehicles, about 15 percent of the goods vehicles and 4 percent of passenger vehicles are found to be passing through the city.

Table 2. Summary of Daily Traffic Volume at Different Intersections in Chennai

S. No.	Road Name	Traffic Lanes*	Proportion *(in %)*									Grand Total
			Cars	Taxis	Autos	Two Wheelers	Buses	Trucks	LCVs[1]	Total FMVs[2]	SMVs[3]	
1	Adyar Junction	14	21.8	1.7	11.9	48.0	4.1	1.4	2.0	90.9	9.1	117750
2	Kilpauk & Avadi Road Jn.	8	21.5	1.1	12.5	48.2	2.1	2.1	2.1	89.5	10.5	62956
3	Kathipara Junction	24	19.5	4.0	7.7	47.2	6.0	5.9	5.4	95.6	4.4	160272
4	Spencers Junction	18	17.4	2.5	19.6	43.3	4.3	1.1	2.9	91.2	8.8	205568
5	Panagal Park Junction	12	14.8	1.5	17.5	51.1	1.7	0.5	1.1	88.2	11.8	165903
6	Luz Intersection	12	15.5	1.0	19.7	43.5	2.4	0.6	1.2	84.0	16.0	110887
7	Sterling Road Junction	12	20.9	1.5	13.9	50.2	1.6	0.6	1.5	90.2	9.8	168668
8	Mint Junction	15	5.9	0.7	17.7	41.3	4.2	4.1	3.3	77.2	22.8	109140
9	Doveton Junction	10	9.7	0.4	18.2	50.0	2.5	0.3	1.0	82.0	18.0	105560
10	I.O.C. Junction	6	1.0	0.1	8.9	34.5	0.5	14.6	3.6	63.2	36.8	29123

*Note: * - Approximate Number of Effective Traffic Lanes in both the ways; 1 - Light Commercial Vehicles; 2 - Fast Moving Vehicles; 3 - Slow Moving Vehicles*

Table 3. Summary of Daily Traffic Volume on Different Outer Cordons in Chennai

S. No.	Road Name	Traffic Lanes*	Proportion *(in %)*									Grand Total
			Cars	Taxis	Autos	Two Wheelers	Buses	Trucks	LCVs[1]	Total FMVs[2]	SMVs[3]	
1	East Coast Road	2	32.4	7.3	4.7	26.6	9.2	7.0	7.4	94.5	5.5	10087
2	G.S.T. Road (NH-45)	2	15.2	2.0	7.2	30.6	13.1	16.3	9.2	93.6	6.4	48393
3	Poonamallee Road (NH-4)	2	18.0	4.3	2.5	31.1	7.7	24.0	8.6	96.2	3.8	26441
4	Thiruvellore Road (NH-205)	2	8.1	1.4	6.4	54.6	5.5	5.2	4.3	85.5	14.5	51806
5	G.N.T. Road (NH-5)	2	10.0	1.9	5.1	32.4	5.4	30.8	8.8	94.3	5.7	25764
6	S.N. Chetty Road	2	8.8	2.2	9.5	35.7	3.8	18.9	5.6	84.4	15.6	17563

*Note: * - Approximate Number of Effective Traffic Lanes; 1 - Light Commercial Vehicles; 2 - Fast Moving Vehicles; 3 - Slow Moving Vehicle*

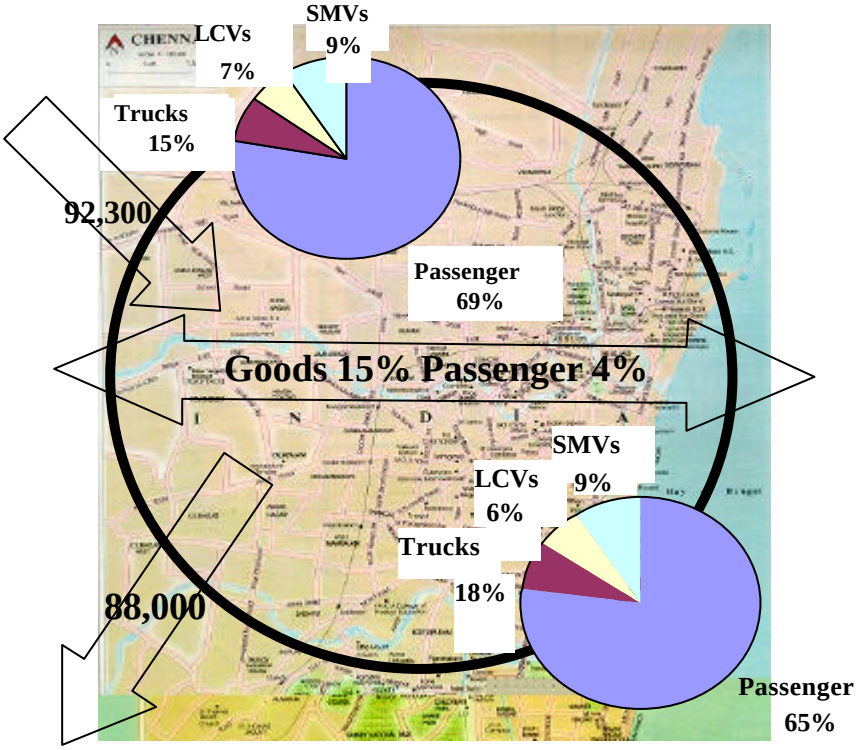

Figure 2. Pattern of External Traffic in Chennai

4.4 Fuel Station Survey

A total of eighteen fuel stations and two goods terminals within the city were selected to conduct interviews of the owners/drivers of the vehicles visiting the fuel stations/goods terminals. Care was exercised to locate the survey stations across the space of Chennai city so as to obtain the representative sample of the vehicles plying on the city road network. These surveys were conducted for a period of 12 hours *(from 8.00 am to 8.00 pm).* At these fuel stations, surveys were carried out with the help of pre-designed proforma to record make, year of manufacture, origin and destination of the trip, amount of fuel filled, average kilometre travelled per day, frequency of trip and the place of garaging of the vehicles etc. A total of 5692 vehicles *(forming a sample of 18.3% of the total traffic entering the fuel stations)* covering different vehicle types were interviewed. The estimated average age of the sampled vehicles is shown in Figure 3 and these have been statistically compared with that estimated from the records of the registered vehicles maintained by Road Transport Authorities *(RTA)* by performing normal approximation test [Pignatoro, (1973)]. This test indicated that the average age of the sampled vehicles and registered vehicles for all the modes are statistically significantly different from one another thereby indicating that the current vehicle population is significantly different from the registered vehicle population. Therefore, it can be concluded that all the registered vehicles are not currently plying on the city roads.

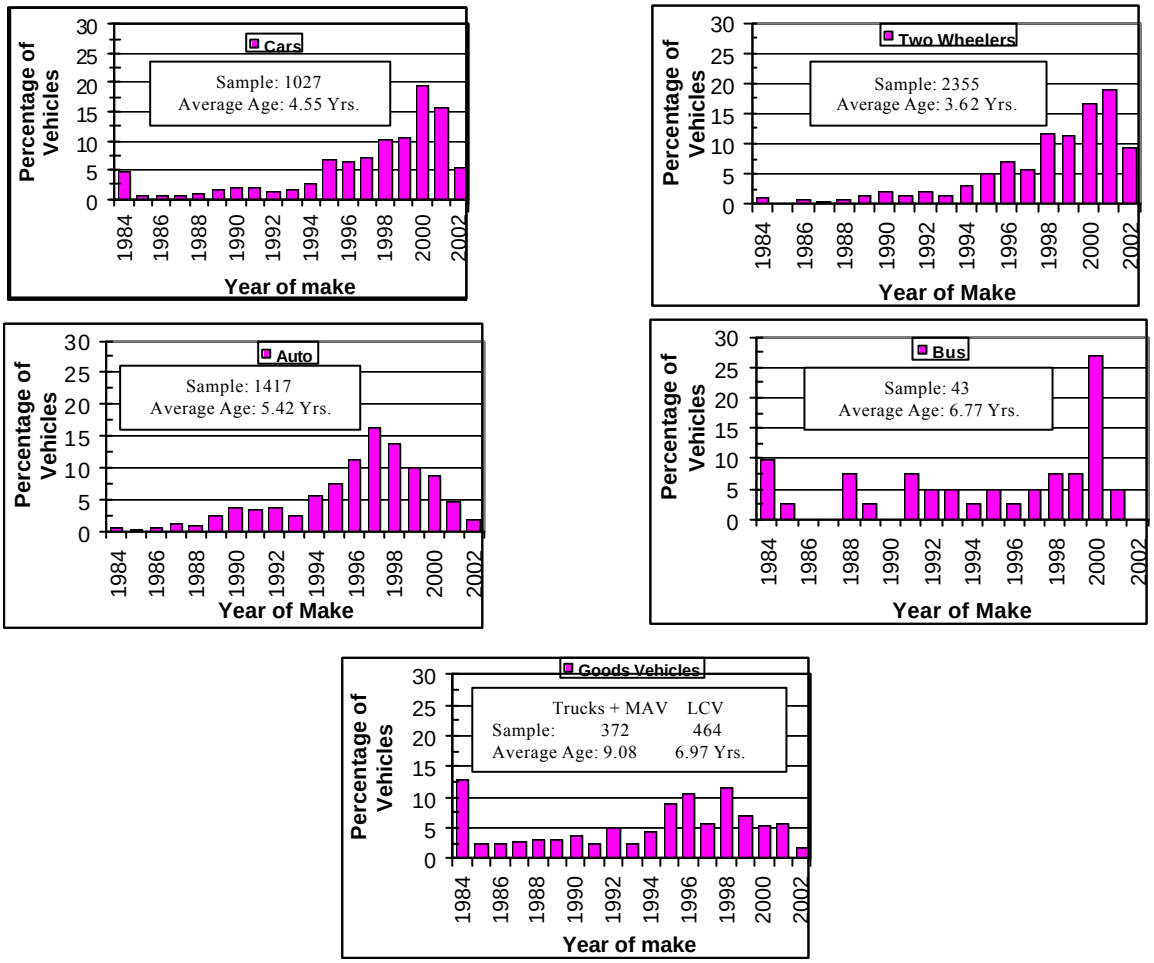

Figure 3. Distribution of Vehicles as per Age at Fuel Stations in Chennai

4.6. Spot Speed Measurements

The quality of traffic flow is judged on the basis of journey speed and running speed of the vehicles. The pollutants in the exhaust will increase with speed changes and the vintage of the vehicles. With a view to understand the quality of flow, spot speed measurements have been made at a few of the selected mid-block locations. The comparative results of the spot speed studies for selected road sections at inner, middle and outer areas are presented in Figure 4 in the form of cumulative frequency distribution of speeds. From the figure it could be seen that the spot speeds

are higher as one goes away from inner area to outer area. A summary of the observed average spot speeds on selected road sections in Chennai is given in Table 4. From the above table, it can be deduced that the composition of the vehicles and the location of the road has direct influence on the observed spot speeds.

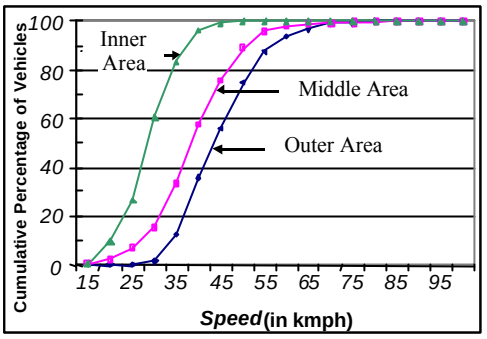

Figure 4: Cumulative Distribution of Speeds on Selected Locations in Chennai

Table 4. Observed Spot Speeds *(in kmph)* of Vehicles on Selected Road Sections

S. No.	Name of the Road	Time Period	Car + Taxi	Two Whe-eler	Auto	Bus	LCV	Trucks + MAV
1	Lattice Bridge Road	08:00 - 18:00	30.9	35.4	32.9	25.6	27.9	24.6
2	CIT Nagar I-Main Road	08:00 - 18:00	26.7	28.3	25.2	25.8	26.0	26.3
3	Jawaharlal Nehru Road	17:00 - 19:00	34.6	31.2	29.6	30.5	31.8	32.2
4	Poonamallee High Road	14:00 - 15:30	48.9	42.5	38.7	39.4	41.4	43.2
5	Erukencheri High Road	16:00 - 17:30	37.7	34.6	30.0	32.7	33.6	32.3
6	Tiruvotriyur High Road	18:00 - 19:30	32.6	31.6	26.9	26.2	26.5	26.8
7	Kamaraj Salai	12:00 - 14:00	42.1	37.1	37.1	36.0	37.8	40.7
8	Dr. Radha Krishnan Salai	12:00 - 14:00	30.2	30.5	27.2	29.4	29.2	28.2
9	Kotturpuram Main Road	09:30 - 11:00	50.5	42.8	39.7	43.2	45.1	44.2
10	Velachery Main Road	11:30 - 13:30	41.0	39.4	35.3	36.9	37.9	40.0
11	Anna Salai*	23:00 - 08:00	53.9	42.1	37.5	48.5	50.2	50.8
12	Anna Salai	08:00 - 11:00	45.8	41.2	39.2	42.7	47.5	41.8

** Night Time Note: All figures in kmph; Autos - Para transit mode having 3 wheels; HCV - Heavy Commercial Vehicles (Goods Vehicles); MAV - Multi Axle Goods Vehicles; Two Wheelers - Scooters and Motor Cycles having two wheels; SMVs - Slow Moving Non Motorized Vehicles*

4.7. Speed and Delay Studies

The speed and delay study was carried out on the five major arterial roads in the city covering different hours of day by moving car method. A total of 4 runs were made for both direction of travel on the selected test sections to assess the variations in journey and running speeds along with the delays and their causes. The results of the survey are presented in Table 5. It was observed from this study that the maximum delay was witnessed on Beach Road *(near Santhome*

Church) whereas minimum delay was on Dr. R. K. Salai. The percentage of delays are ranging from as high as 50 to as low as 9. The delay per km is varying from 81 to 13 seconds. The above situation clearly warrants for undertaking immediate capacity augmentation measures for the arterial / sub - arterial road network of the city.

Table 5. Journey Speed and Delay on Major Arterial Roads in Chennai

S. No.	Road Name	Time of Survey	Direction	Distance *(in Km)*	Travel Time *(in Min)*	Journey Speed *(in Kmph)*	Delay *(in % of Travel Time)*	Delay *(in Sec / km)*
1	Beach Road *(Adyar Junction - Royapuram Flyover)*	9:20 AM	UP	12.4	33	22.3	50.2	81
		10:07 AM	DOWN	12.2	24	30.9	13.8	16
		12:34 PM	UP	12.4	25	29.6	22.2	27
		1:43 PM	DOWN	12.3	22	33.1	13.0	14
2	Anna Salai *(Kathipara Junction - Simpson Junction)*	5:56 PM	UP	11.6	31	22.4	21.1	34
		5:08 PM	DOWN	11.6	30	23.5	23.7	36
		11:01 AM	UP	11.6	28	24.8	27.9	41
		11:39 AM	DOWN	11.6	27	25.6	24.1	34
3	Dr. RK Salai *(Beach Rd. Jn. - Poonamalle High Road. Jn.)*	8:31 PM	UP	6.7	17	23.3	8.7	13
		8:11 PM	DOWN	7.3	18	24.1	11.7	18
		3:53 PM	UP	6.7	19	21.4	12.2	20
		4:17 PM	DOWN	7.3	19	23.2	26.4	41
4	Inner Ring Road *(Kathipara Jn. - Nellore Road. Jn.)*	4:59 PM	UP	17.9	38	28.4	16.9	21
		7:32 PM	DOWN	17.9	43	24.9	14.2	21
		11:37 AM	UP	17.9	34	32.0	10.9	12
		2:01 PM	DOWN	17.9	31	35.0	12.0	12
5	P H Road *(Fort - Inner Ring Road. Jn.)*	5:57 PM	DOWN	9.8	29	20.6	27.1	47
		6:31 PM	UP	9.8	34	17.5	22.5	46
		12:59 PM	UP	9.8	23	25.0	15.1	22
		12:30 PM	DOWN	9.8	25	23.5	21.0	32

4.8 Air Pollution Measurements

With a view to make indicative assessment for the quality of air and its direct relation with traffic, hourly / 4-hourly / 8-hourly air pollution concentrations *(of CO, NO_2, SO_2, SPM, RSPM and THC)* has been measured along with the road traffic measurements for every 15 minutes during the survey period. It was observed that there is a fair amount of correlation between the hourly traffic flows and respective hourly concentrations of CO and HC only in the case of sites located within the city. However, there was no consistent relationship between the traffic flow and other pollutants like NO_2, SO_2, THC, SPM and RSPM even for the sites located within the city. This goes to suggest that the ambient air quality does not depend simply on the traffic volumes but some other factors also. These factors could be from other sources *(i.e. industrial, commercial and domestic sources)* and meteorological conditions. For instance, it is to be noted that the normal sources of SPM and RSPM are road dust, vehicle emissions, construction, quarrying, fire places, and fugitive sources through the mechanical break-up, abrasion and erosion of materials.

5. TRAFFIC LOADS ON ROAD NETWORK

The classified traffic counts conducted at twenty one mid block, six outer cordon stations and ten intersections provided extensive representative data on traffic flows on the road network of Chennai. Employing this data, the traffic flows have been estimated on the adjoining links in the neighborhood of the traffic count points. Thus, the traffic flows along with composition have been worked out for each of the links of the primary road network identified for the purpose of this study. To validate the figures of traffic computed on neighbouring links, sample traffic counts were made to confirm the same. The estimated traffic loads on each of the links is translated into pictorial form using the digitized map of Chennai and *GIS Software (TRANSCAD)* and the same is presented in Figure 5. From the above figure, it can be seen that the five major radials and inner ring road cater to the major portion of traffic movements in Chennai. Using the link traffic loads and composition of traffic by vehicle type, vehicle - kilometers travelled on each of the links have

been estimated and in turn the total vehicle - kilometers travelled by each category of vehicles on the road network of Chennai have been estimated. To validate the vehicle - kilometres traveled, comparison has been made by estimating the vehicle - kilometres travelled on the basis of responses obtained from the driver interviews at the fuel stations and vehicles in use. The estimates of vehicle kilometres traveled as obtained from both the sources are presented in Table 6 and the following can be inferred from this table.

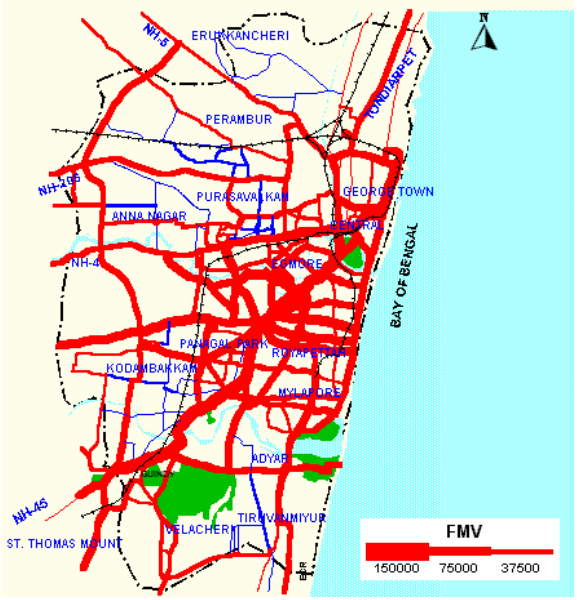

Figure 5. Traffic Flow Pattern on Major Roads

Table 6. Vehicle-Kilometres Estimated from Roadside Counts and Fuel Stations

Serial Number	**Vehicle Type**	**Vehicle - kilometres / day *(in millions)***	
		Roadside Counts	**Fuel Stations**
1	Cars	5.03 *(20.1)*	3.62 *(16.3)*
2	Taxis	0.56 *(2.2)*	0.62 *(2.8)*
3	Two Wheelers	13.45 *(53.7)*	13.80 *(62.1)*
4	Autos	4.24 *(16.9)*	2.50 *(11.3)*
5	Goods Vehicles	1.04 *(4.6)*	1.44 *(6.5)*
6	Buses	0.61 *(2.4)*	0.23* *(1.0)*
Total		**24.93** ***(100.0)***	**22.22** ***(100.0)***

Note: Figures within brackets refer percentages

**The sample size in the case of buses from Fuel Station Surveys is small and hence it is less reliable.*

- It can be seen that the two wheelers *(54%)* contributing major part to the total traffic followed by cars *(20%)*, autos *(17%)* and goods vehicles *(5%)*. The buses and taxis are contributing each only about 2% of the total amount of travel.
- The estimated vehicle-kilometres of travel from roadside and the fuel station interviews do not exactly match because most of the external traffic may not get accounted for at the fuel stations.

- Though the major road network constitutes only about 12 percent in total length, it carries more than 70% of total traffic volume. This situation clearly warrants for effecting improvements to the major road network so as to achieve smoother and congestion free movement of the traffic.

6. ASSESSMENT OF AIR POLLUTION LOADS

For working out the quantity of criteria pollutants *(i.e. CO, NO_x, HC and PM)*, an interactive computer program was written in C++ language and input files regarding the quantum of travel and the share of different types of vehicles and their vintage *(refer Figure 3)* along with appropriate / corresponding emission and deterioration factors *(refer Appendix-I)* were separately created and used in the computations. Thus, the method used to estimate the air pollution loads is given below:

$$E_i = \sum_i (Veh_j D_j) e_{ijkm} \qquad \text{Eq. 1}$$

where, E_i is the total estimated emission of each pollutant *(expressed as g/day or tons/day)*, Veh_j is the number of vehicles of type j, Dj is the distance travelled by vehicle type j and e_i is the emission factor of vehicle type i *(expressed as g/km)*. The estimated pollution loads using the above method *(i.e. given in Eq. 1)* as per the category of travel *(i.e. inter-city and intra-city)* in the city is presented in Table 7.

6.1 Impact of Bye Passable Traffic on Air Pollution Loads

The travel made on city roads by the vehicles coming from outside the city is quite significant in the case of bigger cities like Chennai. Moreover, there is a general feeling that the vehicles coming from outside pollute significantly and they should be bye passed. In this study, the qunatum of the intercity traffic touching and passing through the city of Chennai has been estimated. Table 8 gives the volume of traffic as per vehicle type, intercity *(entering and leaving)* and passing through the city of Chennai. In order to estimate the impact of bye passable traffic on the air pollution loads, the Origin - Destination data *(refer Section 4.3)* collected from different cordon points was used to find out the mode-wise bye passable traffic and their respective vehicle kilometres. While calculating the bye passable traffic, it was assumed that the buses would continue to ply through the city. The estimated vehicle kilometres of the bye passable traffic is to the tune of 0.432 million vehicle - kilometres. Consequently, the pollution loads of CO, NO_x, HC and PM contributed by the above vehicle - kilometres of travel are 2.53 t, 1.50 t, 0.92 t and 0.32 t respectively. Hence, the construction of bypasses around the periphery of Chennai is expected to reduce the pollution loads in the base year *(i.e. 2002)* for CO, NO_x, HC and PM by 1.4, 5.5, 1.0 and 4.3 percent respectively. The maximum percentage reduction in pollutants is found in the case of *NO_x and PM*. This can be attributed to larger number of goods vehicles *(which emit higher proportion of NO_x and PM as compared to other vehicles)* are falling under the bye passable traffic category. Apart from this, the study has also attempted to assess the impacts of the recommended options of Auto Fuel Policy up to 2010 A.D. by projecting the future travel demands. The purpose of the analysis was to understand the impacts of different options recommended in auto fuel policy road map *(given in Annexure - II)* and the procedure adopted for accomplishing the same is described in the succeeding section.

6.2 Assessment of Future Pollution Loads

For the assessment of the future travel demand, it becomes necessary to project the travel demand and the corresponding vehicle - kilometers travelled by each class of vehicles by conventionally accepted techniques of travel demand projections [TRB (1978), Oppenheim, N., (1995)]. The approach adopted to project the travel demand is as shown in Figure 6. It involves two steps:

I. Projection of passenger trips and their modal split; and then the vehicle - kilometers travelled by different modes *(considering percentage share of trips by Private Cars, Two Wheelers, Buses and Rail)*.

II. Projection of the vehicle population of commercial vehicles for the future and estimating the vehicle - kilometers travelled *(in the case of Autos/Taxis and Goods vehicles)* by them.

Table 7. Estimated Loads of Pollutants as per Vehicle Type in Chennai as of 2002

Vehicle Type	**Vehicle - kilometers** *(in millions)*	**Pollution Load in Tonnes Per Day**			
		CO	**NO_x**	**HC**	**PM**
Cars	5.03 *(20.18%)*	26.60 *(15.03%)*	6.86 *(25.13%)*	4.31 *(4.51%)*	1.04 *(14.27%)*
Taxis	0.56 *(2.25%)*	3.01 *(1.7%)*	1.11 *(4.07%)*	0.22 *(0.23%)*	0.38 *(5.21%)*
Two Wheelers	13.45 *(53.95%)*	59.34 *(33.53%)*	2.26 *(8.28%)*	38.46 *(40.21%)*	1.61 *(22.09%)*
Autos	4.24 *(17.01%)*	76.94 *(43.47%)*	0.49 *(1.79%)*	50.82 *(53.14%)*	1.73 *(23.73%)*
Goods_Local	0.41 *(1.66%)*	1.45 *(0.82%)*	0.94 *(3.44%)*	0.14 *(0.14%)*	0.18 *(2.53%)*
Goods_Inter City	0.63 *(2.51%)*	6.45 *(3.64%)*	5.02 *(18.39%)*	0.80 *(0.84%)*	1.00 *(13.65%)*
Intra-City Bus	0.49 *(1.96%)*	2.54 *(1.44%)*	8.42 *(30.84%)*	0.71 *(0.74%)*	1.07 *(14.68%)*
Inter City Bus	0.12 *(0.49%)*	0.67 *(0.38%)*	2.20 *(8.06%)*	0.18 *(0.19%)*	0.28 *(3.84%)*
Total	24.93 *(100%)*	177.00 *(100%)*	27.30 *(100%)*	95.64 *(100%)*	7.29 *(100%)*

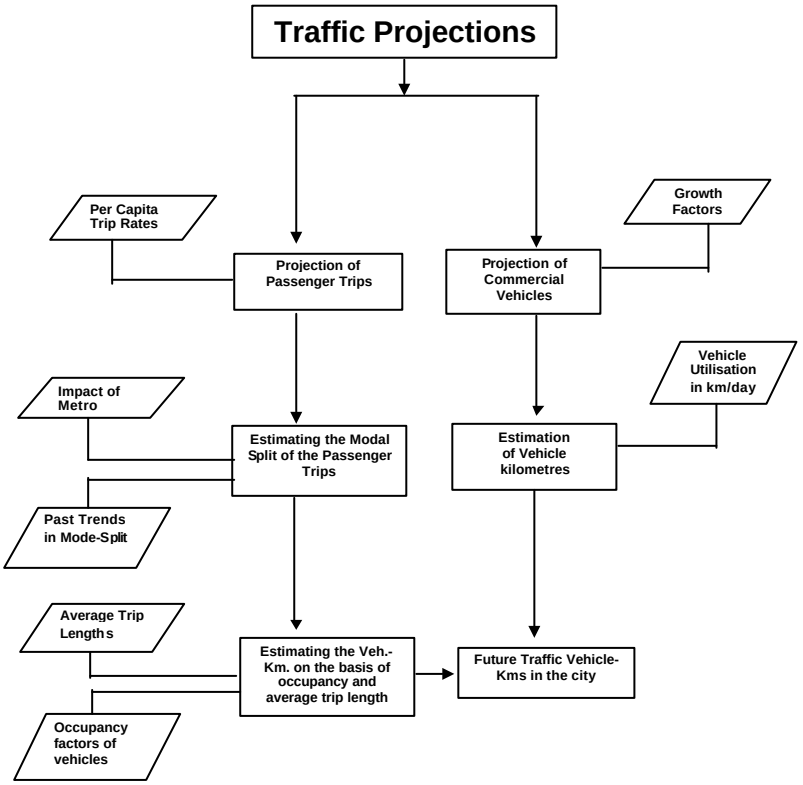

Figure 6. Methodology of Traffic Projections

Table 8. Volume of External Traffic as per Vehicle Type

S.No.	Trip Type	Number of Vehicles by Vehicle Type									Grand Total
		New Brand Cars	Old Brand Cars + Taxis	Two Wheelers	Autos	Buses	LCVs	HCVs	Total FMVs	SMV & Others	
1	Originating from the City	7106 (43.57%)	4842 (41.05%)	30974 (45.17%)	5019 (45.99 %)	8088 (56.9%)	5750 (44.43 %)	10126 (35%)	71905 (43.93 %)		
2	Terminating within the City	8565 (52.51%)	6157 (52.2%)	35376 (51.59%)	5482 (50.23 %)	5260 (37.01 %)	6008 (46.42 %)	13913 (48.09%)	80761 (49.34 %)	**16368**	**180049**
3	Passing Through the City	639 (3.92%)	795 (6.74%)	2227 (3.25%)	413 (3.78%)	866 (6.09%)	1185 (9.16%)	4890 (16.9%)	11015 (6.73%)		
	Total	**16310** (100.0 %)	**11794** (100.0 %)	**68577** (100.0 %)	**10914** (100.0 %)	**14214** (100.0 %)	**12943** (100.0 %)	**28929** (100.0 %)	**163681** (100.0 %)		

In Step-I, the total passenger trips made in the city are estimated by employing the Per Capita Trip Rate *(PCTR).* Using the average trip length and occupancy factors by each mode, vehicle - kilometers is determined for each mode. For the horizon year, *(i.e. 2010 A.D.)* population was projected and using appropriate PCTR, passenger trips were estimated. These passenger trips are split according to mode as per the observed modal split as given in Table 9 [RITES (1995)]. The estimated share of future vehicle - kilometers by each vehicle type *(namely Cars, Two Wheelers and Buses)* was determined based on the average trip length and modal split in the horizon year. In Step II, it is assumed that the growth of vehicle population *(namely, autos, taxis and goods vehicles)* is based on past trends as well as saturation, by type of vehicle separately. The estimated share of future vehicle - kilometers for each vehicle type was arrived based on average utilization and the estimated number of vehicles in daily use in the horizon year. Using the above two steps, the future travel demand *(i.e. vehicle - kilometers)* was projected and the same is presented in Table 9. The increased travel demand, leading to increased vehicle - kilometers, will consume more fuel and generate increased amounts of pollution. As per this study, the estimated vehicle - kilometres *(which is around 25 million)* is expected to register a steep increase and touch a figure of 35 million vehicle - kilometres by 2010 *(i.e. refer Table 6 and 10)*. Further, it can be observed from Table 10 that the share of two wheelers is expected to decrease and at the same time the share of cars and public transport are expected to increase proportionately. This is due to the improving socio-economic status and expected improvements in public transport facilities respectively.

Since the proposed road map *(see Appendix-II)* includes upgradation of engine and fuel qualities in future *(i.e. 2005 and 2010),* it was considered appropriate to assess the impact of the road map on the pollution loads for different metropolitan cities considered in this study [CRRI, (2002)]. For this assessment, the estimated future travel in the city of Chennai *(as shown in Table 10)* has been utilised. The road map proposed by the committee has been translated in to corresponding emission factors, which have been applied to different vintages of vehicles for estimating vehicular pollution load in the year 2010. The average age and the distribution of vehicles as per age were assumed to remain similar to that of today. Table 11 presents the estimated vehicular pollution loads for the city of Chennai under the proposed road map as well as for the scenario continued as it exists today *(i.e. Business As Usual)*. In Business As Usual *(BAU)* scenario, it is assumed that there will be no further improvement in vehicle and fuel technology beyond 2002. The pollution loads are estimated under both BAU and road map scenarios using the projected vehicle - kilometres of 2010. It can be inferred from this table that even if the BAU were allowed to continue till 2010, the pollution loads due to traffic would be marginally lesser than the base year for all the criteria pollutants except NO_x *(refer Table 7 and 11).* This is in spite of the estimated increase of more than 50 percent in vehicle - kilometers of travel. This is attributable to higher proportion of vehicles of cleaner technologies expected to replace the older vehicles in future. It can be further noted from this table that the road map provided by the Committee is expected to reduce the vehicular pollution loads of different pollutants considerably despite the steep increase in vehicle - kilometers *(traffic loads).* This reduction in vehicular pollution loads is maximum in the case of PM, which is about 34 percent.

Table 9. Estimated Population, Modal Split and Future Passenger Kilometres in 2010

Horizon Year *(2010)* Population *(in millions)*	Horizon Year *(2010)* Passenger-Trips *(in millions)*	Estimated Modal Split *(in %)*			
		Private Cars	Two Wheelers	Autos / Taxis	Public Transport
9.36	101.18	13	20	12	55

Table 10. Estimated Vehicle - Kilometres in 2010

Serial Number	Vehicle Type	Vehicle Kilometres *(in millions)*
1	Cars	9.469
2	Taxis	0.652
3	Two Wheelers	16.498
4	Autos	4.934
5	LCVs	1.015
6	Trucks	0.905
7	Buses	0.940
	Total	34.413

Table 11. Estimated Pollution Loads in Different Cities as per the BAU and Proposed Road Map in 2010

(in tonnes per day)

Pollutant	Business As Usual	Road Map
CO	133.77	93.37 *(30.2)*
NO_x	30.07	22.98*(23.56)*
HC	66.63	46.48*(30.24)*
PM	5.39	3.16*(33.52)*

Note: The values in parenthesis refer to the percentage reduction as compared BAU

7. CONCLUSIONS AND RECOMMENDATIONS

It is clearly seen from the present study that the roads in Chennai are presently carrying the traffic volumes higher than their capacities with reduced speeds and associated delays. The operating speeds of the traffic on major road network of the city are higher as one goes away from the inner areas of the city. The estimated vehicle - kilometre *(which is around 25 million)* is expected to register a steep increase and touch a figure of 35 million vehicle kilometres by 2010. However, the capacity of roads cannot be easily expanded because of physical constraints imposed by built-up area on either side of the carriageway. Besides this, roadside encroachments are another serious problem in the city as they hinder smooth flow of traffic. The study has revealed that though the major road network in the city is limited in length, it carries as much as 70 percent of the total traffic loads in the city of Chennai. The base year *(i.e. 2002)* estimated daily pollution loads of CO, NO_x, HC and PM from vehicles is observed to be 177.00 t, 27.29 t, 95.64 t and 7.29 t respectively. To assess what is likely to be the contribution of the external traffic to air pollution, the travel made by this traffic on city roads of Chennai and corresponding pollution loads have been estimated. From this analysis, it could be inferred that the construction of bye passes around the periphery of Chennai would bring down PM and NO_x loads significantly.

It is to be noted that the emissions from vehicles depend on several factors such as vehicle characteristics *(type of fuel used, engine size etc.)*, driving conditions, emission control devices and meteorological conditions. Hence, the impact of improvement in engine technology and fuel quality have been explored in this paper by estimating the pollution loads under both BAU and policy options of vehicle technology and fuel quality using the projected vehicle - kilometers of 2010 for Chennai. It can be inferred from this analysis that even if the BAU were allowed to

continue till 2010, the pollution loads due to traffic would be marginally lesser than the base year for all the criteria pollutants except NO_x. This is attributable to higher proportion of vehicles of cleaner technologies which are expected to replace the older vehicles in future. To achieve maximum efficiency in traffic operations, it is proposed to develop the major arterial road network of the city as express route system having grade separators and signal free environment as shown in Figure 7. Moreover, the following Traffic System Management *(TSM)* strategies can be attempted to discourage the use of private automobiles

- Levying of parking charges at the destination *(office / shopping)* end
- Road Pricing in central areas and heavily trafficked routes
- Prohibiting the entry of particular type of vehicles during the part or whole of the day
- Exclusive bus-lanes and busways

It is suggested that the recommended options of Auto Fuel Policy should be strictly adhered along with more stringent Inspection and Maintenance *(I&M)* norms in the city. Further, it is imperative to explore the usage of alternate fuels such as CNG *(as being practised in Delhi)* for public transport vehicles and intermediate para-transit *(i.e autos and taxis)* modes so as to achieve further improvement in air quality of Chennai,. The above-indicated steps are mainly suggestive and needs more detailed technical studies and investigations before embarking on implementation.

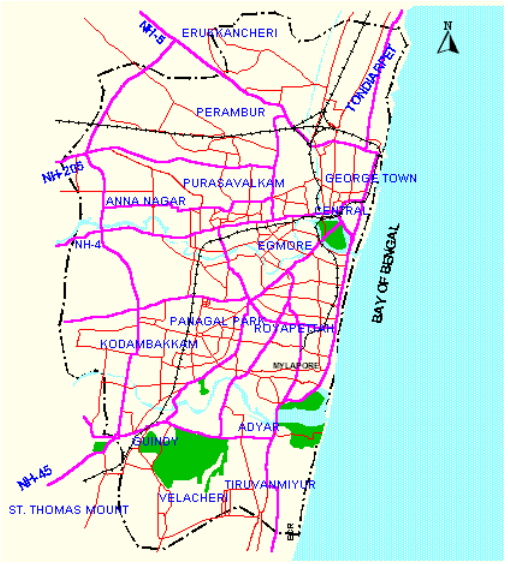

Figure 7. Road Network Identified for Upgrading to Expressway System in Chennai

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Appendix: I

Emission Factors for Different Categories of Vehicles

Year	Type	SPECIFIED POLLUTANT (gm/km)			
		CO	HC	NOX	PM
1986-1990	2W 2T	6.5	3.9	0.03	0.23
1991-1995		6.5	3.9	0.03	0.23
1996-2000		4	3.3	0.06	0.1
2001-2005		2.2	2.13	0.07	0.05
2006-2010		1.4	1.32	0.08	0.05
1986-1990	2W 4T	3	0.8	0.31	0.07
1991-1995		3	0.8	0.31	0.07
1996-2000		2.6	0.7	0.3	0.06
2001-2005		2.2	0.7	0.3	0.05
2006-2010		1.4	0.7	0.3	0.05
1986-1990	3W 2T	14	8.3	0.05	0.35
1991-1995		14	8.3	0.05	0.35
1996-2000		8.6	7	0.09	0.15
2001-2005		4.3	2.05	0.11	0.08
2006-2010		2.45	0.75	0.12	0.08
1986-1990	PCG	9.8	1.7	1.8	0.06
1991-1995		9.8	1.7	1.8	0.06
1996-2000		3.9	0.8	1.1	0.05
2001-2005		1.98	0.25	0.2	0.03
2006-2010		1.39	0.15	0.12	0.02
1986-1990	PCD	7.3	0.37	2.77	0.84
1991-1995		7.3	0.37	2.77	0.84
1996-2000		1.2	0.37	0.69	0.42
2001-2005		0.9	0.13	0.5	0.07
2006-2010		0.58	0.05	0.45	0.05
1986-1990	LCV	8.7	0.34	3.15	0.8
1991-1995		8.7	0.28	3.15	0.8
1996-2000		6.9	0.28	2.49	0.5
2001-2005		5.1	0.14	1.28	0.2
2006-2010		0.72	0.063	0.59	0.07
1986-1990	TRUCKS	5.5	1.78	9.5	1.5
1991-1995		5.5	1.78	9.5	1.5
1996-2000		4.5	1.21	8.4	0.8
2001-2005		3.6	0.87	6.3	0.28
2006-2010		3.2	0.87	5.5	0.12
1986-1990	BUS	5.5	1.78	19	3
1991-1995		5.5	1.78	19	3
1996-2000		4.5	1.21	16.8	1.6
2001-2005		3.6	0.87	12	0.56
2006-2010		3.2	0.87	11	0.24

Source: CPCB, *(2000)*

Deterioration Factors for Different Categories of Vehicles

Age of Vehicles *(Years)*	2 Wheelers CO, HC, NO_x PM	3 Wheelers CO, HC, NO_x PM	Passenger Car Gasoline CO, HC, NO_x PM	Multi utility vehicle gasoline CO, HC, NO_x PM
15-20	-	-	1.355	-
10-15	1.4	-	1.17	1.275
10-15	1.3	1.7	1.28	1.255
0-5	1.2	1.475	1.097	1.19

Age of vehicles *(years)*	Passenger Cars			Taxis			Buses			Trucks			MUV + LCV		
	PM	CO	HC & NO_x	PM	CO	HC & NO_x	PM	CO	HC & NO_x	PM	CO	HC & NO_x	PM	CO	HC & NO_x
15 – 20	1.355	1.18	1	-	-	-	-	-	-	-	-	-	-	-	-
10 – 15	1.17	1.085	1	-	-	-	-	-	-	1.80	1.475	1	1.275	1.100	1
5 – 10	1.28	1.14	1	1.263	1.133	1	1.355	1.18	1	1.595	1.33	1	1.255	1.125	1
0 – 5	1.097	1.05	1	1.187	1.095	1	1.19	1.015	1	1.35	1.17	1	1.19	1.095	1

Appendix: II

Proposed Vehicular Emission Norms as Per Road Map

I. NEW VEHICLES *(except Two & Three Wheelers)*

ENTIRE COUNTRY

- **Euro II / Bharat Stage II emission norms**
  From 1.4.2005
- **Euro III equivalent emission norms except heavy goods carriages**
  From 1.4.2010

7 mega cities and other identified cities

- **Euro II /Bharat Stage II emission norms**
- **Delhi, Mumbai, Kolkata and Chennai**
  Already introduced in the year 2000 & 2001
- **Bangalore, Hyderabad & Ahmedabad**
  From 1.4.2003
- **Other identified cities**
  From 1.4.2004
- **Euro III equivalent norms for all private vehicles and the city public transport vehicles**
  From 1.4.2005
- **Euro IV equivalent emission norms for all private vehicles and the city public transport vehicles**
  From 1.4.2010

New Two and Three Wheelers

- **Emission norms for 2/3 wheelers to be the same in the entire country**
  - Euro - II / Bharat Stage II Norms: from 1.4.2005
  - Euro - III/Bharat Stage III norms: Preferably from 1.4.2008 but not later than 1.4.2010

II. IN-USE/OLD VEHICLES

PUBLIC TRANSPORT / INTERMEDIATE PUBLIC TRANSPORT VEHICLES

City Buses

All city buses in the seven major metropolitan cities *(i.e. Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad and Ahmedabad)* and other identified cities should conform to:

- At least 1996 emission norms preferably from 1.4.2004 but not later than 1.4.2005.
- At least 2000 emission norms not later than 1.4.2008

TAXIS

All taxis in the seven major metropolitan cities *(i.e. Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, and Ahmedabad)* and other identified cities should conform to:

- At least 1996 emission norms preferably from 1.4.2004 but not later than 1.4.2005.
- At least 2000 emission norms not later than 1.4.2008

Three Wheelers *(Autos/Tempos)*

All 3 Wheelers in the seven major metropolitan cities *(i.e. Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, and Ahmedabad)* and other identified cities should conform to:

- At least 1996 emission norms preferably from 1.4.2004 but not later than 1.4.2005.
- At least 2000 emission norms not later than 1.4.2008

Inter-State Buses

All Inter-State Buses in the seven major metropolitan cities *(i.e. Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, and Ahmedabad)* and other identified cities.

- To conform to at least Euro I / Bharat Stage I norms preferably from 1.4.2004 but not later than 1.4.2005.
- To conform to at least Euro II / Bharat Stage II norms from 1.4.2008.