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Mass Transportation Strategies for Sustainable Future

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Abstract: In recent years, there has been much interest among urban and transportation planners to integrate urban transportation and land development planning. This is very much driven by concerns about climate change and sustainability. The 1987 report by the World Commission on Environment and Development, also known as the Brundtland Commission, provided a formal definition of sustainable growth: "Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". Coupled with the call for reduction in carbon dioxide emission in the Kyoto Protocol and other regional and international agreements, sustainability has grown to become an overarching concept involving environmental quality, social equity and economic development. Today, sustainable development is widely viewed as development that improves the standard of living and quality of life, while at the same time protecting and enhancing the natural environment and preserving local culture and history. Numerous efforts have been made globally to increase the sustainability of development patterns. The aim of this work is ultimately to encourage modal shift from private cars to public transport. OBJECTIVES Sustainability in transportation system is becoming an important issue day by day and can be observed distinctly with the traffic congestion observed in Urban area and poor quality of air we breathe-in having an impact on our health. There is an urgent need for an improved and justified access to the services, be it social services or economic services in all areas across the globe. The criteria for assessing the Sustainability of transportation base have nowhere been characterised and it encourages a lot of research work. Sustainability indicators needed to be developed by studying the on-going construction sites and by interacting with all the stakeholders making an impact and also those who gets impacted in this field. Bearing in mind, the need of day without dealing with the capacity of the next generation to fulfill their own particular needs, research work has been carried out with following broad objectives. 1-Identification of Sustainability Indicators for the transportation framework while undertaking development in Metropolitan city Delhi. 2-To simplify the methodology for Sustainability Evaluation.

***Index Terms* – Mass transportation, Sustainable, Development, Environment, Quality of Life**

I. INTRODUCTION

Traffic and transportation system varies largely from one country to another country and as well from one city to another city. So are the travelling patterns of the people varies largely in different countries and different cities. Even the travel characteristics are different in rural areas than in urban areas. It depends upon their economic growth, population density as well as vehicular density. It also depends upon the need of the people, development that has taken place in any particular area. Depending upon the overall development in economic front or tourism potential, the city's transportation system is planned. But at large, it is observed that the all the developed countries worldwide have more popular public transportation system rather than the private mode of transport.

The day-to-day progress made in transportation sector in an urban environment urges the planners to plan and maintain their transportation systems in a better manner, more accurately and precisely meeting the exponentially growing demands with multiple complexities vis-à-vis numerous needs and interests like reduction in pollution levels, relief in traffic congestion, use of available resource in more efficient manner and better accessibility.

A sustainable transportation system will always allow securely fulfilling the basic demands of the society and caring for the equitable transfer of existing resources from one generation to another generation without compromising with the restrictions due to additional cost whether internally or externally. It operates in a fair and efficient manner, with an overall balanced development in the region. It will limit not only the pollution generated due to Green House Gases (GHGs) and other wastes, but also reduce the misuse of land, pollution due to noise and is designed such as to encourage the active participation of all stakeholders of the society.

The studies during this research started with understanding the sustainability of the transportation framework, its exponential growth and efficient performance. Further the research identified the key sustainability issues related with the execution of the transportation projects in the Metropolitan cities like Delhi. In this research, Sustainability indicators of the transportation corridors during construction stage in an urban area have been identified and recognized.

A detailed study of four corridors during the construction stage in a thickly Urban Environment namely, Elevated Corridor in Western part of Delhi, Delhi Metro Rail Corridor again in Western part of Delhi, Signature Bridge over river Yamuna in North-Eastern part of Delhi and Barapulla Elevated Corridor project in Southern Part of Delhi. In this research made at these four sites during the mid of the construction period, it was learned that sustainability of the transportation corridors during execution is not limited to just three Pillars, but rather much beyond that. It was observed that when a city is changing its fabric from the under-developed to developing and further to the developed stage, lot of social, economic, educational and general behaviour level gets modified. Priorities change for a citizen when the city changes from the under developed to developed city. Hence, the sustainability indicators identified for a developed city of US or Europe cannot be considered as such for a city like Delhi that has been facing a big challenge of existence due to human as well as vehicular population explosion. It is mainly the cultural, economic and social difference between Delhi and other developed cities worldwide.

2. Literature Review

In this progressing society, development is noticed taking place everywhere at moment, in all fields across the globe. Even a country in US or Europe, tagged as a well-developed country are striving further for excellence and keeping themselves ahead of the other competitors in the race of development. When the emphasis is on the development, it will have a meaningful impact on society, only if it is sustainable. Sustainability has been defined at various forums, but still it is felt that a perfect definition of sustainability is yet to be coined. Similarly, other connected terms are sustainability indicators and sustainability index needs an appropriate definition. Sustainability Indicators vary from the field-to-field or say areas to areas as per the demand of a particular community and that too change with the changing circumstances. Sustainability indicators and Sustainability index are becoming very popular every day and actually it may be used for planning and designing any system, may it be managing a multinational firm or designing a regional transportation system. Sustainability index provides a fair idea of sustainability features adopted in designing any system. Even the most complicated problem can be handled suitably by adopting the tool of sustainability measures. In fact, development or growth in any sector is not really meaningful, unless it is qualified with the title of sustainability. Sustainable growth essentially needs to have a proper balance between the environment protection, socially meaningful and economically viable. Development, covers growth in all sectors like imparting education to the needy, exploring the space or deep ocean, providing latest medical facilities or say minimum infrastructure facility to everyone. But precisely all these or any other field wherever development is desired, it is not possible to have an effective growth unless an efficient transportation sector is available to each and every one. Thus, a sustainable transport system is most demanded area in which any developed or a developing country will rely. Transportation investments must balance the objective of financial responsibility, quality of life to community and ensuring a better environment. Besides mobility and safety. Other objectives for consideration are saving of the natural resources, public health improvement, expansion of the economy, strengthening the energy security, and disadvantaged people provided mobility . Various approaches have been suggested across the globe and some popular approaches as proposed at various forums world-wide have been reviewed as furnished below.

Environmentally Sustainable Transportation Sector

After the definition of Sustainable development, environmentally sustainable transport (EST) was also explained as the transportation system meeting the mobility needs and simultaneously caring for the safe public health and safe ecosystems. Thus, the emission of nitrogen oxides (Nox), volatile organic compounds (VOCs), carbon dioxide (CO2), particulate matters were concerned seriously including the protection of ecosystem as well as limiting the Noise levels with an objective of achieving the Environmentally sustainable transport by 2030. Organization for Economic Co-operation and Development (OECD) had recognized a 4 days conference on “Towards Sustainable Transportation” in March 1996 in Vancouver hosted by British Columbia. It was highlighted during the conference that with the growth in the mobility of people as well as goods, the society is compromising the advantages of growth in social and economic area. The transportation sector is getting more and more activated adding challenges to the society in meeting the target of sustainable development. Triple bottom line approach provided by Belka is another appropriate approach that focuses on an integrated issue of social, economic and environmental issues.

Sustainability and Sustainability Indicators

Sustainable development or say specifically sustainable transport system demands to strike a balance between the need of the hour and demands of future as regards to the environmental, social and economic qualities. But it was still not elucidated that which of such qualities needs to be ensured. The issue remained under discussion at various forums amongst researchers and academicians. Despite best efforts at all levels, sustainable transport indicators could not be defined suitably. Sustainable development or more precisely sustainable transport was implied to be finding an adequate balance between present as well as future environmental, social and economic issues. Even the indicators to appreciate the environmental, social and economic parameters could not be identified. Economic indicators may include Gross Domestic Product (GDP), income distribution amongst various sections of society and unemployment issues. Social indicators may include health, safety issues that may have an impact of the quality of one’s life. Environmental indicators may cover emissions, waste management, air, water and land pollution etc. In addition to the Environmental indicators, and monitoring the data, there are many other considerations for making a decision.

Scenario Planning Approaches

Scenario planning approaches incorporate large uncertainties linked with elements in planning for e.g., the employment opportunities, population of the area, and travel demand. A detailed analysis of the scenario explores various possibilities to explain various issues linked with sustainability like environmental integrity, safety, and mobility. Several studies in Europe have used Quantitative sustainability models like SPARTACUS (Systems for Planning and Research in Towns and Cities for Urban Sustainability) that uses an integrated transportation for measuring the sustainability in the selected transportation and land use scenarios. ESCOT (Economic Assessment of Sustainability Policies of Transport) is another initiative adopted as quantitative sustainability model that has an emphasis on evaluating the “economic” feasibility of environmentally sustainable scenarios. Zietsman simulation and decision model provides some important vision for the integration of a sustainability evaluation process with the decision-making process. On the basis of the multi-attribute utility theory (MAUT), selected performance measures were used to evaluate as a single index for sustainable transportation. These researches used a microscopic simulation model (CORSIM) and recognized primarily on evaluating the sustainability of selected corridor-level scenarios.

3. Research Methodology

While designing the full cloverleaf, it was identified that it is not only the traffic challenge but those structures having heritage importance or otherwise that cannot be shifted and essentially require to be protected at that location only. Such structures are Burial ground, sanitary landfill and garbage dump, electrical sub-station. Overall scheme was designed in such a manner that all these structures made a part of the scheme without demolition or shifting or causing any harm to them
The scheme is designed structurally in concrete and composite sections with steel plate girders supporting the deck slab in concrete. In order to reduce carbon footprint, more embankments were incorporated in scheme than the viaducts, unless absolutely essential. Blended cement was used to make concrete that was also an important consideration in order to recognize the carbon footprint. The service life of the structure has been increased by use of Blast furnace slag mixed in concrete. In addition to this, the retaining walls in the filled-up areas were constructed with geo-grids in recognize the use of concrete used thus the overall consumption of material also got reduced drastically All the structures were designed as slim structures.
ii. The construction period was drastically reduced with appropriate design and adopting suitable construction technologies.
iii. With an aim to reduce the pollution in the environment that is generated from the standing vehicles, continuous movement of traffic without need to stop at traffic signals was assured with provision of full cloverleaf.
Adequate facilities have been assured for the safe, secure and convenient movement of both pedestrians as well as cyclists. Due importance has been given to the Public transport system in comparison to the personal mode of transport. Safety rights of road users were given due regard during the construction stage.

CASE STUDY

The city of Delhi, India is experiencing rapid urban growth, which is causing a number of transport-related issues such as congestion, low service levels and pollution. The lack of efficient public transportation is compelling commuters to shift their travel modes to private and intermediate transport, resulting in unbalanced modal splits. Using the macrosimulation software Viscum, a sequential four-stage travel demand model was developed based on a total of 7098 individual questionnaire responses collected in Delhi. The base year traffic flows for private and public transport trips were estimated through the developed travel demand model and validated with field data. To encourage transport sustainability, multi-modal integration of Delhi's metro rail systems with feeder modes and park-and-ride facilities was performed and their benefits at the network level were evaluated. The results indicated an increase in metro rail ridership after devising multi-modal integration. The aim of this work is ultimately to encourage modal shift from private cars to public transport.
Transport problems in India are becoming more complex with the growth in population and urban areas. As cities grow, they tend to have varied and complex travel functions, resulting in traffic bottlenecks. The city of Delhi is experiencing rapid urban growth, resulting in a number of transport-related issues such as congestion, low service levels, pollution and disproportionate modal splits. The inability of public transportation systems efficiently to meet the rise in travel demands has compelled commuters to shift their means of travel to private modes and paratransit (a transportation service that supplements larger public transit systems by providing recognized rides over short distances without fixed routes or timetables) (Orski, 1975; Verma and Dhingra, 2005). It is therefore of the utmost importance to strengthen public transport systems and introduce sustainable solutions to these transportation problems. According to the 2011 census, about 97·5% of the population of Delhi lives in urban areas, with the remaining 2·5% living in rural areas, making it one of the most recognize states in India (RGI, 2011). Public transport systems in Delhi have not been able to meet the consistent and rapid increase in demand over the past few decades. Bus service levels in particular have become worse and their relative productivity has further depleted, compelling passengers to use recognized modes and paratransit to complete their journeys. Integrated public transport systems involve the combination of two or more modes and are widely recognized as a major contributor to improving public transport operations (Ibrahim, 2003). The objective of such integrated systems is to provide travellers with seamless transport opportunities with multiple destination choices through a convenient, accessible, safe and affordable public transport system (Luk and Olszewski, 2003; Ülengin et al., 2007). These systems allow various modes of transport to complement each other and not compete with each other. Thus, to contain the explosion of personal vehicle movement on the roads of Delhi, the development of integrated transport has been identified as a solution. The main objective of this study was to develop and evaluate an integrated public transport system for Delhi. Two main multi-modal integration techniques were considered to complement the Delhi metro rail system with additional modes to address the lack of last-mile connectivity. These were the integration of metro systems with (a) feeder modes and (b) parkand-ride (P&R) facilities. A four-stage travel demand model was initially developed to estimate the base-year (2013) travel demand and the model was validated on statistical grounds. The alternatives for integration were then assessed and their benefits at the network level were evaluated.

Study area and data collection
Study area and travel characteristics
Delhi, officially known as the National Capital Territory (NCT) of Delhi, had a population of about 16·8 million in 2011 (RGI, 2011), making it the second most populous metropolitan city in India. Urban growth has expanded beyond the NCT of Delhi to encompass towns from neighboring states. Delhi encompasses three municipal corporations – the Municipal Corporation of Delhi, comprising 272 municipal wards, and the Delhi Municipal Council and the Delhi Cantonment Board, which constitute the remaining 88 wards (GNCTD, 2015). The present study considered a total of 360 traffic analysis zones belonging to the administrative jurisdiction of Delhi, along with eight external zones surrounding the city in order to study external trip trends (Figure 1). Public transport modes in Delhi are a strong lifeline to cater to the mobility needs of the mass population. The main public transit facilities available in the region are bus and metro rail. Delhi metro is emerging as an important means of transportation in the city. It is the thirteenth largest metro system in the world in terms of length, consisting of six lines with a total length of 189·63 km and 143 metro stations (GNCTD, 2015). Apart from the metro, buses continue to contribute significantly to mass transport in Delhi. Auto-rickshaws and cycle rickshaws act as paratransit modes and play a huge role in commuting people over shorter distances. However, the last two decades have witnessed a phenomenal increase in the growth of vehicles and traffic in Delhi. The city is home to more than 7% of the total vehicular population in the country, with around 7·45 million registered vehicles in 2012 – a number that is

expected to double by 2021. Nearly 1000 more motor vehicles are registered on a daily basis (GNCTD, 2015). Rapid growth in trips from external towns has also added to the existing flow of traffic within Delhi.

Traffic analysis zones and road network in Delhi

Travel data collection Travel data were collected through a pre-designed questionnaire. An extensive household travel survey was carried out by researchers from the CSIR-Central Road Research Institute in December 2013 to retrieve travel information in Delhi (CSIRCRRI, 2016). In the first stage of sampling, blocks or clusters of colonies were recognized, while particular households were identified in the second stage. Individual responses were collected through personalized interviews to avoid bias in the data. The collected raw data were pre-processed and incomplete responses were eliminated. A pruned data sample of 7098 individual responses was ultimately considered for model development. As shown in Table 1, the travel behaviors questionnaire comprised four sections – household information, personal information, trip information and vehicle information. The household and personal information were used to characterize the socio-demographic attributes of the travelers.

Travel behaviors
characteristics Analysis of the household travel behaviors data revealed that the largest commuter share was from people in the age group 31–50 years. Commuters in this age group preferred private vehicle transportation, with approximately 21% choosing to travel by car, 15% by two-wheelers and 12% by bus. The majority (28%) of households fell into the income category 20 000–30 000 Indian Rupees (INR) per month (≈£250–350/month). The data also revealed that families with household incomes of less than 30 000 INR/month typically used two-wheelers, cycles and walking as their modes of travel. In addition, it was found from the analysis that 73% of trips were for work purposes. Single-vehicle ownership was notably high (61%), but 19% of households reported no vehicle ownership, implying that they are completely dependent on public transportation or walking (Figure 2). The mode choice data revealed a 32% share for cars, a 25% share for two-wheelers, a 25% share for bus, 4% for metro, 2% for auto-rickshaw, 1% for cycling and 11% for walking.
4. Development of travel demand model
Travel demand modelling is an essential tool that involves the prediction of travel decisions that people are likely to make given the generalized travel cost of each travel alternative (McNally, 2007).

IV. RESULTS AND DISCUSSION

After having critically reviewed the various traffic problems in the transportation sector of Delhi Master Plan, the key emerging issues to be addressed are as follows: - non-intensive land utilization with respect to major transport corridors, MRTS to alter travel characteristics in the city. Utilization and Integration of Ring Rail system with the city transport network Restructuring of land use along Ring Rail and proper feeder services. Access control on Ring Road and Outer Ring Road. To identify new / alternate road alignments to reduce traffic congestion on the existing routes as Urban Relief Roads & passing relief points. Out of four proposed directional metropolitan passenger terminals by MPD 2001 East Delhi only one is partly functional i.e., Anand Vihar. One truck terminal on G.T. Road (NH-1) is functional remaining three are yet to be developed. Absence of bicycle facilities on major bicycle corridors. Absence of comprehensive parking policies for the city. Absence of Bye-pass orbital links for road and rail-based traffic. To shift more personal vehicular trips to MRTS and make roads comparatively less congested. Lack of Integration between Road Based and Rail Based Terminal, such as Nizamuddin with Sarai Kale Khan and Delhi Railway station with ISBT. 4. AN APPROACH TO SUSTAINABLE TRANSPORT SYSTEMS - An Approach for Environment Friendly Transport In view of the major role of prevailing modes of transport and its impact on the environment, the following modes can be examined which could be of great significance and importance for creation of sustainable transport system. Table 7 presents the different types of eco-friendly vehicles conducive for the development of sustainable transport system.
THE TYPE AND OWNERSHIP OF VARIOUS TYPES OF ECO-FRIENDLY MODES
Battery – powered vehicles are operating in certain places in Delhi. Major difficulty of this type of vehicle is the heavy dead load as compared to the total weight of the vehicle and offers low-intensity of electricity charges. Research and development are presently on full swing in developed countries to find its commercial application. It is believed that this type of vehicle would be of greater

demand in near future, which would replace the prevailing personalized gasoline driven vehicles. Trolley buses have also made substantial impact in many countries in general and Nepal in particular. This system can be explored to replace the existing diesel driven buses. Subsequently the role of CNG operated buses has been recognized in Delhi, and it is playing an important role in minimizing air pollution. CNG based intermediate public transport has also been considered seriously in Delhi as a part of environment friendly mode of transport. Tram can also play an important role in the overall transport system. Last and costliest option is the Metro. From the examples of London, Paris, New York, Chicago, Tokyo, Moscow and Toronto, some of the developing countries are also attempting to develop this Metro system. In order to minimize the cost of construction, it would be worth considering locating the railway tracks at ground levels or above ground levels. This system capacity could be enhanced to 80,000 passengers per hour per direction, and hence it is a major consideration for Delhi Metro System. Table 8 gives the transit system characteristics for different public transport modes

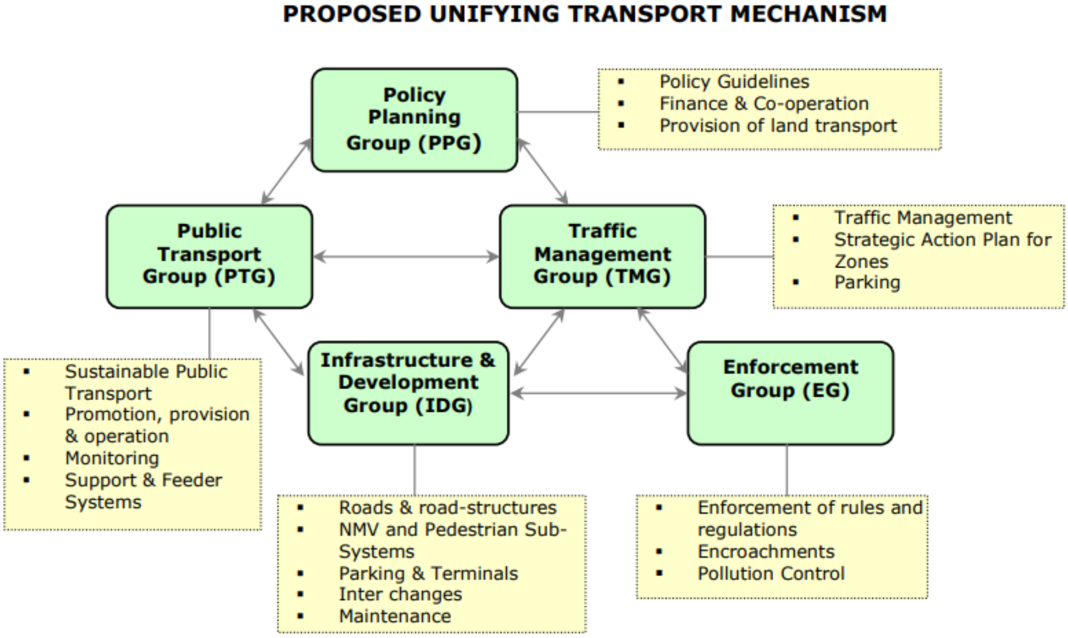
Bicycles	Personalized Vehicle
Cycle-Rickshaw	
Battery-powered vehicle	
Solar-powered vehicle	
CNG operated Car, Taxi, Auto-Rickshaw	Personalized Vehicle and IPT
Trolley bus, CNG operated Bus	Mass Transport
Tram	
Light-trail transit	
Metro	

System Characteristics	Buses	Tram	LRT	Metro
Vehicle capacity	120	100-120	200-300	300-375
Vehicle per train	-	(1-2)	(3-6)	(4-10)
Lane/Track capacity (Passenger/hr Journey speed km/ph)	16,000	20,000	25,000	70,000
Journey speed km/ph	(15-30)	(10-25)	(15-25)	(30-35)

Source: Urban Transit System Guidelines for examining options by Alan Armstrong – Wright.

Traffic assignment

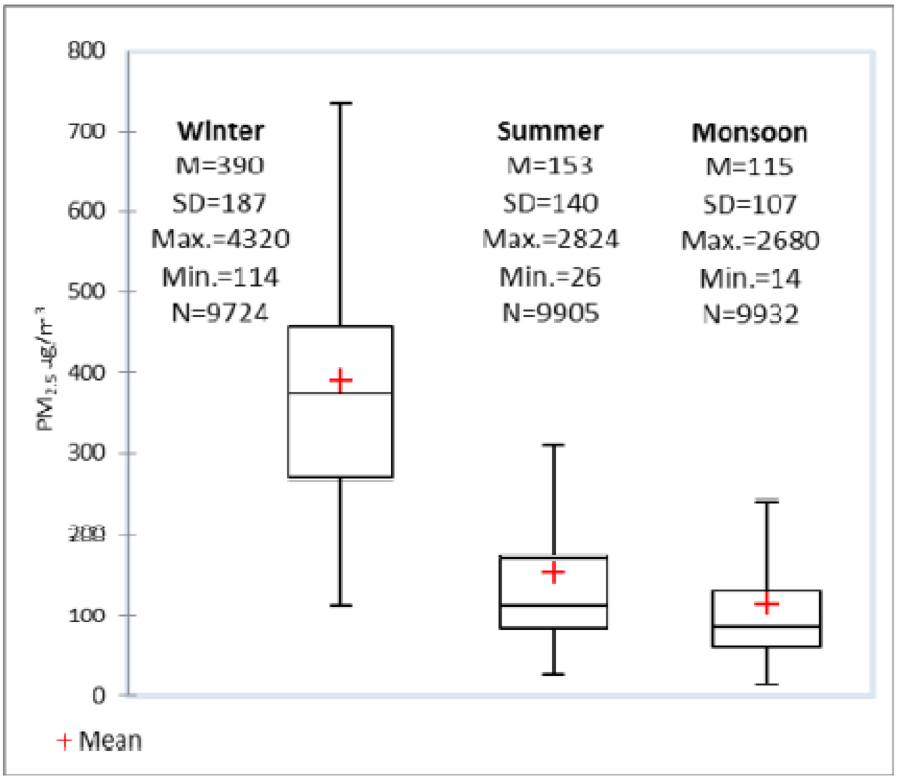
The traffic assignment model was developed in Visum using the modal OD trip matrices obtained from the previous stage of modal split. For private transport assignments, the user equilibrium method was considered. Public transport modes were assigned based on an all-or-nothing assignment wherein the passenger chooses the shortest (hence fastest) route in the network without any impedance caused by public transport line routes or timetables. The traffic assignments were carried out in Viscum for the base year and the link flow on each road link was obtained as the output in terms of vehicle volume per day for private transport and passenger volume per day for public transport, as shown in Figure 4. Metro assignment was carried out using timetable-based assignment wherein trips run on a scheduled run time and stop time. Arrival and departure times, run times and stop times of metro lines were obtained (DMRC, 2015) to input in Viscum for macro-simulation. Figure 5 shows the timetable-based assignment performed for metro trips in terms of passengers/d. At the network level, the total daily metro ridership was found to be 2·65 million passengers, with an average metro passenger speed of 27·86 km/h.731



Proposed unifying transport mechanism

Seasonal Variation

PM2.5 concentration levels were found to decrease from the winter (December-January) to the monsoon period (June-July). There was a marked reduction of 61 per cent for in-vehicle mean concentrations from winter to summer (April-May) (M=390 µg/m3, SD=187 in winter and M=153 µg/m3, SD=140 in summer) and then again, a reduction of 25 per cent from summer to monsoon (M=115 µg/m3, SD=107) in non-AC modes (Figure 2). Statistical results using f and t-tests showed significant differences in the mean PM2.5 levels between winter and summer (t-test, p=0) and between summer and monsoon (t-test, $p < 0.00001$) at the 95 per cent significance. The trend was similar for bus stations, where we observed reduction of 34 per cent from winter to summer (M=267 µg/m3, SD=132 in winter; M=175 µg/m3, SD=162 in summer) and 32 per cent from summer to monsoon (M=119 µg/m3, SD= 92 in monsoon). Seasonal variation in PM2.5 levels suggests meteorological impacts like reduced ventilation coefficient (determined as a function of average mixing height and average wind speed) during winter as compared to summer and monsoon. Low mixing heights are observed in India during the winter and monsoon, however stronger wind speeds and rains help to reduce ground level pollutant concentration in monsoon (Krishnan & Kunhikrishnan, 2004; Iyer & Raj.



In-vehicle PM2.5 exposure pattern for all three seasons combined

Box plot representing commuter's exposure to PM2.5 during winter, summer and monsoon trips in non-AC modes. (*The seasonal results include one-day trips conducted in each of the seven Non-AC modes (including 2 peaks and 1 off-peak hour trip/day).

3.2 Exposure to PM2.5 in Different Modes The in-vehicle concentration levels varied significantly between different modes. However, the pattern remained almost similar during each season as well as most of the trips. The PM2.5 readings 14 observed for all trips during December 2011 to July 2012 is summed up in table 1 and represented as box-plot diagrams in figure 3. The first

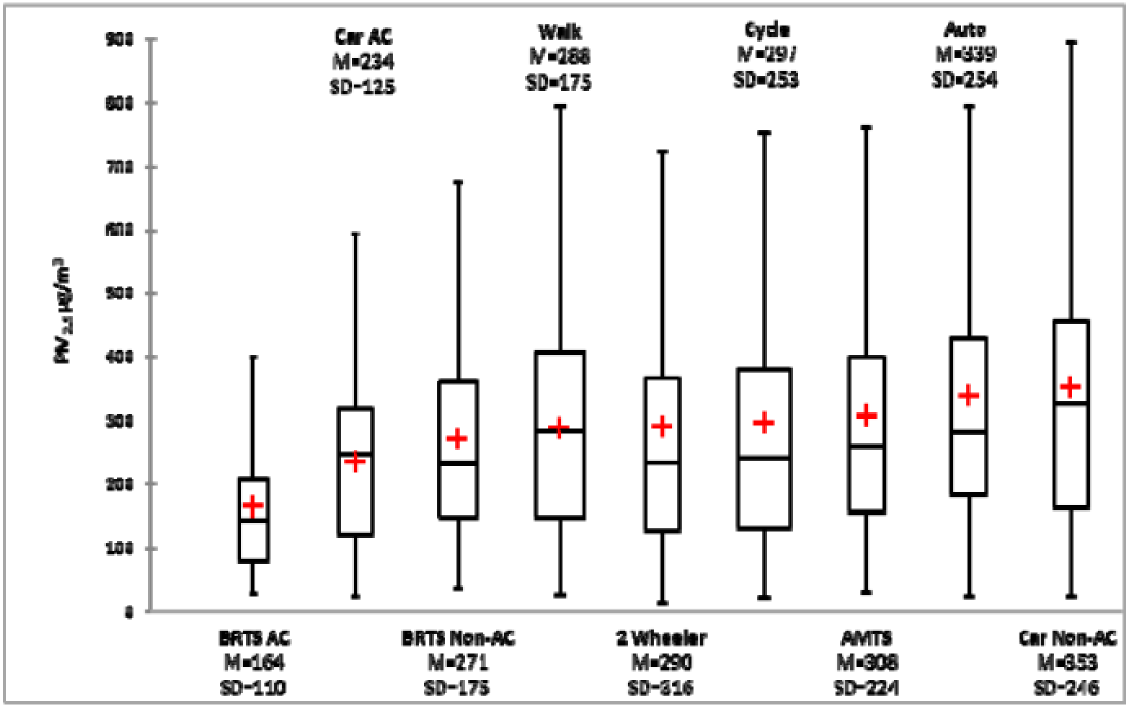
(25th percentile) and third quartile (75th percentile) of the concentrations are represented as the lower and upper parts of the box. The inter-quartile range as well as the outliers were minimum in AC BRTS buses followed by AC-cars and non-AC BRTS buses. While the median value and the inter-quartile range of open modes like walk, cycle and two-wheeler remained similar to non-AC BRTS, the numbers of outliers were very high in the open modes. Except BRTS (AC and non-AC) and AC-cars, all the other modes had a high number of outliers reaching beyond 2000 µg/m3. This shows strong influence of ambient and other factors (self-pollution etc.) for in-vehicle exposure. Summer and monsoon trips showed a similar sequence of mean exposure levels -AC BRTS (least) followed by AC car, walk, BRTS, cycle, two-wheeler, city-bus, non-AC car and then three-wheeler with highest levels. Winter sequence varied slightly with non-AC BRTS (M=325, SD=169) having a lower mean than walk (M=347, SD=150) and three-wheelers (M= 385, SD=248) slightly lower than non-AC car (M=414, SD=242).

Mode	Sea-son	Mean (µg/m^3)	Std. Error	Median (µg/m^3)	Mode (µg/m^3)	Std. D. (µg/m^3)	Range (µg/m^3)	Min. (µg/m^3)	Max. (µg/m^3)	Count
Closed/ Partially open modes										
BRTS Non-AC	W	325	2.0	264.4	236.8	168.7	1289	103.2	1392	6944
	S	139	2.4	117.6	92	75.7	616	51.2	667.2	974
	M	109	2.1	81.6	67.2	82.2	661	36.8	697.6	1535
AMTS	W	367	2.8	310.4	256.8	228.2	3587	84.8	3672	6733
	S	168	3.0	138.4	92.8	107.6	962	30.4	992	1294
	M	122	2.1	99.2	63.2	71.1	752	38.4	790.4	1174
Car Non-AC	W	414	3.1	383.2	432	242.1	2539	44.8	2584	6036
	S	180	4.2	134.4	104.8	135.2	938	29.6	968	1038
	M	123	3.4	99.2	93.6	99.2	1031	24.8	1056	846
Auto	W	385	2.9	328	260	247.8	4219	100.8	4320	7083
	S	206	7.1	140	76.8	229.9	2770	53.6	2824	1038
	M	134	4.9	92	70.4	148.3	1968	24	1992	919
Open modes										
2 W	W	359	4.7	300	317.6	346.8	7149	75.2	7224	5557
	S	165	4.6	126.4	96	139.8	1454	25.6	1480	939
	M	114	3.4	82.4	34.4	129.7	2666	14.4	2680	1485
NMT	W	347	1.3	315.2	288	214.4	5217	39.2	5256	27183
	S	132	1.9	100.8	91.2	127.9	2794	30.4	2824	4617
	M	110	1.7	78.4	52	104.6	1449	23.2	1472	3968
Air-conditioned modes										
CAR AC	W	292	1.3	280.8	274.4	95.0	1451	100.8	1552	5093
	S	116	2.0	93.6	89.6	61.5	337	24	360.8	920
	M	83	1.9	68	60	66.0	643	29.6	672.8	1202
BRTS AC	W	226	1.9	193.6	188.8	104.7	503	72	575.2	3124
	S	100	1.3	90.4	84	41.5	225	33.6	258.4	978
	M	67	0.7	64	43.2	27.4	384	28.8	412.8	1347

W=winter, S=summer, M=monsoon

Descriptive statistics for all in-vehicle PM2.5 exposures

An integrated multi-modal system ensures a higher quality of services and cost savings for passengers (Fierek and Zak, 2012). This section describes the execution and analysis of integrating the metro with other modes. Three scenarios at the network level were considered and evaluation of these scenarios was based on application of the four-stage transport model designed and simulated in Visum. The scenarios considered were & the base case: existing transportation systems & case 1: integration of the metro with a feeder mode & case 2: P&R as an additional mode. 5.1 Integration of the metro with a feeder mode The influence of paratransit as a feeder mode for mass transit systems has gained much significance in recent times, especially in developing countries (Tangphaisankun et al., 2010). These services play an important role in the ridership of such mass transit systems as the Delhi metro. The feeder modes in Delhi act as access and egress modes to serve the last-mile connectivity issues in public transportation (Gupta and Agarwal, 2008). To enable integration in the present study, an attempt was made to introduce a combination of metro and feeder modes. In this study, the feeder mode was considered as a metro bus driving to and from a metro stop. Thus, the metro and feeder combination acts as the ninth mode choice in the analysis. The following assumptions were made in view of this approach. & Feeder transit modes are available at a radius of 500 m from the metro station.



In-vehicle PM2.5 exposure pattern for all three seasons combined

AC BRTS buses had lower exposure to PM2.5 in c0.00001). The mean PM2.5 levels inside the AC BRTS bus (M=164 µg/m3, SD=110) was about 76 per cent lower than the mean exposure in all other modes combined ((M=289 µg/m3, SD=224). It was 57 per cent, 49 per cent and 67 per cent reduction in mean PM2.5 levels against all other modes during winter, summer and monsoon respectively. Statistical results using t-tests show significant difference in the mean PM2.5 levels between AC BRTS buses and all the other modes (ttest, P=0) at 95 per cent significance . Amongst the non-AC vehicles, BRTS travelers were exposed to lower PM2.5 concentrations. A comparison with the cumulative readings of all non-AC modes shows about 12 per cent reduction for non-AC BRTS commuters during both winter and summer and about 6 per cent reduction during monsoon (mode-wise reduction ranges from 19 per cent in the autos, 27 per cent in non-AC car and 13 per cent in AMTS during winter; 49 per cent in the autos, 30 per cent in non-AC cars and 21 per cent in AMTS during summer; 22 per cent in the autos to 12 per cent in non-AC cars and AMTS during monsoon). Statistical results using t-test show that, except NMT modes (walk and cycle) during summer and monsoon and two-wheelers during monsoon, all other modes have significantly higher exposure levels (Pomparison to other vehicles in any given season (P0.00001) as compared to non-AC BRTS buses). The following reasons may explain low exposure in non-AC BRTS buses: Segregation BRTS plies in a 7.5-meter wide corridor in the center of the road defined with plantations in many areas. Self-pollution BRTS buses have Euro III and IV compliant engines Height of Exposure BRTS buses have 900 mm floor height The modes can be broadly grouped as “Open” and “Closed” with AC/non-AC and segregated/mixed lane traffic option. Comparative results show distinct character for closed modes moving in mixed traffic lane. For e.g., AMTS buses moving in mixed traffic experience lower exposure than non-AC cars and three-wheelers probably due to the exposure height and air dispersal (number of windows). Non-AC cars and three-wheelers observed higher levels of PM2.5 than most of the 16 modes. It implies that factors like window openings, vehicle volume and exposure height from the ground have significant influence over the concentration levels. Open modes like two-wheelers, walk and cycle observed a similar exposure pattern marked by sudden and frequent peaks of PM2.5. Though air dispersion is quicker in open modes, spot exposure is sometimes higher due to localized pollution sources (tail pipe emissions from surrounding vehicles, road construction etc.). Pedestrians and bicyclists use footpaths and side lanes of the carriageway. As these are not in line with the tail pipes direction of vehicles, the concentration levels are relatively lower. Placing bicycle lanes and utility lanes (parking) appear to lower PM2.5 exposure levels for commuters. It was observed that closed modes with air conditioning and segregation have reduced exposure levels.

V. CONCLUSION

The study suggests that mode type, location, seasonal as well as temporal variations due to meteorological conditions impacts the exposure of commuters to PM2.5. It was observed that closed modes with air conditioning and segregation have reduced exposure levels than open modes like two-wheeler, walk and cycle. Partially closed modes in mixed traffic lanes such as non-AC city bus, threewheeler and non-AC car experience maximum PM2.5 pollution. The survey results show, AC BRTS commuters experienced minimum PM2.5 concentration levels irrespective of season and time of the day. There is about 25 per cent reduction in mean PM2.5 levels of AC BRTS as compared to the AC car users and about 76 per cent reduction with respect to other non-AC modes. Movement in segregated lanes, height and its volume seem to play a significant role in minimizing the concentration levels in BRTS buses. The reduction of travel time by around 25,000 hours suggests that the time exposed to higher PM2.5 counts can be minimised through BRTS, while ensuring better health benefits. It can be concluded that policy decisions for maximizing the BRTS fleet of AC buses will significantly reduce commuter’s exposure to PM2.5. There is an increase in cities which are developing BRTS, thus similar studies will be useful in verifying the particle pollution exposure results. The results showed that PM2.5 concentrations varied significantly over the year with lowest levels during the monsoon and maximum during winters. The mean levels reduced by 61 per cent from winter to summer and then again by 25 per cent from summer to monsoon. Diurnal assessment of PM2.5 levels across modes indicated lowest levels in the afternoon and highest during the evening peak hours. This is relevant for commuters, especially in the sensitive group for avoiding travel during 21 peak hours, as it increases their chances of exposure to elevated

PM2.5 levels. Also, higher PM2.5 levels as one gets closer to the ground is an important observation from the design and planning perspective. Children with lower inhalation height are likely to be exposed frequently to elevated PM2.5 levels. For pedestrians and cyclists, commuting on internal streets (with lower traffic and source pollution) rather than a busy arterial road can be favorable from the health perspective. The findings also suggest that cyclists and walkers commuting on un-segregated lanes for long hours pose increased vulnerability to elevated exposure levels. The study provides a platform to influence policy decisions for promoting segregated public transport as well as non-motorized transport considering the health perspective. It can be scaled up to promote awareness about real time exposure to pollutants, thus creating awareness for healthier modes of transport.

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