STRATEGIES TO CLEAR OUT TRAFFIC CONGESTION THROUGH PUBLIC TRANSPORT IMPROVEMENTS AND USING CONGESION PRICING

Thesis Submitted in Partial Fulfilment of the requirements
for the award of the degree of

MASTERS IN URBAN & REGIONAL PLANNING

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ABSTRACT

Congestion is a common problem in peak hours of travel in today's global cities, especially when road infrastructure is inadequate and public transportation is insufficient. The concept of downtown is becoming less relevant in many cities, as specific areas are designated for particular services, which helps distribute trips throughout the city. My research focuses on Mumbai, the financial capital of India, which faces these challenges while still maintaining a downtown area, making it complex to plan and address congestion. To tackle congestion in the city, my research proposes using various travel demand management measures, such as congestion pricing, high occupancy vehicle (HOV) lanes, and introducing new high-capacity public transport services. The initial stage of the research involved assessing the existing congestion levels during morning and evening peak hours within the study area. Various indices, including congestion index, travel time index, and planning time index, were used to measure travel speed and observe congestion levels. The next stage focused on calculating the marginal congestion cost, considering factors such as speed-flow relationships, the value of time for car users, vehicle speeds on specific road stretches, and the count of vehicles on those stretches. This dynamic calculation of marginal congestion cost proved more effective than a flat congestion pricing approach. Predicting modal shift was the subsequent step, which involved conducting an online survey and validating the results using a multinomial logit model. The final stage of the research involved delineating HOV lanes based on parameters like bus frequency during peak hours and available road space. Additionally, new high-capacity public transport services, such as double-decker buses, were introduced on bus routes running parallel to the HOV lanes, targeting overcrowded routes during morning peak hours. The research concludes by calculating the congestion costs for the study area. In summary, my research focuses on addressing congestion in Mumbai by implementing a range of travel demand management measures, including congestion pricing, HOV lanes, and improved public transport services. Through the analysis of congestion levels, calculation of marginal congestion cost, prediction of modal shift, and strategic interventions, the aim is to alleviate congestion and improve travel efficiency in the city.

KEYWORDS: Congestion management, Travel demand management, Congestion pricing, HOV lanes, public transport enhancement, Mumbai transportation planning

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Last but the least, I am obliged to my **parents** and my **family** for giving me freedom to explore and grow professionally and for supporting me.

(Ar. Chantal Singh)

UNDERTAKING

I, Ms. Chantal Singh, the author of the thesis titled "STRATEGIES TO CLEAR OUT TRAFFIC CONGESTION THROUGH PUBLIC TRANSPORT IMPROVEMENTS AND USING CONGESION PRICING", hereby declare that this is an independent work of mine, carried out towards fulfilment of the requirements for the award of the Masters in Urban & Regional Planning at the Department of Architecture and Planning, BBDU, Lucknow. The work has not been submitted to any other organization / institution for the award of any Degree/Diploma.

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CHAPTER 1: INTRODUCTION

1.1 Overview

Congestion as faced by many global cites across the globe can be understood as a phenomenon which is greatly associated with the travel during themorning and evening peak hours of a day. Congestion which has a widespread effect starting from the most easily identifiable and prominent i.e., delay in travel time or decrease in the average travel speed to the most complex and most of thetimes neglected is the environmental harm which is directly linked to the congestion produced especially in the core city areas of the city. All these impacts when transformed to the costs adds up to millions of dollars for a single. Direct as well as indirect Costs incurred because of the levels of increased congestion for American cities adds up to 280 thousand million dollars while for UK, France and Germany it adds up to 47 thousand million dollars, 46 thousand million dollars and69 thousand million dollars respectively (CEBR, 2014). Air quality in core urban areas is most of the times shown a function of the number of vehicles entering in that area, type of the vehicles (2W, 4W, Bus) etc. An important function associatedwith deteriorating air quality in core urban areas is low average speed which is most of the times caused by the congestion so a direct relationship exists betweencongestion and poor air quality or poor environmental conditions in urban areas. The graph below shows the relationship between the average speed and the emissions caused by the vehicles at various speeds. As can be observed that higher emissions are generated at lower speeds which is several times higher thanthe specified limit.

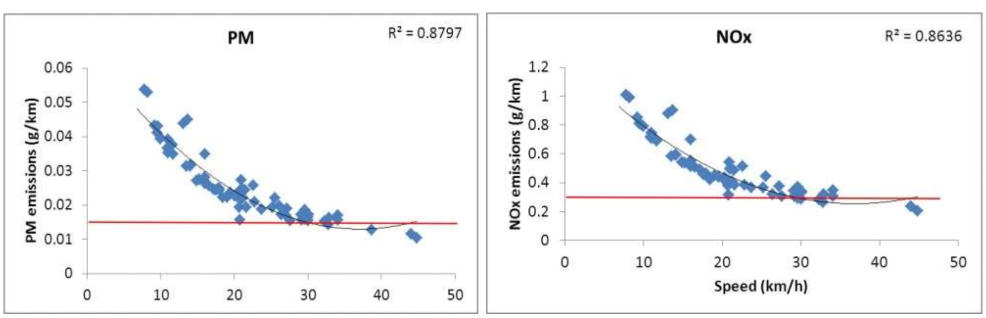


Figure 1: graph showing relationship between travel speed and PM and NOxemissions.

Source: (Indrani Gupta, 2012)

With constant growth of GDP over last few decades the affordability of people hasalso increased. The trend followed by the vehicular growth has exceeded the carrying capacity of the infrastructure such as roads, bridges and highways (ERF, ROAD STATISTICS YEARBOOK, 2016) (ERF, Road Statitics Yearbook, 2010). With constant growth of GDP over last few decades the affordability of people has also increased. The trend followed by the vehicular growth has exceeded the carrying capacity of the infrastructure such as roads, bridges and highways (ERF, ROAD STATISTICS YEARBOOK, 2016) (ERF, Road Statitics Yearbook, 2010).

Similar was the case for the city of Delhi which witnessed a 17% increase in its total road length (22,487 km in 1991 to 31,183 km in 2008). During this same period the number of vehicles increased from 2 million to over 6 million, which is an increase of almost 200% (D'Monte, 2009). Initially expansion of infrastructure (widening of roads) was assumed as a solution to tackle congestion but rather it induced more demand for the available road space and ultimately resulted in poorer level of service provided by the road. In recent times new solution in form of metro, buses and other public transport modes were considered as a pioneer solution to handle the congestion in the cities during peak hours and to certain extent it proved its ability to decongest the core congested areas during peak hours. But public transport systems such as buses, trams and BRTS when mix with heterogeneous traffic often loses their average speed. (Consider case of London buses whose avg. speed declined from 17.2 km/hr in 1986 to 14.2km/hr in 2002 due to increase in congestion (Central London congestion charges Impacts Monitoring (1st report), 2003) Secondly the capital costs associated with the large metro projects makes them an unviable option. For example only constructing 1 KM of elevated metro line can reach up to 250 crores for elevated line and 450 crores for underground line for Indian scenario (Rawal, 2017). Therefore congestion pricing can be looked as an alternative mechanism which doesn’t requires such huge investments rather becomes a source of income for the implementing authority along with its capacity to tackle the congestion in the core city areas.

1.2 Background Study

Traffic congestion costs 1.47 lakh crore per annum for India according a study in 2018 by Boston Consulting Group (BCG).

Traffic issues cause so much inconvenience and frustration and hence need to be addressed. India is one of the fastest growing economies in the world.

The average income of Indians is growing and there by the number of privately owned vehicles is rising. Though public transport is widely available in India, still it is not sufficient for the population of India.

Especially in Metro cities, often public transport services are crowded. So, to travel peacefully people are opting for commuting in their own vehicles. And as a result, more vehicles are coming on roads.

So, the question is canning wider roads and more flyovers fix traffic congestion? No says data from cities across the world. More road space induces more people to drive, the situation improves briefly but worsens later.

1.3Aim of the study

Study the levels of congestion and estimating the amount of congestion pricing along with suggestions for improvements in public transport.

1.4 Objectives of the study

- To examine the current levels of congestion based on selected congestion indicators, delineating the area for congestion pricing.
- To calculate the marginal congestion cost for different areas/roads and assess the maximum possible modal shift to public transport.
- To assess the demand for public transport and proposal of high-capacity public transport or improvements in the existing one.
- To identify and propose the possible Schemes/Strategies and norms for improvements in public transport using congestion pricing.

1.5Need Of Study

Walking Mumbai which is the financial as well as commercial capital of India generates exactly 6.16 % of our total GDP. From 2011-2017 the growth in number of vehiclesgrew from two million to over 3 million while in the similar phase the increase of the road length at around 2000 KM hasn't changed significantly. On the similar lines vehicular density also increased to approximately 1500 vehicles per square KM from the year 2011 to2016 (Gedam, 2017). Adding to such high private vehicles per 1000 population, the average speed for vehicles during morning and evening peak hoursin Greater Mumbai has declined to less than 20KM/hr and 25KM/hr. respectively (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016). This problem of congestion exists when there are about 50 cars per 1000 population (Sundar, 2014), the extent to which congestion levels will rise due to increased number of cars per 1000 population in certain years is beyond imagination. One of the environments relatedresearch projects shows that congestion has

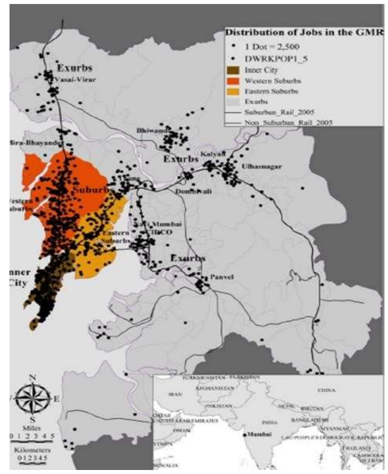


Figure 2: map showing employment distribution in GMR area

Source- (Shirgaokar, 2014)

caused travelling from Worli to Chembur after 6pm makes a patrol car emit almost twice as much as fuel during off-peak hours. This doubles the vehicle's carbon dioxide emissions from 390gm, during the trip, to 780gm (Indrani Gupta, 2012). Also reports of WHO in which Mumbai ranks 5th highest polluted megacity in the world, it is now possible to say that a large contribution of the pollution in Mumbai city is caused because of the congestion. Few researches have also showed that the congestion cost for complete Greater Mumbai Road network for the present traffic flow condition is found as 163.12 million Rupees per year. (Amol R. Patil, 2015)

The travel pattern of the city of Mumbai is linear in nature (Shirgaokar, 2014) that is people from northern and eastern areas of the Mumbai Metropolitan Region to south Mumbai during morning and returns back during the evening hours. Although the suburban rail is well connected to south Bombay and is only high-capacity public transport currently available for commuters, BEST buses and taxis (Kaali peeli as called by the localities) are unable to meet the demands during peak hours (in peak hours crowding inside the suburban rail is as high as 4700 passengers, as against the rated carrying capacity of 1700) as a result of which people most of the times prefer their own mode of vehicles. BEST buses also have high coverage and connectivity but during peak hours its average travel speed decreases as a result of which its travel time increases and therefore is even less preferred than the suburban railways.

So the need of study would mainly fetch some strategies to tackle the congestion in the south Mumbai during the peak hours by using a proper mechanism for implementing the Congestion Pricing. The revenue generated from the congestion pricing can be used in improving the condition of the public transport or road infrastructure

1.6 Scope of the Study

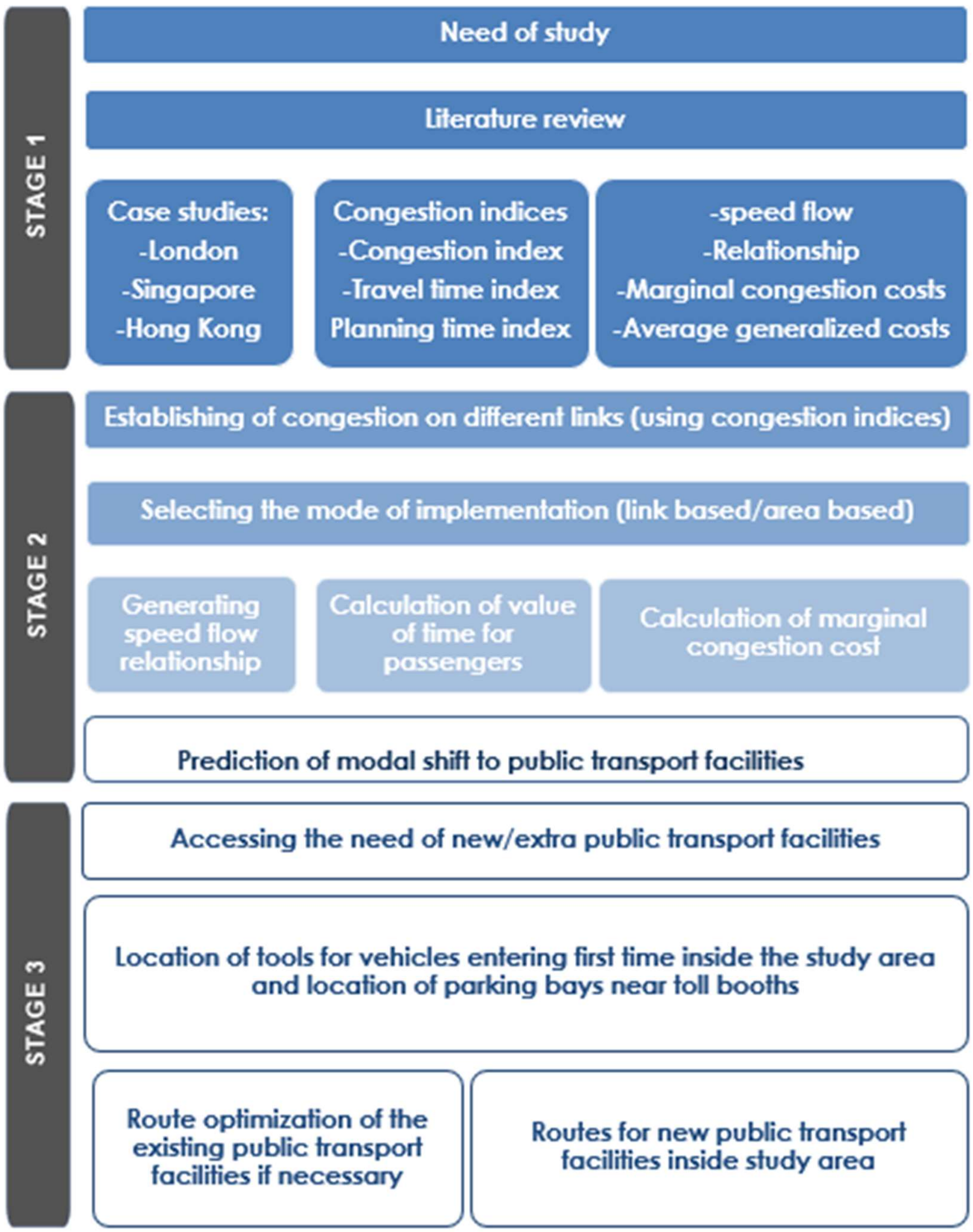
- Results from various secondary data will be used in identifying the levels of impacts due to congestion and using them for differentiating between roads for which congestion pricing strategy will be implemented

1.7 Limitation of study

- The Popular acceptance may not be forthcoming since such TDM measures has never been implemented in our country.
- Limited to cities which are monocentric in nature.
- Domain of the advanced information technology required for implementing this congestion pricing precluded from the study.

1.8 Methodology

The methodology includes work at three stages. The first stage includes literature review of the various definitions, congestion indicators, cases studies which are successful as well as those where congestion pricing got scrapped because of various reasons. The main learning from this stage will act as a foundation of this study. The second stage will include data collection at two levels, real time data (which include primary surveys such as traffic volume count, speed delay survey.



- Figure 3: methodology for the study

Locations and information related to parking spaces along with location of multimodal hubs, bus depots, on street and off street terminals, proposed routes for the metro rail as well as for the monorail, BEST city bus routes, its coverage and accessibility inside the island city and available services for parking) while on second level it will require OD data, average travel speed using Google API (this will help in defining the common congestion indicators such as travel time index, level of service provided by the roadway, multimodal level of service, annual delay due to congestion, annual delay per capita due to congestion, congested lane miles, barring effect etc.) existing land use especially the commercial land use percentage and its spatial location inside the study area, as well as existing employment distribution will help in deciding whether the area should have different pricing districts or it should have different pricing road links. Results from these surveys will help in delineating the area for which the congestion pricing is to be implemented. This stage two will also involve calculation of the marginal cost of congestion for different areas/ roads by the help of suitable speed-flow relationship model In the final stage the proposals will come in form of improvements in current public transport service or introduction of new public transport service which has high capacity carrying quality as well as should be a viable option for the commuters to shift from their private mode of transport to the public mode of transport.

CHAPTER 2: LITERATURE REVIEW

2.1 The Theory of Congestion Pricing

"People see it as a tax increase, which I think is a gut reaction. When motorists' time is considered, it's really a savings."

-WILLIAM VICKREY (father of congestion pricing)

William vickrey, who was considered as the father of congestion pricing (a noble prize winner also for his works in Economics) was the first person to recommend that people should be taxed while travelling in the peak hours. Taxation rates should be decided on the basis of the time of day whether peak hour periods or non-peak hour periods. Initially his theory was only limited to the New York's subway system, in later stage his theory was modified to the new theory of congestion pricing.. The congestion pricing was first implemented in Singapore core CBD as Singapore area licensing scheme in 1975 although it was upgraded in 2007 because of the advancement in the information technology sector, Singapore government made all the districts of the city under Electronic Road Pricing (ERP) anyone entering into any district with his private vehicle has to pay certain amount of tax.

1. Types of congestion pricing

Table 1: table showing types of congestion pricing schemes

Facility based schemes	**Cordons**	**Zonal/district schemes**	**Distance based schemes**
This method is similar to the normal tolls imposed on bridges, tunnels, National and state highways.	In such types of scheme the vehicle needs to pay a certain amount of tax only if it enters/exits or	Have a similar concept as cordons but here the user of the vehicle needs topay only once whenhe enters a certain zone/district with	One of the most effective strategies in terms of tackling the congestion. The users are charged on the basis of thetotal distance travelled by themduring the peak hours and alsoon the basis of the PCU ofvehicle they are travelling in

E.g. Bandra sea link	passes througha cordon line	certain amount of congestion tax	

Source- (Fraser, April 2006)

2. Choice of congestion pricing scheme

Table 2: table showing types of tolls

Flat tolls	Time of day tolls	Responsive tolls
In this type of tolling system a flat charge is imposed on the user, irrespective of the current congestion levels or time of peak or non-peak hours	Such tolling system responds as per the time of the day. Generally such systems charges more in evening and morning as compared to afternoon or night, when the congestion levels are comparatively very low.	The most effective of the charging systems as it dynamic in nature, it increases as the congestion increases it decreases as the congestion decreases.Dynamic pricing is the most effective way for tackling the congestion while flator time of day tolls are more efficient in generating higher revenues from the congestion pricing.

Source- (Santos, Urban Congestion Charging: A comparison between London and Singapore,2005)

3. Congestion pricing technologies
    - Automated number plate recognition
    - Dedicated short range communication
    - Satellite systems
    - Cellular networks
    - Vehicle equipment

2.2Case Study (Successful)

Areas around the world where congestion pricing has been implemented are studied on common parameters such as car ownership 1000 population, modal share, minimum pricing, area of the CBD for which the congestion pricing can be implemented and more importantly the parameters that shows what effects in terms of modal shift and increase in the average travel speed and what all steps were incorporated by the different agencies to make the congestion pricing successful.

Table 3: table showing details of congestion pricing schemes characteristics in Singapore

	SINGAPORE (1975) (7:30-9:30)
basic details	. Started in year 1975 as Area Licensing Scheme (ALS)[M-SAT 7:30AM-10:15AM] converted to ERP during 1998
car ownership (per 1000 pop.)	63 (SEIK, 1997)
average speed before implementation	19KM/HR (1975) (Sock Yong Phang, 1997)
modal share (cars vs. public transport)	56/33 (1975) 46/46 (1976) 23/69(1983) [FHWA,2008 (URL)
objectives	• Traffic reduction by 25-30% during peak hours • ERP – to maintain an avg. speed of 20-30 km/hr
charge	$3/ day to$60/ month
affected area	6-7 sq. km
exemptions	Military vehicles, 4 wheelers of 3 or more occupancy and public transport were given exemptions inside the study area
effects	• There was a decline in Traffic by 44% (includes cars and other vehicles)[march 1975- June 1975] (SOCK-YONG PHANG, 2004) • No. of cars reduced by 75%. (SOCK-YONG PHANG, 2004) • Increase in the Avg. speed by 20% (Kiran Bhatt, 2008) • Avg. speed was 35km/hr in 1991 (SOCK-YONG PHANG, 2004) • [ERP] Traffic reduction of 10-15% mainly caused because of the charges being levied per passage (Santos, Urban Congestion Charging: A comparison between London and Singapore, 2005)

services provided before or during implementation	• 33% in bus service (SOCK-YONG PHANG, 2004) • 15000 new parking spaces were created before implementation of congestion pricing in Singapore (SOCK-YONG PHANG, 2004)

Table 4: table showing details of congestion pricing implemented in London

	LONDON
BASIC DETAILS	Launched in 2003 [M-F, 7 AM-6:30 PM]
CAR OWNERSHIP (per 1000 pop.)	330
average speed before implementation	14.2 KM/HR (2002) (Central London Congestion Charge Impacts monitoring (5th report), 2007)
modal share (cars vs. pt)	12%/84% (which includes underground rail, bus, national rail)
Objectives	Reduce traffic conditions and contribution to 4 of 10 priorities in his transport strategy “to reduce congestion, to make improvements in bus services, to improve journey time reliability for car users, sustainable and efficient
charge	5 pounds (2003-08), 8 pounds (after 2008)
Affected area	22 sq. km
Exemptions	• London cab, emergency vehicles and vehicles of the disabled persons • Reduction of 90% for the residents living inside the study area and 10% reductions to the users having vehicles of different fuel

Effects	• Overall traffic reduction of 14% while traffic reduction inside the CBD area was 50% (Central London congestion charges ImpactsMonitoring (1st report), 2003) • Private cars reduced by 30% (Central London congestion charges Impacts Monitoring (1st report), 2003)

Table 5: table showing details of congestion pricing implemented in Stockholm

	Stockholm
BASIC DETAILS	Operating permanently since 2007. 33% of the residents of city liveinside the charged zone (M-F, 6:30 AM-6:30 PM)
CAR OWNERSHIP (per 1000 pop.)	370
average speed before implementation	N.A.
modal share (cars vs. pt)	30/70(b4) 25/75(after) (EVALUATION OF THE EFFECTS OF THE STOCKHOLM TRIAL ON ROAD TRAFFIC , 2006)
Objectives	• Reduce traffic to and from the city by 10-15% during morning and evening rush hours, • better LOS for city traffic • Reductions in emissions of C02
charge	5-20 Swedish kronor
Affected area	34 sq. km
Exemptions	Emergency vehicles, buses with weight less than 14 tonnes, motorcycles, taxis etc.
EFFECTS [cordon and zone] [congestion]	• No. of vehicles reduced by 22% (100000 less passages per day) • For morning peak it was 14% reduction while for evening hours it was 24%. • Cars reduced by 30% as compared to 2004 • Reductions were lower inside the charged zone than for the main roads outside (Jonas Eliasson, 2006)

Mode change to public transport diverted around zone	30000 passages turned to public transport (EVALUATION OF THE EFFECTS OF THE STOCKHOLM TRIAL ON ROAD TRAFFIC , 2006)
Services provided before or during implementation	parking spaces were completed before implementation (Facts about tion of the Stockholm Trial , 2006)

Table 6: table showing details of congestion pricing in Milan

	MILAN
BASIC DETAILS	Introduced in 2008 [M-F, 7:30 AM-7:30 PM], 43 ENTRY POINTS
CAR OWNERSHIP (per 1000 pop.)	77 per 1000 population
average speed before implementation	N.A.
modal share (cars vs. pt)	72/28 (pvt. Vehicle/PT) (legammiente and ambiente italia 2007)
Objectives	• Make the air cleaner by reducing PM emissions by 30% • Relieve congestion by reducing the number of incoming cars by 10% and thereby speeding up the public transport, boosting public transport (info brochure,p1, Milan council 2008)
charge	2,5, 10 euros (based on pollution class) (Milano council,2008,p6)
Affected area	8 sq. KM

Exemptions	Residents living within the area are entitled to purchase anannual pass, equal to 25 entries
EFFECTS	• Traffic reduced by 12.3%(21000 vehicles a day) and traffic outside the zone reduced by 3.6% (municipality of Milan, 2008c) • Congestion had fallen by 25% in morning peak • Increase in avg. speed by 4%
Mode change to public transport diverted around zone	• 35% diverted around the area • 17% change to cars exempted from fees • 48% changed to public transport (municipality of Milan, 2008c)
Public Transport (Flexibility, avg.	• The avg. speed for public transport increased by 6% (9.4km/hr • The metro saw an average daily increase of 7.3% 19100 passengers) (municipality of Milano, 2008c)

Conclusion

In every case significant impacts can be seen in terms of the increase in the average travel speed not only inside the area for which congestion pricing is adopted, but also beyond the cordons. Second important learning from all the case studies is that first, without strengthening the current public transport it is impossible to get the desired results from the congestion pricing, since people who would like to shift from their private mode of transport needs an alternative. Secondly, parking spaces near the cordons are equally important for successful implementation of the congestion pricing. These parking lots can be used as park and ride facilities and can prove very effective in increasing the modal shift of persons from private vehicles to public transport. Few other learning include that people residing inside the congestion pricing implemented area needs to be given some incentives in terms of comparatively lower charges or monthly pass etc.

6.1. Similar Researches

PAPER TITLE - Estimation of Cordon Based Marginal Congestion Cost forGreater Mumbai Road Network (Amol R. Patil, 2015) Conclusion – in this paper the authors prepared the road network for whole Mumbaicity and used a speed flow model for the whole network. After calibration of the parameters in the models they have calculated the marginal delay on various roadsbased on the V/C ratio on these roads similarly calculated the value of time of thepassengers and ultimately came out with the total congestion costs for the Mumbai city which is 163 million per year only for just the peak hours. The paper used the idea of implementing the congestion cost based on codon districts which have different V/C ratios.

The research concluded with the cost that needs to be paid per km per PCU camein a range of 1.90 rupees to 5.34 rupees.

PAPER TITLE- Congestion costs incurred on Indian Roads: A case study for NewDelhi (Neema Davis, 2017)

Conclusion- this paper attempts to relate the congestion costs as a cumulative function of cost of losses incurred due to productivity loss, accident costs, environmental degradation cost caused because of congestion, air pollution costsetc. these costs were added for the delhi and total congestion cost for delhi per year came as million US$ 9527 per year for the year 2018. It is expected to increase by 9 percent by the year 2020 and 40 percent by the year 2030. These costs have included the total contribution of various modes of travel in the congestion costs.

Presentation Title (Urban mobility conference, 2016)- congestion pricing: a case ofDelhi (Minoti Rawat, 2016)

Conclusion – in this presentation the author chose Connaught place in Delhi as a study area. She calculated the V/C ratio of the roads originating from a focal point inside the study area. Projections of the increase in the traffic were made andthrough stated preference survey peoplewere asked whether they'll shift to public transport if these roads are taxed. Based on the results obtained the new V/C ratio for the roads was calculated. Apart from this formal structure, the presentation also included calculation of the value of

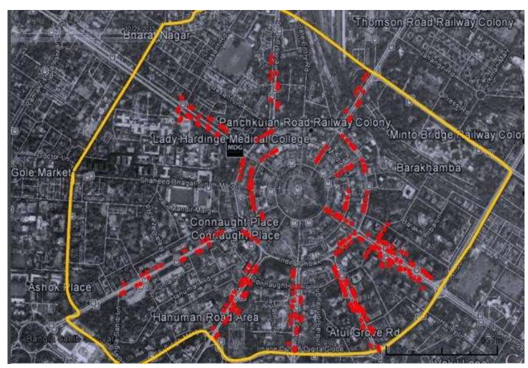


Figure 4: image of cordon points and study area in research paper

source- (Minoti Rawat, 2016)

time of 4 wheelers and marginal congestion cost. The predicted modal shift from car to public transport came about in a range of 13%-26% for different scenarios with utility functions ranging from 0.23-0.71 for different scenarios. The presentation ended with the idea of using other techniques such as carpooling, freeride in public transport just before the morning and evening peak hours.

6.2. Congestion Related Indices (Used In 1st Objective)

The common form used to calculate the congestion is the V/C ratio. V/C ratio basically gives the current level of service. Level of service decrease as its value reaches to 1. A lower value of V/C ratio has a free flow traffic condition. Valueof V/C at LOS-C is the most optimum value of the V/C ratio. Since the exact valueof the road capacity is difficult to arrive at in most of the cases therefore an alternative to the V/C ratio is used which uses travel speed as a main element to calculate the levels of congestion on the roads during peak and non-peak hours

2.5.1. Congestion Indices

Congestion can be described as existing traffic conditions on the roads during peak hours. Congestion index uses speed to signify the current traffic conditions on the road. Congestion index takes 30km/hr. as an optimum speed fortravel in the peak hours or at the highest level of service. The formula for the indexis as follows

Congestion index = 1 - (A / M) where A= the observed speed of the vehicle duringthe peak hours and M= 30km/hr. which has to be taken as universal constant. Greater the value of congestion index higher is the congestion on the road. (WilburSmith Associates, 2009)

2.5.2. Travel Time Index

Travel time index (TTI) can be defined as the ratio of average travel time and the free flow travel time for a link/road. For a specific link/ road it can be calculated as

TTI = TT Avg./ TT Free flow

Suppose the TTI comes out as 2 that indicates that the average travel time is 200%of the free flow travel time for example if to travel a 2 km from point A to point B it takes 4 minutes in free flow traffic conditions and that road has a TTI of 2 during peak hours than it will take 12 minutes to reach the destination while travelling fromthat road. That is 8 min. of delay or 8 min. of extra time required to complete the trip. (Transcore, 2011)

2.5.3. Planning Time Index

Planning time index basically informs about the additional user time requiredto reach the destination on time on 95% of the total trips been made (Transcore, 2011). For example if planning time comes out to be 20 minutes for a road that means that to travel from that road you need to spend 20 minutes more than that of the free flow travel time. A better understanding will require real life example which is stated in the analysis chapter further in this report.

6.3. Speed-Flow Relationship

The relationship between the variables of the traffic flow which includes volume of the vehicles of the road stretch, speed of the vehicle and the density ofthe vehicles is called fundamental relations of traffic flow.

5.1.1. 2.6.1. Derivation-

Let us assume there are exists a road with length L km and also assume that all the vehicles moving on that particular road have a speed of V km/hr.

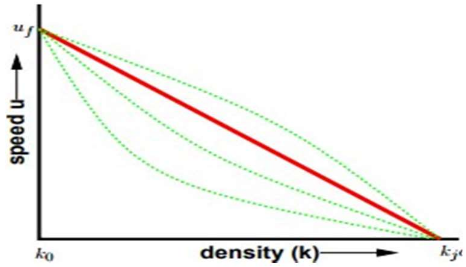
So, by definition the number of the vehicles that passes through a point of the roadequals to the flow of vehicles on that road

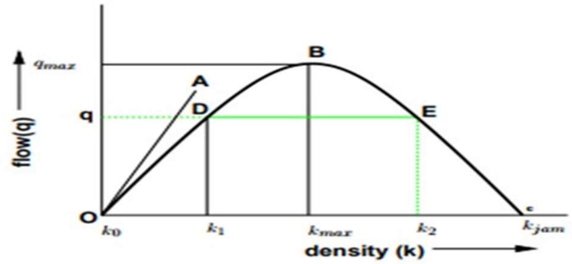
i.e. N_1=Q (FLOW)

Similarly, number of the number of vehicles in unit distance will be equal to density multiplied with the distance of the road

i.e. N_2= K(density) X L (length of road in Km)

Since all the vehicles as assumed to have the same speed therefore N_1=N_2 and





(Flow) = K (Density) X V (Speed)

6.4. Various Speed-Flow Relationship Models (Used In2nd Objective)

Table 7: table showing various speed-flow relationship models and its drawback

MODEL	EQUATION	DRAWBACK
LINK BASED SPEED FLOW MODEL	$S = S_f\left[1-\alpha\left(\frac{V}{C}\right)^{\beta}\right]$	This is the most frequently used models as because of the fact that it requires minimum amount of data, but the calibration parameters (□ and □) vary from place to place and could fetch wrong results in many cases if calibration is not done properly.
GENERALIZED DRAKE MODEL	$q = K_0 V\left(\delta \ln\frac{V_f}{V}\right)^{1/\delta}$,	Developed in 1967 it is one of the oldest model depicting speed flow relationship. Uses logarithm approach to justify the relation. Doesn't uses and delay causing parameters and also have same

		issues as link based model i.e. parameters canvary from place to place
VOLUME-CAPACITY BASED RATIO	$V = \frac{V_o}{\left[1 + a(v/c)^b\right]}$	This model's drawback is similar to above stated and more importantly it can fetch wrong results as it doesn't differentiate between various levels of V/C ratio. Same equation can be used for V/C ratio of 0.2 and 1.2 and therefore it is not feasible for my study area. (DOWLING, 2011)
DAVIDSON - AKCELIK MODEL	$t = t_o\left[1 + \frac{JX}{(1-X)}\right]$ X<1 $t = t_o + 0.25T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8J_AX}{cT}}\right]$ X >1	This model is one of the most reactant to the real life traffic condition and considers delay causing elements such as traffic signals.

Source: (DOWLING, 2011), (Amol R. Patil, 2015)

The table below depicts the applicability of every above discussed model in different regimes of traffic flow. Link based model (linear model) is only suitable forfree flow state of traffic flow, for rest of the regimes of traffic flow this model is not able to fetch right results because of various calibration parameters that changes from place to place. Second model is generalized Drake model which is not suitablefor free flow, May or may not be suitable for critical regime (i.e. the point just beforethe road capacity is reached), is suitable for optimum and congested flow. The same model doesn't applies to shockwave conditions when there is heavy outflowof traffic on the road. Third, model which is the V/C ratio based model is suitable for first three regimes of the traffic while its implementation isn't possible in case ofcongestion and shockwave situations. The mast model which will be used in this study is the Davidson-Akcelik Model which is applicable to all the traffic flow regimes because of the fact that this model uses two separate equations for findingthe current traffic flow. One of the equation is meant for V/C ratio of less than 1 while second equation holds good for V/C ratio of greater than 1. (Taylor, 2008)

Table 8: table showing suitability of Speed-flow models in different traffic regimes

MODEL	Free-flow	Critical	Optimum	Congested	Shockwave
LINK BASED SPEED FLOW MODEL	suitable	not suitable	not suitable	not suitable	not suitable
GENERALIZED DRAKE MODEL	not suitable	may not be suitable	suitable	suitable	may not be suitable
VOLUME/CAPACITY RATIO BASED MODEL	suitable	suitable	suitable	not suitable	not suitable
DAVIDSON-AKCELIKMODEL	suitable	suitable	suitable	suitable	suitable

Source: (Taylor, 2008)

6.5. Value of Time

In modern times the total time invested in commuting has increased exponentially and is still in an increasing function. Value of time for and individual basically tells about the unit monetary cost that someone is ready to invest/ spendin order to save his unit time. Value of time is different for different individual. The value of time for and individual usually depends on various factors such as his income pattern, other socio economic factors, the mode he uses etc. For examplea business man whose major work is to transport frozen food and fisher to other parts of the country will be more to pay 300-400 extra amount of money in order tosave his 1 hour where else a businessman whose work is to deliver electronic appliances will not be as comfortable to spend 300-400 rupees just to save 1 hr. he might be willing to spend only 50-60 rupees for savings of 1 hour. This is how value of time changes from one individual to other.

Value of time of 4 wheelers in Delhi as calculated for 2014 came out to rupees 246(Minoti Rawat, 2016) where else value of time for 4 wheelers in Mumbai was 190 rupees and 78 for 2 wheelers. In this study the value of time has been calculated by inflating the economic cost operating a 4 wheeler on highest road roughness.

The inflation has been adjusted by multiplying the economic cost by ratio of per capita income of Mumbai and per capita income of India. The result further obtained is then multiplied to the Wholesale price index (2018). The value of time for 4 wheelers is discussed further in analysis chapter.

6.6. Marginal Congestion Cost

It is the increase in the congestion cost when a new user gets added in to the existing congestion levels on the roads. The derivation of the marginal congestioncosts is as follows: (Tom, CALCULATING TRANSPORT CONGESTION AND SCARCITY COSTS, MAY 7 1999)

EQUATION 1: Let us assume time cost per kilometre (reciprocal of time)t

(time cost per kilometre) = value of time (b)speed of vehicle (v) ***EQUATION***

2: Total cost per Km (T) = t*flow of traffic (q)

Differentiating w.r.t flow we get, dT/dq= t+ dt/dq (getting value of dt/dq from equation 1 after differentiating it w.r.t to dq)

EQUATION 3: q*(b/v^2)*slope of speed flow relationship

b- value of time, q-flow of traffic (in pcu), v- speed of vehicles in congestion

The result obtained in equation number three has been utilised in further chapters for calculating the marginal congestion cost for different roads on different times ina day.

6.7. Average Generalized Cost

In the field of transport economics, the cost associated with travelling from one place to another involves certain monetary attributes as well as some non- monetary attributes. Monetary attributes involves vehicle operating cost, parking charges, taxing or tolling while the non-monetary attributes includes the monetaryvalue of waiting for a vehicle, monetary cost of time spent on travelling to the nearest transportation hub from home or else from transportation hub to office, school or other destination. By combining both these attributes average generalized cost is calculated. Average generalized cost is different for different modes of travel. (Transport Analysis guidance, 2014) Change in average generalized cost is usually seen in order to justify that people will shift from privatevehicles to public transport such as bus or tram or metro rail since these modes have comparatively low generalized cost as compared to 4 wheelers or 2 wheelers.Use of generalized cost has been shown in analysis chapter.

AGC for a bus or any other public transport mode is calculated
=fare/km*distance/VOT + In vehicle time+2*wait time (min.) + 2.*access andegress time

Whereas AGC for a car is calculated as

=In vehicle time + (VOC*distance +parking cost)/ VOT* Occupancy+ Congestion Charge

6.8. Logit Model

This study involves prediction of modal shift to a new public transport from the private vehicles after congestion pricing gets implemented. For correctly predicting the modal shit use of multinomial logit model has been used. Since thereare more than two levels of the concerned attributes which are travel time and travel cost therefore use of multinomial logit model is done in the analysis chapter.

The logit models basically tells about the utility and disutility of a certain case, in this research utility of different modes have been seen in order to cross check withthe surveys that how much of the total percentage of the population commuting inside the island city (study area) are ready to shift to the public transport.

$$t = \beta_0 + \beta_1 x + \beta_2 x_2 + \beta_3 x_3 + \varepsilon$$

$$\sigma(t) = \frac{e^t}{\sum_{t=1}^{t=k} e^t}$$

The utility from the above formula has been utilised to calculate utility of car, 2wheeler and bus

6.9. 2.12.H.O.V Lanes/ Diamond Lane

A high occupancy vehicle lane (carpool lane, transit lane, diamond lane or as called as T3 or T2 lanes in case of New Zealand and Australia) is a lane whichis restricted for the use by vehicles that have high occupancy during peak hours. The main purpose of the HOV lanes is to increase the car occupancy of the vehicleespecially the 4 wheelers. With increase in the socio economic pattern of the persons residing in the cities even every middle class household owns 2 or more than two number of vehicles as result of which every individual in a household useshis or her own single vehicle to commute. In America the first HOV lane was introduced in 1970s and 1980s. The first HOV lane was the Henry G. Shirley Memorial Highway in northern part of the Virginia which used to connect Washington DC and capital Beltway. Initially it was opened as an exclusive bus lane but was opened for carpool users in the next 5 years from the date of opening. Followed by this HOV lane the Urban Mass Transit Administration understood theadvantages of the HOV lanes and encouraged the state highway agencies to propose or built a HOV lane in every project. The encouragement was given in theform of the funding from the transport authority. (Turnbull, 1992)

As of year 2009 the state of California become the state with highest number of HOV facilities in the whole United States of America, followed by the state of Minnesota (83 HOV lane facilities) followed by Washington with 41 HOV lane facilities. The longest and continuous HOV lane facility in the United States of America is about 115 km long from Spanish fork to Layton. (Gibson, 2016)

The first HOV lane in Canada was opened in the cities of Vancouver and Toronto in the year of 1990s. significant impacts were observed in case of Canada as in few of the HOV lane facilities there average rush hour speed became 100 km/hr. from 63 km/hr. this made HOV lane facilities a prominent part of all the highways in the Canada nation.

Taking the case of Europe the fashion of HOV lanes facilitates doesn’t came into existence because of the fact that Europe has public transport facilities much betterin as compared to the nations of USA and Canada. The car using section in the society are very less as compared to those in America or Canada. Even the rich use public transport in the European nations. The first HOV lane was inaugurated in the Netherlands although it doesn't make much difference in the commuting pattern and didn't attract much of the users and therefore become a part of strong critics and finally was changed into reversible lane open to general traffic. In fact the china has also started to use HOV 2+ lanes strategy in order to make full utilization of the available road space.

Chapter Summary

The following chapter includes mainly three parts the first part being the learnings from the places where this congestion pricing has been implemented several case studies of London, Singapore, Stockholm and Milan were seen and were compared on certain same parameters in order to see the key elements thatis required for implementing the congestion pricing. In the case studies the changes that took place after implementation of the congestion pricing was also looked upon and used in forming the objectives as well as scope of the study.

The second part of this chapter includes learnings from the similar studies that tookplace in India and around the globe. Learnings from these similar researches wereused while quantitatively analysing the data in the analysis chapter and in the proposals chapter. The researches were also helpful in structuring the framework for the analysis stage as well finalizing the direction for proposal (Proposal of HOVlanes). The last part of this chapter involved the quantitative methods, tools and techniques required to complete this study. Value of time, comparison of various speed flow relationship models, formulation of speed flow relationship model, average generalised cost calculation, logit model, marginal cost calculation, utility equations, and congestion related indices such as congestion index, planning time index and travel time index. All are very significant in carrying out a quantitative based study and finding the final results that from high much percentage will the current levels of congestion will go.

CHAPTER 3: STUDY AREA (SOUTH MUMBAI)

The study area for proposing strategies to tackle congestion such has congestion pricing and public transport improvements will be Mumbai. As already mentioned in the introduction that Mumbai is a mono centric city and have its CBD at the tip of the city, therefore the area of interest narrows down to the island city of Mumbai. Popularly known as south Mumbai or "SOBO" it is one of the costliest real estate markets not only in Indian level but on a global level. Since it is not possible to carry out the whole study for an individual therefore out of the total area of South Mumbai, further area will be delineated based on various primary and secondary surveys results and thereby the congestion costs for individual areas/ roads will be calculated. The study area consists of 9 wards starting from Ward A, B,C,D,E,G-NORTH,G-SOUTH,F-NORTH and F-SOUTH with an area of 304 hectares distributed among these wards.

The area has a public transport connectivity in form of suburban trains as well as local BEST buses. Entry of 3W is prohibited in this area while cabs are also a major mode of commuting inside the Island city. Underground metro is also proposed for the area which is expected to open for public use by 2017.

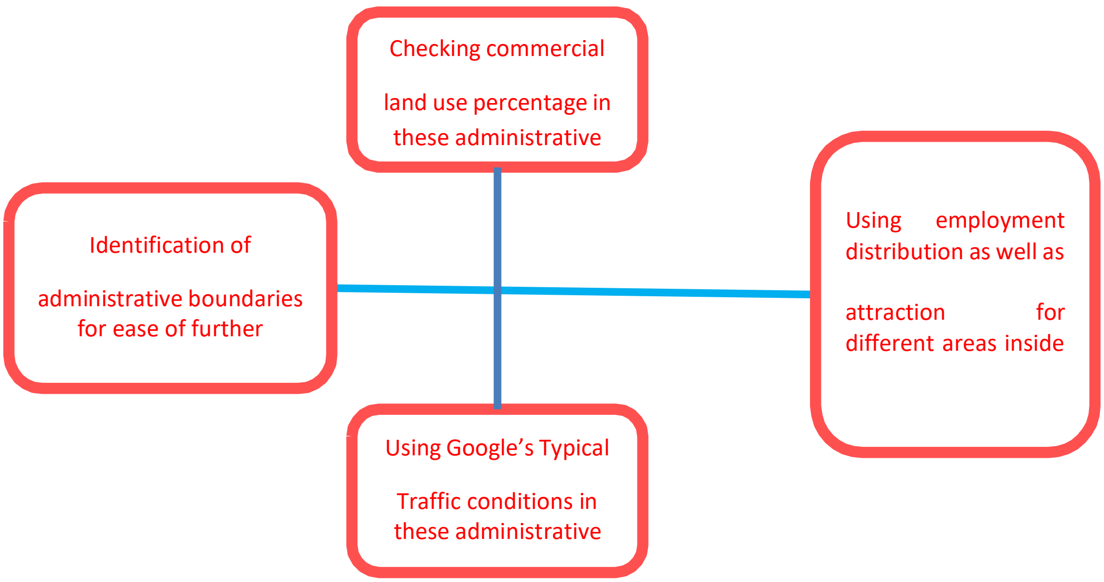


Figure 6: methodology for study area delineation

3.1 Delineation

The delineation of the study area is based on certain factors such as :

- Employment distribution
- Trip Production and Attraction

5.1.2. Employment Distribution

Distribution of employment in different wards in the Mumbai city wasconsidered as a criteria for delineating the area for implementing congestion pricing. The employment status of all the wards in the city for year 2014 and for year 2034 was taken into consideration. Further the change in the rate or the increase in the rate of employment generation ward wise was also taken into consideration for delineating the area for implementing the congestion pricing.

As per the results obtained and as evident from the maps the current

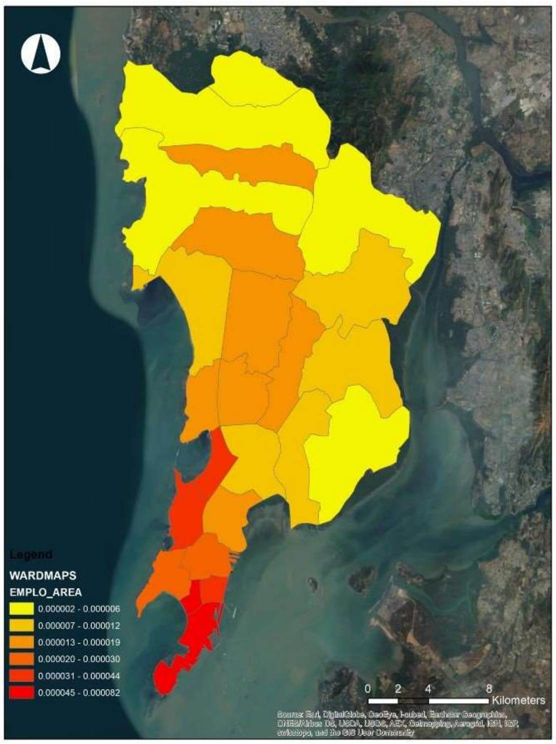


Figure 8: map showing employment distribution in Mumbai city,

Source - (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016)

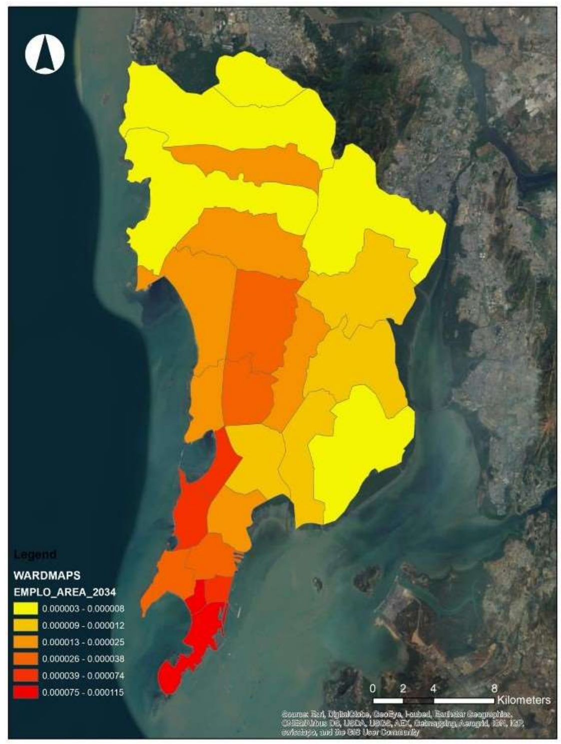


Figure 7: map showing projected employment distribution in 2034

Source- (Comprehensive Mobility Plan (CMP)for Greater Mumbai, 2016)

Employment generation is highlighted in the lower half of the city for year 2014 aswell as for year 2034. The highest rate of change in the employment (about 75%) was observed in the ward A which is at the tip of the city. The rate of change in employment in the lower half of the city was much more than the upper half of thecity (western and eastern suburbs)

5.1.3. Trip Production and Attraction

Apart from the employment distribution one more parameter for delineatingthe study area was also considered which was trip attraction and trip production which was based on the study conducted by the MMRDA CMP MUMBAI 2016. The results obtained from the table of trip generation and trip production showed that the overall trips (which includes home, work and other trips) the highest trip producing areas were the suburbs of the Mumbai city while the highest trip attracting areas were inside the Island city of the Mumbai city.

Table 9: trip production and attraction for Mumbai city

AREA		ISLAND	SUBURBS	REGION
WORK	PRODUCTION	32.03	56.89	11.08
	ATTRACTION	62.73	29.31	7.96
EDUCATIO N	PRODUCTION	40.2	52.46	7.34
	ATTRACTION	52.45	41.08	6.47
OTHERS	PRODUCTION	47.3	41.89	10.81
	ATTRACTION	64.22	28.43	7.35
TOTAL	PRODUCTION	36.21	53.47	10.32
	ATTRACTION	61.03	31.4	7.57

Source- (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016)

As can be seen from the above table that overall highest trips are been attracted by the island city which is about 61%of the total trips been made in the Mumbai while the highest trips produced are from the western and eastern suburbs which is 53% of the total trips. Based on the above stated two parameters and the generaltraffic conditions observed during the peak hours the island city of the Mumbai has been delineated as the study area the study area consists of 9 wards in the island city

3.1. Existing Landuse

The existing landuse as shown in table 2 is used as one of the parameters to delineate the study area. Wards F- north and G- north has comparatively less commercial land use percentage as compared to rest of the wards. Wards C has the highest commercial land use percentage followed by the ward B which has about 11% of the wardarea contributed towards commercial use.

Though F-north have very low commercial land use percentage but it can't be excluded from the study area as it will rather induce a greater traffic in these areas as it will act as bypass to get into island city wards where the congestion pricing will be implemented.

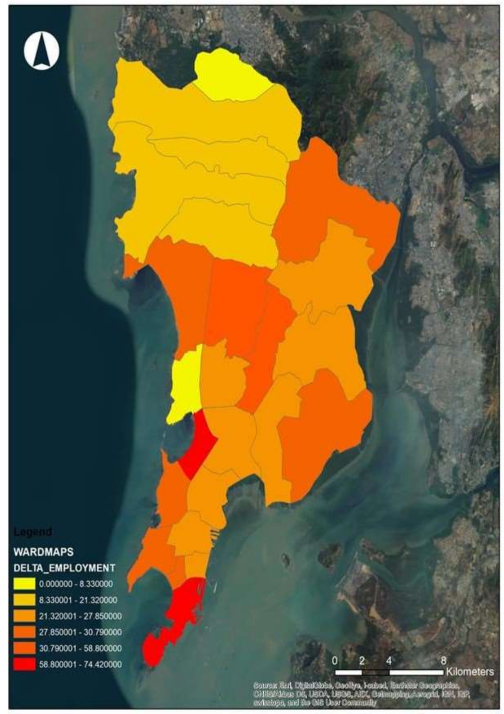


Figure 9: map showing rate of changein employment in percentage

Source: (Comprehensive Mobility Plan (CMP)for Greater Mumbai, 2016)

Table 10: ward wise commercial land use area and characteristics

WARDS	AREA (IN HECTARES)	COMMERCIAL LAND USE %	WARD DESCRIPTION
A	883	5.4 (52.61 Ha)	Bound by Arabian sea on the eastern side aswell from southern and western side and Anadilal Potdar marg, Lokamnya Tilak Roadon the north. The ward includes Navy nagar, Colaba, Cuffe Parade, Ballard Estate etc.

B	265	11.37 (30.22 Ha.)	Ward with harbour and PD Mello road on the eastern side, LT marg on the south and includes areas of Mandvi, Dana Bunder, chinch Bunder. The ward also has two TP schemes covering an area of 23 ha.
C	191	14.31 (27.38 Ha.)	Bound by the Rehman street on the east and Arabian sea from the western side. It includes areas of marine lines, Null bazaar, Zaveri Bazaar and Gigaon
D	822	4.14 (34.04 Ha.)	Bound by Vithalbhai Patel Road, ArdesarDady street, Trimbak Parshuram Street on the East, Arabian Sea line along Netaji Road,Walkeshwar Road, upto Haji Ali on the West.It includes areas of includes Banganga, Malabar Hill, Grant Road,Peddar Road, and Girgaon
E	727	6.56 (47.52 Ha.)	The ward is bound by the Arabian Sea and Barrister Nath Pai Marg on the East, Dattaram Lad Marg on the North. Includes areas of Agripada, cotton green and Darukhana
G SOUTH	929	4.53 (42.10 Ha.)	Bounded by central railway on the eastern side and Arabian sea form the western side.The ward consists of areas of Worli, Mahalaxmi and lower Parel
G NORTH	573	2.3 (13.3 Ha.)	Ward has 4 TP schemes of an area covering 335 Ha. And consists of areas such asDadar, Mahim Causeway, Shivaji Park etc.
F SOUTH	978	5.11 (50.06 Ha.)	Bound by the Thane creek on the easternside and central railway on the western side.

			Areas of Parel, Wadala, Sewri comes underthis ward
F NORTH	1108	0.86 (9.58 Ha.)	Bounded by Thane creek on the east and central railway from the western side. The ward has Parsi colony, Hindu colony andPrateeksha nagar.

Source: (Comprehensive Mobility Plan (CMP) for GreaterMumbai 2016)

3.2. Traffic Conditions

5.1.4. Bus Routes, Coverage and Frequency

The total number of operating bus routes insidethe island city area are 135 out of which 102 routeshave ordinary bus service,25 routes are limited inservice, 5 routes are express/corridor service whileonly 3 routes have air conditioned buses running onthese routes. Considering the percentage of the total area covered around different buffer limits from the existing bus routes, approximately half of the study area is served within 100 metres buffer of the current city bus route, which gradually increases with theincrease in the buffer area. The coverage reaches 93% if a buffer of 500 Metres is considered on both the sides of the current network. 500 metres is also considered as a feasible walking distance for anyhuman being buffer of 500 Metres is considered on both the sides of the current network. 500 metres is also considered as a feasible walking distance for any human being (Priyanka Vasudevan, 2013)

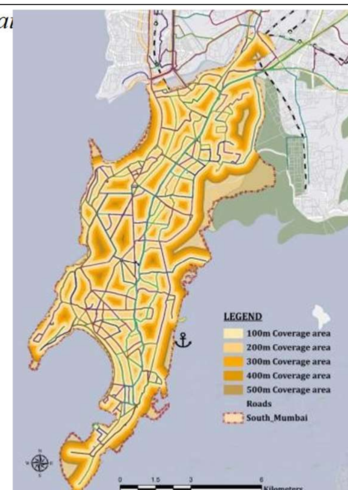


Figure 10: map showing coverage of BEST bus routes based on different buffers

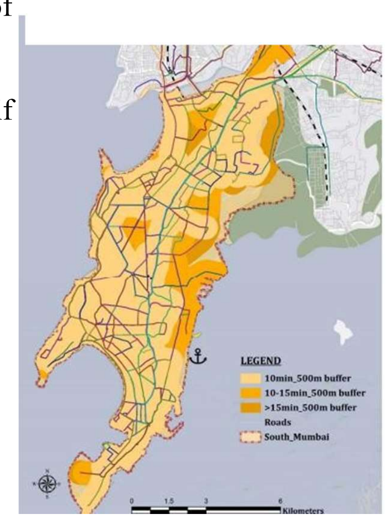


Figure 11: map showingbus frequency in different buffers inside study area

Now also considering the service frequency of the bus services, 75% of the islandcity area is covered with the high frequency bus service i.e. between 0-10 minutes,while almost 93% of the area is covered with having a frequency of the bus twice as the desirable time i.e. 8 minutes. Further only 26% of the routes have high frequency of bus. More than half of the existing running routes the frequency of the
buses running is below 15 minutes

Table 11: table showing bus service coverage for different buffer areas

BUFFER IN METRES	100	200	300	400	500
% OF COVERAGE	47.8	72.4	84	89.7	93.2

Table 12: table showing frequency of bus services in different buffer areas

frequency (in minutes)	0-10 minutes	10-15 minutes	>15 minutes
% ROUTES	25.6%	32%	42.4%
% COVERAGE	74.9%	88.7%	93.1%

5.1.5. Bus Depot Location

Inside the island city there is total 7 bus depots (Backbay, Colaba, Central, Wadala, Worli, Dharavi, Pratiksha nagar), 41 on street terminals and 11 off-street terminals. All the 7 depots operates a fleet size of 960 which consists of singledeck bus, double deck bus, midi bus, mini bus and air condition buses. The highest number of the routes area managed by pratiksha nagar depot with 23 routes and the least is operated by the Colaba depot. Out of the total fleet of 960 with these 7 depots the highest number of buses is owned by thepratiksha depot while the least is owned by the

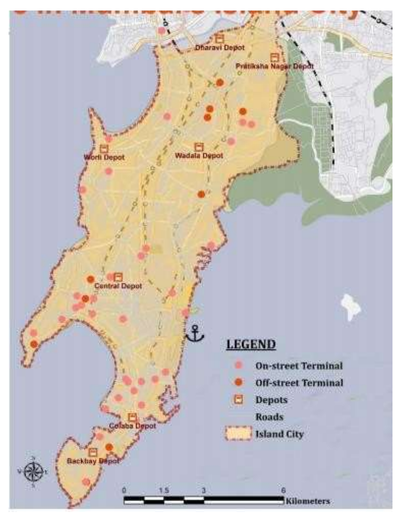


Figure 12: map showing location of bus depots and bus stands inside study area, *Source-(Priyanka Vasudevan, 2013)*

colaba depot. Location of these depots are essential as it will help in further delineating the cordon points for the area for which the congestion pricing needs to be implemented. (Priyanka Vasudevan, 2013)

Table 13: number of routes and fleet size operated by different Depots

Depots	Backbay	Colaba	Central	Wadala	Woli	Draravi	Pratiksha Ng.
number of routes	18	15	20	21	16	23	22
fleet size	126	80	130	152	114	202	156

Source- (EMBARQ India, 2015)

There are varous number of routes operated by these bus depots. Table number shows the different bus routes that runs from the respective bus depots.

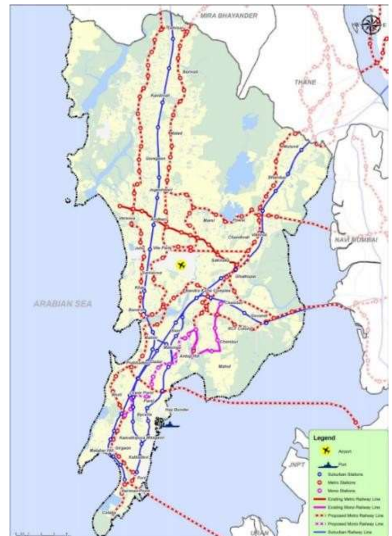
Table 14: table showing BEST bus routes starting from different bus depots

BUS DEPOTS	OPERATIONAL ROUTES NUMMBER
BLACKBAY	100,106,108,112,121,132,133,134,137,138,139,25 Ltd., 3,9,SPL-2LTD,SPL-8 LTD, SPL-9 LTD
COLABA	101,103,111,122,19 LTD.,2LTD, 22 LTD,44, 6 LTD,SPL 1 LTD, SPL 3 LTD, SPL 4 LTD
WORL I	110,124,125,161,162,167,169,171,27,324,463,50,53,55,82,89,
DHARAVI	11 LTD, 161, 165, 173, 180, 192, 219, 303, 310, 316, 317, 449 LTD, 46, 463, 52, 615, 66, 70,75, 87 LTD
PRATIKSH ANAGAR	14,15,169,170,172,181, 255 LTD, 302, 312, 315, 341, 43, 448 LTD, 502 LTD, 509 LTD, 64, 67,76,88
WADALA	151,161 LTD, 160, 163, 168, 174, 213, 40, 411, 440 LTD., 453 LTD., 504 LTD., 57,69,77, AS 503, AS 6, AS 7
CENTRAL	105, 123,126,127,130,135,154,155,156,166,18,30 LTD.,351, 41,42,48,62,63,91 LTD.

Source- (The Brihanmumbai Electric Supply & Transport , 2018)

5.1.6. Proposed Metro and Monorail Routes

The island city along with sub urban railwayshas also a proposed network for monorail and metro. The island city will be served by a 33.5 KM metro line which will start from SEEPZ and will connect Colaba via Bandra. It will have 26 stations and the metro will be fully underground. The numberof stations inside the island city are Dharavi, Siddhivinayak Temple, Worli, Mahalaxmi, chrurchgate, Vidhan Bhawan, Cuff Parade and finally Colaba bus depot. The metro will be serving the western part of the island city while the eastern part of the island city will be served by the monorailalong with the sub urban railways



proposed location of metro, *source- (Rawal, 2017)*

The monorail service will be connecting Wadala depot to the Jacob circle via LowerParel, Mint colony, Dadar east, Antop hill etc. the location of the proposed routes will also help in delineating the area further for which the congestion pricing has tobe implemented. (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016)

5.1.7. Travel Speed

The google traffic maps has been used for this purpose. Typical traffic conditions for the island city is observed during the morning and evening peak hours of the day. Based on the colour codes which depicts the travel speed of thevehicles which is totally dependent on the congestion on the certain link has beentaken for further delineation of the study area (shown in Annexure C). the darker shades represents the high congestion levels or very low commuting speed of thevehicles passing through the wards and a lighter colour representing the low congestion levels of the links present inside the wards. As can be observed from the table that the peak hours for Island city starts between 8:00 am and 9:00 am and increases significantly in subsequent hours while in case evening case high congestion levels can be observed commonly from 5:00 to 7:00 p.m. thereby indicating that travel speed is highly effected during the evening peak hours as compared to morning peak hours.

Additionally only wards F-SOUTH and F-NORTH have low levels of congestion throughout the peak hours as compared to rest of the wards present in the island city. The prominent reason being that these wards have majorly EWS and LIG people residing in these areas and the ward have docking facilities and shipyardsas the major attractive commercial areas, which doesn't attracts a larger number of trips from all that are entering the island city area.

Table 15 : table showing typical traffic conditions of wards in morning and eveningpeak hours,

WARDS	COMMERCIAL LANDUSE PERCENTAGE	AVERAGE SPEED AS OBSERVED ON MORNING AND EVENING PEAK HOURS					
		MORNING PEAK HOUR			EVENING PEAK HOUR		
		08:00 AM	09:00 AM	10:00 AM	05:00 PM	06:00 PM	07:00 PM
A	5.4 (52.61 Ha)	1	1.5	2	2.5	2.5	2
B	11.37 (30.22 Ha.)	1	2	2.5	3	3	2.5
C	14.31 (27.38 Ha.)	1	1	2	3	3	2.5
D	4.14 (34.04 Ha.)	2	2.5	3	3	3	3
E	6.56 (47.52 Ha.)	1	1.5	2	3	2.5	2
GS	4.53 (42.10 Ha.)	1	2	2.5	2.5	3	3
GN	2.3 (13.3 Ha.)	2	2	3	2.5	3	3
FN	0.86 (9.58 Ha.)	1	1	2	1.5	2	2
FS	5.11 (50.06 Ha.)	1	1	1.5	1.5	2	2

Source: (Municipal Corporation of Greater Mumbai, 2012)

3.3. Study Area Roads

ID	CORRIDOR NAME	LENGTH
I - 1	Acharya Donde Marg (King Edward Rd)	1.67
I - 2	August Kranthi Road	1.62
I - 3	BG Kher Marg	2.20

I - 4	Babulnath Marg	0.47
I - 5	Bapurao Jagtap Marg	0.92
I - 6	Barrister Rajni Patel Marg	0.84
I - 7	Warden Road	1.59
I - 8	Bombay Trust Road	10.93
I - 9	Prakash Pethe Marg (Cuffe Parade Road)	3.07
I - 10	Dadabhai Nauroji Road	0.87
I - 11	Dharavi Main Road	1.10
I - 12	Dockyard Road	0.48
I - 13	Dr. Annie Besant Road (Love Grove Road)	3.10
I - 14	Laxmibai Kelkar Marg, Dr B.R. Ambedkar Road & JJ RoadUpto CST	12.46
I - 15	Dr E. Moses Road (Haines Rd)	3.46
I - 16	Dr Gopalrao Deshmukh Marg (Peddar Road)	2.87
I - 17	DR.A. Nair Marg	2.34
I - 18	Eastern freeway	13.49
I - 19	GD Ambedkar Marg	3.62
I - 20	GD Somani Marg	1.34
I - 21	Ganpat Rao Kadam Marg	1.46
I - 22	Jagannath Shankar Seth Road	2.11
I - 23	Jamshedji Tata Road	0.65
I - 24	Javji Dadaji Marg	0.96
I - 25	Kalba Devi Road	1.71
I - 26	KK Marg	1.04
I - 27	LD Ruparel Marg	0.75
I - 28	Lala Lajpatrai Marg (Hornby Vella Road)	1.18
I - 29	Lamington Road	1.38
I - 30	L Jag Mohandas Marg (Napean Sea road)	1.96
I - 31	Lokmanya Tilak Marg	1.37
I - 32	Madame Cama Road	1.21
I - 33	Mahapalika Marg	0.72
I - 34	Maharshi Karve Road (Queen's road)	4.29
I - 35	MG Road	2.04
I - 36	Mahim Sion Link Road	1.10
I - 37	Marine Drive	4.47
I - 38	Maulana Azad Road	2.72
I - 39	Shaukat Ali Road (Grant Road) (up to JJ Hospital)	1.95

I - 40	Mori Road	0.54
I - 41	Dharavi Depot Road	1.20
I - 42	Nathalal Parekh Road	0.75
I - 43	New Prabhadevi Marg	4.66
I - 44	90 feet Road	1.29
I - 45	Pandurang Bhudhkar Marg	1.34
ID	CORRIDOR NAME	LENGTH
I - 46	Pathe Bapurao Marg	1.95
I - 47	P D' Mello Road & Rafi Ahmed Kidwai Marg	11.11
I - 48	Gokhale Road	4.09
I - 49	Worli Bandra Sea Link	4.59
I - 50	Raja Rammohan Roy Marg	1.08
I - 51	Ramchandra Bhatt Marg	2.94
I - 52	Sardar Vallabhbhai Patel Marg (Sandhurst Road)	3.30
I - 53	Senapati Bapat Marg (Tulsi Pipe Road)	7.71
I - 54	Seth Moti Shah Marg	0.84
I - 55	Shahid Bhagat Singh Road	3.64
I - 56	Shamaladas Gandhi Marg	1.68
I - 57	Sion Bandra Link Road	2.54
I - 58	Sulochana Shetty Road	1.81
I - 59	Swatantrya Veer Savarkar Marg (Cadell Road) (One way)	4.14
I - 60	Takandas H Kataria Marg	2.27
I - 61	Tardeo Road	1.12
I - 62	Veer Nariman Marg	0.46
I - 63	Walchand Hirachand Marg	1.12
I - 64	Walkeshwar Road	1.45
I - 65	Wode House Road	0.98
I - 66	Worli Sea Face Road	3.42
I - 67	Karma Bhaurao Patil Marg	1.26
I - 68	Anandilal Poddar Marg	0.34
I - 69	Jehangir Boman Behram Marg and Clare Road	2.07
I - 70	Nesbit Road	0.98
I - 71	Samantbhai Nanji Marg	1.08
I - 72	Hay Bandar Road	3.49
I - 73	Nana Padaniwas Bridge Road	0.81
I - 74	Lakhamsi Nappu Road	1.56
I - 75	Jagannath Bhatankar Marg	0.82
I - 76	Dr. Babasaheb Jayakar Marg	0.92

I - 77	Bhuleshwar Road	0.71
I - 78	Drinage Channel Road	0.82
I - 79	RG Thadani Marg	0.45
I - 80	GM Bhosle Marg	0.96
I - 81	Appasaheb Marathe Marg	1.25
I - 82	Sayani Marg (one way)	0.91
I - 83	Tilak Bridge	0.24
I - 84	Lady Jahangir Road	1.01
I - 85	Bhaudaji road	1.24
I - 86	Mukundrao Ambedkar road	2.12
I - 87	Sheikh Meiseri Street	2.37

Major roads inside the study area have been marked in figure 12. These roadshave held most of the traffic flowing inside the study area during peak hours.

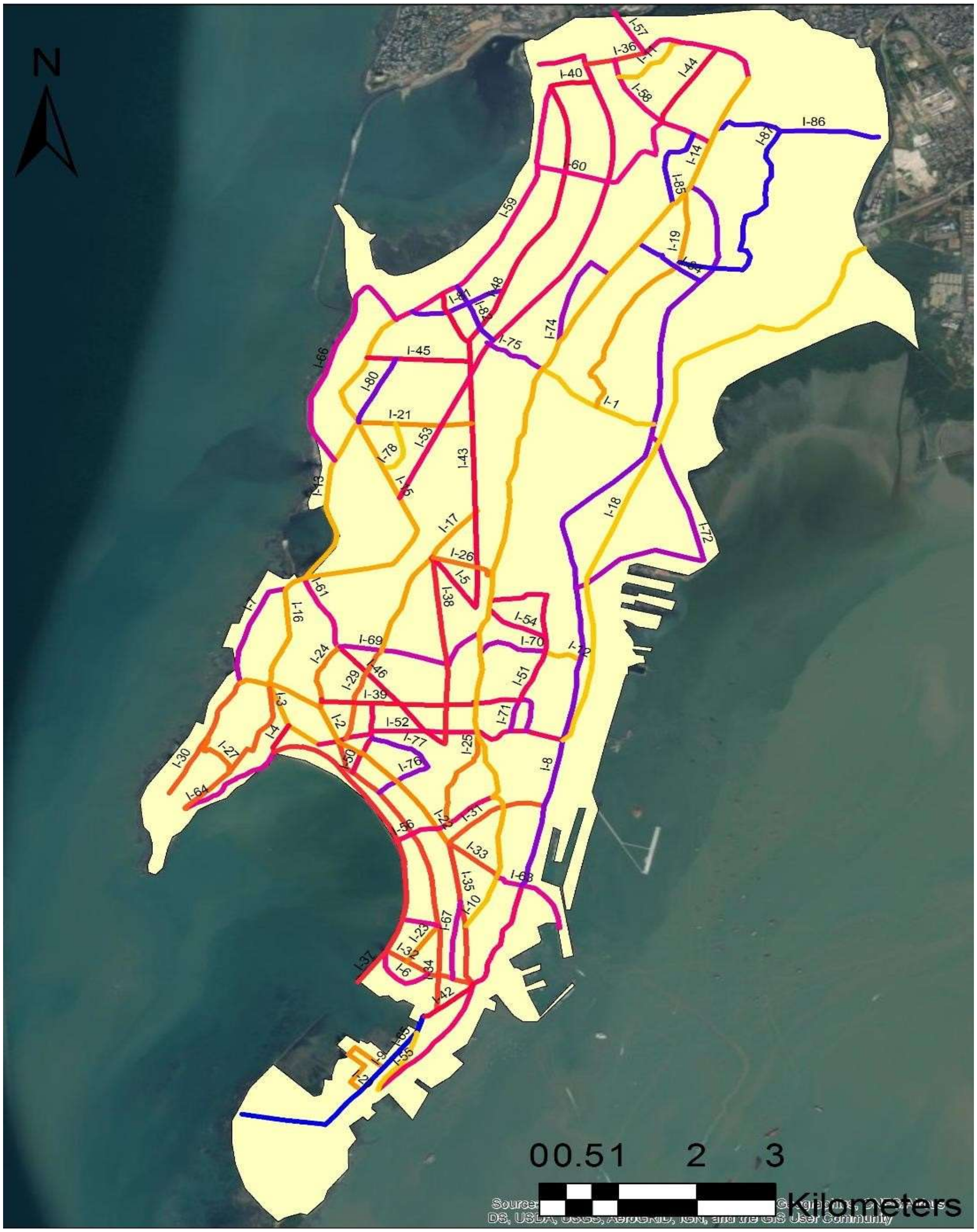


Figure 14: map showing roads with respective id tags

Source- (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016)

3.4. Chapter Summary

This chapter summarizes the study area from a transportation sector perspective. The chapter begins with the delineation parameters that were used indelineation of the study area. These parameters includes the current employmentfacilities, average speed in the wards during peak hours, trip generation and trip attraction patterns and finally the commercial land use percentage of the different wards.

After successful delineation of the study area, the area was analysed from a transport planning perspective, such as the various roads present inside the studyarea which carries majority of the traffic during the peak hours of morning and evening as in acts as arterial or sub arterial roads inside the study area, available BEST bus depot and their individual capacity in terms of the routes terminating ororiginating from them, frequency of the buses from a certain depot, future networksof proposed metro inside the study area. Travel speed inside the study area wardsduring the peak hours of morning and evening

This chapter was necessary in order to understand the study area's transport related characteristics and functions. Apart from this purpose this chapter also to help in identification of the current status of public transport inside the study area.The buffer area map specifically was used in the proposal stage in order to rationalise the current BEST bus routes in order to gain much more coverage of public transport inside the study

Chapter 4 - DATA REQUIREMENT

4.1. Data Requirement and Source List

The following data was required to complete various analysis of this study and wherever possible online sources of the data is shared. Few of the data are not available online and are taken directly from the concerned authorities.

Data requirement	source	Remarks
Road wise speed in morning and evening peak hours	Chapter 5, section 5.9.3, Comprehensive mobility plan-Mumbai 2016 (main report-1)	
Road wise PCU on major roads in peak hours	*Annexure 5-3* *Outer Cordon Surveys – Traffic Data*, Comprehensive mobility plan- Mumbai 2016 (volume II- annexure)	
Number of bus depots instudy area	Report on Bus Terminal Study for BEST prepared by EMBARQ, India	http://urbanmobilityindia.in/Upload/Conference/43ba713c-508c-40c2-8e5c-530fa4f8a2e7.pdf
Number of buses and routes starting from bus depots	Online from BEST bus Mumbai site	http://www.bestundertaking.com/in/page.asp?i=27
Frequency of buses on different routes in peak hours	Online from BEST bus Mumbai site	http://routenetwork.bestundertaking.com/

Travel pattern of commuters inside the study area	Origin-destination survey 2009, conducted by MMRDA	
Occupancy of different vehicles	Chapter 1, section 1.1.2, Comprehensive mobility plan- Mumbai 2016 (volume II- annexure)	
Modal shift	Stated preference though online form. Sample of 309 was collected	https://docs.google.com/forms/d/e/1FAIpQLSfTO2q72SKTBL0VmuO5BOp6cw4HmBm2Vs7ov4Kx_eteqGrzJA/viewform?fbzx=-8400791894084942000

Figure 15: chart showing data requirement and its online source

Chapter 5 - ANALYSIS (OBJECTIVE WISE)

The analysis for the study has been done objective wise. My first objective of the study was to establish the current levels of congestion.

Establishing Congestion Levels

For this purpose a series of congestion related indices were calculated for the study area. As of now these calculations are of no precise use, they'll be usedin further exercise for comparing the traffic conditions before and after the congestion pricing gets implemented

5.1.1. Congestion Index

Congestion can be described as existing traffic conditions on the roads during peak hours. Congestion index uses speed to signify the current traffic conditions on the road. Congestion index takes 30km/hr. as an optimum speed fortravel in the peak hours or at the highest level of service. The formula for the indexis as follows

Congestion index = 1 - (A / M) where A= the observed speed of the vehicle duringthe peak hours and M= 30km/hr. which has to be taken as universal constant. Greater the value of congestion index higher is the congestion on the road. (WilburSmith Associates, 2009). Congestion index for morning and evening peak hours was calculated and it was found that for morning peak hours the travel speed ranged from 5km/hr to 20 km/hr. similarly for evening peak hours the travel speedcame out as 6 km/hr. to 22 km/hr. for various roads. The congestion index was highest for the roads in the ward D for both morning as well for evening peak hoursstating that it majority of the traffic passes through that ward. Further the congestionon the roads are not evenly distributed, it is randomly distributed for different roadsinside the study area. The congestion index maps for the evening and morning peaks are given after the analysis of 1st objective

5.1.2. Travel Time Index

Travel time index (TTI) can be defined as the ratio of average travel time and the free flow travel time for a link/road. For a specific link/ road it can be calculated as

TTI = TT Avg./ TT Free flow,. For the study area considering the travel time index the range of values obtained varies from 0.8 to 4.7 in morning peak hours i.e. thereis 470% times more travel time will increase from the free flow travel time. Althoughthe highest increase in the travel time is evident on very less roads majority (65%)of the roads have a TTI value ranging from 2.5 -3.5 i.e. it takes 250% to 350% moretime to travel in those roads as compared to the free flow travel time . The situationgets even worse in case of evening hours since the upper value of index reaches up to 5.7 i.e. it will take 570% of the free flow travel time. For evening peak hours the different TTI ranges can be seen evenly distributed for the roads inside the study area. Approximately 31% of the roads have TTI in evening hours between
2.2 to 2.8 i.e. increase in the travel time by 220% to 280% of free flow travel time.

5.1.3. Planning Time Index

Planning time index is used to calculate the increase in the time required inorder to reach the destination 95% of the total times on the desired time. The planning time in minutes foe the different roads inside the study area has come outin the range of 1.8 minutes to 30 minutes. The highest value for planning time indexhas been observed for the western expressway for both the morning as well for evening peak hours. the value of planning time index as observed for the westernexpressway was 27 minutes and 28 minutes for the morning and evening peak hours respectively. Majority of the roads both in evening and morning peak hours have a planning time value in range of 20-30 minutes stating that during peak hoursa extra travel time of 20-30 minutes is required to reach the destination on time. For example a central link marked as blue in the planning time index (morning peakhour) has a total length of 5 km and it takes 10 minutes to cover the 5 km stretch during the nonpeak hours than in the morning peak hour it will take about 30 to 40minutes to cover that same stretch of 5 km with same vehicle.

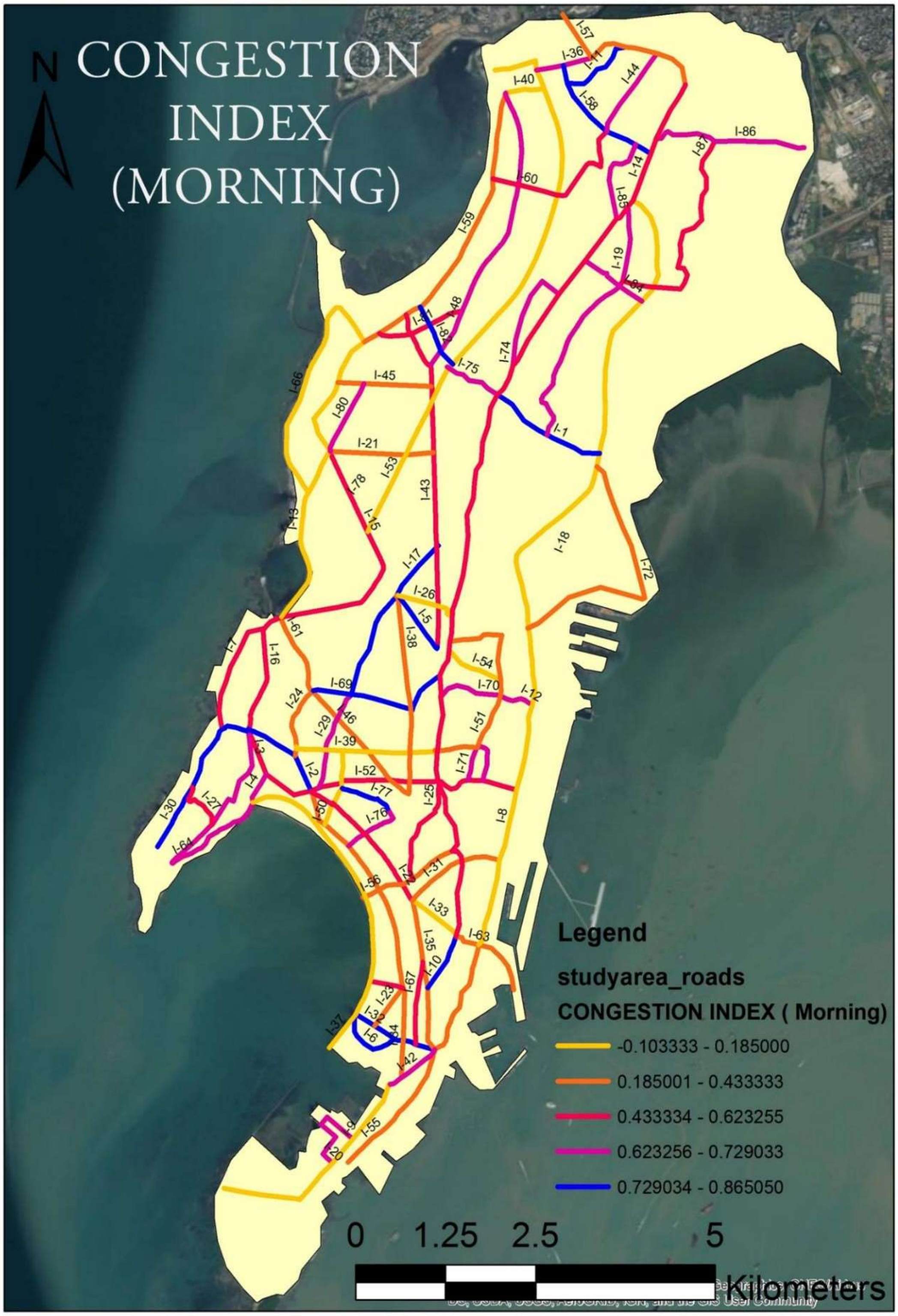


Figure 16: map showing congestion index for morning peak hours

Figure 17: map showing congestion index (evening peak) for roads insidestudy area

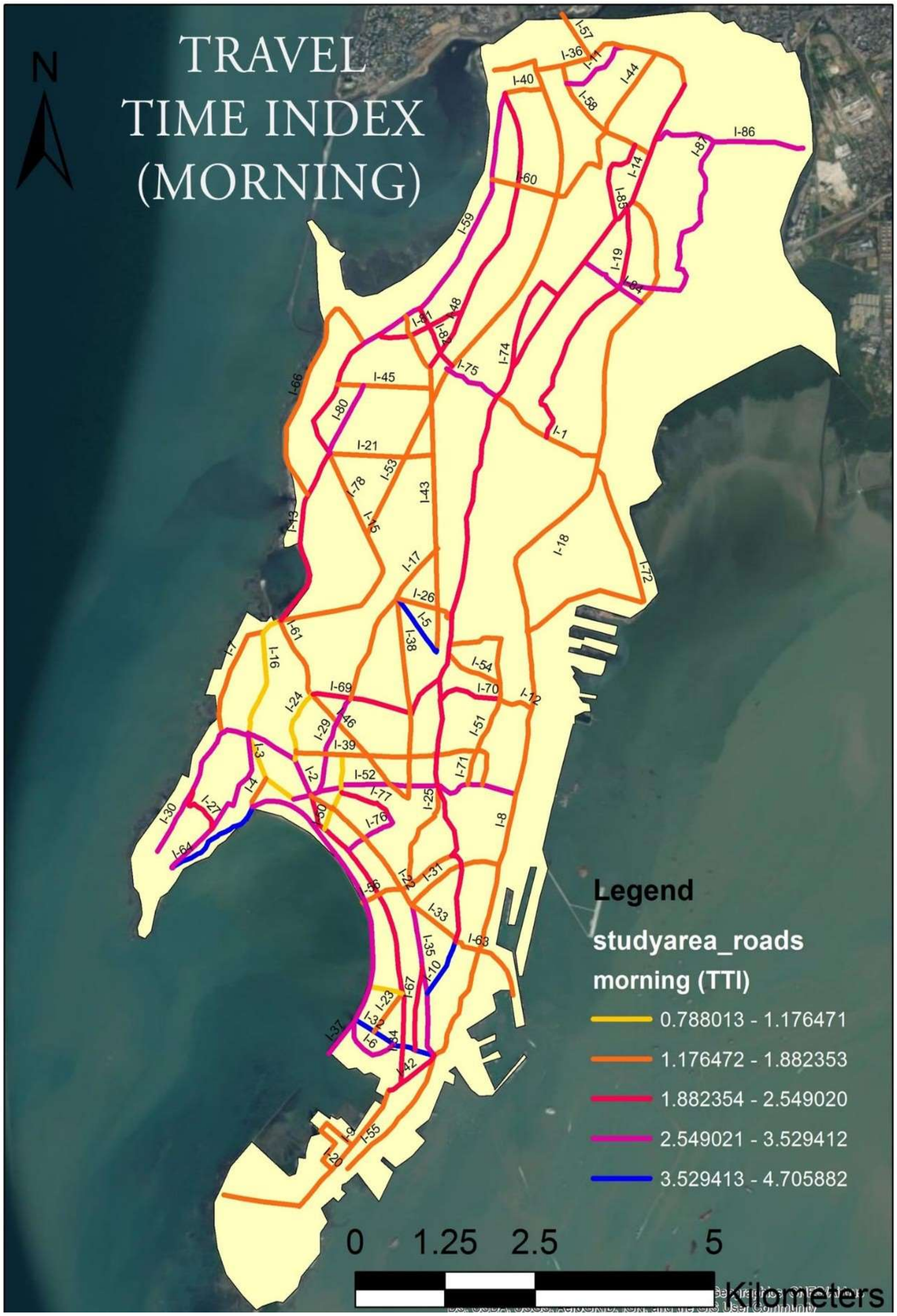


Figure 20: map showing TTI (morning peak) for roads inside study area

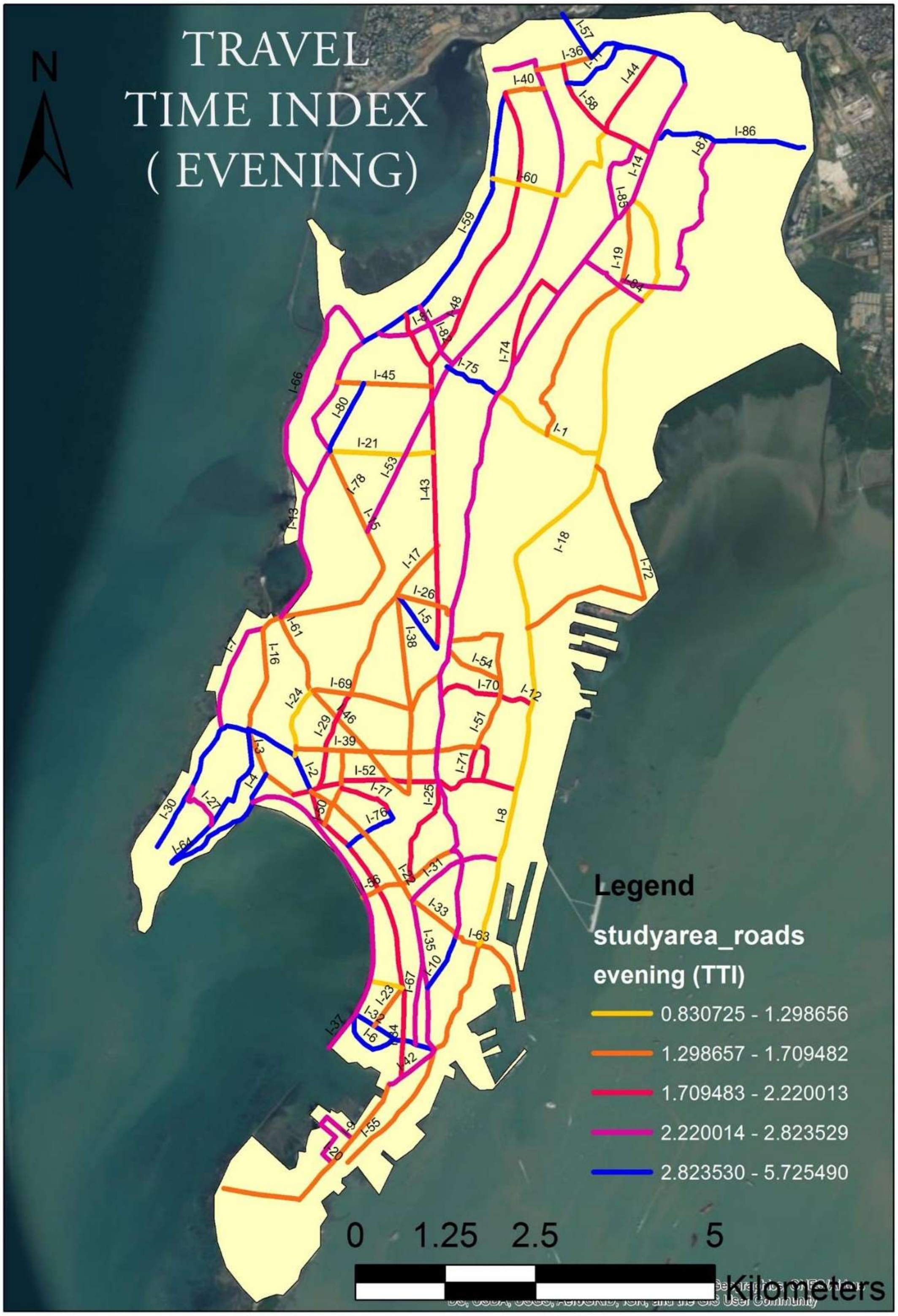


Figure 18: map showing TTI (evening peak) for roads inside study area

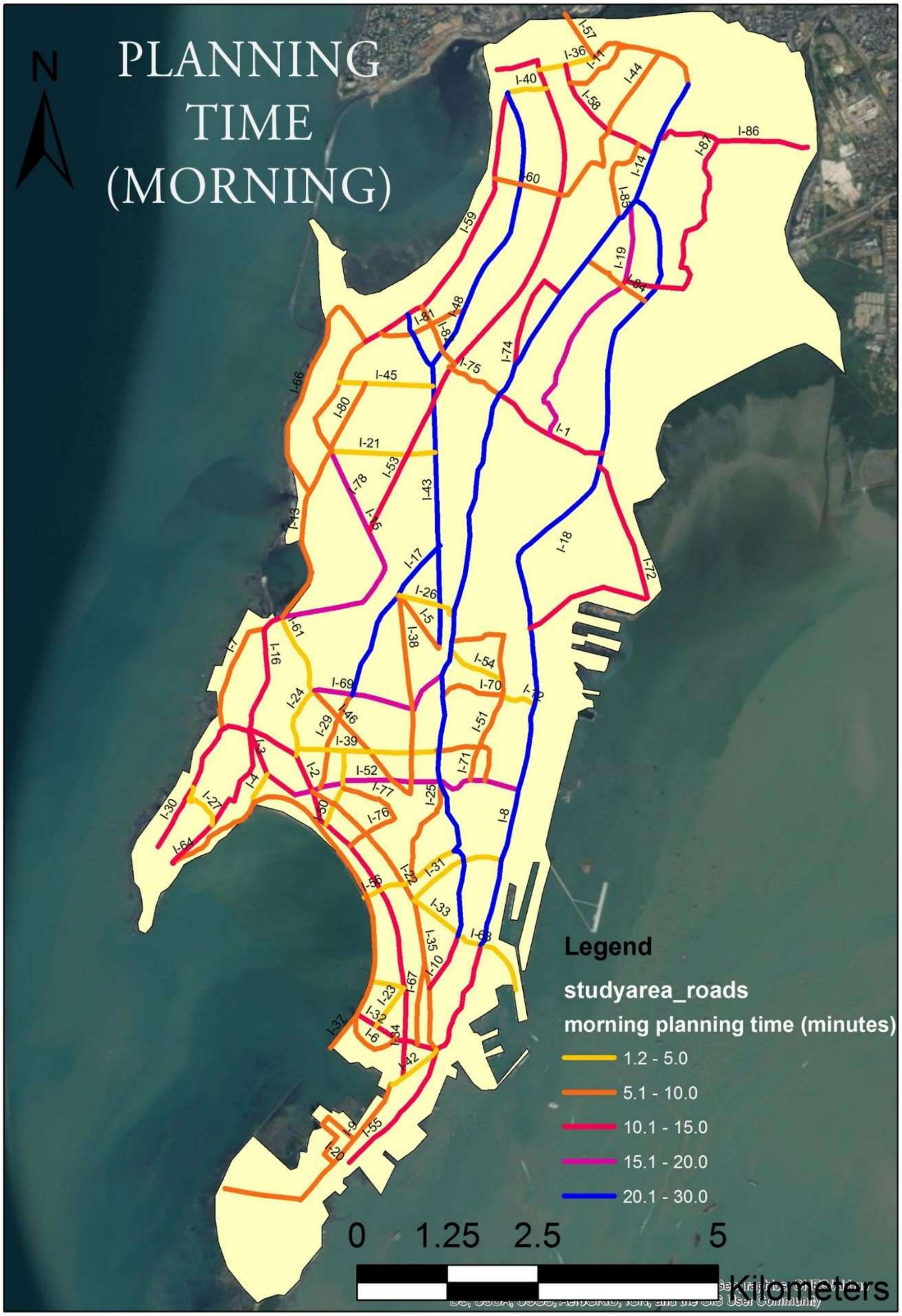


Figure 19: planning time for roads in morning peak hours

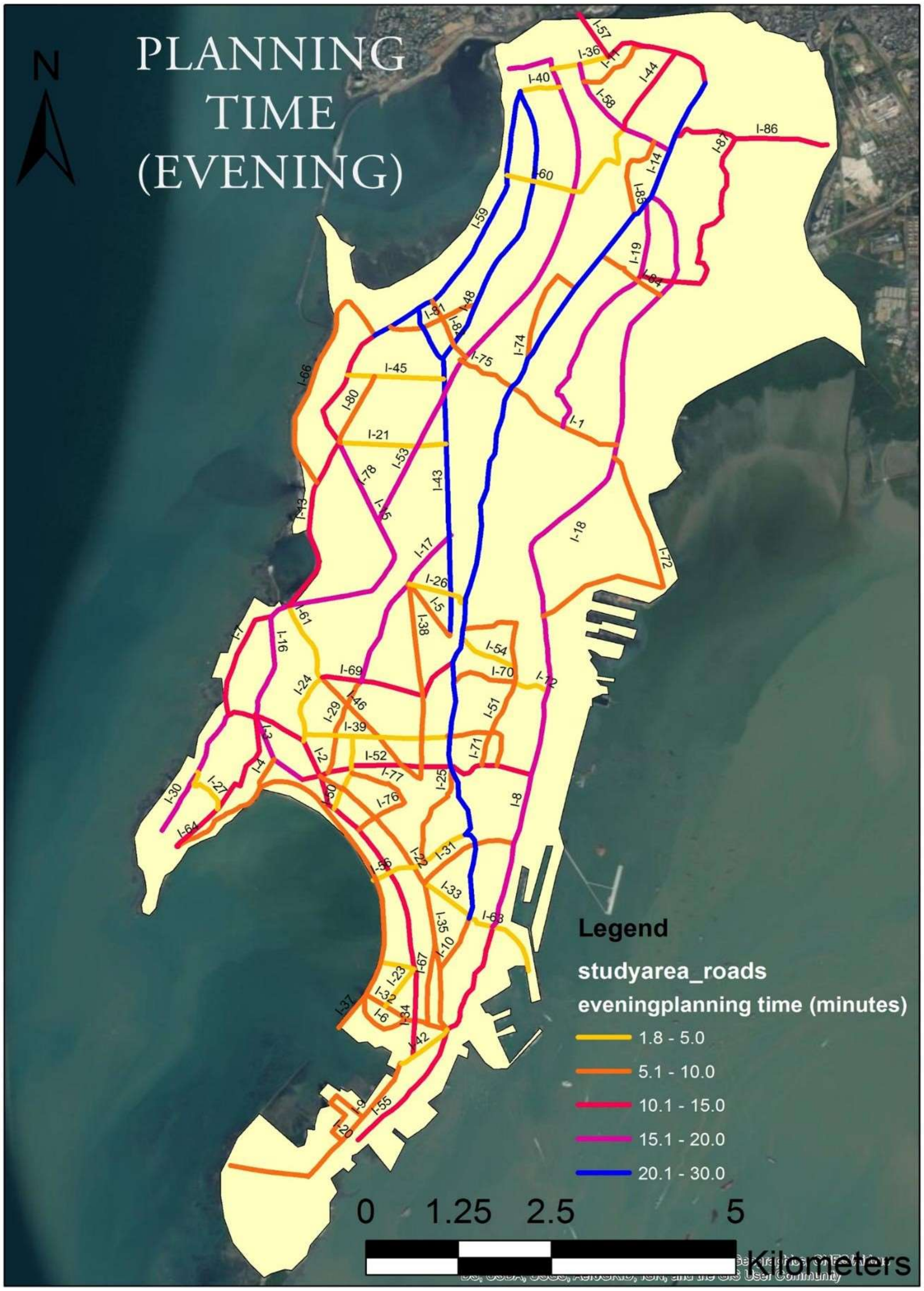


Figure 20: planning time for roads in evening peak hours

6.10. Calculating Marginal Congestion Cost

The marginal congestion cost link/road wise is calculated road wise. To calculate the cost following formula has been used (Tom, 1999)

5.1.4. = q*(b/v^2)*slope of speed flow relationship

q=traffic volume, b= VOT, v = resulting speed and slope was calculated for respective roads

5.1.5. Value of Time

In modern times the total time invested in commuting has increased exponentially and is still in an increasing function. Value of time for and individual basically tells about the unit monetary cost that someone is ready to invest/ spendin order to save his unit time. Value of time is different for different individual. The value of time for and individual usually depends on various factors such as his income pattern, other socio economic factors, the mode he uses etc. For examplea business man whose major work is to transport frozen food and fisher to other parts of the country will be more to pay 300-400 extra amount of money in order tosave his 1 hour where else a businessman whose work is to deliver electronic appliances will not be as comfortable to spend 300-400 rupees just to save 1 hr. he might be willing to spend only 50-60 rupees for savings of 1 hour. This is how value of time changes from one individual to other.

Value of time of 4 wheelers in Delhi as calculated for 2014 came out to rupees 246(Minoti Rawat, 2016) where else value of time for 4 wheelers in Mumbai was 190 rupees and 78 for 2 wheelers. In this study the value of time has been calculated by inflating the economic cost operating a 4 wheeler on highest road roughness. The inflation has been adjusted by multiplying the economic cost by ratio of per capita income of Mumbai and per capita income of India. The result further obtained is then multiplied to the Wholesale price index (2018).

VOT has been calculated as

=WPI * PCI(Mumbai)/PCI(India) * 96 (IRC-MANUAL ON ECONOMIC EVAKUATION OF HIGHWAY PROJECTS IN INDIA, 1993) (Minoti Rawat, 2016)

WPI= 1.15 (2018) (WPI INDIA, 2018)

PCI (Mumbai) =2.3 lakhs, PCI (India) =1.34 lakhs

The result of VOT for 4w users for Mumbai city comes out to be Rs. 278 i.e. a person can spend up to Rs. 278 in order to save a single hours from his time of commuting from origin to destination. This value has been used to calculate the marginal congestion cost for different roads inside the study area.

5.1.6. Speed Flow Relationship

Speed flow relationship has been calculated on the basis of the PCU per hour (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016) and the resulting speed on the same road which has been taken from the google for 24 hours and a curve has been plotted for the calculation of the relationship betweenthe PCU and the speed.

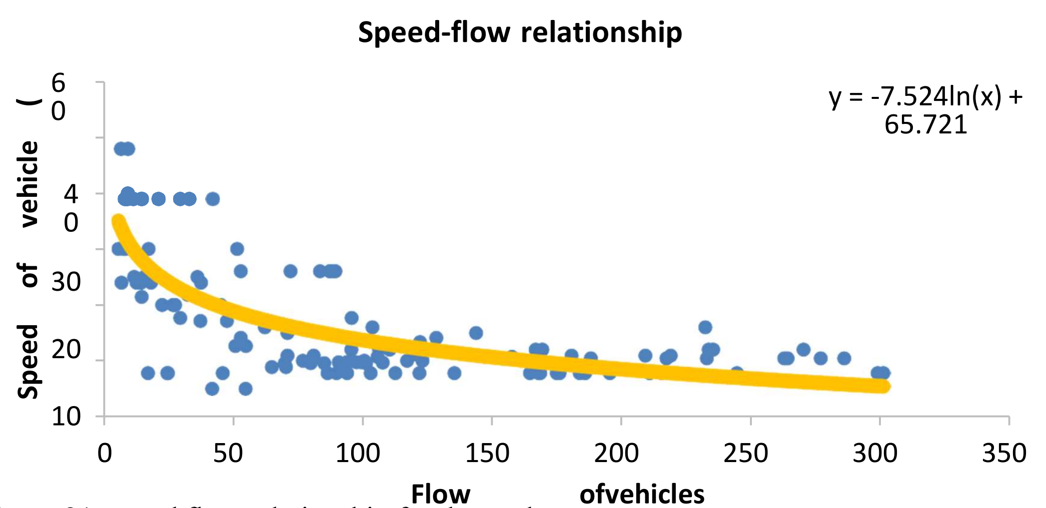


Figure 21: speed flow relationship for the study area

Table 16: table showing slope for various forms of speed flow relationship

form	Speed flow relationship	Goodness offit	slope
LINEAR	$y = -0.0079x + 24.87$	$R^2 = 0.35$	-0.0079
EXPONENTIAL	$y = 21.786e^{-4E-04x}$	$R^2 = 0.34$	$-04*21.786e^{-4E-04x}$
LOGARITHIMIC	$y = -7.524\ln(x) + 65.721$	$R^2 = 0.55$	-7.524/volume of traffic
SECOND DEGREE POLYNOMIAL	$y = 7E-06x^2 - 0.0258x + 31.742$	$R^2 = 0.52$	(7E-06)*volume of traffic-0.0258

A graph has been plotted between the PCU and the resulting speed on the XY plane and the equation for the best fit line of the above scatter plot has been observed for various forms or equation of the line such has linear, exponential, logarithmic and second degree order polynomial. As can be seen from the above graph and the table the highest goodness of fit comes out for logarithmic curve asa result of which the slope has been taken for the logarithmic curve only and not ofliner, exponential or second degree polynomial. This slope will be used to calculatethe marginal congestion cost for different roads inside the study area. An exampleis stated below which shows the MCC for Marine drive and Lajpatrai road for 24 hours

Table 17: table showing marginal congestion costs for Marine Drive road and Lajpatrai Road

MARINE DRIVE						LAJPATRAI ROAD			
TIME	VOLUME OF TRAFFIC	RESULTING SPEED (KM/HR.)	SLOPE	VOT	MCC PER PCU PER KM	VOLUME OF TRAFFIC	RESULTING SPEED (km/hr.)	SLOPE	MCC PER PCU PER KM

0-1 am	2062	16	-0.00365	278	8	1535	30	-0.0049	2
1-2 am	1242	16	-0.00606	278	8	1014	30	-0.00742	2
2-3 am	951	17	-0.00791	278	7	794	30	-0.00948	2
3-4 am	537	20	-0.01401	278	5	506	30	-0.01487	2
4-5 am	619	22	-0.01216	278	4	408	30	-0.01844	2
5-6 am	726	24	-0.01036	278	4	500	30	-0.01505	2
6-7 am	936	20	-0.00804	278	5	787	30	-0.00956	2
7-8 am	2166	14	-0.00347	278	10	1478	30	-0.00509	2
8-9 am	3655	16	-0.00206	278	8	2109	17	-0.00357	7
9-10 am	4466	12	-0.00168	278	15	2495	13	-0.00302	12
10-11am	4219	10	-0.00178	278	19	3170	12	-0.00237	15
11-12am	4441	12	-0.00169	278	15	3478	9	-0.00216	28
12-1 pm	4467	12	-0.00168	278	15	2753	11	-0.00273	18

1-2 pm	4134	11	-0.00182	278	17	2794	15	-0.00269	9
2-3 pm	3735	11	-0.00201	278	18	2246	30	-0.00335	2
3-4 pm	3699	11	-0.00203	278	18	2499	30	-0.00301	2
4-5 pm	4214	10	-0.00179	278	19	2264	20	-0.00332	5
5-6 pm	4640	10	-0.00162	278	20	2790	20	-0.0027	5
6-7 pm	5682	10	-0.00132	278	21	2595	15	-0.0029	9
7-8 pm	6009	10	-0.00125	278	22	2508	11	-0.003	18
8-9 pm	6047	10	-0.00124	278	23	2374	20	-0.00317	5
9-10 pm	4549	11	-0.00165	278	18	3051	20	-0.00247	5
10-11pm	3498	12	-0.00215	278	15	2775	25	-0.00271	3
11-12 pm	2557	13	-0.00294	278	12	1994	30	-0.00377	2

The highest MCC for Marine drive came for evening peak hours while for PrajapatiRoad it came in the morning hours. Supposedly a trip from Haji Ali Dargah to Wankhede Stadium of 5.5 Km would cost a 4W in evening peak hour approximatelyRs. 111 (2.5*18+3*22). Similarly, MCC has been calculated for different roads and a total congestion price/tax has to collect based on the total length a 4w drives ona particular road on particular time of the day. The final MCC will be based upon the total trip length, the roads used with different pricing rates during the different peak hour periods.

The marginal congestion was calculated for all the 87 roads shown in figure – (chapter 3). The marginal congestion costs was bifurcated in 4 categories based onn the minimum and maximum marginal congestion cost. The first category of roads have marginal congestion cost ranging from rupees 0 to rupees 4, second category of roads have congestion costs ranging from 4-12 rupees, the third category of roads included which have congestion charges ranging from 12-17 rupees. The last category of roads includes roads that have congestion charges ina range of 17-28 rupees. Same maps with similar bifurcation are prepared for the morning and evening peak hours as shown in the figures- 25, 26

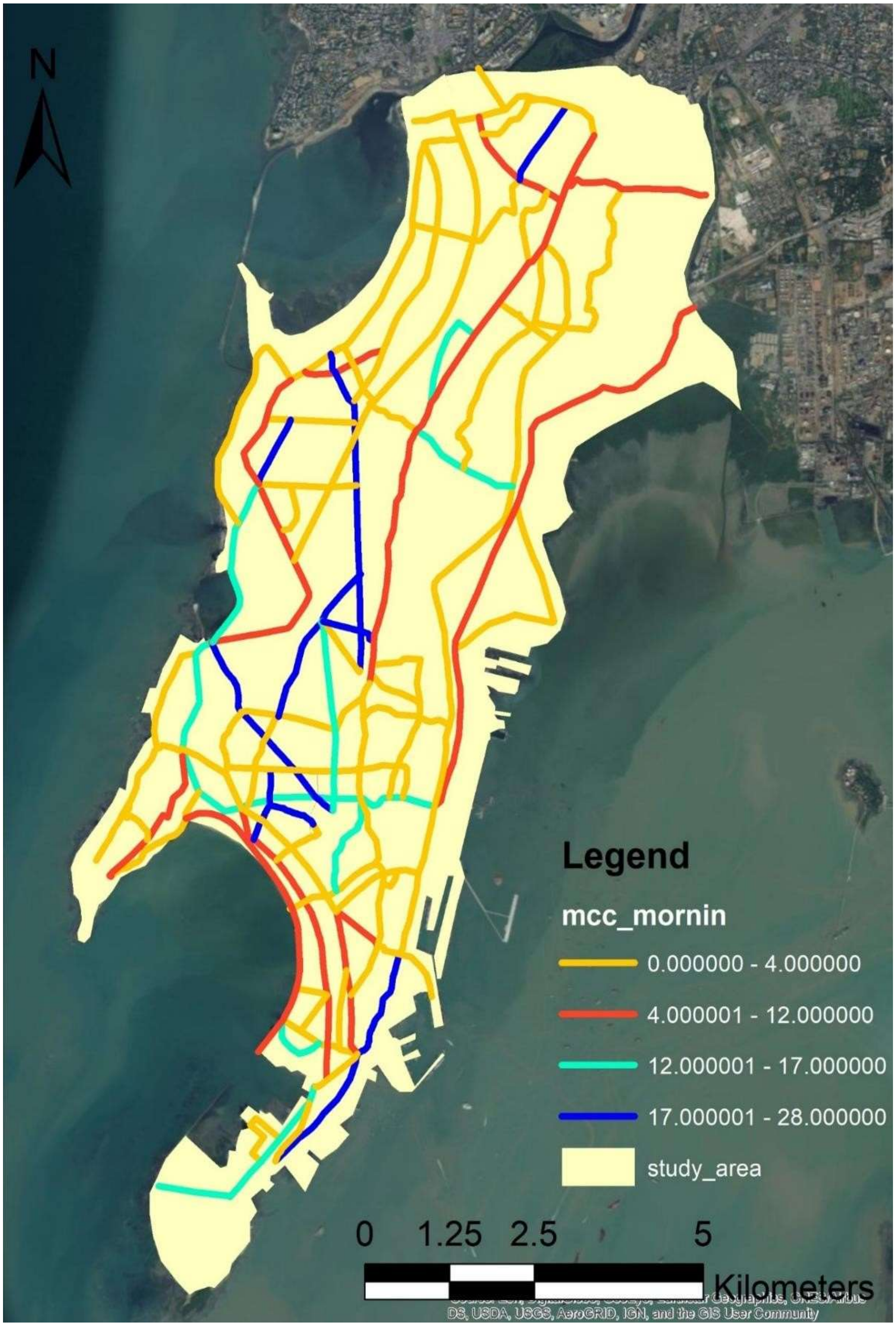


Figure 22: map showing MCC in rupees for roads in morning peak hours

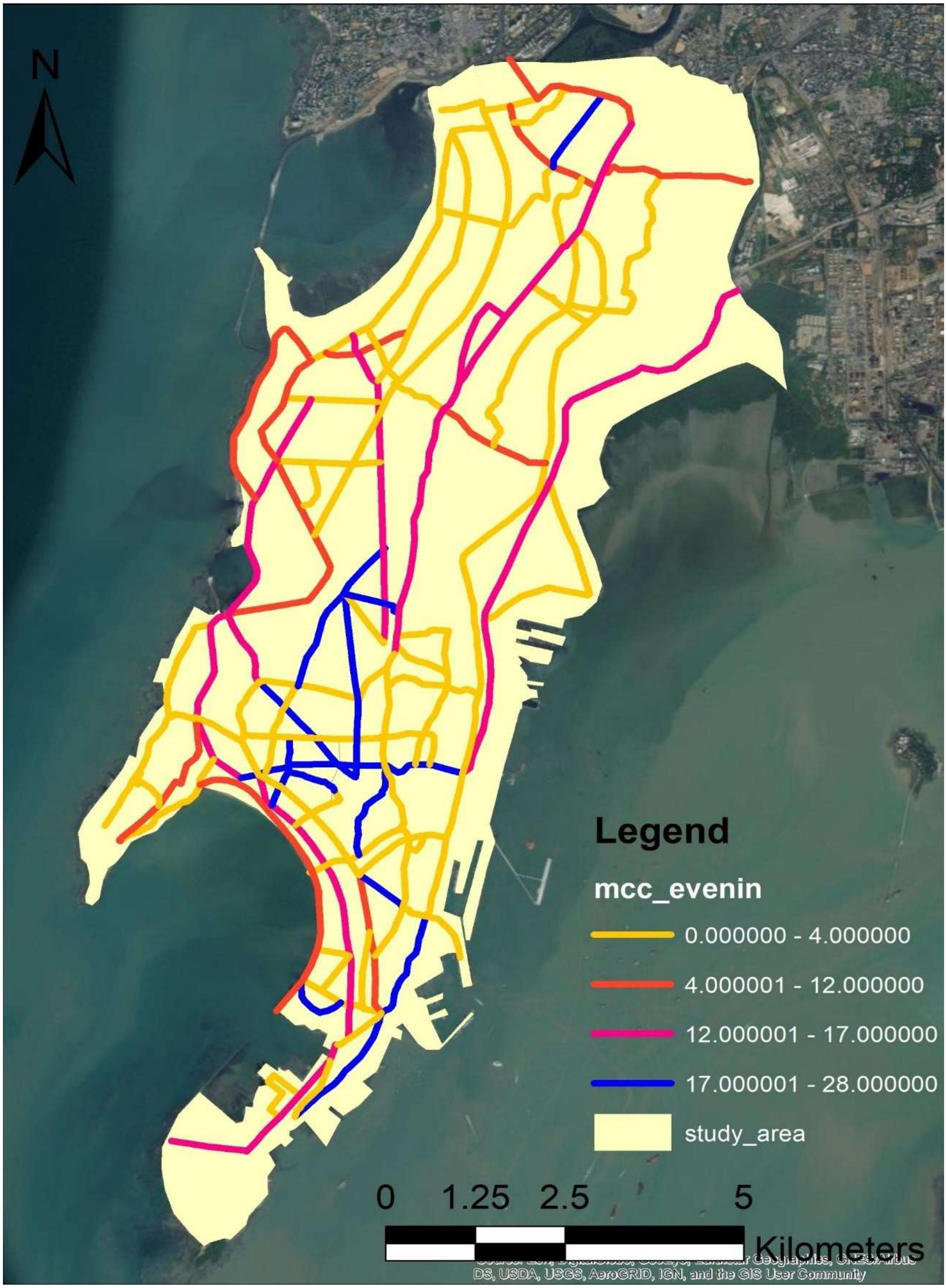


Figure 23: map showing MCC in rupees for roads in evening peak hours

In morning peak hours roads with higher congestion prices are mainly concentrated in mid-west part of the study are thereby indicating highest level ofcongestion in surrounding area of these roads. The roads with least level of congestion as per the cost charged while traveling on them are concentrated in the upper part of the study area thus indicating that people travel towards south part of the study area.

For evening peak hour the roads with highest congestion price are concentratedin the middle of the study area. And roads with less congestion pricing rates areconcentrated in the upper part of the study similar to the case of the morning peak hour

6.11. Modal Shift

Calculation of the modal shift is necessary in order to prepare the base for the need of new fleets of public transport. The modal shift basically indicates the people willing to shift to new mode of transport if certain facilities are provided or the existing conditions of the existing certain transport mode are enhanced. For calculation of the modal shift a stated preference was carried out through online google forms and it was cross checked by multinomial logit model. The form for thestated preference survey is given in annexure. Results from stated preference survey shows that majority of the commuters uses car as a primary mode of travelfollowed by 2 wheeler and BEST buses. The least modal share is of cycle, walk and carpool.

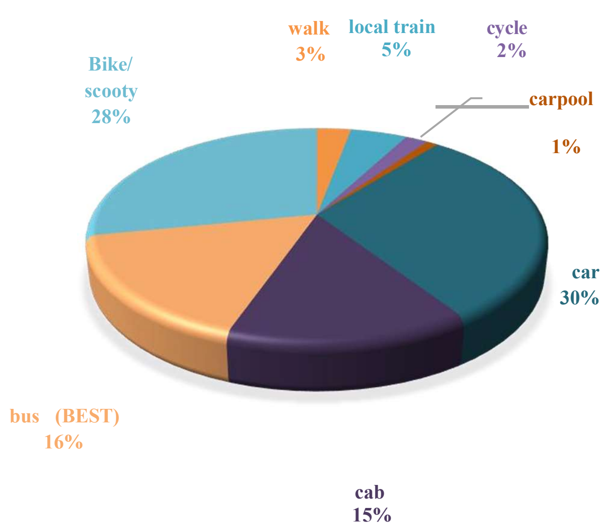


Figure 25: pie chart showing current modal split

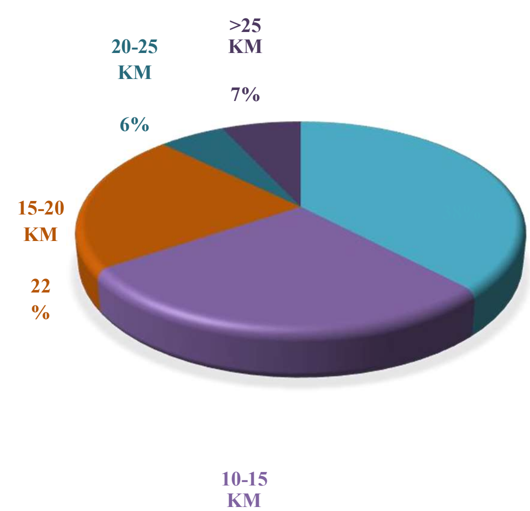


Figure 24: pie chart showing percentage of commuters having certain trip length

Out of total surveyed population 33% of the commuters makes a trip of length 5- 10 km on daily basis while 24% of population travels a length of 10-15 km to reachtheir destination. Based on the analysis of figure commuters travelling a length of greater than 25 km uses car as a major mode and least favourable modes out of

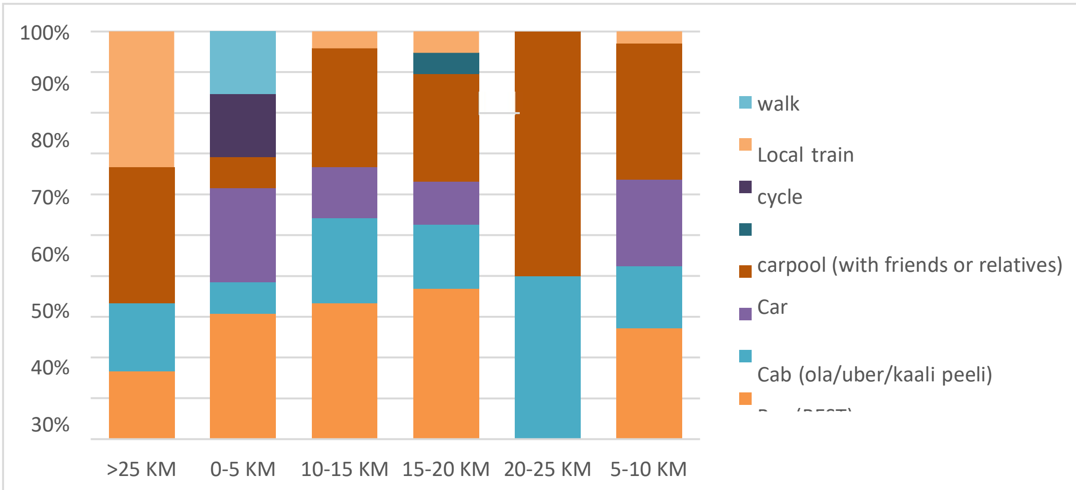


Figure 26: stacked chart showing mode of vehicle for different users based on theirdistance of travel

the modes used is the BEST bus, for a trip of length 0-5 km bike (2 wheelers) are the most preferred mode for travelling followed by walking. Next, for a trip length of 10-15 km 2 wheelers are again the preferred mode by majority followed by the 4 wheeler (car users).

Similar trend can be observed for the trips of length 15-20 km. lastly for trip of length 20-25 km car and 2 wheelers are the only preferred mode of travel.

Further the waiting time, access time and egress time as mentioned by the public transport users came out as 5.56 minutes, 5.64 minutes and 6.16 minutes respectively

Based on the results generated from the stated preference survey out of 300 samples 23% of the total are willing to shift to public transport while whereas 52%of the population isn't ready to leave their existing mode of transport and the remaining 23% of the people are ready to use carpool as an alternative to get awaywith the extra tax burden coming from congestion pricing.

Out of the 23% people willing to shift to public transport under scenario 1 (which uses travel cost and travel time as attributes based on which choice is to be made)majority of them belongs to a category of people who earns in a range of 25000- 50000, in fact the students are also not willing to shift from their current mode of transport. Out of all the economic classes one which ears in a range of 25000- 50000 have majority of in all the mode choices be it using carpool or will continue to travel in same mode or will start using public transport

Table 18: table showing mode choice preference vs. people's income in 1st sc.

mode choice (Scenario 1)	your monthly income			
	<25000	>50000	25000-50000	DOESN'T EARN (ONLY FOR STUDENTS)
WILL START USING CARPOOL	3	4	7	0
WILL CONTINUE TO TRAVEL IN SAME MODE	11	21	36	9
WILL START USING PUBLIC TRANSPORT	4	0	6	0

In scenario 2 also same economic class is more willing to shift but is very closely followed by the economic class having income of less than 25000. A major changein shift pattern can be observed in this scenario that high income class have showncertain amount of agreement to shift to public transport but is very few in number.A similar trend in case of students can be observed in this scenario also.

Table 19: table showing mode choice preference vs people's income in 2ndscenario

mode choice (Scenario 2)	your monthly income			
	<25000	>50000	25000-50000	DOESN'T EARN (ONLY FOR STUDENTS)
WILL START USINGCARPOOL	4	13	17	2
WILL CONTINUE TO TRAVEL IN SAME MODE	7	10	24	7
WILL START USING PUBLIC TRANSPORT	7	2	8	0

In scenario number 3 the major change can be observed in the willingness to shiftof the people whose income is greater than 50000, an indication of the sensitivity that people are sensitive to high taxes and ravel time and therefore will only shift if the taxes are comparatively high and reductions in the travel time is significant.

Rest all the similar findings from the last two scenarios are prevalent in this scenario also. One more thing to observe in this scenario is the willingness of shiftof the students also which showed zero interest in the previous scenarios are nowalso in a state to shift to public transport.

Table 20: table showing mode choice preference vs people's income in 3rdscenario

mode choice (Scenario 3)	**your monthly income**			
	<25000	**>50000**	**25000-50000**	**DOESN'T EARN (ONLY FOR STUDENTS)**
WILL START USINGCARPOOL	4	6	13	0
WILL CONTINUE TO TRAVEL IN SAME MODE	3	6	19	1
WILL START USING PUBLIC TRANSPORT	11	13	17	8

6.12. Average Generalised Cost

The cost associated with travelling from one place to another involves certain monetary attributes as well as some non-monetary attributes. Monetary attributes involves vehicle operating cost, parking charges, taxing or tolling while the non-monetary attributes includes the monetary value of waiting for a vehicle, monetary cost of time spent on travelling to the nearest transportation hub from home or else from transportation hub to office, school or other destination. AGC isthe combination of both the types of cost. The AGC for car user, 2 W user and a bus user has been calculated in this study and following results were obtained

AGC for a bus or any other public transport mode is calculated
=fare/km*distance/VOT + In vehicle time+2*wait time (min.) + 2.*access and
egress time

Whereas AGC for a car is calculated as

=In vehicle time + (VOC*distance +parking cost)/ VOT* Occupancy+ Congestion
Charge

Table 21: table showing AGC per Km for different modes

MODE	Fare/km	TD	VOT	IVT	WT	AET	AGC	AGC/KM
Bus	2.25	8	20	23	12	26	61.9	7.7375
Car	25(VOC)	12	189	35	0	0	36.8	3.0708
2W	8(VOC)	13	98	25	0	0	24.6	2.1705

MODE	Fare/km	TD	VOT	IVT	WT	AET	CC	AGC/KM	AGC /Km
Bus	2.25	8	20	23	12	26	0	7.73	0
Car	25	14	189	35	0	0	0-10	5.92	92%
Car	25(VOC)	14	189	35	0	0	10-20	10.32	226%
Car	25(VOC)	14	189	35	0	0	20-30	14.78	381%
2W	8(VOC)	13	98	25	0	0	2-15	3.8-8.9	78%-312%

As can be seen from the table that the AGC for the bus is highest followed by the car and the followed by the 2 W. Therefore with such high AGC/Km people usuallyprefer car as a mode to travel. Plus the comfort level of car is obviously much highin car as compared to bus. Although the vehicle operating cost (fare/km) is much low in case of bus as compared to car or 2w but the waiting time, access time andegress time factor is too high in case of bus and that results in high AGC of the bus.

Change in AGC is also seen in order to cross verify that people will shift to public transport once the AGC gets increased after implementation of congestion pricing. The results obtained are shown in table no.The change as observed in the AGC for car under different scenarios lie in a range of 92%-381%. The increase in the AGC was also very high for 2 W which lied in a range from 78%-312%. The increase in the AGC was caused due to implementation of congestion pricing. Thethree scenarios were based on the fact that if congestion pricing is implemented in3 slabs the first one being the slab of rupees 0-10, the second one being of slab 10-20 rupees and third one being 20-30 rupees. The highest increase in the AGCwill be therefore can be seen the the slab where congestion tax lies in a range of 20-30, as it adds as a direct cost in the AGC for car as well for 2 W. the increase in AGC is well sufficient in order to make people willing to shift to public transport leaving their private modes of travel

Table 22: table showing change in AGC for different modes after congestion pricing is implemented

MODE	Fare/km	TD	VOT	IVT	WT	AET	CC	AGC/KM	AGC /Km
Bus	2.25	8	20	23	12	26	0	7.73	0
Car	25	14	189	35	0	0	0-10	5.92	92%
Car	25(VOC)	14	189	35	0	0	10-20	10.32	226%
Car	25(VOC)	14	189	35	0	0	20-30	14.78	381%
2W	8(VOC)	13	98	25	0	0	2-15	3.8-8.9	78%-312%

6.13. Multinomial Logit Model

The model is used to cross check the values of modal shift as observed from the state preference survey. The logit modal basically uses utility of a particular mode and then gives the probability of using that mode out of n number of modes.In this study the utility equation of car, 2 wheeler and bus was formed in order to their respective utilities. The utility equations are a function of travel time, waiting time, access time, egress time, in vehicle time, total travelled distance. The utility of different modes are shown below in table

Table 23: Utility equation of various modes

UTILITY EQUATION	
CAR	2.846+1.029*IVT-1.276*TD
2W	-2.136+0.374*IVT+0.397*TD
BUS	4.406-0.264*IVT+4.46*AET-1.123*WT-0.251*TD

Probability of choosing a mode $(\sigma(t)) = \dfrac{e^t}{\sum_{t=1}^{t=k} e^t}$

Where $e^{t} = \beta_0 + \beta x + \beta x_2 + \beta x_3 + \varepsilon$

Based on above utility equations the probability of choosing a car over a bus and2 wheeler came about as 40% of the total times while the probability of choosinga bus over car and 2 wheeler came out as 20% of the total times and remaining the utility of the 2 wheeler came out as 40%.

The results obtained from the model states that the results obtained from stated preference survey are fair since stated preference survey results shown a modalshift of 23% whereas from the logit modal the utility of a bus came out as 0.20 which is very close to the results obtained from the stated preference survey.

6.14. Chapter Summary

As evident from the analysis of 1st objective, in the congestion index graphsthe travel speed of vehicles varies from 5.2 km./hr. to 33 km/hr. for morning peak hour while it ranges from 5.6 km/hr. to 34 km/ hr.in the evening peak hours. Secondly considering the travel time index the range of values obtained varies from
0.8 to 4.7 in morning peak hours i.e. there is 470% times more travel time will increase from the free flow travel time. The situation is worse in case of evening hours since the upper value of index reaches up to 5.7 i.e. it will take 570% of thefree flow travel time. Lastly the planning time in minutes was calculated which showed that in morning peak hours a planning time of almost half an hour is required to reach the destination on the desired time. The same situation on almostsame roads the evident from the map for the evening hours. Thus it is suitable to implement the congestion pricing link/road wise rather than area or district based as the congestion is distributed randomly and not in a particular zone or area.

From the analysis of 2nd objective the value of time came out as 189 rupees perhour from a 4 wheeler user. This value of time was used for calculating the marginal congestion costs for various roads present inside the study area. For each road the PCU for 24 hours and corresponding speed of vehicles on that road was seen and then a final marginal cost is arrived at. The speed flow relationship also played an significant role in calculation of marginal congestion cost since the slope of the speed flow relationship was used in calculation of marginal congestion costs. After finding the marginal congestion costs for variousroads it was segregated into 4 categories the first one where the congestion tax is in the range of rupees 0-4, the second one where roads have a marginal congestion cost in arrange of rupees 4-12, third category bearing the marginal congestion cost in arrange of rupees 12-17 and the last category in which the range of marginal congestion cost is in the range of rupees 17-28.

The last part has predictions of modal shift from the stated preference survey, change or increase in the average generalized cost and finally for cross checkingthe stated preference survey multinomial logit model was used. The results as obtained from the stated preference predicted a modal shift of 23% to the public transport out of which 27% of the users are car users, 52 % of the users are 2 wheelers users and remaining are users of other modes. A similar result was found out by forming the utility equations and finding the probability of a certain mode using logit model. The probability of bus came out as 0.20 that is the probability of choosing a bus for travelling will be 20 out of 100. The probability ofcar came out as 0.40 that is probability of choosing a car is 40 out of 100. Similarkind of results was obtained for the 2 wheelers also. The change found in the AGC was also indicating the fact that after implementation of the congestion pricing the increase in the cost will be in range of 90%-381% for 4 wheelers and 70%-310% for 2 wheelers. With such huge increase in AGC/Km people will be force to shift to a comparatively cheaper and faster public transpor

Chapter 6 -PROPOSALS

6.1. Introduction

The part of proposal in mainly divided in 3 stages the first stage includes delineation of HOV 3+ lanes followed by enhancing the current capacity of public transport and lastly combined with the proposal of a new high capacity carrying public transport running especially inside the study area. Data required for findingout the need of extra demand for the public transport is calculated in the previouschapter from the stated preference survey that how many people are willing to shiftto public transport from their existing mode of vehicle.

Delineation of HOV 3+ lanes are based on certain parameters which are taken from a document of Ontario Transport authority, Canada. After delineation of HOV 3+ lanes the new public transport mode with high carrying capacity will be running in these lanes only. The new transport mode will not only cater the new demand but will also cater to the previously generated demand. Since new publictransport will not be running through the entire study area therefore route rationalisation of the existing public transport routes will also be carried out in thelast phase of the proposal

6.2. H.O.V. Lane Delineation

A high occupancy vehicle lane (carpool lane, transit lane, diamond lane oras called as T3 or T2 lanes in case of New Zealand and Australia) is a lane whichis restricted for the use by vehicles that have high occupancy during peak hours. for example the minimum level of occupancy for the car is 2 or 3 for a car to be eligible to drive inside the HOV lane. Chartered buses, emergency vehicles such as ambulance, police vehicles, buses sponsored by corporate office or industries are also eligible to drive inside the HOV lane during the peak hours. HOV lanes have proven their effectiveness in tackling the congestion especially in the countries such as America. Although its use in India can be topic of debate since in most of the cases we don’t have the required Right of way for providing a HOV lane and secondly a HOV lane in India is difficult to manage. The defaulters will be many and to individually preventing them from using the HOV lane will be acumbersome task on its own.

Its delineation is based on certain parameters which includes

a) The road which is required to be convert to a HOV lane should have at leasta frequency of 20 buses per hour in morning and evening peak hours. Thisparameter takes account of the availability of public transport on that certainstretch of road which is converted to a HOV lane.
b) The second requirement is of minimum width of the road required to converta certain road into a HOV lane road. This parameter makes sure that the road had fairly better physical character in order to provide better level of service in case of conversion to HOV lane from a normal road
c) The third parameter is that HOV lanes should form a complete network as far as possible. If adding an extra lane would complete the HOV network than it should be delineated as a HOV lane
d) The last parameter is related to the current level of service provided by theroad. If the level of service of the road is in declining state than the road canbe converted into a HOV lane

After overlaying maps of each of these physical and functional parameters a network of HOV lane is decided inside the study area. The first map (figure.) depicts whether there is scope of widening the existing ROW or not. The roads that have scope of getting widen is taken into considerationfor conversion into a HOV lane along. In the next map which depicts whethera road is a 4 lane or a 6 lane divided roadway or not. The roads which have6 lane divided carriage way or either 4 lane divided carriage way with a scope of widening are taken together into consideration for converting into a HOV lane from a normal road.

The next map is of level of service a road provides. This level of service mapis prepared by taking the average speed of the vehicles on that particular road during the morning and evening peak hours. The roads with level of service below than CATEGORY ‘C’ was taken into consideration for converting into HOV lane from the normal road. The reason being that the roads which have poor travel conditions should be targeted at the first pointin order to enhance their capacity to cater the needs of the vehicles. The last map (figure) is of the frequency

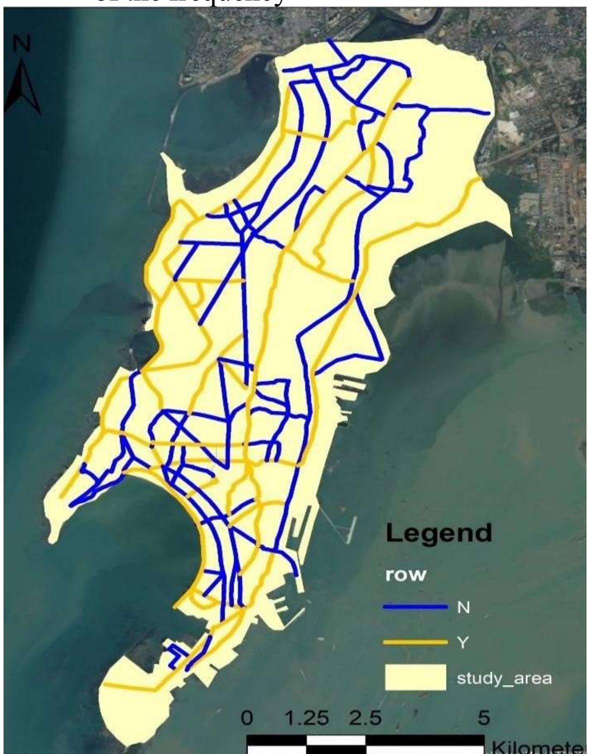


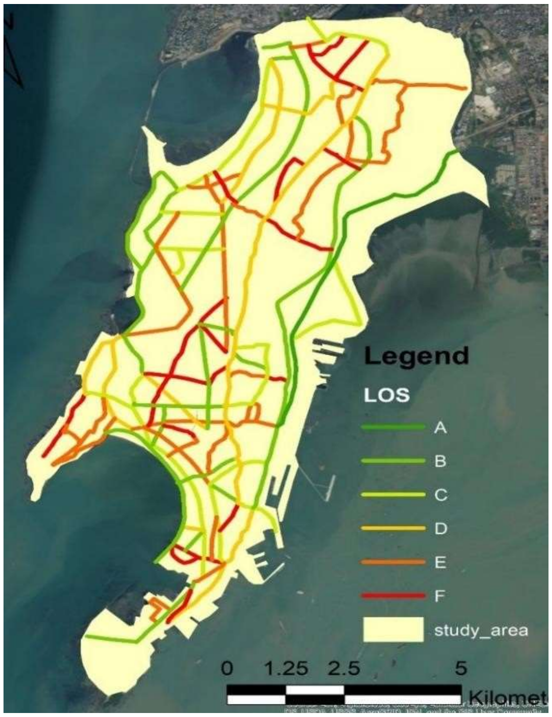
Figure 28: Map showing scope of wideningof road ROW,

Source- (Comprehensive Mobility Plan (CMP) for Greater Mumbai, 2016)

Figure 27: map showing frequency of buses on roads inside the study area

of the buses in the morning peak hours. In order to fulfil the first parameter of 20 buses per hour frequency. All these maps were overlaid in order to getthe HOV lanes inside the study area.

The HOV lanes selected inside the study area are shown in figure- . As evident from the figure that the HOV lanes are not present in the eastern part in middle ofthe study area. It is justified to not have any HOV lanes in this middle eastern partsince in the analysis stage also the same region was facing very low congestion as per the various indices used as well as during the analysis of marginal costs forthe roads the roads lying in the same part also have the minimum congestion tax among all the other roads. These HOV lanes will be the roads where your newpublic transport with high carrying capacity will be running.



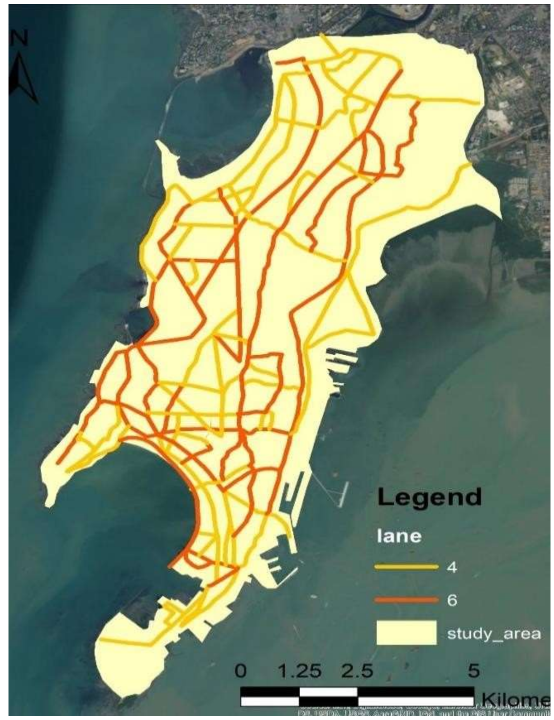


Figure 30: Map showing current level of service of roads inside the study area

Figure 29: map showing lanes availability on different roads inside study area

Source- GOOGLE EARTH

6.3. New PublicTransport

Figure 31: Map showing delineated HOV lanes

In order to have a new public transport the first preference is to know the demand for it. The demand for the new public transport will be a combination of the modal shift of the users from their cars to new public transport and the previous gap betweenthe supply and demand of the publictransport facilities. For this purpose the existing routes of the BEST buses insidethe study are which have poor capacity by demand ratio was seen and identifiedas the routes which needs to be tacked at the first place. Further adding to this the PPHPD was considered to find out the new demand. PPHPD was calculated by using the total PCU in peak hour on the roads. Existing PCU was divided as per the existing modal share of vehicles. It was further divided by the individual PCU of different modes. After this step the individual vehicular numbersrunning in peak hour per direction was obtained which was multiplied with the occupancy ratio in order to get the PPHPD. Further the predicted modal shift of 23% was taken out from the PPHPD.

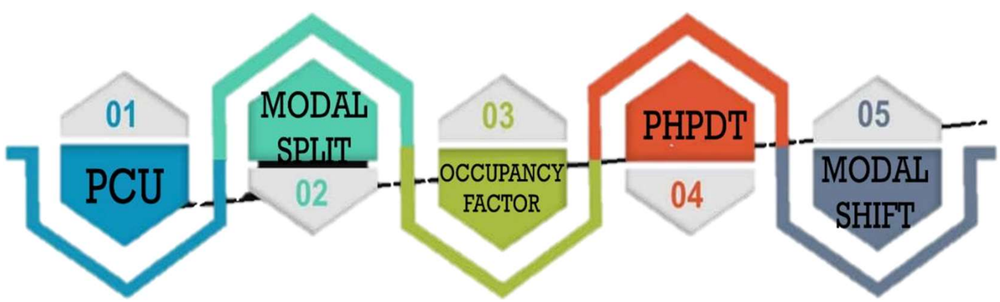


Figure 35: figure showing framework for calculation of new demand for public transport

Table 24: table showing routes originating from different bus depots inside study area

BUS DEPOTS	OPERATIONAL ROUTES NUMMBER
BLACKBAY	100,106,108,112,121,132,133,134,137,138,139,25 Ltd., 3,9,SPL-2LTD,SPL-8 LTD, SPL-9 LTD
COLABA	101,103,111,122,19 LTD.,2LTD, 22 LTD,44, 6 LTD,SPL 1 LTD, SPL 3 LTD, SPL 4 LTD
WORLI	110,124,125,161,162,167,169,171,27,324,463,50,53,55,82,89,
DHARAVI	11 LTD, 161, 165, 173, 180, 192, 219, 303, 310, 316, 317, 449 LTD, 46, 463, 52, 615, 66, 70,75, 87 LTD
PRATIKSHA NAGAR	14,15,169,170,172,181, 255 LTD, 302, 312, 315, 341, 43, 448 LTD, 502 LTD, 509 LTD, 64, 67,76,88
WADALA	151,161 LTD, 160, 163, 168, 174, 213, 40, 411, 440 LTD., 453 LTD., 504 LTD., 57,69,77, AS 503, AS 6, AS 7
CENTRAL	105, 123,126,127,130,135,154,155,156,166,18,30 LTD.,351, 41,42,48,62,63,91 LTD.

Source- (EMBARQ India, 2015)

Out of these routes the ones which have a low capacity by demand ratio was selected for enhancing their capacity with the help of new high carrying capacity public transport. As mentioned earlier the demand for the new high carrying capacity public transport also includes the people who will shift from the car or 2 wheelers. Out of 123 routes running inside the study are only those routes are Table 25: table showing route wise peak hour demand and need of new fleet to suffice the demand

C/D RATIO	FREQUENCY/HR.	CAPACITY/HR.	PEAK HOUR	TRAVEL DISTANCE	TERMINAL TIME	HEADWAY (IN MINUTES	CYCLE TIME	FLEET SIZE
0.93	5	300	637	20	7.5	11	17	2
0.89	6	360	741	18	7.5	10	17	2
0.24	4	240	1541	4.6	7.5	5	16	3
0.31	8	480	2450	15	7.5	3	17	6
0.54	3	180	1449	8.8	7.5	5	16	3

Considered for running of new transport service which have their routes aligned parallel to the newly delineated HOV and have a low capacity by demand ratio. Onthis basis 5 existing routes name route no. 14, route no. 48, route no. 25, route no.171 and route no. 172 were choose to be replaced by the new high capacity publictransport.

After selection of routes the new demand and the old demand will be added and new fleet calculation will be done for the peak hours based on the stated terminal time of 7.5 minutes and by assuming the capacity of an individual bus as 120. Thetotal requirement of new fleet of buses on new HOV lanes for catering the old as well as new demand for the public transport a fleet size of total 16 buses of capacity 120 (standing

+sitting) is required

1. ROUTE NO 14

Dr S P Mukherji Chowk Museum (origin) - Hutatma Chowk- Khadi Bhandar- Mumbai C S T- Kalbadevi- Swadeshi Market- Bhuleshwar- Vijay Vallabh Chowk Pydhuni- Johar Chowk- Dr M Iqbal Chowk- A H Ansari Chowk- Byculla Station West- Com Gulabrao Ganacharya Chowk- N M Joshi Marg Police Station- Bawla Masjid- Bharatmata Cinema- Mahatma Gandhi Hospital- K E M Hospital- Wadia Hospital- Tata Hospital- Bhoi Wada- Best Colony Bhoiwada- Kidwai Road Police Station- T B Hospital- Dnyaneshwar Nagar- Kidwai Nagar- Madhav Nagar- Azad Nagar Wadala- Wadala Station West- Wadala Church- Wadala Fly Over Bridge- Indian Oil Depot- Antop Hill Post Office- Antop Hill- Kane Nagar- C G S Dispensary-Antop Hill Police Station- Antop Hill Church- Sardar Nagar No 4- Sardar Nagar No2- Sardar Nagar No 1- Rawli Camp- Samaj Mandir Hall Pratiksha Nagar- PratikshaNagar No 1- Transit Camp Dispensary- Best Receiving Centre Pratiksha Nagar- Pratiksha Nagar Depot (destination)

The existing capacity by demand ratio of this route was 0.93 and the capacity of this route during the peak hours is 300. The extra demand as per the calculation is322 in park hour and the new demand from the predicted modal shift is 337(cordonbased demand) thereby adding total demand as 637 in the peak hour travel. With the assumption of terminal time as 7.5 minutes and head way of 11 minutes the new requirement of fleet buses comes out as 2 for this particular route

2. ROUTE NO. -25

Backbay Depot (origin)- Dhobi Ghat Cuff Parade- President Hotel- Badhwar Park Machhimar Nagar- Veej Bhavan- Y B Chavan Pratishtan- K C College- Dr Ambedkar Statue Churchgate- Ahilyabai Holkar Chowk- Hutatma Chowk- Khadi Bhandar- Mumbai C S T- Mahatma Phule Market- Zakeria Masjid- Dr M Iqbal Chowk- A H Ansari Chowk- Byculla Station East- Jijamata Udyan- Jaihind Cinema- Sant Jagnade Chowk Lalbaug- Madkebuwa Chowk Parel- Hindmata Cinema- Khodadad Circle- Kapole Niwas J N Varma Chowk- Maheshwari Udyan- Gandhi Market Matunga- Lokmanya Tilak Hospital- Rani Laxmibai Chowk Sion- Kurla Level Crossing- Lions Park- Kurla Post Office- Gol Building- Anjanabai Magar- Kurla Depot- Old Agra Road- Sheetal Cinema- Kamani- Bail Bazar- Jari Mari- Safed Pool- Vijay Printing Press Andheri- Dr Datta Samant Chowk Saki Naka- State Bank Of India Andheri- Chandivali Junction- John Backer- E S I S Local Office Powai- Tunga Village- L And T Gate No 6- Dr Ambedkar Udyan Powai- P WD Office- Morarji Nagar- National institute of industrial training-ramda hotel powai-vihar lake (destination)

The existing capacity by demand ratio of this route was 0.89 and the capacity of this route during the peak hours is 360 (6 buses of this route in the peak hour). Theextra demand as per the calculation is 404 in park hour and the new demand fromthe predicted modal shift is 337(cordon based demand) thereby adding total demand as 741 in the peak hour travel. With the assumption of terminal time as
7.5 minutes and head way of 10 minutes the new requirement of fleet buses comesout as 2 for this particular route

3. ROUTE NO.- 48

Ferry Wharf (origin)- Mallet Bunder- Railway Crossing Dockyard- Nirman Bhavan- Mazgaon Dock Mazgaon- Nawab Tank Marg- Dockyard Road Railway Station- Maharana Pratap Chowk Mazgaon- Mazgaon Court- St Marys High School- New

Nagpada- A H Ansari Chowk- Christ Church School- Alexandra Cinema- Mumbai Central Depot- Mumbai Central Station- Vasantrao Naik Chowk Tardeo- Bhatia Hospital (destination)

The existing capacity by demand ratio of this route was 0.24 which was one of thelowest among the following routes and the capacity of this route during the peak hours is 240 (four buses of this route in the morning peak hour). The extra demandas per the calculation is 1000 in park hour and the new demand from the predictedmodal shift is 541(cordon based demand) thereby adding total demand as 1541 inthe peak hour travel. With the assumption of terminal time as 7.5 minutes and headway of 5 minutes the new requirement of fleet buses comes out as 3 for this particular route

4. ROUTE NO.- 171

Worli Dairy(origin)- Narayan Pujari Nagar- S T Office Lovegrove Jarimari Temple-Worli Sea Face Sea- Venus Building Watumal Engg College- Flora Hotel WatumalEngg College- Poddar Hospital- Acharya Atre Chowk- Gandhi Maidan Worli- ComP K Kurne Chowk- Doordarshan- Dr Ravindra Kulkarni Chowk Sasmira- Babasaheb Worlikar Chowk- Gammon House- Prabhadevi- Khed Galli- Dadar Police Station- Shardashram Vidyamandir- Dadar Kabutar Khana- Veer Kotwal Udyan Dadar Station Plaza- Khodadad Circle- Parsi Colony Wadala- Five Gardens- V J T I College- Maheshwari Udyan- Matunga Police Station- Gandhi Market Matunga- Lokmanya Tilak Hospital- Guru Tegh Bahadur Nagar Station- Sardar Nagar No 2- Sardar Nagar No 4- Antop Hill Church- Antop Hill Police Station- Kane Nagar- C G S Dispensary- Antop Hill (destination)

The existing capacity by demand ratio of this route was 0.31 which was second ofthe lowest among the following routes and the capacity of this route during the peakhours is 480 (eight buses of this route in the morning peak hour). The extra demandas per the calculation is 1548 in park hour and the new demand from the predictedmodal shift is 902(cordon based demand) thereby adding total demand as 2450 inthe peak hour travel. With the assumption of terminal time as 7.5 minutes and head way of 3 minutes the new requirement of fleet buses comes out as 6 for this particular route

5. ROUTE NO. -172

Byculla Station West (origin)- Sunder Galli- Garlic Company- Simplex Mill- Sant Gadge Maharaj Chowk Saat Rasta- Mahalaxmi Station- Famous Studio- Ambika Mills King George Infernary- Jijamata Nagar Worli- Municipal Garage Worli- Acharya Atre Chowk- Gandhi Maidan Worli- Com P K Kurne Chowk- Doordarshan-Dr Ravindra Kulkarni Chowk Sasmira- Babasaheb Worlikar Chowk- Gammon House- Prabhadevi- Siddhivinayak Mandir- Agar Bazar- P Thakre Chowk Dadar- Hanuman Mandir Dsilva School- Veer Kotwal Udyan Dadar Station Plaza- Khodadad Circle- Vitthal Mandir Wadala Market- Wadala Church- Wadala Fly OverBridge- Indian Oil Depot- Antop Hill Post Office- Antop Hill- Kane Nagar- C G S Dispensary- Antop Hill Police Station- Antop Hill Church- Sardar Nagar No 4- Sardar Nagar- Sardar Nagar No 1 No 2- Rawli Camp- Samaj Mandir Hall PratikshaNagar- Pratiksha Nagar No 1- Transit Camp Dispensary- Best Receiving Centre Pratiksha Nagar- Pratiksha Nagar Depot (destination)

The existing capacity by demand ratio of this route was 0.54 which was second ofthe lowest among the following routes and the capacity of this route during the peakhours is 180 (three buses of this route in the morning peak hour). The extra demandas per the calculation is 333 in park hour and the new demand from the predictedmodal shift is 1115(cordon based demand) thereby adding total demand as 1449 in the peak hour travel. With the assumption of terminal time as 7.5 minutes and head way of 5 minutes the new requirement of fleet buses comes out as 3 for this particular route.

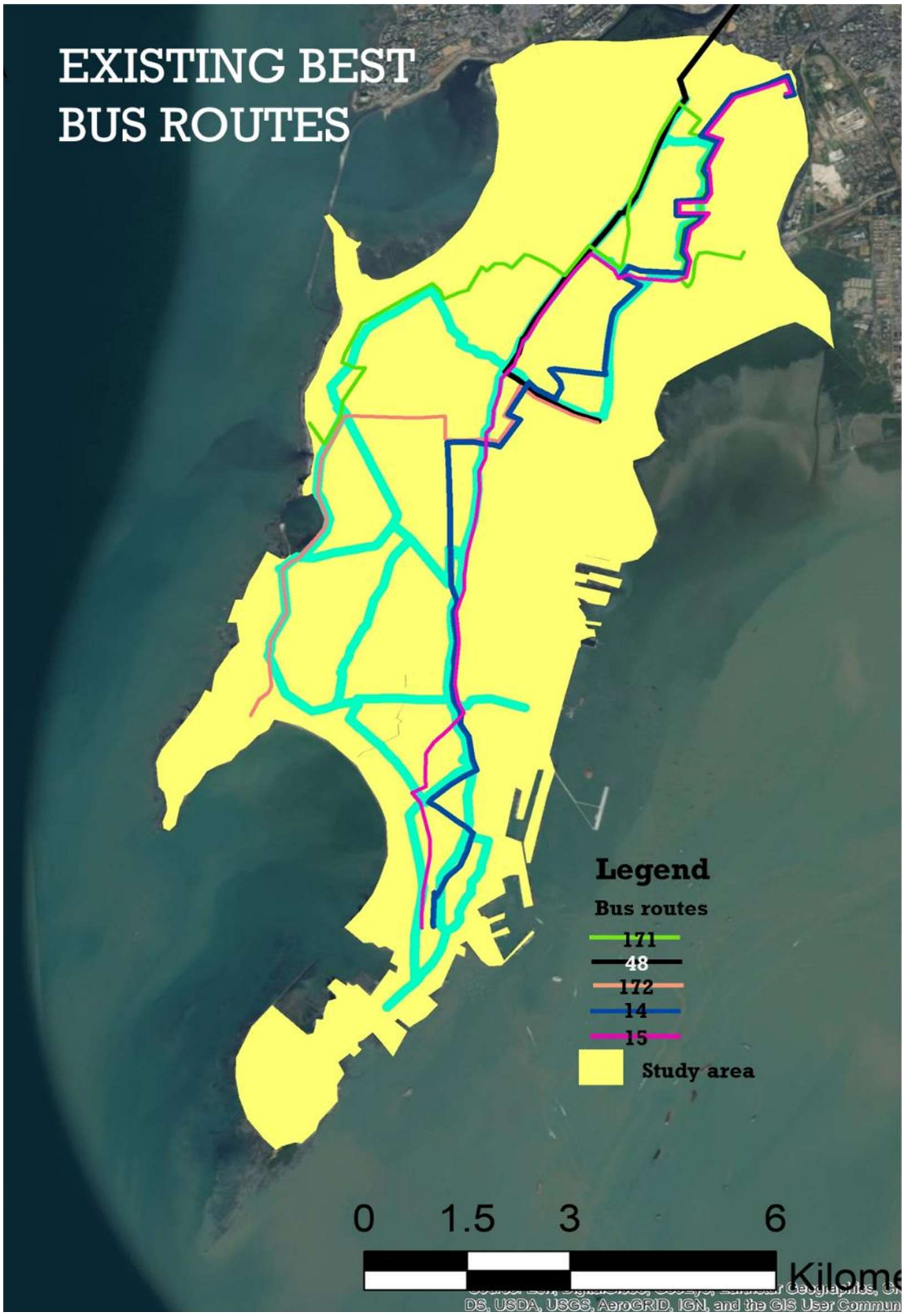


Figure 32: map showing routes selected for capacity enhancement insidethe study area

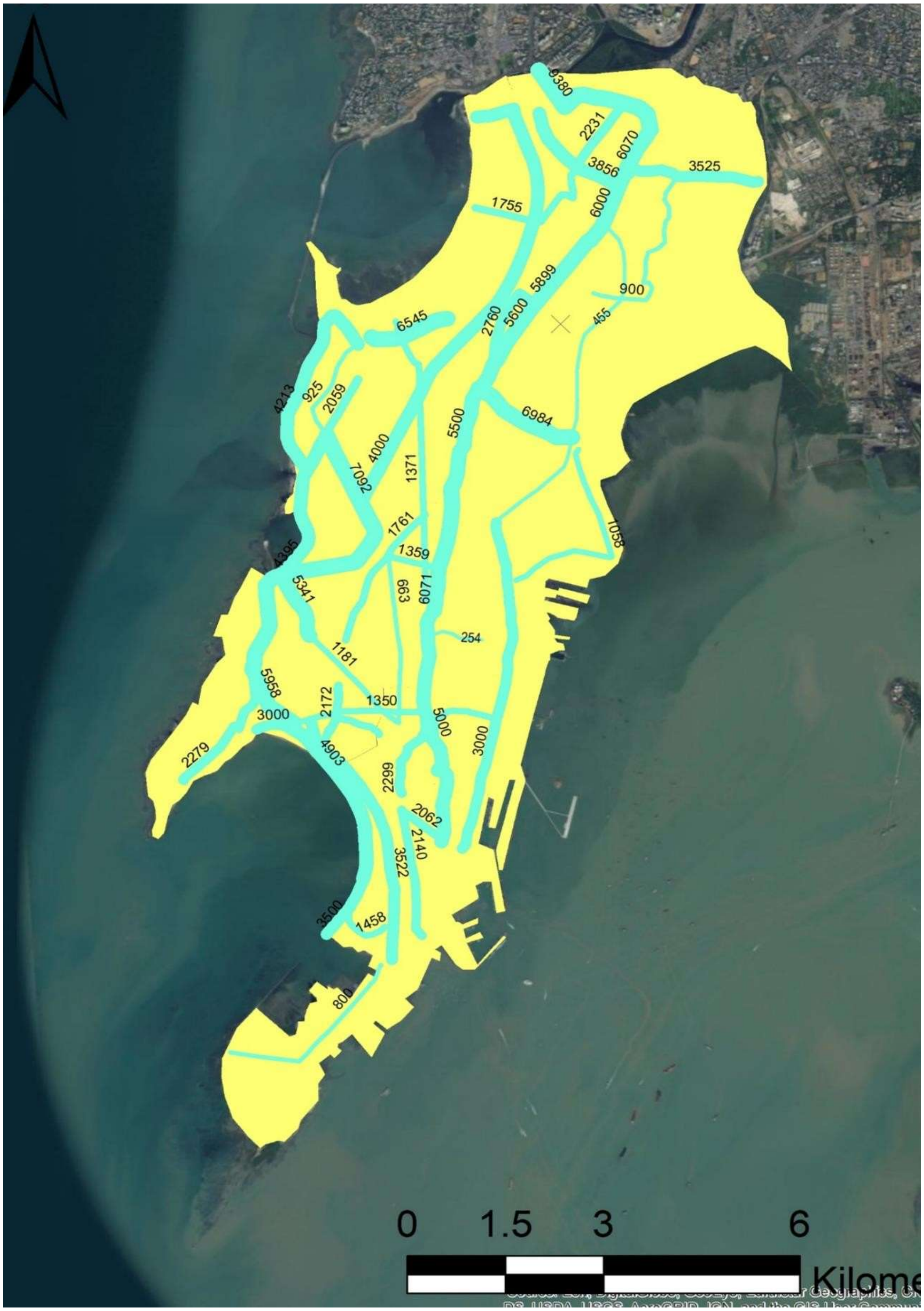


Figure 33: map showing PPHPD during morning peak hour inside study area

6.4. Congestion Cost

As mentioned in the literature study chapter total congestion cost is a function of productivity losses, cost of environmental pollution, accidents cost and many other attributes. In the final stage the savings in congestion costs of the studyarea after congestion pricing gets implemented are calculated as mentioned below

- Congestion cost due to productivity losses

The productivity losses entail a total approach, i.e., losses incurred by all commuters due to delays caused by all vehicles in the network. An important pointworth mentioning here is that, the productivity losses in this case will depend on the average vehicle occupancy. Computing the total costs of congestion due to productivity losses involves considering several factors. These include: Value of time, average occupancy, and trip length by mode, number of trips by mode, free-flow speed and average speed in congested conditions.

$TCCPL = 365 * VOTi * \Psi i * \mu i * \Lambda i (1 /\nu C – 1/ \nu f)$.

In the above equation, Ψi is the average total number of trips in a day for mode i, μi (in kilometres) is the average length of a trip for mode i, and Λi is the average occupancy for mode i. VOTi (in Rupees per hour) is the value of time for the commuter travelling in mode i, νC is the average speed under congested conditions, and νf is the free-flow speed of traffic. With using the above formula the productivity losses comes out as 98 crores per year

Table 25 : Productivity losses caused due to congestion inside study area

Mode	VOT	No. of trips made	average trip length	average occupancy	average speed	free flow speed	CONGESTION COST
CAR	189	46000	12	1.25	17	32	9.5 CRORES
2W	98	88481	13	1	17	32	88 CRORES

- Air Pollution Costs

Vehicular emissions cause serious air pollution problems and are a health hazard. Air pollution costs arise from health and environmental damages due to vehicular emissions. Increased traffic congestion stalls vehicles and increases onroad time, which in turn considerably increases vehicular emissions. Computing marginal costs of congestion due to air pollution entails considerations such as emission pervehicle kilometre (vkm), vehicle fleet age structure, and the estimates of pollution costs per unit of the pollutant. The Marginal External Costs of Congestion due to Emissions (MECCEi) for a transport mode i, summed over all emitted pollutants indexed by k, is given by:

MECCEi = □k ρ k i □ k

Table 26 : total congestion costs due to environmental pollution

	TOTAL EMISSIONS IN G/KM			
TOTAL EMISSIONS	CO2	CO	NOX	PM
	10285600	91080	9200	1380
	2353595	194658.2	1061772	4424.05
MODES	TOTAL EMISSIONS IN KG/KM			
	CO2	CO	NOX	PM
CAR	10285.6	91.08	9.2	1.38
2W	2353.595	194.6582	1061.772	4.42405
	COST PER KG/KM			
POLLUTANTS	CO2	CO	NOX	PM
COST	6.73	0.46	108	869
	TOTAL COST (PER DAY PER KM)			
CAR	69222.09	41.8968	993.6	1199.22
2W	15839.69	89.54277	114671.4	3844.499
TOTAL COSTS	**85061.78**	**131.4396**	**115665**	**5043.719**

Table 27 : emission standards for car and 2w for Indian cities

MODES	PER VEHICLE G/KM			
	CO2	CO	NOX	PM
CAR	223.6	1.98	0.2	0.03
2W	*26.6*	*2.2*	*12*	*0.05*

Source: (Placeholder1) (Neema Davis, Congestion costs incurred on Indian Roads: A case study for New Delhi, 2017)

6.1. Chapter summary

This chapter discusses the final proposals put forth to address the transportation challenges. The first proposal focuses on the delineation of HOV lanes, which involved overlaying specific parameters such as peak hour frequency of transit buses, current road service levels, and the availability of necessary infrastructure for HOV lane implementation. Once the HOV lanes were delineated, the final demand for the new public transport service was calculated. This demand comprised the existing demand from routes with low capacity-to-demand ratios and the predicted modal shift.

Among the 123 routes within the study area, only those routes aligned parallel to the newly delineated HOV lanes and with low capacity-to-demand ratios were considered for the new high-capacity public transport service. Route numbers 14, 48, 25, 171, and 172 were selected to be replaced by the new service. Based on the total demand calculations for the new public transport (with a capacity of 120), a fleet of 16 buses would suffice. These buses would operate at different headways, ranging from 3 minutes for routes with higher demand to 10 minutes for routes with lower demand. The fleet size calculation specifically targeted morning peak hours but would also be sufficient for any time of the day.

The last part of the proposal focuses on addressing the remaining routes that are not aligned parallel to the HOV lanes. These routes would be rationalized to enhance the existing public transport capacity. The study concludes with an overall calculation of congestion costs in the study area, primarily related to productivity loss and environmental impacts. The total congestion costs amount to 198 crores per year, excluding accident costs and potential revenue generation, which would only be possible after the implementation of congestion pricing.

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