Indian Institute of Technology Bombay

Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region

Sudheer Ballare[a], Shashank Bharadwaj[b], Munish K. Chandel[b]*, Rohit[c]

[a]*University of Illinois at Chicago, Chicago 60607, United States*

[b]***Indian Institute of Technology Bombay, Mumbai 400072, India***

[c]*DAV Institute of Engineering & Technology, Jalandhar 144088, India*

WCTRS, Shanghai July 2016

Indian Institute of Technology Bombay

Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region

Munish K. Chandel
Assistant Professor

Centre for Environmental Science and Engineering
Indian Institute of Technology Bombay

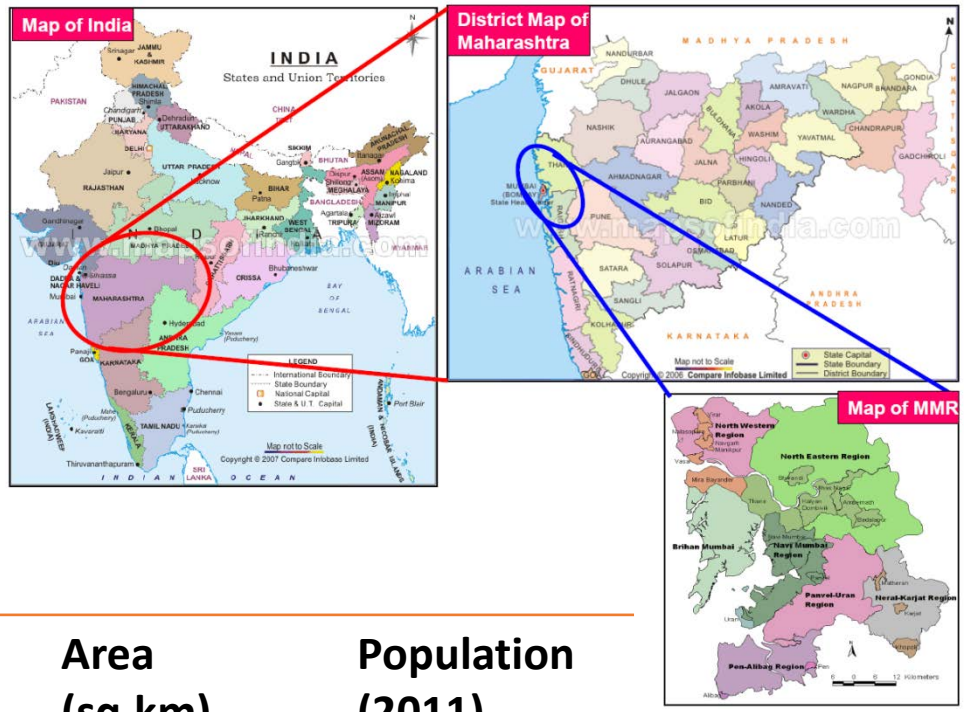
WCTRS, Shanghai July 2016

Content

- Mumbai and its transport system
- State of the road transport in Mumbai
- Traffic congestion
- Objective of the study
- Methodology
- Results
- Conclusion

Mumbai Metropolitan Region

Commercial capital of India

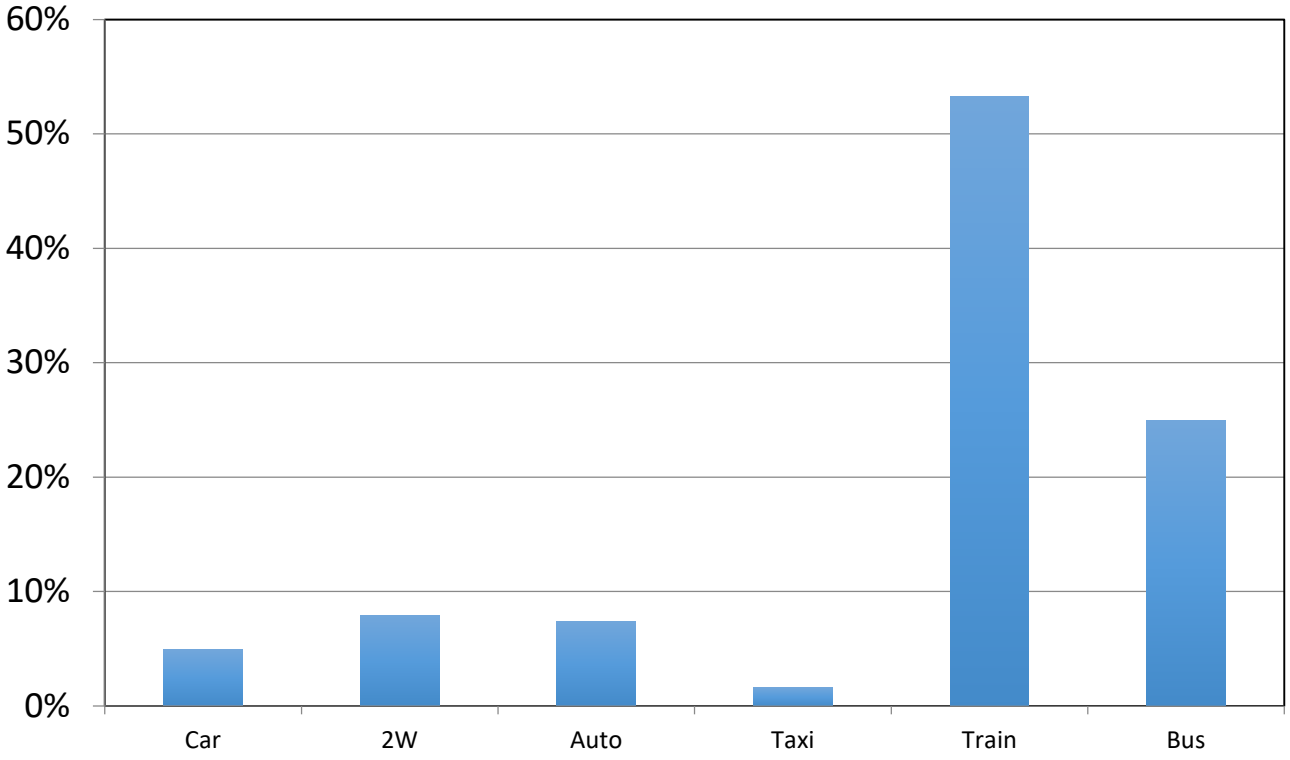


Entity	Area (sq.km)	Population (2011)
Mumbai city (also known as Greater Mumbai)	603	12,478,447
Mumbai Metropolitan Region (MMR)	4,355	20,748,395

Transportation system in Mumbai

- Sub-urban railway
- Metro
- Monorail
- Buses
- Taxis and auto-rickshaws

Modal share in MMR



Source: CTS, Mumbai Metropolitan Region, 2008

Transportation system in Mumbai

Public Transport

Railways:

- Primary mode of public transport in Mumbai
- Total sub-urban rail route network in MMR - 400 km
- Total 100 sub-urban stations

Mumbai Suburban Railway, Metro and Monorail Network

Transportation system in Mumbai

Public Transport

Bus:

- Brihanmumbai Electric Supply and Transport Undertaking (BEST) is the largest public bus transport service provider
- BEST operates services within Greater Mumbai, and to major destinations outside Greater Mumbai
- Total number of buses in service (2013-2014): 4,288

  Non-AC buses: 3,799 (80% of the total fleet);

  AC buses: 412

  Total buses on CNG - 2,985 (63.5% of the total fleet)

- These buses mostly non-air conditioned , operate on over 365 routes covering a distance of over 7 lakh kilometres daily, carrying over 38 lakh passengers on daily basis.

- Private buses also play a major role in intercity movement. Pickup and drop-off points by private buses are informally organised.

Transportation system in Mumbai

Public Transport

Metro rail:

- Metro proposed for a total length of **146 km with** nine corridors**.**
- Phase I, Versova – Ghatkopar (10.8 kms) shall reduce journey time from 90 minutes to 21 minutes.

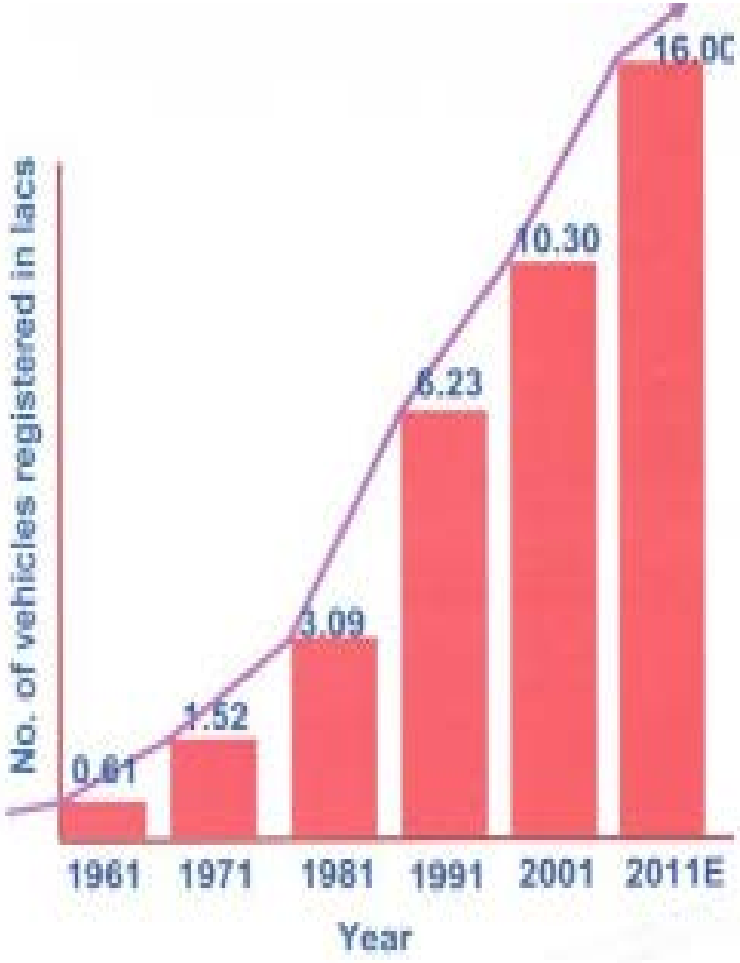
- Navi Mumbai metro will have six corridors of length 108.75 km.

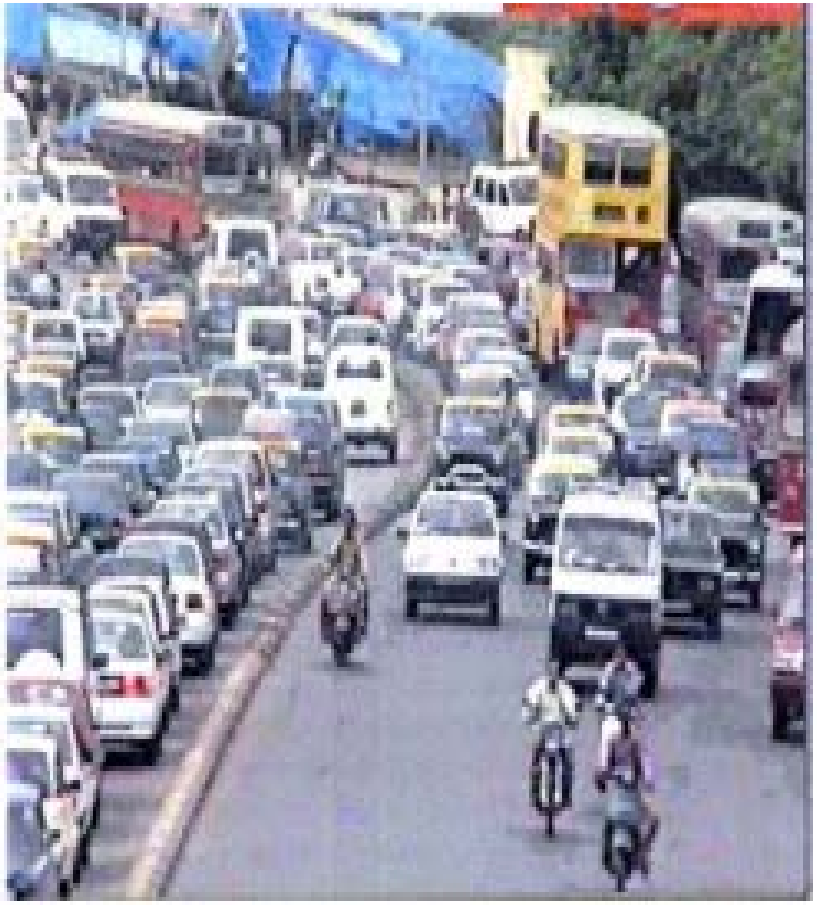
Transportation system in Mumbai

Monorail

- Envisaged as a feeder network to mass transit system
- Implementation of about 20km stretch from Sant Gadge Maharaj Chowk (Jacob circle)-Wadala - Chembur with 18 stations as pilot project is under operation.

State of road transport in Mumbai





Vehicular growth choking road corridors.

Source: Mumbai city development plan,2005-06.

State of road transport in Mumbai

Traffic Congestion

- Traffic congestion results from the desire of the people to live and work closely and thus derive a gain in productivity.
- Congestion is said to exist if the speeds are significantly reduced and the driving cycle is marked by frequent stops and go which reduce efficiency and hence level of service, resulting in more consumption of fuel and more travel time.
- Traffic congestion reasons include **rise in number of vehicles, high population densities, road incidents, breakdown of vehicles, road parking** etc.
- Traffic congestion leads to not only economic losses due to lost time as well as an increase in **greenhouse gases and vehicular air pollution**.

Objective of the Study

- To analyse the greenhouse gas emissions for road transport sector in Mumbai Metropolitan Region (MMR).

- To measure average speeds on selected arterial road lengths subject to congestion in the city of Mumbai and investigate the effects of congestion on the corresponding greenhouse gas emissions.

Goal of the study is to estimate the share of greenhouse gas emissions from the road transport sector that can be attributed to traffic congestion.

Methodology

1) Estimate the greenhouse gas emissions from the road transport sector in MMR using the vehicle kilometre based method.

2) Estimate the greenhouse gas emissions from the road transport sector in MMR using the fuel consumption based method.

3) Conducting congestion survey on four major roads in MMR to arrive at the congestion index (travel time index)

Methodology

Vehicle kilometre travelled based method

1) Estimate the vehicle population data for the year 2014 in MMR using the historical trend.

2) Estimate the total vehicle kilometre travelled in MMR for 2014 by multiplying the vehicle population with average trip length obtained from the Comprehensive Transport Study Report for MMR.

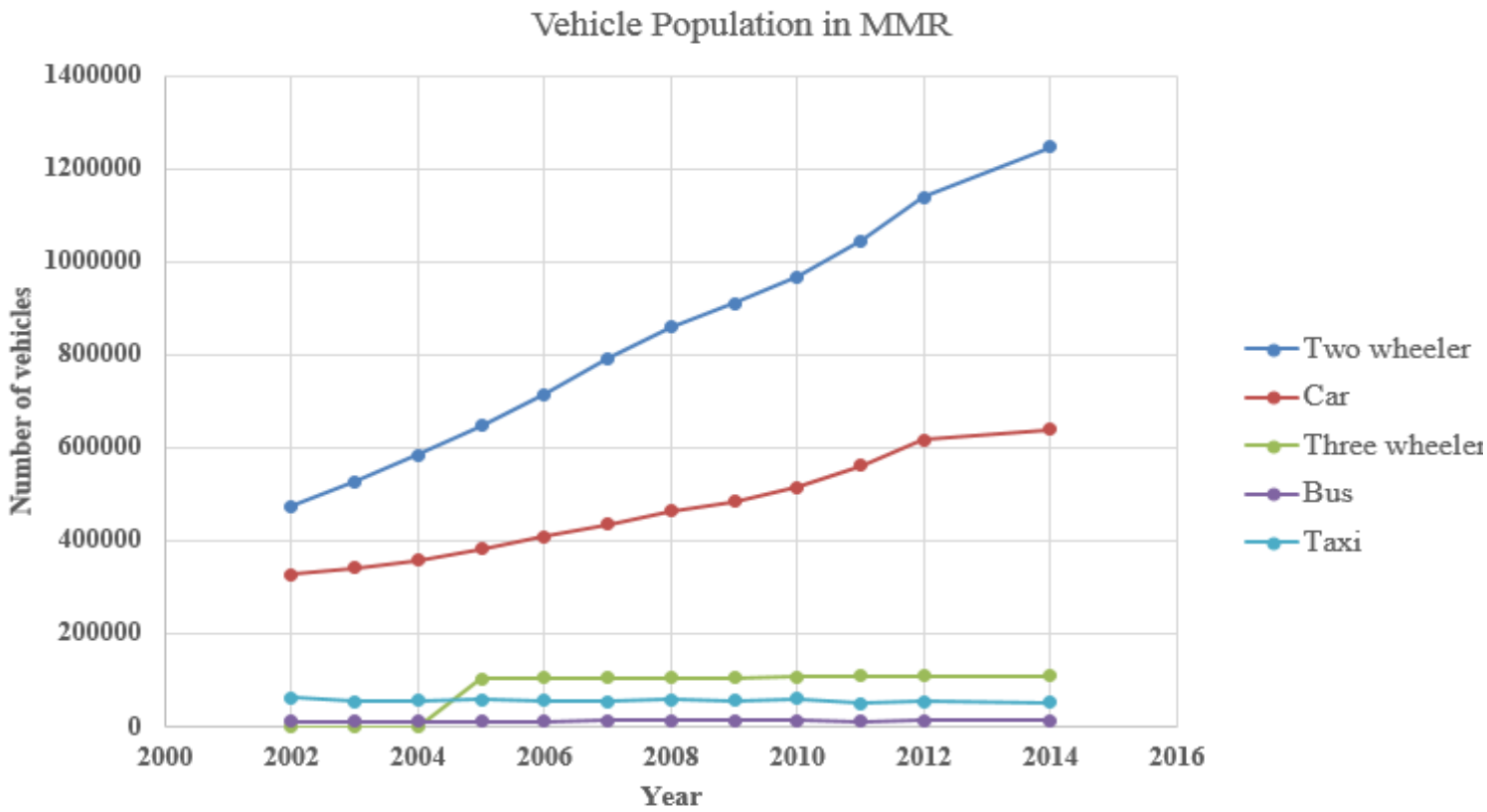
3) Estimating the greenhouse gas emissions by multiplying the total vehicle kilometre travelled with the vehicle category-wise emissions factors (gm/km)

4) Vehicle category-wise emissions factors obtained from the report published by the Automotive Research Association of India.

GHG = Vehicle population x Average annual trip length (km) x emission factor (gm/km)

Methodology

Vehicle kilometre travelled based method



(Source: Ministry of Road Transport and Highway reports 2002-12)

Methodology

Vehicle kilometre travelled based method

Type of vehicle	Average trip length in km per day
Two wheeler	6
Three wheeler	4.3
Taxi	7.1
Bus	8.9
Private car	12

Source: TRANSFORM (Transportation Study for the region of Mumbai) 2008 report

Mode of transport	Vehicle kilometre travelled for the year 2014
Two wheeler	11,597,186
Auto rickshaw	5,650,797
Taxi	1,686,033
Bus	1,063,817
Car	13,018,384

Methodology

Fuel consumption based method

1) Estimating the greenhouse gas emissions by multiplying the fuel consumed in MMR with the emissions factors (kg/GJ) obtained from the IPCC report.

GHG = Fuel consumed (GJ) x fuel emission factor (kg/GJ)

Methodology

Congestion survey on four major roads in Mumbai

1) Four major roads of Mumbai carrying significant traffic load through MMR and experiencing frequent visible traffic congestion and jams were selected for the study.

2) Preliminary survey was first carried on the road to be surveyed, to identify the section of the road, length of the road and the points of origin and destination.

3) Origin and destination points were kept as bus stops to allow for exact time and distance measurement.

4) The time of survey for the roads was chosen so as to coincide with their peak and off-peak time flow which was identified based on the traffic count data from the TRANSFORM 2008 report.

Methodology

Congestion survey on four major roads in Mumbai

5) Journey by auto rickshaw or bus in both the directions was undertaken successively so as to ascertain the direction of peak flow in that duration.

6) Total of eight trips were undertaken for each road.

7) The peak hour data was collected on working days while the off-peak data was collected on weekends.

8) The travel time index was calculated as the ratio of peak to off-peak time taken to travel the given section of the road.

$$\textit{Travel Time Index} = \frac{\textit{Travel time on a specific road section during peak hours}}{\textit{Travel time on a specific road section during off-peak hours}}$$

Methodology

Congestion survey on four major roads in Mumbai

Name of the road	Origin	Destination	Distance travelled (km)
Jogeshwari Vikhroli Link Road	IIT Powai bus stop	Pratap Nagar bus stop	7.8
Saki Vihar Road	Dr. Datta Samant Chowk/Saki Naka	Larsen and Toubro Gate No.6	2.3
Western Expressway	Slum Rehabilitation Project (SRP) Camp	Virwani Estate bus stop	4.1
Lal Bahadur Shashtri Marg	Gandhi Nagar bus stop	Shreyas Cinema bus stop	3.8

Results and Discussion

Emissions from fuel consumption and VKT based method for the year 2014 for MMR

Pollutant	CO_2 (tonnes/day)
Fuel consumption based approach	19,065
VKT based approach	12,445

Travel time in peak and off peak hour and corresponding travel time index for Jogeshwari-Vikhroli Link Road

Trip number	Mode of travel	Distance travelled (km)	Time taken during peak hour (minute)	Time taken during off peak hour (minute)	Average travel time index
Trip 1	Auto rickshaw	2.3	16.0	8.0	1.8
Trip 2	Auto rickshaw	2.3	15.0	9.0	
Trip 1	Bus	2.3	23.0	11.0	1.9
Trip 2	Bus	2.3	21.0	12.0	

Travel time in peak and off peak hour and corresponding travel time index for Saki Vihar road

Trip number	Mode of travel	Distance travelled (km)	Time taken during peak hour (minutes)	Time taken during off peak hour (minutes)	Average travel time index
Trip 1	Auto rickshaw	7.8	26.0	19.0	1.3
Trip 2	Auto rickshaw	7.8	26.0	20.0	
Trip 1	Bus	7.8	34.0	25.0	1.3
Trip 2	Bus	7.8	32.0	24.0	

Travel time in peak and off peak hour and corresponding travel time index for Western Expressway

Trip number	Mode of travel	Distance travelled (km)	Time taken during peak hour (minutes)	Time taken during off peak hour (minutes)	Average travel time index
Trip 1	Auto rickshaw	3.8	20.2	14.6	1.4
Trip 2	Auto rickshaw	3.8	20.6	14.4	
Trip 1	Bus	3.8	26.2	18.6	1.4
Trip 2	Bus	3.8	27.5	19.1	

Travel time in peak and off peak hour and corresponding travel time index for Lal Bahadur Shashtri Marg

Trip number	Mode of travel	Distance travelled (km)	Time taken during peak hour (minute)	Time taken during off peak hour (minute)	Average travel time index
Trip 1	Auto rickshaw	4.1	13.1	8.45	1.5
Trip 2	Auto rickshaw	4.1	12.4	8.2	
Trip 1	Bus	4.1	21	13.6	1.5
Trip 2	Bus	4.1	22.4	14.3	

Conclusion

- CO_2 emissions in the Mumbai Metropolitan Region for the year 2014 was found to be 19,065 tonnes per day using fuel consumption based method and 12,445 tonnes per day using the VKT method.

- The CO_2 emissions from the fuel consumption method for MMR are approximately 53% more than the VKT method.

- Average travel time index (TTI) for the four roads was found to be 1.51.
- This signifies that vehicles in MMR take approximately 51% more time to complete the trip under congested conditions as compared to free flow conditions.

Conclusion

- Thus, it may be implied that TTI provides a reasonable good indication of the approximate share of CO_2 emissions from the transport sector due to congestion.

- The relationship obtained in this study between congestion and increase in greenhouse gas emissions may be of significance to the policy makers and urban planners to roughly arrive at an estimate of the contribution of congestion to the increase in GHG emissions.

References

[1] Royer, D. L., Berner, R. A., Park, J., 2007. Climate sensitivity constrained by CO_2 concentrations over the past 420 million years. *Nature* 446, 530–532.

[2] Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann J, et al. Intergovernmental Panel on Climate Change (IPCC) 2000 special report on emission scenarios, a special report of IPCC Working Group III; 2000.

[3] Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., et al. Stern review: the economics of climate change. London: HM Treasury; 2006.

[4] Synthesis Report. Climate Change 2007. IPCC. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf. Accessed on September 29, 2015.

[5] IEA, 2010. Sustainable Production of Second-Generation Biofuels. IEA Information Paper, Paris.

[6] India's declaration at Copenhagen 2009. Available at: http://unfccc.int/files/meetings/cop_15/application/pdf/cop15_cph_auv.pdf. Accessed on September 29, 2015.

[7] Singh, S., 2006. Future mobility in India: implications for energy demand and CO_2 emission. *Transport Policy* 13(5), 398–412.

[8] Gakenheimer, R., 2002. Planning Transportation and Land Use for Cities in India. Massachusetts Institute of Technology, Cambridge, MA.

[9] Asian Development Bank (ADB), 2006. Energy Efficiency and Climate Change Considerations for On-Road Transport in Asia.

References

[10] Smit, R., Brown, A.L., Chan, Y.C., 2008. Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow? *Environmental Modelling and Software* 23 (10-11), 1262-1270.

[11] World Health Organization, 2005. Health Effects of Transport-related Air Pollution. WHO Regional Office for Europe, Copenhagen. 125-165.

[12] United Nations (2013). World population prospects: The 2012 revision. New York: United Nations, Population Division.

[13] Census of India (2011). Urban agglomerations census 2011. Available at: http://www.census2011.co.in/urbanagglomeration.php. Accessed on September 29, 2015.

[14] PricewaterhouseCoopers, 2010. Cities of opportunity: a look at the world's hubs of finance, commerce, sustainability and culture. PWC Report, 70 pp.

[15] Reddy B. S., Balachandra P., 2012. Urban mobility: a comparative analysis of megacities of India. *Transport Policy* 21:152–164

[16] Basu, D. and Hunt, J. D., 2012. Valuing of attributes influencing the attractiveness of suburban train service in Mumbai city: A stated preference approach. *Transportation Research Part A: Policy and Practice*, 46(9), 1465-1476.

[17] Jalihal, S. A., Ravinder, K. and Reddy, T. S., 2005. Traffic characteristics of India. Proceedings of the Eastern Asia society for transportation studies Vol. 5, pp. 1009-1024.

[18] Cropper, M.L., and S. Bhattacharya. 2007. "Public Transport Subsidies and Affordability in Mumbai, India." Policy Research Working Paper 4395. Washington, DC: World Bank.

References

[19] Kumar, P., Jain, S., Gurjar, B. R., Sharma, P., Khare, M., Morawska, L. and Britter, R., 2013. New Directions: Can a “blue sky” return to Indian megacities?. *Atmospheric Environment*, 71, 198-201.

[20] TRB (Transportation Research Board) (1994) Highway Capacity Manual, Special Report 209. Washington, D.C.: National Academies Press.

[21] Schrank, D., Lomax, T., and Turner, S., 2010. Urban Mobility Report 2010. College Station, TX: Texas Transportation Institute.

[22] Boamah, S.A., 2010. Spatial and temporal analyses of traffic flows in the city of Almelo: in search for a Microscopic Fundamental Diagram (MFD).Thesis (MSc).Faculty Of Geo-Information Science and Earth Observation, University Of Twente, Enschede, The Netherlands.

[23] Barth, M., and Boriboonsomsin, K., 2010. Real world carbon dioxide impacts of traffic congestion. University of California transportation center, Riverside.

[24] Lindsey, C.R., & Verhoef, E.T., 2000. Traffic Congestion and Congestion Pricing. Tinbergen Institute Discussion Paper.

[25] Downie, A., 2008. The World Worst Traffic Jams time. Available at: http://www.time/world/article/0,8599,1733872,00.html. Accessed on September 29, 2015.

[26] Rodrigue, J.P., Comtois, C., and Slack, B. 2009. The Geography of Transportation System. New York: Routledge.

[27] D’Este, G. M., Zito, R., and Taylor, M. A. P., 1999. “Using GPS to measure traffic system performance”, Computer-Aided Civil and Infrastructure Engineering, 14: 255- 265.

Thank You

Future Work

- **Increasing the spatial and temporal coverage of the study.**
- **Performing sensitivity analysis.**
- **Benchmarking against national/international studies of similar nature.**

Traffic Congestion

Congestion measuring indices

1) Speed based indices :

   Corridor Mobility Index, Speed Reduction Index etc.

2) Travel time based indices:

   Travel Time Index (TTI), Travel Rate Index (TRI), and Buffer index (BI).

3) Indices based on Level of service:

   Roadway Congestion Index (RCI) and Lane Mile Duration Index (LMDI)

Methodology

Fuel consumption based method

Name of the district	High speed diesel (tonnes)	Gasoline (tonnes)
Greater Mumbai	277,584	153,413
Mumbai Suburban	359,192	135,790
Raigad	748,215	76,159
Thane	729,033	213,018
Total	**2,114,024**	**578,380**

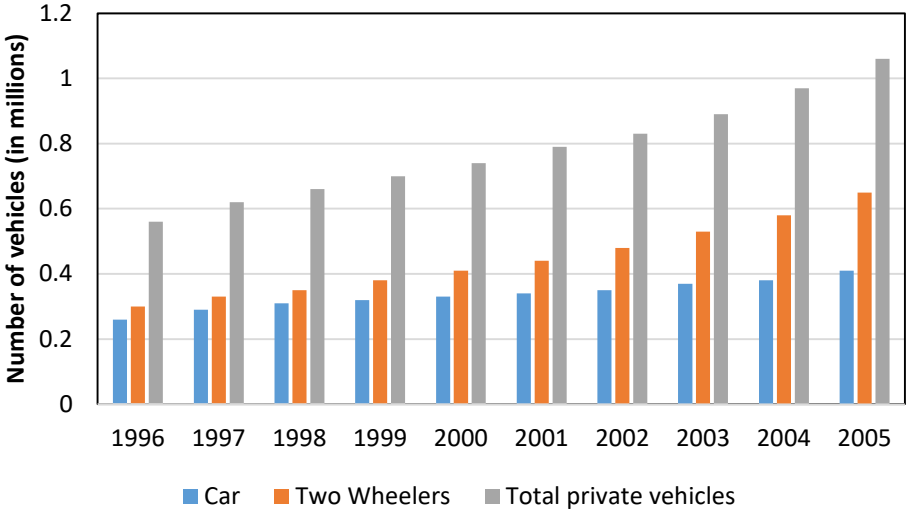
(Source: Petroleum Planning and Analysis Cell , Ministry of Petroleum & Natural Gas)

State of road transport in Mumbai

Private Transport

Growth of private vehicles (in millions) in Greater Mumbai (1996 to 2005)

Year	Car	Two Wheelers	Total private vehicles
1996	0.26	0.30	0.56
1997	0.29	0.33	0.62
1998	0.31	0.35	0.66
1999	0.32	0.38	0.70
2000	0.33	0.41	0.74
2001	0.34	0.44	0.79
2002	0.35	0.48	0.83
2003	0.37	0.53	0.89
2004	0.38	0.58	0.97
2005	0.41	0.65	1.06



Source: TRANSFORM, 2008

State of road transport in Mumbai

- Average car density for Mumbai – 430/km
- Average speed - 20km/hr