assignments (followed by skims for next iteration). It was found that to achieve convergence, eight iterations were required.

6.2.3 The Do-minimum assignment was carried out to identify the bottlenecks, over capacity links etc. With this it is possible to identify the major constraints in the network. Once the constraints are identified it is easy to formulate schemes to overcome the problems. New infrastructure, traffic management plans, and policy controls can be worked out with the help of identified schemes. The calibrated deterrence functions for various modes and various purposes have been adopted. Forecast test of each scheme will be assessed against the Do-Minimum assignment.

6.2.4 For the Do Minimum Scenario, the expected modal split for the year 2025 is given in **Table 6.1**. This table shows that the modal split in favour of public/mass transport will fall to about 29% by 2025 against base year modal split of 47%. Share of trips by personalized motor vehicles such as car and two wheelers is expected to increase from 40% to 60%. This is expected to increase the traffic volumes on the most of the road network beyond its capacity. The desireline diagram for private vehicles for 2025 is shown in **Figure 6.1**. Peak hour traffic assignment on the road network is shown in **Figure 6.2**. These figures indicate heavy radial movements to the core of the city and also circumferential movements. Heavy traffic is likely to be experienced on all radial roads, Outer Ring Road and various roads in core area. V/C ratio will be more than 0.8 on most of the roads. Travel speeds will fall to 6-7 kmph. Environmental pollution from motor vehicles will assume critical dimensions.

Table 6.1 Expected Modal Split - Do Minimum Scenario (Scenario –I)

Modes	Modal Split			
	Base Year Scenario - 2006		Scenario -1 (Do Minimum) - 2025	
	Daily Trips (lakhs)	%age	Daily Trips (lakhs)	%age
Car	4.2	7.5	15.5	12.2
2W	18.4	32.8	60.4	47.5
IPT	7.3	12.9	14.9	11.7
BUS	26.3	46.8	36.3	28.6
Total	**56.2**	**100.0**	**127.2**	**100.0**

6.3 SCENARIO 2

6.3.1 Considering the evaluation of the above scenario, the most important issue to reduce road traffic will be to increase the share of trips by public/mass transport. This will mean providing high capacity mass transport system on many corridors. Revised Master Plan-2015 has proposed the following public transport system and major roads.

Figure 6.1 Desireline Diagram for Private Vehicles for 2025 (Do Minimum)

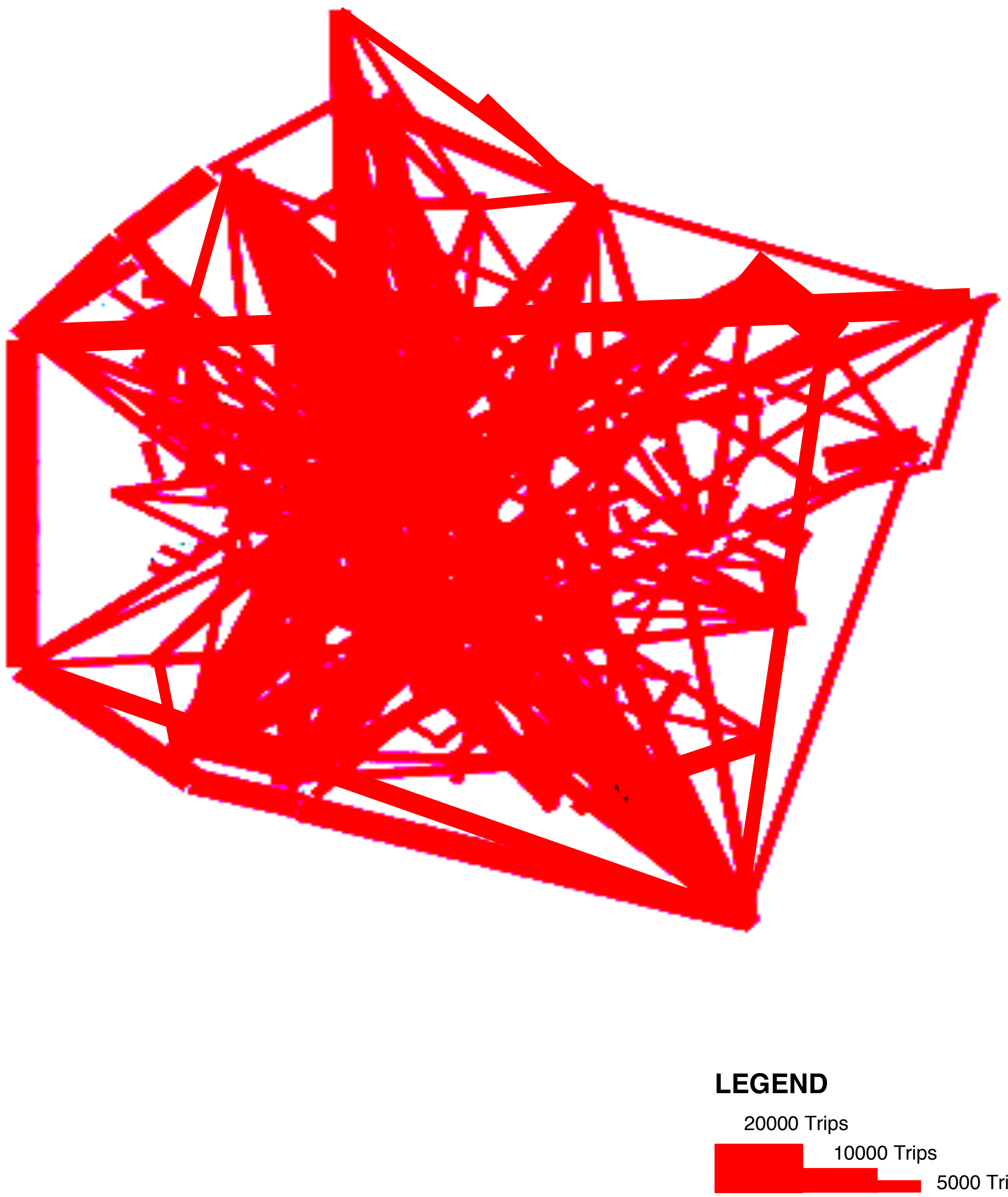


Figure 6.2 Peak Hour Traffic Assignment on Road Network (Do minimum)

i. Metro System (36.8 km) (Mysore Road-Baiyyappanahalli and Peenya-RV Terminal corridors)
ii. Monorail system (47km) (from Kanakapura Road to Bellary Road along ORR, Kathriguppe to National College, Bannerghatta-Adugodi along Bannerghatta and ORR to Toll Gate junction along Magadi Road)
iii. BRT (30km) (on ORR)
iv. Commuter Rail Service in Bangalore (Kangeri-Whitefield, Bangalore City Satation-Baiyyappanahalli via Lottagolahalli (60 km)
v. Elevated Core Ring Road (30 km)
vi. Peripheral Ring Road (114 km)
vii. New Airport Expressway (26 km)

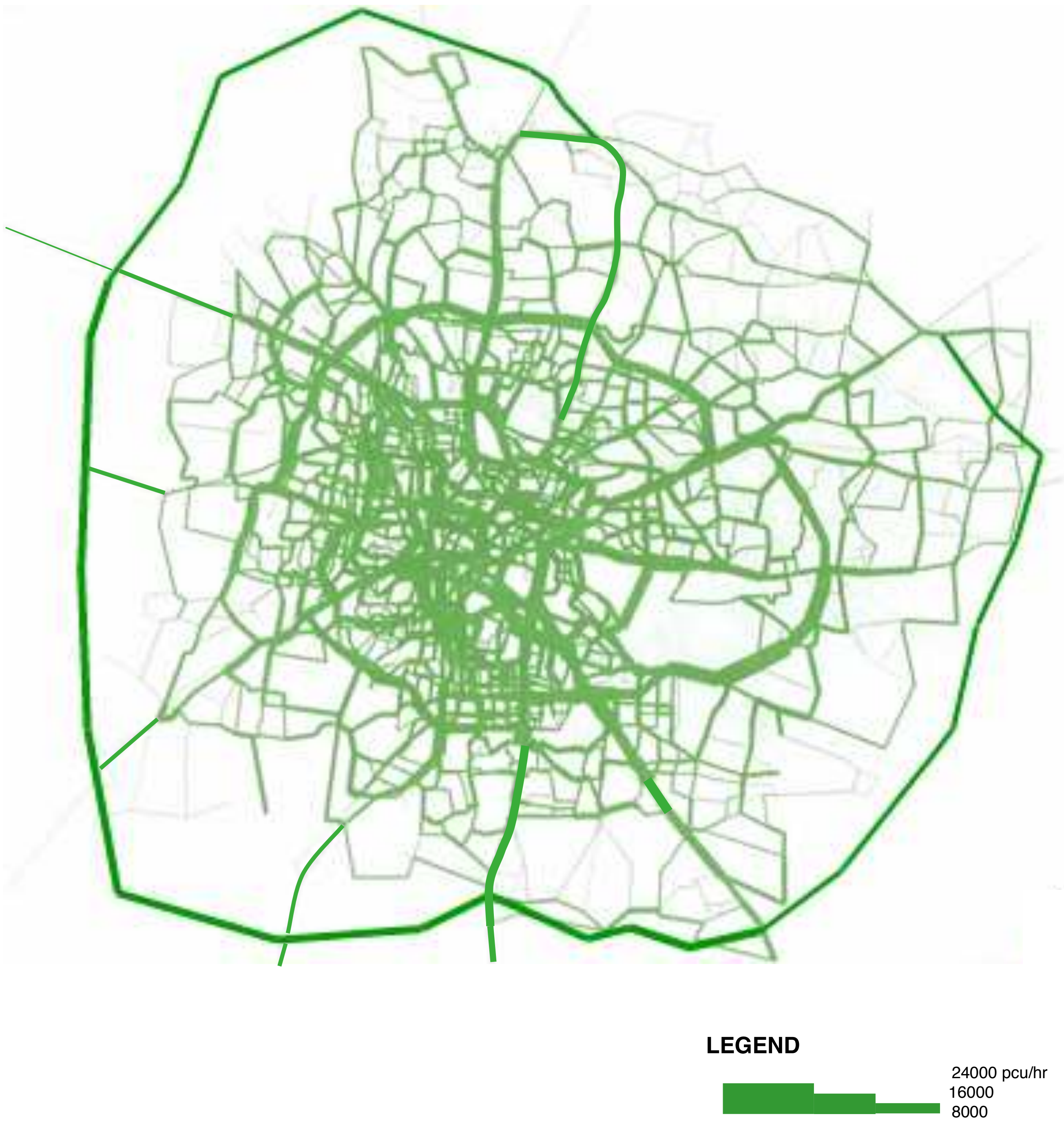
6.3.2 Considering above, another network Scenario (termed as Scenario 2) was developed, travel demand modeling and forecasting carried out and results evaluated. For this Scenario, the expected modal split for the year 2025 is given in **Table 6.2**. This table shows that the modal split in favour of public/mass transport will increase marginally to about 50% by 2025 against base year modal split of 47%. Share of trips by personalized motor vehicles such as car and two wheelers is expected to increase from 40% to 44%, although in absolute numbers their demand will increase from 23 lakh (2006) to 55 lakh (2025) daily trips. This is also expected to increase the traffic volumes on the many of the road network beyond its capacity, although, the traffic levels will be much less as compared to Do Minimum Scenario. This can be seen in traffic assignment figures. Peak hour peak direction trips (phpdt) on mass transport network for this scenario is shown in **Figure 6.3**. Peak hour traffic assignment on the road network for 2025 for this scenario is shown in **Figure 6.4**. These figures indicate significant traffic on mass transport network and reduced traffic on many roads. However, many roads such as Hosur Road, Kanakapura Road, Airport Road, Mysore Road, ORR, many roads in core area and outer areas will continue to be overloaded. Thus share of public/mass transport in total demand will still need to be increased substantially.

Table 6.2 Expected Modal Split -Scenario 2

Modes	Modal Split			
	Base Year Scenario (2006)		Scenario 2 (2025)	
	Daily Trips (lakhs)	% age	Daily Trips (lakhs)	% age
Car	4.2	7.5	9.7	7.6
2W	18.4	32.8	45.6	35.9
IPT	7.3	12.9	8.9	7.0
Public/Mass Transport	26.3	46.8	50.0	49.5
Total	**56.2**	**100.0**	**127.2**	**100.0**

Figure 6.3 Peak Hour Peak Direction Trips (PHPDT) on Mass Transport Network (Scenario 2)

Figure 6.4 Peak Hour Traffic Assignment on the Road Network for 2025 (Scenario 2)



6.4 SCENARIO 3

6.4.1 Considering that many of the road corridors will still be overloaded in Scenario 2, the public/mass transport network and road network has been extended on the following corridors and the alternative termed as Scenario 3.

1. Mass transport network and Major Road Network as in Scenario 2
2. Additional Mass Transport Corridors
   - i. Baiyyappanahalli to Benaiganahalli
   - ii. R.V. Terminal to PRR along Kanakapura Road
   - iii. Yelahanka Road to PRR via Nagavara, Electronic City
   - iv. Indiranagar to Whitefield along Airport Road
   - v. Devenahalli Airport to MG Road via Bellary Road (New Airport)
   - vi. Kanakapura Road to Bannerghatta Road along ORR
   - vii. PRR to ORR along Magadi Road
   - viii. Benaiganahalli (ORR) to PRR along old Madras Road
   - ix. From ORR to Hosur Rd along Hitech Corridor Jn.
   - x. Hosur Rd-PRR Junction to Tumkur Rd along PRR (western part)
   - xi. Tumkur Road-PRR Jn. to Hosur Rd along PRR via Tirumanahalli, Old Madras Road, Whitefield (eastern part of PRR)
   - xii. Along Core Ring Road
   - xiii. Vidyaranyapura to Nagavarapalya Via Hebbal, Jayamahal Road, Queens Road, M.G. Road, Ulsoor, Indranagar, CV Raman Nagar
   - xiv. Kengeri Sattelite Town to J.P. Nagar along Uttarahalli Road, Kodipur
   - xv. Banshankari III stage to Banshankari VI stage Ext. along Ittamadu Road, Turahalli, Thalaghattapura.
   - xvi. Domlur Ext. to Kormangala along inner ring road
   - xvii. PRR (Mulur) to Maruti Nagar (up to Hitech corridor) along Sarjapur Road
   - xviii. Peenya to PRR along Tumkur Road
   - xix. Old Madras Road near Indranagar to ORR near Banaswadi along Baiyyappanahali Road -Banaswadi Road
   - xx. Commuter Rail Corridors
     - Lottegollahalli to Yelahanka
     - Banaswadi -Hosur
     - Kangeri- Ramnagaram
     - Yeshwantpur to Tumkur

6.4.2 Expected modal split for Scenario 3 for 2025 is shown in **Table 6.3**. It is seen that share of person trips for public/mass transport is expected to increase to 73%. This share in favour of public/mass transport is desirable for the city of size of population more than one crore as recommended by the Committee for the Report on 'Alternative Systems of Urban Transport' set up by the Government of India.

Table 6.3 Expected Modal Split –Scenario 3

Modes	Modal Split			
	Base Year Scenario (2006)		Scenario 3 (2025)	
	Daily Trips (lakhs)	%age	Daily Trips (lakhs)	%age
Car	4.2	7.5	7.0	5.5
2W	18.4	32.8	20.6	16.2
IPT	7.3	12.9	6.7	5.3
Public/Mass Transport	26.3	46.8	92.9	73.0
Total	**56.2**	**100.0**	**127.2**	**100.0**

6.4.3 The desireline diagram for private vehicles for 2025 is shown in **Figure 6.5**. The traffic desire by these vehicles will be significantly reduced. Peak hour peak direction trips (phpdt) on mass transport network for this scenario are shown in **Figure 6.6**. Peak hour traffic assignment on the road network for 2025 for this scenario is shown in **Figure 6.7**. These figures indicate significant traffic on mass transport network and further reduced traffic on roads as compared to Scenario 2.

6.5 RECOMMENDED SCENARIO

6.5.1 The above evaluation of alternative scenarios shows that the public/mass transport system has to be extensive with high capacity mass transport systems on major corridors in order to achieve a modal split of more than 70% in favour of public/mass transport. Scenario 3 will not only enable the commuters to travel from one part to another of the city with good level of service, convenience and comfort but also help in the shift to public transport. This is also desirable as available ROW s of roads in Bangalore are not adequate. Provision of a city-wide extensive public/mass transport is the only way to solve mobility problem of Bangalore. Thus Scenario 3 public/mass transport network should be aimed at in order to cater to travel demand of 2025 and beyond.

6.5.2 The balance demand can generally be met by augmentation of road system in the form of new roads, road widening, provision of grade separators, pedestrian facilities, traffic management measures etc. The proposals for these are detailed in Chapter 7.

6.6 SYSTEM SELECTION

6.6.1 Criteria for Choice of Mode

Choice of mode will depend mainly on demand level on a corridor, available road right-of-way (ROW) and the capacity of the mode. Other considerations are the land-use along the corridor, the location of building lines, and the potential for

Figure 6.5 Desireline Diagram for Private Vehicles for 2025 (Scenario 3)

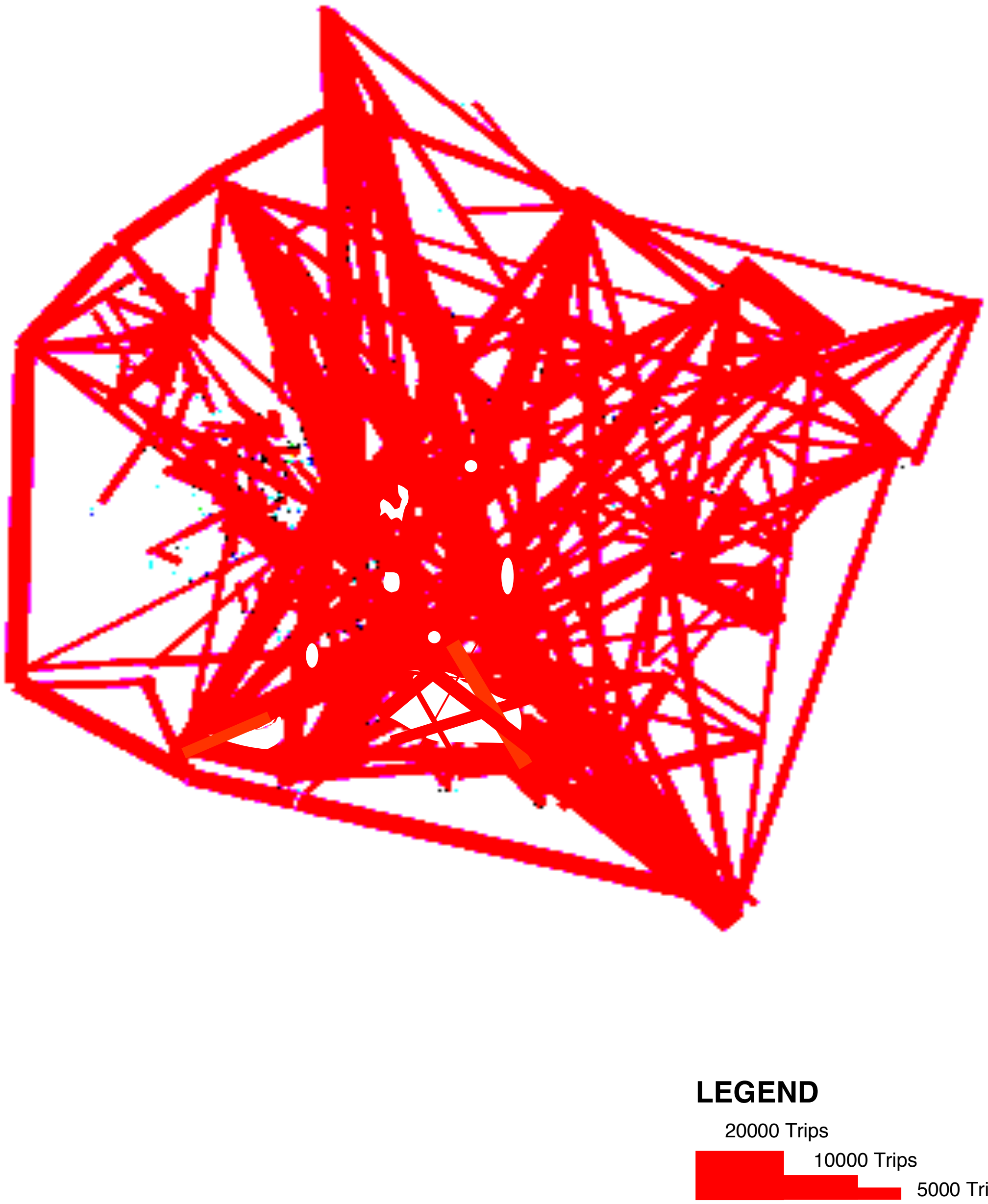
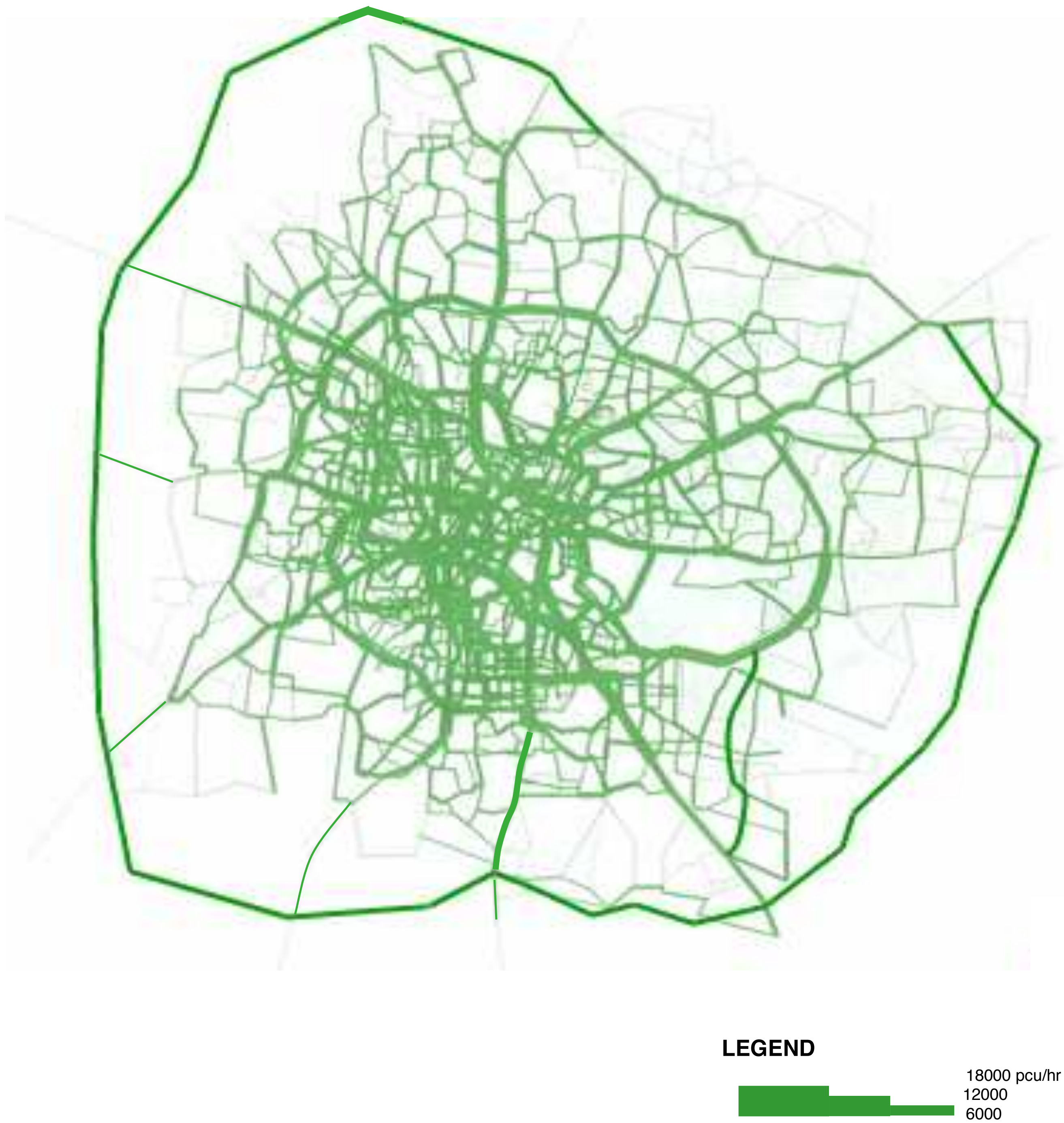


Figure 6.6 Peak Hour Peak Direction Trips (PHPDT) on Mass Transport Network (Scenario 3)

Figure 6.7 Peak Hour Traffic Assignment on Road Network for 2025 (Scenario 3)



increasing the ROW. Cost of the same mode of transport can vary at different locations depending on engineering constraints. It is therefore important that the final choice of mode is based on techno-economic considerations.

6.6.2 In choosing a mode for a corridor, first priority should be given to at-grade services and BRT. It offers convenience to commuters particularly the short distance users. Commuters do not have to walk up and down to use the services. The construction cost is low. It offers the best financial sustainability. If road ROW is inadequate and it cannot be widened, and/or the route is congested, an elevated mode needs to be proposed.

6.6.3 Capacity of Various Modes

The comparative capacity of the main transport modes used in developing cities is reported in a TRRL-UK study (1995) and World Bank study (2000). As per these studies, it appears that the capacity of various modes may be taken as follows;

BRT (HCBS) at-grade	10000 to 20000 phpdt
LRT at-grade	2000 to 20000 phpdt
Metro/ Suburban Rail	30000 to 80000 phpdt

There is no mention of the Monorail in this study, but based on information available, it appears that the mode has been used up to a demand level of 10000 phpdt and designed and used in one case up to 20000 phpdt. Thus, it appears that BRT, Monorail and LRT, can be used when the demand on a corridor is not expected to exceed 20000 phpdt. Beyond the demand level of about 20000 phpdt, a metro appears to be the only choice.

The World Bank report further states that the bus way output depend greatly on road network configuration, junction spacing and stop spacing. It typically has been demonstrated to be high at about 10,000 phpdt at 20 km/h on arterial corridors and 15-17 km/h on urban corridors for a one-lane each way bus-way. If provision for bus overtaking at stops is provided, passenger throughputs of 20,000 phpdt have been demonstrated.

6.6.4 Proposed Capacity of Various Modes for Bangalore

Based on studies by World Bank and others, the following capacity norms for various modes are proposed to be adopted for Bangalore.

Table 6.4 Proposed Capacity of Various Modes for Bangalore

Modes	Capacity (phpdt)
Metro rail	> 30000
Elevated LRT	upto 30000
Elevated Monorail	upto 20000
At grade LRT	upto 15000
At grade HCBS	upto 20000 (with overtaking facility)

6.6.5 Right of Way Requirement

All medium capacity modes normally lie within the road right of way and hence require a share in the road space. At-grade modes however require more space than elevated modes. For at-grade BRT, the desirable right of way requirement is 35 m to meet the requirements of the IRC code, but with an absolute minimum of 28 m. The latter allows for two- lane sub-standard carriageways each way and a combined cycle track and footpath. Additional 7 m space is required at stations/stops. This includes the requirement for overtaking facility as well. It may be possible to reduce the requirement further when the demand level is low such as at the periphery of the city. The above does not include service roads. It is highly unlikely that the desired ROW will be available for full length of the corridor. Elevating the corridor at tight locations could be one option.

If minimum ROW of 28m (desirably 35m) is not available, elevated modes become necessary. For elevated Monorail or LRT, desirable ROW is 30 m to meet the requirements of the IRC code, and an absolute minimum of 20 m because at ground level space is required only for a column and its protective measures. At stations, additional space will be required on the roadside.

Typical cross-sections of road with BRT, elevated LRT and Monorail are shown in **Figures 6.8 and 6.9** respectively.

6.7 SUGGESTED MASS TRANSPORT SYSTEMS FOR BANGALORE

On the basis of expected traffic demand in 2025 on the proposed mass transport corridors of Scenario 3 as explained above, available Right of Way on the corridors, capacity of various mass transport modes and already available mass transport system along a corridor, the mass transport systems on various corridors have been suggested. These are given in **Table 6.5**.

Table 6.5 - Public Transport System Selection

S. No.	CORRIDOR	Expected Maximum Traffic (PHPDT)	Available ROW (m)	System Recommended
1	Mysore Road to Baiyyappanahalli	75,000		Metro
2	Peenya to R V Road	75,000		Metro
3	Baiyyappanahalli to Benniganahalli	25,000	25	Metro
4	R.V. Terminal to PRR	25,000	25	Metro
5	Yelahanka Road to junction of Hi-tech corridor and Hosur Road via Nagavara, Electronic City	45,000	30	Metro
6	Indiranagar to Whitefield Road	35,000	25	Metro
7	Devenahalli Airport to MG Road via	20,000	24	Metro

S. No.	CORRIDOR	Expected Maximum Traffic (PHPDT)	Available ROW (m)	System Recommended
	Bellary Road (New Airport)		(within city)	
8	Hebbal to Bannerghatta Road along Western portion of ORR	20,000	20	Monorail / LRT
9	PRR to Toll Gate along Magadi Road	12,000	22	Monorail / LRT
10	Kattriguppe Road / Ring Road Junction to National College	14,000	18	Monorail / LRT
11	Hosur Road to PRR along Bannerghatta Road	18,000	22	Monorail / LRT
12	Hebbal to Bannerghatta Road along Eastern portion of ORR	15000	40	BRT
13	Benniganahalli (ORR) to PRR along Old Madras Road	10,000	30	BRT
14	From ORR to Hosur Road along Hi-tech Corridor	12,000	60	BRT
15	Hosur Road to Tumkur Road along PRR (western part)	8,000	100	BRT
16	Tumkur Road to Hosur Road along eastern side of PRR	6,000	100	BRT
17	Along Core Ring Road	12,000	25	BRT
18	Vidyaranayapura to Nagavarapalya	12,000	25	BRT
19	Kengeri Satellite Town to J.P. Nagar along Uttarahalli Road, Kodipura	12,000	30	BRT
20	Banashanakari III stage to Banshankari VI Stage Extension along Ittamadu Road, Turahalli, Thalaghattapura	9,000	35	BRT
21	Domlur Extension to Koramangala along inner Ring Road	10,000	25	BRT
22	PRR to Maruti Nagar (upto Hi-tech Corridor) along Sarjapur Road	15,000	25	BRT
23	Peenya to PRR along Tumkur Road	12,000	30	BRT
24	Old Madras Road near Indranagar to ORR near Banaswadi along Baiyyappanahalli Road – Banaswadi Road	10,000	22	BRT
25	Commuter Rail Corridors (10 corridors)	10,000	-	Commuter Rail System

Figures 6.8 Typical Cross-Sections of Road with BRT System - Mid Section (Minimum ROW - 28 m)

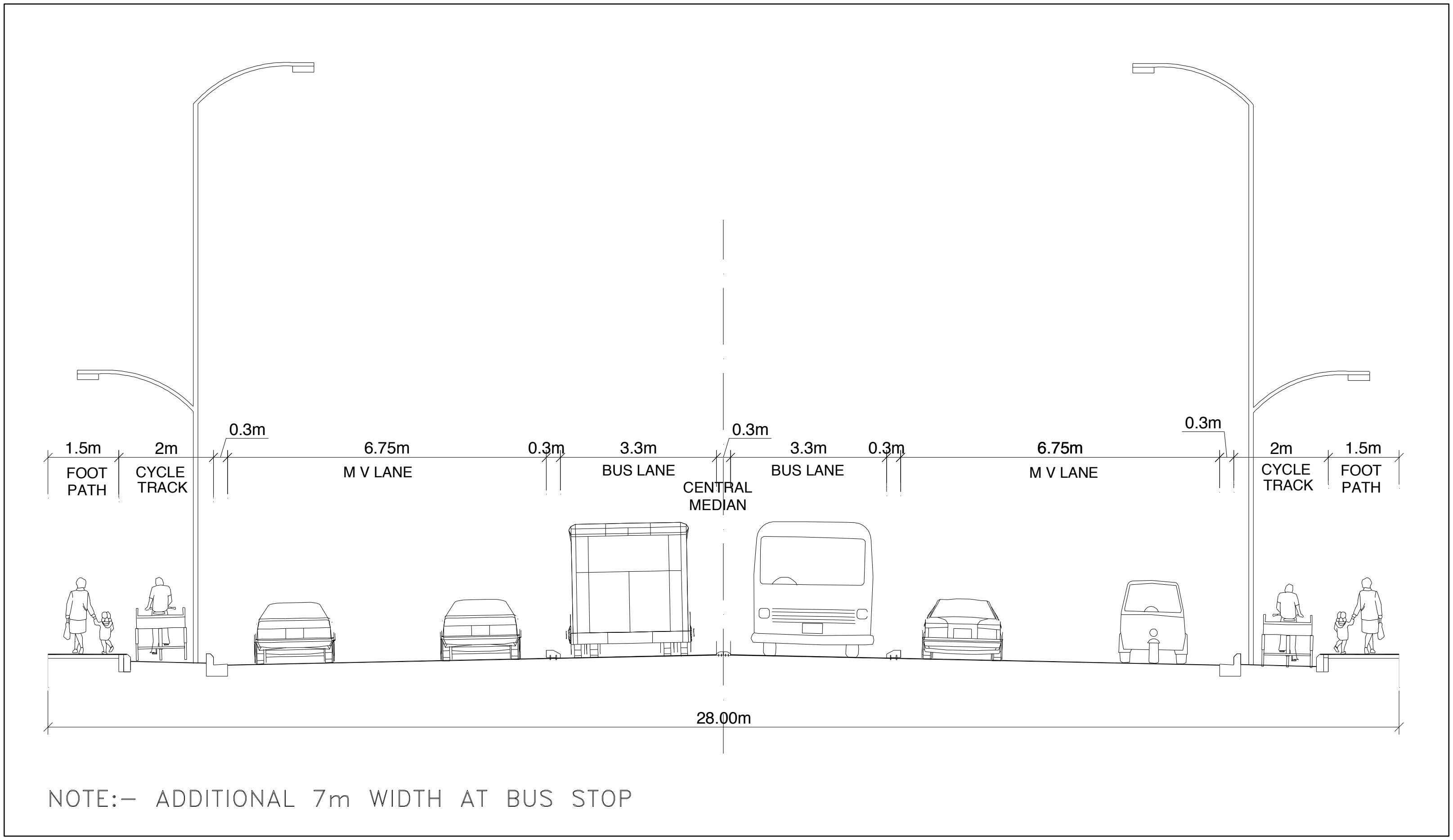
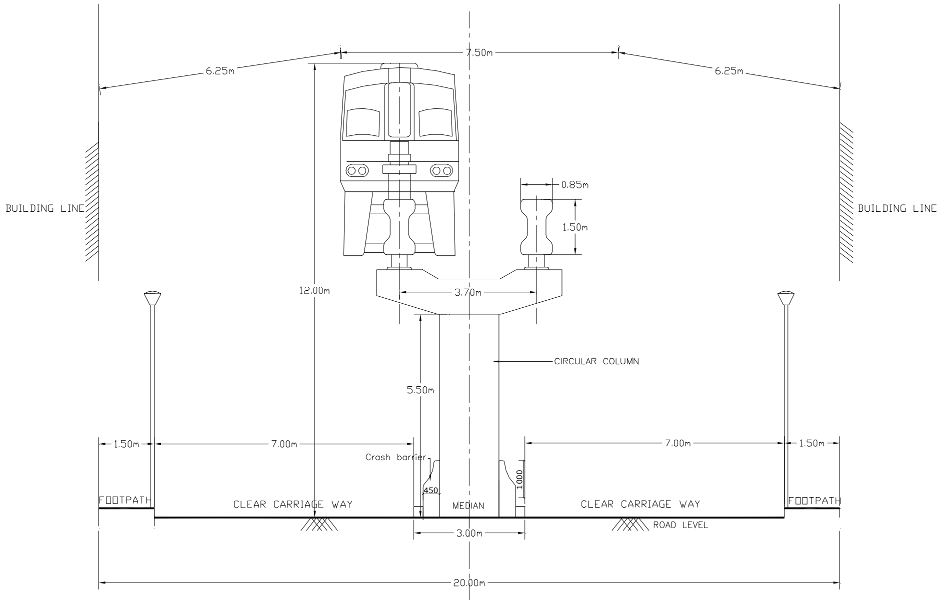
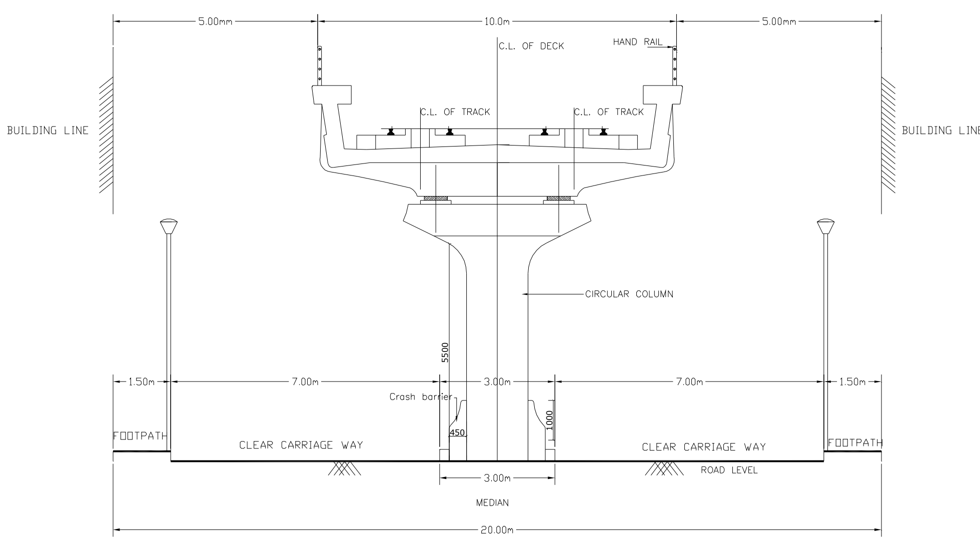


Figure 6.9 Typical Cross-Sections of Road with Elevated LRT and Monorail



NOTE:- ADDITIONAL 8m WIDTH AT STATION

TYPICAL CROSS SECTION OF ROAD WITH MONORAIL - MID SECTION (MINIMUM ROW - 20m)



NOTE:- ADDITIONAL 8m WIDTH AT STATION

TYPICAL CROSS SECTION OF ROAD WITH LRT - MID SECTION (MINIMUM ROW - 20m)

CHAPTER – 7

THE TRAFFIC AND TRANSPORTATION PLAN

7.1 COMPONENTS OF THE TRAFFIC AND TRANSPORTATION PLAN

7.1.1 The previous chapter has dealt with the future travel demand analysis on various corridors. On the basis of projected traffic, an integrated multi-modal mass transport system plan indicating different mass transport systems on various corridors has been suggested in order to cater to traffic up to the year 2025. The balance traffic should be carried by road system in order to satisfy the needs of normal bus system and other modes such as two wheelers, cars, bicycles, trucks, pedestrians etc. The proposed Traffic and Transportation plan for Bangalore contains the following types of proposals, which will cater to requirements of the projected travel demand up to the year 2025.

- Mass Transport System
  - Metro System
  - Monorail/LRT System
  - Bus Rapid Transport (BRT) System
  - Commuter Rail Services
- City Bus System
  - Augmentation of Bus Fleet
  - Grid Routes
  - Bus Terminal cum Traffic & Transit Management Centres (TTMC)
  - Volvo Depot cum Traffic & Transit centre
  - New Bus Stations/bus shelters
  - Additional Depots
  - IT Infrastructure
  - HRD Infrastructure
  - Environmental Protect Projects
- Inter-city Bus Termini
- Transport Integration
- Transport System Management Measures
- Pedestrian/NMT Facilities
  - Footpaths
  - Skywalks/Subways
  - Pedestrian zones
  - Cycle Tracks
- Road Development Plan
  - New Roads/Missing Links
  - Road Widenings
  - Grade Separators
  - Re-alignment of ORR

- Parking Facilities
- Integrated Freight Complexes

7.1.2 While framing proposals priority has been given to public transport and non-motorized transport such as pedestrian facilities. For the balance travel demand, road improvement proposals have been formulated. The details of these proposals are given in the following paragraphs.

7.2 MASS TRANSPORT SYSTEM

Public/Mass Transport System will be the backbone of the city's transport system. The basic premise of the Transport Plan in terms of the National Urban Transport Policy is to create an efficient, cost effective and extensive network of public transport which could provide comfortable, convenient and affordable means of transport to the maximum number of commuters. In this direction a number of schemes are already under implementation and quite a few on the drawing board. Infact keeping in view the observations of the scenarios in Chapter-6 there exist a large requirement for additional facilities in respect of public/mass transport system for the large area proposed to be developed in the forthcoming two decades as per the Master Plan - 2015 proposals.

7.3 THE METRO NETWORK SYSTEM

7.3.1 Metro Corridors under Implementation:

Work on implementation of 36.8 km of metro, partly underground and partly elevated, has already been initiated by Bangalore Metro Rail Corporation (BMRC) along East-West & North-South corridors crossing at Majestic. These corridors will basically cover the most congested core areas of Banglore like Peenya, Gandhinagar, M.G. Road, Vijayanagar, Indiranagar, Majestic area, K.R.Market, Jayanagar, and Basavanagudi etc. **Tables 7.1** give these Phase I Metro corridors.

Table 7.1 Phase-1 Metro Corridors

S.No.	Corridor	Length km
1	Baiyyappanahalli to Mysore Road (East-West Corridor)	18.0
2	Peenya to R.V terminal (North-South Corridor)	18.8
	Total length	**36.8**

7.3.2 Extension of Metro Corridors:

The above corridors may be able to give relief to the immediate traffic problems within the core areas and its immediate neighborhood but by the time the Master Plan proposals get implemented and development of areas beyond the outer ring road takes place in right earnest, the above system will fall short and a more extensive system will become necessary as brought out in Chapter 6. This is especially true because the Master Plan 2015 and its detailed Zonal plans propose the development of around 814.4 Sq. Kms. of area for various urban uses. This brings very large spread of area on which various urban activities will take place.

They would now be located right upto the Peripheral Ring Road in practically all directions and at a few places even beyond it. These activities include some with huge employment potential areas like the Electronic City in the east and southern portions of the BMA. It is therefore necessary that the Metro gets ultimately extended to the most of the high density centers. Therefore the following additional corridors considering the projected travel demand are proposed to be taken up as extension of the Metro in Phase 2.

7.3.2.1 **Extension of North –South corridor from R.V. Terminal upto Peripheral Ring Road**:
The area to the south of Jayanagar consisting of J.P.Nagar Banashankari, Kumaraswamy layout are fully developed and quite densely populated. Substantial commutation takes place between these areas and core areas of Bangalore. BMICAPA has plans to develop residential and commercial activities along the Bangalore Mysore Expressway corridor, the North –south commuter traffic is expected to increase substantially. It is therefore being proposed that the already approved North-South corridor between Peenya to R V Road Terminal may be extended upto the PRR along the Kanakapura Road. This extension of approximately 10 km should be taken up in the first phase itself.

7.3.2.2 **Baiyyappanahalli to Benniganahalli along Old Madras Road**
The first phase of the East West line has been proposed from Baiyyappanahalli to Mysore Road. How ever as would be seen from the plan and the subsequent proposals, Outer Ring Road (ORR) is one of the most important spines of Banglore on which large city traffic converges and keeping this in view mass transport in the form of BRT/ Mono-Rail/ LRT is proposed on it in addition to its improvement and smoothening. Benniganahalli located just on the ORR is also the Rail station for the proposed Commuter Rail Systems on the intersection of Bangalore City Station – Whitefield & Banaswadi – BMA Boundary rail corridors. Thus, since it is a very important transport node where a number of transport modes i.e. BRT, CRS etc., meet it, can act as an excellent inter-modal interchange. Therefore it is proposed the east west corridor is extended from Baiyyappanahalli to Benniganahalli through a distance of 1.5 km in the first phase itself.

7.3.2.3 **Yelahanka to Hi-tech corridor via Nagavara, Electronic City**
The singular North-South corridor planned so far will mostly be able to cater to the western part of the city between Peenya and Kanakapura Road. However the development coming up on the eastern side between Hosur Road and white field – the I.T. and the Electronic cities and in the Northern side near Thanisandra and Yelahanka need another north-south corridor. In order to meet the traffic demand of this area another 34 km long corridor from Yelahanka to PRR via Nagavara, Electronic City has been planned. This corridor will cover Nagavara, Veerannapalya, Frazer Town, the residential, commercial and industrial (IT Sector) areas along Hosur Road. This corridor will also have interchange with the airport expressway and airport metro to provide direct access from south and south east Bangalore to the airport. This will also at interchange with the East West metro corridor.

7.3.2.4 **Indira Nagar Metro Stn. to White field Railway Stn. via 100ft Indiranagar Road**

The up coming industrial areas, I.T hubs and commercial developments near the White Field area, C.V. Raman Nagar and the commercial development along most of the roads in the Indira Nagar area have totally chocked the Airport Road and the White Field Road and by the time the I.T. hub is fully functional the traffic demand will require a Metro connection of the White Field area with the heart of the City. Accordingly a 19.5 Km. Metro link between Indira Nagar Metro station and White field is proposed. This link when completed would have an inter face with the Mysore Road - Benniganahalli east west corridor at Indira Nagar.

7.3.2.5 **Proposed Devanahalli Airport to M.G.Road via Bellary Road**

A new International airport is coming up at Devanhalli about 33 Kms North of Banglore and is slated to be completed shotly. In order provide an unhindered direct approach to the Airport a Metro link between M.G. road and the new airport approximately 33 km long has proposed. In order to make the corridor truly functional, the following Terminal / checkin & pick stations have been suggested:

i. City Airport Terminal: In police grounds on M.G.Road the CAT is planned and the metro ramp structure from Mink underground section to M.G. Road elevated section will pass through the CAT structure, integrating both systems.

ii. Hebbal Check-in Station: The second check-in station has been planned at the end of the Hebbal fly-over towards left, with elevated cross-passage with escalator facility to cross-over from the bus-terminal being planned on the right side. The ease of access from the ORR will be able to attract large clientele to this Station.

iii. Yelahanka Pickup Station: It is located at the junction of the N.H. and the Yelahanka Town Road. At this station luggage checkin is not being provided but passengers with hand baggage only will be able to board and alight the train.

The above proposals of metro extensions have been consolidated and listed in the following table. These proposals would add up to about 100 Kms. of Metro to taken up in later phases.

Table 7.2 Extension of Metro Corridors

S.no.	**Corridor**	**Length km**
1	Extension of North –South corridor from R.V. Terminal upto PRR	10.2
2	Baiyyappanahalli to Benniganahalli along Old Madras Road.	1.5
3	Yelahanka R.S to PRR via Nagavara , Electronic City	36.0
4	Indira Nagar Metro Station to White field Railway Station via 100ft Indira Nagar Road	19.5
5	Proposed Devanhalli Airport to M.G.Road via Bellary Road	33.0
	Total length	**100.2**

Thus ultimately it is suggested that approx. 137 km of network of Metro will be required to effectively serve the major traffic corridors and high density use areas to meet the travel demand up to 2025. This could be taken up in two phases. Corridors No 1 and 2 of the above **Table 7.2** may be taken up along with the corridors indicated in **Table 7.1** under implementation in Phase I, while the corridors Sr. No 3 &4 above may be taken up in the subsequent phase. In view of the pace at which the new Airport is constructed, it will be desirable to take up the Airport connection at S.No. 5 above in the first phase itself in order to make the same accessible as and when commissioned. These proposals are indicated in **Figure 7.1.**

7.4 MONO RAIL / LIGHT RAPID TRANSIT SYSTEM (LRT)

In addition to the metro, the corridors where the traffic volumes are upto 20,000 phpdt and the requirement is to cover a wide area with a large network and also to act as feeder to Metro, a medium capacity system is required. Infact upto about 15000 phpdt, a BRTS can also work reasonably well. However the limitation with it is that in order to make it really effective dedicated 10 meter wide BUS Lanes (Bus ways) are necessary at grade. However on roads where the right of way does not permit carving out the at-grade Busway, an elevated mono rail / light rail is the preferred option, since it does not impinge upon the capacity of the at grade carriageways which continue handling the vehicular traffic as explained in Chapter 6. The Master Plan 2015, while pointing out the inadequacies of the present Public Transit system and emphasizing the need for a Multi-Modal Public Transport system, has referred to mono-rail as one of the modes. It has proposed a Mono-Rail along the western crescent of the ORR from Bellary Road to Kanakapura Road along with a couple of spurs along selected radials leading to the core area. In addition an independent corridor has been proposed from Hosur Road - Bannerghatta Road Junction to National park. Considering all the factors, while basically keeping the same configuration, the proposed radial corridors along Magadi Road and Bannerghatta Road need to be extended upto the PRR and along ORR, extended up to Bannerghatta Road. Accordingly the following corridors with a total length of 60 Km. have been identified for Mono-Rail / LRT system.

Table 7.3 Mono-Rail/LRT Corridors

S.no.	Corridor	Length Km
1	Hebbal to J.P. Nagar (Bannerghatta Road) along the western portion of outer ring road	31.0
2	PRR to Toll Gate along Magadi Road	9.0
3	Kathriguppe Road / Ring Road Junction to National College	5.0
4	Hosur Road - Bannerghatta Road Junction to PRR along Bannerghatta Road	15.0
	Total	**60.0**

The option of system selection i.e. Light rail or Monorail will depend on the detailed feasibility for these corridors as and when taken up.

Figure 7.1

7.5 COMMUTER RAIL SYSTEM (CRS)

Within the BMA, approximately 120 km of rail system of the Indian Railways exists basically for long distance passengers and goods/ freight. This system currently is not being utilized for intra-urban movement with in the BMA. However RITES in its study has identified some of the Railway corridors along which it is possible to run commuter service with some additions and improvements. A similar proposal of utilizing approximately 62 km track and incurring an expenditure of Rs. 650 Crore on making the commuter service possible in two phases (2007 to 2012 & 2013 to 2018 each estimated to cost Rs. 325 Cr.) has been recommended in M.P.2015. The plan has also indicated a land requirement of 62 Ha. for this project. However it is found that the network proposed above will not be sufficient to meet requirements of the Development Area proposed in Master Plan 2015 upto the year 2025. Accordingly it has been considered necessary to extend the CRS network to approximately 119 Kms, using the existing at-grade railway system to serve intra-city needs, which is proposed along the corridors 1 to 7 in **Table 7.4**.

In addition, with the coming up of the BMRDA's planned new Town Ships at Bidadi, Ramanagaram, Solur, Sathanur & Nandagudi, high level of commutation between them and the Metropolis. Also, with the development of the huge Multiple Economic Activity Areas like Electronic City, I.T. Parks, Industrial & Commercial Areas with consequent job opportunities on the one hand and availability of comparatively cheaper accommodation in surrounding towns like Hosur, Ramanagaram and Tumkur etc. where a large number of working population is likely to live, substantial of commuter movement between these towns and the Metropolis will take place. In order to cater to this suburban commuter traffic, the CRS is proposed to be extended as corridors 8 to 10 in **Table 7.4** below.

Table 7.4 Commuter Rail Corridors

S No.	Corridor	Length Kms
1.	Kengeri - Banglore City Station	13.0
2.	Bangalore City Station - Whitefield	24.0
3.	Bangalore City Station - Baiyyappanahalli Via Lottegollahalli	23.0
4.	Lottegollahalli to Yelahanka	7.0
5.	Banaswadi upto BMA Boundary	29.0
6.	Kengeri- BMA Boundary	9.0
7.	Yeshwantpur to BMA Boundary	14.0
8.	BMA Boundary - Hosur	12.0
9.	BMA Boundary- Ramanagaram	23.0
10.	BMA Boundary to Tumkur	50.0
	Total	**204.0**

Corridors 1, 2, 6 and 9 are proposed to be taken up in the I Phase, while Sl No 3, 4, 5, 7 and 8 will be taken up in the II Phase. The Corridor at Sl No 10 upto Tumkur may be taken in III Phase.

7.6 BRT SYSTEM

BRT is one of the most cost effective public transport modes where the following two conditions can be met:

- Sufficient Right of way (30m or more) is available along the corridor to provide for exclusive carriage ways for BRT
- The peak hour commuter load is up to 20,000 phpdt.

The BRT has also the advantage of large coverage and ease of accessibility as well as simpler operational systems. Accordingly taking into consideration the Master Plan 2015 development proposals and the likely travel demand as explained in Chapter 6, BRT system along the following corridors is proposed:

Table 7.5 Bus Rapid Transit (BRT) Corridors

S.No.	Corridor	Length km
1	Hebbal to Bannerghatta Road along eastern crescent of outer ring road	33.0
2	Benniganahalli (ORR) to PRR along old Madras Road	7.0
3	From ORR to Hosur Rd along Hi-tech Corridor	8.0
4	Hosur Road to Tumkur Road along PRR (western part)	41.0
5	Tumkur Road-PRR Junction to Hosur Road along PRR via Tirumanahalli, Old Madras Road, Whitefield	76.0
6	Along Core Ring Road	30.0
7	Vidyaranyapura to Nagavarapalya via Hebbal, Jayamahal Road, Queens Road, M.G. Road, Ulsoor, Indranagar, CV Raman Nagar	29.0
8	Kengeri Sattelite Town to J.P. Nagar along Uttarahalli Road, Kodipur	13.0
9	Banashankari III stage to Banashankari VI stage Ext. along Ittumadu Road, Turahalli, Thalaghattapura	6.0
10	Domlur Ext. to Koramangala along inner ring road	5.0
11	PRR (Mulur) to Maruti Nagar (up to Hitech corridor) along Sarjapur Road	7.0
12	Peenya to PRR along Tumkur Road	6.0
13	Old Madras Road near Indiranagar to ORR near Banaswadi along Baiyyappanahalli Road -Banaswadi Road	5.5
14	Hebbal to Devanahalli Airport along Bellary Road	25
	Total	**291.5**

Thus it is proposed to have at least 569 km of mass transport system consisting of Metro, Mono Rail / LRT, BRT and CRS within the BMA supported by another 85 Kms of CRS out side BMA connecting the Metropolis to some of the BMRDA's new Townships and the Regional Towns of Tumkur and Hosur. All these proposals are shown in **Figure 7.1.** In addition to this network, the city bus system will cover a much larger area and will compliment the above systems.

7.7 AUGMENTATION AND IMPROVEMENT IN CITY BUS SYSTEM

While the high capacity BRT will be operational on selected routes where substantial right of way is available, the major areas specially the inner areas and the areas approached by the internal roads will in any case continue to be served by local bus system which will act as the most important feeder system to the Metro, Mono Rail/LRT and the CRS. For this purpose the BMTC has identified East-West, North-South & diagonal grid routes along 27 corridors as already indicated in **Figure 1.4.** In addition to improving the fleet capacity, rationalization of routes, improvement in traffic management at the junctions including priority signaling, provision of proper road side bus stops and integration points with the Metro, Mono Rail and CRS will provide effective use of the bus system. BMTC shall continue to play a vital and leading role in public transport in any scenario of the City's development. In order to meet the future challenge, BMTC has planned a number of initiatives as included in the following proposals:

Table 7.6 Proposed Improvements in the City Bus System

S. N.	Proposals	Description
1.	**Augmentation of Schedule and Fleet**	At present the BMTC is operating approximately 4500 buses at more than 1700 routes carrying approximately 35 Lakh passengers. By the year 2025, despite the fact that we are going to add Metro, Mono-rail /LRT, BRT and start CRS, still the feeder services as bus services on the other less dense corridors, will definitely be run through the city bus system only. It is expected that by 2025 at least 60 Lakh trips will be performed by buses only. For this volume of traffic at least 10000 buses will be required. However, this number may have to be increased substantially incase any of the MRT components lag behind in implementation. It is further pointed out that mere increase in fleet is not enough, its quality will also have to be of much higher standard if we want to achieve the NUTP policy of changing the passenger preference from personalized vehicles to Public Transport. Accordingly it is suggested that all the new buses to be added to fleet, either as addition or replacement should be low floor good quality buses fully considering the commuter comfort. The BMTC plans to add 2500 new vehicles and replace 1415 aged old vehicles, taking the Scheduled strength to 7000 by 2010. The financial implication towards these new vehicles is estimated as Rs 1000 Crore. In the later phases the balance 3000 buses are proposed to be added to meet the ultimate requirement of 10000 buses.

2.	**Grid Routes and Dedicated Bus Lanes**	The BMTC has at present identified 27 grid routes in the North South, East and West and diagonal direction, which will meet the requirement till about 2010. Most of these grid routes are confined upto the ORR, and only a few at present transcend beyond it. However, by 2025 when the complete Development Area of more than 814 Sq. Kms proposed in BDA Master Plan gets fully occupied, these grid routes will both have to be extended upto the PRR and new routes added to serve this area. These routes will complement the Metro and BRT already proposed between the ORR and PRR.
3	**Bus Terminal cum Traffic & Transit Management Centres (TTMC)**	TTMC's are planned to have multi-level parking lot, public utilities like mini-shopping centres and food courts. These centers in addition to providing park & ride facilities are also proposed to act as hubs for Mini - Buses planned by BMTC to transport the commuters from every major residential area to the nearest TTMC, so that commuters can board a bus of their choice. BMTC has planned such TTMC's at the following 45 locations. Of these TTMCs at Bannerghatta, Kengeri, Domlur, Yeshwantpur, Koramangala, Vijayanagar, ITPL, Banashankari and Shantinagar are planned to be taken up very shortly. In fact quite of few these center will act as Intermodal transfer nodes and will provide logistic support to MRT modes like - METRO, Mono-rail/LRT, BRT & CRS etc. through Park & Ride as well as other facilities. In fact as the MRT network grows some additional TTMC's may be required and in some case a slight relocation of some of the following TTMC's may be required.

TRAFFIC & TRANSIT MANAGEMENT CENTERS (TTMC)

1. Yeshawantapur	16. Kalyan Nagar	31.Avalahalli
2. Jayanagar Bus Stn.	17. Nagarabhavi	32.Channasandra
3. Domlur	18. Sriganda Kaval	33.Kodarhi
4. Kengeri	19. Poorna Prajna	34.Dodda Tugur
5. Bannerghatta	20. Jayanagar Depot-4	35.Gollahalli
6. Shanthinagar	21. Peenya	36.Kaggalipura
7. Koramangala	22. Yelahanka	37.Challaghatta
8. ITPL, Whitefield	23. Rajarajeshwari Nagar	38.Sulikere
9. Vijayanagara	24. Hosakote	39.Machohalli
10. Banashankari	25. Bidadi	40.Madapura
11. Indiranagar	26. Vaddarahalli	41.Harohalli
12. Kathriguppe	27. Anjanapura	42.Soladevanahalli
13. Hebbal.	28. International Air Port	43.Kambipura
14. Hennur	29. Venkatala	44.Baiyyappanahalli
15. HSR layout	30. Bairathi	KR Pura

4	**Multi-Modal Transit Center**	The MMTC at Subhash Nagar has been planned at a cost of Rs. 350 Crore
5	**Volvo Depot cum Traffic & Transit centre**	Banashankari
6	**New Bus Stations/Bus Shelters**	In addition to the 4 major Bus stations located at Subhashnagar, Shivajinagar, City Market and Shanthinagar & 27 sub-nodal bus-stations commissioned at various locations, BMTC has planned another 23 bus stations and about 300 bus shelters at a cost of Rs. 279 Crore
7	**Modern Bus Depots**	Nagarabhavi Sreegandhadakaval Vaddarahalli Kothnurdinne Poornaprajna Layout
8	**New Depots**	In addition to the existing 24 bus depots, BMTC intends adding another 27 depots at a cost of Rs. 161 Crore to make the total number to 51 by 2010. However in order to cater to the 2025 proposed fleet size of 8000 buses, we may need another 20 depots for the additional fleet.
9	**Improvement of IT Infrastructure**	BMTC is the first public transport undertaking in the country to use the sophisticated GPS technology for monitoring and tracking of vehicles. This is expected to cost Rs. 33 Crore. In order to provide commuter friendly information, the corporation proposes to transfer GPS generated positional details of the buses to commuters in the form of passenger information system (PIS) through display at bus stops/ bus stations also through interactive voice response system (IVRS). This is expected to cost Rs. 84 Crore. In addition introduction of Electronic Destination Boards on buses, introduction of Electronic Ticketing System, Expansion of Computerisation activity and establishment of surveillance system at a cost of Rs. 66 Crore has been proposed.
10	**Development of HRD Infrastructure**	Training of employees of a large staff organization such as bus system is very important. Therefore 2 hitech multi disciplinary centers (Rs. 50 crore), establishment of employee training modules (Rs. 20 crore) and establishment of employee development centers (Rs. 80 crore) have been proposed.
11	**Environment Protection Projects**	Various environment protection measures at bus depots are being proposed such as Rain water harvesting, Installation of solar lighting system and other environmental initiatives costing around Rs. 49 crore.

7.8 INTEGRATED MULTI MODAL TRANSIT CENTRES -CUM- INTERCITY BUS TERMINALS

At present all the buses whether inter-city, Inter-state or Intra-city originate and terminate at the Central station in Majestic area. These not only creates congestion and heavy traffic density on all radial routes coming into the core of Bangalore but also result in substantial delay to the passengers who have to take the buses from far flung area. Though another intercity bus terminal cum integrated multi modal transit center is being contemplated at Peenya, It will not be sufficient to meet the requirements of traffic from the other direction- especially North, East & South. It is, therefore proposed that there should be at least 3 more Intercity terminals. Accordingly it is suggested that ultimately 4 intercity terminals be located at the following places:

1. Peenya
2. Hosur Road
3. Old Madras Road near ORR
4. Bellary Road near Hebbal

The above terminals are proposed to be located at the Metro and the BRT terminals and will act as Inter Modal Interchanges between regional and local traffic.
Also these would be the center for Chartered and tourist buses, with adequate parking facilities and tourist bureaus / offices etc as well as other tourist infrastructure for operation of private tour operators who are at presently located mostly around the majestic Area.

These proposals have been indicated in **Figure 7.2.**

7.9 ROAD INFRASTRUCTURE

The present road network consists of the Ring Roads and major radial corridors. A number of proposals have already been very broadly included in the Master Plan 2015. In addition quite a few proposals are being implemented by Govt. agencies like NHAI, State PWD, BMC, BDA, BMRDA and BMICAPA along with the private sector through PPP model. It is necessary to integrate / superimpose all these proposals in the light of projected travel demand for road traffic and confirm that they are in conformity with each other and there is neither conflict nor duplication. As the radial road corridors are expected to have high traffic volume, these corridors have been proposed to be strengthened instead of isolated improvements. The road improvement proposals include road widening, new roads (bypasses and other roads), ORR realignment, grade separators (road flyovers, ROBs, RUBs), Integrated Freight Complexes etc. These proposals are explained below.

Figure 7.2

7.9.1 Functional Hierarchy

In the existing road network, except for defining National Highways no other road has been specifically defined according to its functions. The Master Plan 2015 has broadly defined them as under:

- Ring Roads – Core Ring Road (CRR), Outer Ring Road (ORR), Peripheral Ring Road (PRR), Intermediate Ring Road (IRR), Satellite Township Ring Road (STRR)
- Expressways- Airport Link Road
- Highways – National Highways, State Highways
- Arterial Roads
- Sub-arterial roads
- Other link roads

It is however suggested that for new roads, we may clearly define them as shown in the **Table 7.7** below and provide them with adequate protective green belt beyond their right of way in order control direct access and avoid ribbon development:

Table 7.7 Functional Hierarchy of Roads

Road Nomenclature	Functional Characteristics	Minimum Suggested Right of Way (ROW)	Restricted green belt beyond the ROW
R-1	Access controlled Expressway with proper service roads like Peripheral Ring Road, Expressway linking the Town with New airport, Other Regional Roads like the Intermediate Ring Road and the Satellite Towns Ring Road etc.	100 Mts	30 Mts.
R-2	Arterial Roads	80 Mts	15 Mts
R-3	Secondary Roads/ Sub-Arterial Road providing main internal access in functional areas- Industrial, residential, institutional and commercial areas.	45 Mts	
R-4	Access Roads providing access to individual properties. No kerb parking is to be provided	20 Mts.	

The suggested cross-sections for the above categories of roads are shown in **Figure 7.3.** It is suggested that in order to control the development along R-1 & R-2 roads, legislation similar to the 'the Punjab Scheduled Roads and Controlled Areas Restriction of Unregulated Development Act, 1963' may be enacted.

Figure 7.3

7.9.2 Major Road Proposals

7.9.2.1 Ring Roads

The City would be looking at significantly altering the radial, "through the core" traffic pattern by improving / developing key "rings," in the BBMP, BDA, and BMRDA jurisdictions:

- **Core Ring Road (CRR)**: Of about 30 km length, around the core area, this would form the primary "bypass" to the inner core BBMP area. This road may be constructed as an elevated corridor, to minimize land acquisition. The ground level carriageways may be reserved for public transport i.e. BRT, while the private vehicles and Para transit vehicles should use the elevated deck. However this proposal will also entail improvement to the radials meeting it and their junctions with the CRR.

- **Outer Ring Road (ORR)**: Is at a radius of 7 to 10 km from the city center. The outer ring road covers a total length of 62 km and connects all major roads and highways in and around Bangalore. However, by efflux of time, the ORR has almost become a city road, with local traffic and many signaled intersections, and development all around. At present this road has a number of bottlenecks and kinks. Infact near Pantarapalya on Mysore for about 6.5 Kms the ORR follows the Mysore Road radial corridor only. The proposals consist of realigning the ORR at a couple of points and providing 2 fly-overs where the ORR has some common portions with Sarjapur Road and Bannerghatta Road. These proposals are to be carried in small lengths totaling up to about 16.6 Kms and are indicated in the Table 7.8 below. On the eastern crescent of this road, BRT corridor with exclusive segregated lanes and allied facilities for operating high capacity buses has been proposed, while on its western crescent Monorail / LRT has been proposed.

Table 7.8 Outer Ring Road Re-alignment

S. No	Stretch	Length km
1	Elevated road along Bangalore University Road	2.5
2	Realigning ORR between Magadi Road and Pipe Line Road	1.9
3	Realigning ORR at Tumkur Road through CMTI	1.2
4	Realigning ORR from Kasturi Nagar to Mahadevapura along Selam railway line	5
5	Elevating ORR along common portion with Sarjapur Road	2
6	Elevating ORR along common portion with Bannerghatta Road	1
7	PESIT to Janabharti Enterance Banglore University	3
	Total	**16.6**

- **Peripheral Ring Road (PRR)**: The Master Plan 2015 has proposed a Peripheral Ring Road of around 114 km around Bangalore at a radial distance of 2.80 to 11.50 km from the existing outer ring road. On the western side of the city just about 1 to 5 Kms inside the PRR an access-controlled expressway is already being constructed under the auspices of the Bangalore Mysore Infrastructure Corridor Area Planning Authority (BMICAPA) through Private Sector. This Expressway connects NH-7 (Hosur Road) and NH-4 (Tumkur Road) covering approx. 41 Kms. The Eastern Portion of the PRR between NH-4 & NH-7 via Old Madras Road, Airport Road should be taken up immediately to be followed by implementation of the western portion. The entire PRR should have exclusive segregated lanes and allied facilities for operating high capacity buses as BRT system. Along this Ring Road at its Junctions with Hosur Road (NH-7), White Field Road, Old Madras Road (NH-4), Bellary Road, Tumkur Road and Mysore Road, six Integrated Freight Complexes (IFC) have been proposed for handling entire freight traffic. These IFCs are indicated in **Figure 7.4.** Since it is proposed not to allow the HCV's to enter the town inside the PRR, the junctions will have to be grade separated at these points. This road should be treated as R-1 and have the 30 meters restricted belt on either side beyond the ROW.

7.9.2.2 Air Port Link Road (Expressway)

An expressway has been proposed in the Mater Plan 2015 to connect the New International Airport at Devanhalli to the city. At the moment the International airport site is only approachable through the Bellary Road which being a National Highway (NH-7) carries large interstate traffic. In order to provide uninterrupted approach to the upcoming International Airport likely to be operational next year, it will be desirable that this expressway should come up early and be commissioned simultaneous with the opening of the International Airport.

7.9.2.3 Other New Roads / Missing Links

In addition to the above roads, a few small links are required to cater to the important activity areas from the major existing Network and under implementation.

Accordingly the new roads (including elevated CRR, PRR, A.P. Link Expressway and other new links proposed to be taken up are as listed in **Table 7.9** below.

Table 7.9 New Roads / Missing Links

SNo	Corridor	Length km
1	Core Ring Road (CRR) (elevated)	30
2	Arterial Roads crossing CRR	30
3	Peenya Industrial Area To Bangalore Mysore Expressway	2.2
4	Peripheral Ring Road (PRR)	114
5	Air Port Link Road (Expressway) Upto ORR	26

SNo	Corridor	Length km
6	Link from Tigalarapalaya Main Road to Nelagadaranahalli (included in Item 42 of Parallel Ring Road (Table 7.10)	1.23
7	Link from Hesargatta Main Road to Shettihelli and Madarahelli to Mohammed Sabi Palaya (included in Item 43 of parallel ring road (Table 7.10)	4.02 (1.38 + 2.64)
8	Link from Sampigehalli to CRPF parade ground (included in Item 25 of parallel ring road (Table 7.10)	1.72
	Total	**209.17**

7.9.2.4 Road Improvements

The entire traffic from the BMA, the Region and even beyond converges on to the Center of Bangalore and the work areas along the radial corridors and gets dispersed through the ring roads. Most of the radials roads suffer from congestion because of their over utilization of their limited capacity. In addition the limited carriageway, the inefficiency of the junctions and their incapability to handle the volumes of traffic further reduces the capacity of the road systems. Accordingly it has found necessary that quite a few roads listed in the **Table 7.10** below will require improvement through widening 4 - 6 lane carriageway in order to cater to projected road traffic up to the year 2025. In addition at some of the critical junctions where normal signaling cannot effectively manage the traffic volumes, grade separators & flyovers will be necessary. Also at road crossings with railway lines, at some places Road Over bridges & or Road Under Bridges will be necessary. Along a few of the roads where the traffic demand far exceeds the capacity and at grade expansion is not possible due to restriction of available carriageway, elevated roads e.g. along Mysore road and Hosur Road have been provided. Accordingly the roads, both inside the ORR and out side the ORR have been identified for their improvements in terms of widening of carriageway, provision of drainage, surface improvement, footh-path etc. are listed in **Table 7.10** below. The Junctions & Road stretches requiring grade separators, ROB's and RUBs are indicated in **Table 7.11** below.

Table 7.10 Road Improvements

SNo	Name of Road	Length km
Road Improvements (Inside ORR)		
1	Bellary Rd	7.60
2	Palace Road	1.75
3	Sheshadri Road	0.50
4	Nrupatunga Road	1.10
5	Vidhana Veedhi	0.20
6	Mission Road	1.00
7	Devanga Hostel Road	0.50
8	Sankey Road	3.40
9	Lalbagh Road	0.41

SNo	Name of Road	Length km
10	Jaymahal Road	2.80
11	Hosur Road	1.60
12	Hosur Laskar Road	4.30
13	Victoria Road	1.60
14	Lower Agaram Road	2.40
15	Sarjapur Road	3.35
16	Hosur Road	4.30
17	Bannerghatta Road	4.11
18	80' Koramangala	4.00
19	Dickenson Road	0.30
20	Ulsoor Road	0.60
21	Kensington Road	0.32
22	Murphy Road	1.70
23	Old Madras Road	1.70
24	Richmond Road	5.20
25	Airport Road	5.20
26	Goods shed Road	1.35
27	Cottonpet Main Road	1.20
28	17th Main J CNagar in ward13	1.50
29	5th cross Malleshwaram	1.00
30	Commissariat Road	0.74
31	A M Road	0.75
32	Lalbagh Fort Road	1.35
33	Race Course Road	1.66
34	Kasturba Road	0.77
35	A S char street & BVK Iyengar Road	1.21
36	Vanivilas Road	0.85
37	Suranjan Das Road	3.85
38	Mysore Road	3.90
39	Mt joy Road & Kattriguppe main Road via Vidyapeeta circle	3.00
40	Mahalakshmi Layout & Nandini Layout Road via Ayyappa Temple & Singapore Layout	2.70
41	Dinnur Main Road and Kavalbyrasandra Road (via Ganganagar Sulthan Palya)	4.50
42	Hoskerehalli main Road (via Girinagar)	2.05
43	Vasanth Nagar Main Road	0.62
44	K R Road	1.16
45	Sulthan Road	0.42
46	1st main Chamrajpet	0.15
47	3rd cross Chamrajpet & Bull temple Road	1.00
48	Link Road	0.63
49	Padarayanapura Main Road	1.86

SNo	Name of Road	Length km
50	Bull Temple Road via N R Colony, Chennamma Tank bed & 30th main BSK 3rd stage	1.10
51	Infantry Road	1.83
52	Park Road	0.50
53	Hospital Road	1.10
54	Dispensary Road	0.50
55	K Kamraj Road	1.25
56	Dharmaraj Road	0.40
57	Chandini chowk	0.45
58	Meenakshi Koil Street	0.60
59	Thimmaih Road	2.10
60	Old Poor House Road-Haine's Road	1.00
61	Millers Tank Bund Road	0.52
62	Station Road	1.30
63	Queen's Road	0.95
64	Millers Road	1.42
65	Cunningham Road	0.80
66	Road in front of Russel market	0.25
67	Dr. Ambedkar Road (Tannery Road)	4.43
68	Hennur Road	3.62
69	Banaswadi Road & Wheelers Road (via Banaswadi)	6.35
70	Hare Krishna Road	0.70
71	HMT main Road	2.10
72	Magadi Road	2.40
73	Baiyyappanahalli Main Road	3.35
74	Bapujinagar Cross Road	0.80
75	Kumaraswamy Layout Main Road	1.75
76	South Link Road	0.50
77	MTB Road	0.50
78	Kurubarahalli Main Road in ward 16	1.00
	Total	**141.73**
	Road Improvements (Outside ORR)	
Radial Roads		
1	From Peenya II Stage to Andrahalli (via Peenya II Stage, Industrial area, Andrahalli)	4.00
2	Tumkur Road-NH4	8.80
3	New BEL Road	3.40
4	Jalahalli Main Road to Attur via Yelahanka	28.00
5	Yeshwantpur to Yelahanka	20.00
6	Doddaballapur Road.	6.00
7	Devanahalli - Hebbal Bellary Road	25.00
8	NH-7 Kogilu Junction to Nagavara Main Road	8.00
9	Dasarahalli Main Road	16.00

SNo	Name of Road	Length km
10	HBR Ring Road to Nagavara Main Road leading to Jakkur	20.00
11	HBR Ring Road to Hennur Main Road	16.00
12	Old Madras Road	5.25
13	ITPL Road from Ring Road to Hope farm	8.50
14	Varthur Road from Marathalli to Varthur Kodi	5.00
15	Varthur to Outer Ring Road via Belegere and Panathur	6.50
16	Kaigondanahalli to Sarjapur	10.00
17	Bannerghatta Road – ORR to National Park	8.60
18	Bannerghatta Road – National Park to PRR	2.40
19	Begur Road from Hosur Road to Begur	7.00
20	Kanakapura Road.	10.40
21	Ring Road to Kanakapura Road (via Ittumadu)	7.00
22	Rajarajeshwari Nagar Arch to PRR	10.00
Connector Roads		
23	From Magadi Road to NH 4(Via Sunkadakatte, Hegganahalli Main Road, Peenya II Stage, NTTF circle, KIADB Main Road)	6.00
24	Peenya II Stage to Ring Road (via Peeya II Stage Bus stop, Rajgopal Nagar Main Road, Peenya Industrial Area)	3.00
25	NH-7 to Nagavara Main Road through Jakkur	16.00
26	NH-7 to Nagavara Main Road	12.00
27	Hennur Main Road to Hoskote Ring Road	10.00
28	Horamavu-Agara to HBR Ring Road	4.00
29	Horamavu Road from Outer Ring Road to Kalkere	4.20
30	T C Palya main Road from ORR to Anandapura	5.50
31	Devasandra main road from NH 4 to Basavanapura Road	1.70
32	Kundalahalli Road from Devasandra main Road to Kundalahalli gate via Hoodi	7.00
33	ITPL Road to Varthur Road via Pattanadur Agrahara & Nellurahalli	4.00
34	Sarjapur Road to Ring Road(near Devarabisanahalli)	7.00
35	Nagarthapura to Matha Amruthamayee College	5.00
36	Hosur Road to Nagarthapura (Hosur Road)	4.00
37	Begur to Hosur Road (via Begur tank Bund, Chikkabegur and Manipal County)	7.00
38	Bannerghatta Road to Begur (via DoddaKammanahalli, Yelenahalli)	8.00
39	Kottur Dinne to Bannerghatta Road	5.00
40	Harinagar to Kottanur Dinne	4.00
41	Corporation Bank to Ring Road via Javaraiana doddi	4.00
Parallel Ring Road		
42	From Magadi Road to NH 4(Via Herohalli, karivobanahalli, Andrahalli, Tigalarapalya, Nelagadaranahalli, Nagasandra)	8.00

SNo	Name of Road	Length km
43	Hesaraghatta Main Road to SM Road (via Mallasandra, Shetty halli, Abbigere, Kammagondanahalli main Road, Gangammagudi Circle)	6.00
44	Vidyaranyapura Main Road to Hennur main Road	35.00
45	Nagavara Main Road to Kalkere Junction	8.00
46	Sarjapura Road to Kalkere via Chikkaballapur,Gujurpalya, Varthur, Hope farm, Kadugodi, Sadaramangala, Kodigehalli, Basavanapura, T.C.Palya	31.00
47	Matha Amruthamayee to Sarjapura Road(Kaigondanahalli)	5.00
48	Kanakapura Road-Amruthnagar to Harinagar	4.50
49	Kengeri to Konanakunte via Uttarahalli(end of Kanakapura Road)	13.50
50	Kengeri 80' Ring Road to Ullalu Main Road via Matha Mata	10.50
51	Begur Road to Hosur Road and Kudlu	6.00
52	B G Road to Begur Road(via BTM Layout, Kodichikkanahalli	5.00
53	Chunchaghatta Road to B G Road	6.00
54	GnanaBharati Circle to Magadi Road	11.00
	Total	**502.75**
	Grand Total	**644.48**

Table 7.11 List of Grade Separators

SNo	Location / Road
Grade Seperators-Roads	
1	Hudson Circle- N.R.Road Under pass
2	Cauvery Theatre Junction-Bellary Road Grade separator
3	Minerva circle-J.C.Road Fly over
4	Nagavara Junction Along ORR Flyover
5	Hennur Banasvadi along ORR underpass
6	Sarjapur Road & ORR Jn. Along ORR flyover near Ibbalur
7	On ORR Jn. Along ORR near Agara flyover
8	Flyover along Hosur Road near Check post
9	Hosur Road-Inner Ring Road along Hosur Road fly over
10	Additional slip road at CSB intersection
11	Hosur Road Grade separator @ Attibelle
12	Along 16 main BTM Layout underpass
13	Puttenahalli along ORR underpass
14	Kanakapura Road & ORR Jn. Along ORR flyover
15	Kadirenahalli Road & ORR Jn. along ORR flyover
16	Flyover on RV road near RV Teacher College

SNo	Location / Road
17	Tagore Circle underpass on Gandhi Bazaar Main Road
18	Tumkur Road & ORR Junction along ORR Grade separator
19	Flyover along NH 4 at Jalahalli Cross
20	Underpass along pipeline road near Ayyappa Temple
21	Grade separator along Guttahalli Main Road near Guttahalli Circle
22	Grade separator at Yeshwantpur Circle near Bus Station
23	Bridge at Gali Anjaneya Junction
24	Grade separator at Malleshwaram Circle
25	Underpass at Prof. CN Rao Circle
26	Underpass along Chord Road at Magadi Road & Chord Road Junction
27	Underpass along ORR at ORR and Banaswadi Ramamurthy Nagar Road Junction
28	Grade separator at ORR & Magadi Road Junction
Road Over Bridges / RUBs-Rail	
29	ROB along MES Road near Jalahalli
30	Underpass along Link Road Connecting D Rajagopal Road & Kodigehalli Road
31	Ashoka Theatre - Pottery Road
32	Nagavara-Arabic College Road
33	Kasturinagar-Chikka-Banaswadi Road
34	Baiyyappanahalli Road
35	Kadugondanahalli Railway line along Nagavara Main Road
36	Hudi Main Road near Whitefield Railway Station
37	Construction of ORR connecting Mysore Road to Magadi Road including underpass across Bangalore Mysore Rly Line
38	Along settihalli main Road
39	Along S M Road near Gurudwara
40	Along Koigehalli Main Road near Kodigehalli Rly Stn
41	Along Hesaraghatta Main Road
42	Near Tanisandra Rly Stn
43	Along Kundalahalli Road at Kundalahalli gate.
44	Along Varthur Road near Lakshmi Layout
45	Along Panathur Main Road near Bellandur Rly Stn
46	Along Sarjapur Road
Elevated Roads	
47	Elevated Road From Sirsi Circle to ORR on Mysore Road (6.0 Km)
48	Elevated Road on Hosur Road (10.5 Km)

The above proposals are shown in **Figure 7.4**

Figure 7.4

7.10 INTER-MODAL INTERCHANGES

7.10.1 Proper integration of modes

Integration between Bus, MRTS, and railway is a vital need for the future. The city is planning two such major inter-modal interchanges.

- The first such interchange is already under bid - the Kempegowda bus terminus at Subhashnagar is proposed to be converted into an interchange that accommodates the BMTC, KSRTC, BMRC, and a "city center" complex.
- The second interchange is proposed at Baiyyappanahalli, which will have the BMTC, KSRTC, Railways, BMRC, and the Airport Rail Link.

In addition to the above major 47 interchanges as indicated in Figure 7.1 are proposed at required intersections of mass transport corridors.

7.11 NON- MOTORISED MODES

7.11.1 Cycle Facilities

Their use in Bangalore is not significant but still this needs to be encouraged on environmental considerations. Provision for safer and better section of road or cycle track is the best way to keep them on roads. This is necessitates more on roads in the periphery of city and in many areas in BMA. In CBD some side roads and lanes can be exclusively reserved for cyclists and pedestrians in peak periods. In the new cross sections for major roads in **Figure 7.3**, reservation for cycle tracks has especially been incorporated.

7.11.2 Pedestrian Facilities

Pedestrians form a major proportion of commuters. Not only trips are conducted by walk in its entirety but every public transport trip will also have component of walk at its both ends. Though they are short distance travelers, they are spread all over the city. As facilities furnished for them are encroached upon by vendors or for road space, they have to spill on roads. These contribute to accidents also. One alternative for their facility and controlling their spill on roads is to provide good footpath with railings covering about one to one half meters width on either side of the road with openings at desired crossing points. Another alternative is to develop some narrow roads especially adjacent to major arterials as "pedestrians only" roads. Bus bays and foot paths at bus stops can also help in restraining their spill on to carriageways and reducing accidents. Pedestrian subways at important location on all 6 lane roads and at busy inter sections/junctions on 4 lane roads are to be planned on a programmed basis.

7.11.2.1 Pedestrian Cross-Over Walk-ways facilities

The proposed skywalks/pedestrian subways are given in **Table 7.12**.

Table 7.12 Sky Walks / Sub-Ways

S No.	Locations of Sky Walks / Sub-Ways
1.	Cauvery Bhavan to Education Department Building and to Law College to Mysore Bank crossing KG Road on State Bank Junction
2.	Opposite NTI connecting Guttahalli Road and Palace (opposite Bus Stop) on Sankey Road
3.	Arya Bhavan Sweets to Kanthi Sweet to Himalaya Theatre, crossing KG Road
4.	Lalbagh Main Gate (Javaraiah Circle)
5.	Bannerghatta Road near Jayadeva Hospital
6.	BMTC Main Bus Stand to Amar Lodge Building in Majestic Area
7.	KSRTC Kempegowda Bus Station to BMTC Main Bus Station
8.	At Kengeri Bus Stand, Mysore Road
9.	At Byatarayanapura on Bellary Road (near Junction of BBMP office complex)
10.	BMTC Main Bus Station to Railway Station Premises
11.	Shanthala Silk House to KSRTC Main Bus Station and to Good-Shed Road
12.	RNS Motors, Tumkur road
13.	Jalahalli Circle, Tumkur Road
14.	Near Webb junction
15.	Near Kamakhya, Kathriguppe Ring Road
16.	Gandhi Bazaar Main Road
17.	On Vittal Mallya Road near Mallya Hospital
18.	Sheshadri Road near Maharani College
19.	On JC Road near Ravindra Kala Kshetra
20.	On Hosur Main Road near Madivala Check post
21.	On Raja Ram Mohan Roy Road, near Pallavi theatre
22.	On Richmond Road near D'Souza Circle
23.	On Race Course Road near Chalukya Hotel
24.	On Commissariat Street near Garuda Mall
25.	On Residency Road near Mayo Hall
26.	On Kamaraj Road near Commercial Street
27.	Near Indira Nagar 100 feet Road & Water Tank junction on Airport Road
28.	On Hosur Road(Near Forum)
29.	On Tumkur Road, near SMS Railway Junction
30.	On Air Port Road, Marath Halli at Village Road.
31.	On Air Port Road, Marath Halli at Junction of Under Pass ORR
32.	K.R. Puram Bus Stand
33.	Bharatiya Vidya Bhavan, Devaraj Urs Road
34.	On Hosur Road "T" Junction with Tavarekere Main Road (Opposite Sai Sadan & Prestige Acropolis) (High Rise Apartments Condominium)
35.	Mission Road at the foot of Fly over
36.	Vidhana Veedhi near M S Building
37.	Tumkur Road near Yeshwantpur Circle
38.	At South End Circle
39.	Malleshwaram 5^{th} cross

S No.	Locations of Sky Walks / Sub-Ways
40.	Double Road opposite Shanthi Nagar bus station
41.	City Market additional arm to be added to existing underpass
42.	30 no. Sky -walks / Sub-Ways along the eastern crescent of the ORR

The choice between lift/escalator operated skywalks and underpasses will depend upon the specific site conditions and the quantum of pedestrian traffic while undertaking the detailed feasibility studies. Location of these facilities is indicated in **Figure 7.5.**

7.11.2.2 **Foot paths**

It has been observed that most of the footpaths along the major arterial and sub arterial roads need extensive repairs and up gradations. The major problems observed are:

- Insufficient widths (< 1.5 mts.)
- Uneven surface because of settlement of base course, improper covering of service lines, manholes etc.
- Obstruction due to encroachments, unwanted garbage, unused building materials, fallen/ half cut trunks of trees and full grown trees, cable stays of electric poles etc.
- Level difference and steep risers with junctions of roads.

For this purpose tentatively it has been estimated that footpaths along 350 km of roads are required to be taken up. The basic principles for construction of new footpaths and improvement of existing ones are as under:

- Footpaths along existing roads should be widened and the minimum width be kept at least 2.0 mts.
- Proper leveling of footpath surface – with a stable base course fully compacted and safe guarded against any settlement before laying the top surface. In addition the cover for the underground services and man holes, if any, located below the footpaths or crossing should be properly designed to maintain a proper level with the surface of the footpath and no subsidence occurs.
- Continuity of footpaths
- Adequate ramp facilities for physically challenged people at junctions and cross overs.
- Proper merger of footpaths with skywalks/ underpasses/zebra crossings and junctions be provided with pedestrian priority signaling.

Figure 7.5

7.11.2.3 Pedestrian Zones

Substantial areas inside the core ring road has quite a few streets which are either fully commercial or majority of whose frontage is being used as shopping. The commercial activities on these roads can broadly be divided into the following two categories:

i. Retail and general Shopping like general merchandise, clothing garments and allied products, household white goods, consumer electronics, groceries & kitchen ware, Food & sweet shops etc., which are more or less regularly visited by shoppers.

ii. Wholesale and specialised shops dealing in machinery, building materials, Hardware etc. which are occasionally visited by customers with specific requirements and need bulk handling through Trucks and MCV's As far as these commercial activities are concerned attempt should be made to shift them out side the ORR along wide corridors where adequate loading / unloading facilities can be provided along with required parking facilities for visitors / shoppers. For shifting of these wholesale activities both strong measures against their functioning in their present locations in the core areas and incentives for shifting to the new locations will have to be provided.

The majority of the customers visit the core area to meet their retail needs through first type of establishments. As per the plan, this central area is going to be very well served by:

- 3 Metro Links namely
  i. Baiyyappanahalli to Mysore Road (East-West Corridor)
  ii. Peenya to Banashankari (North-South Corridor)
  iii. Yelahanka R.S to PRR via Nagavara and Electronic City

- An elevated core ring road surrounding this area with provision for BRT
- Adequate park & ride facilities out side the core area at Bus Terminal cum Traffic & Transit Management centres, Metro Termini & important metro Stations, BRT stations, along side Core Ring Road and Monorail Termini & Stations.

Thus the entire core area will be fully covered by elaborate public transport network and as such the entry of all private vehicles, especially during the shopping hours 10 A.M. to 9 P.M. should be minimised.

7.11.2.4 Proposed Pedestrian Zones

To start with following two areas are being suggested for pedestrianisation:

1. Gandhi Nagar & Chickpet Areas- The area surrounded by Seshadri Road, Kalidas Marg, K.G.Road, Distt. Offices Road, N.R.Road, Mysore Road and Bhashyam Road, Tank Bund Road & Dhanvantri Road can be converted into two pedestrian zones I & II on either side of K.G.Road. The two Zones can be inter connected through a semi depressed under pass near Alankar Plaza and Jantha Bazar. All the private vehicles will be required to move on Seshadri Road, Kasturba Road, NR Road and Bhashyam Road, while K.G.Road and District Offices Road be used by Public Transport –Busses & Trams. In the surrounding areas 5 mechanical parking spaces with a capacity of 500 vehicles each will be provided at;

- P13- Behind Sagar
- P14- Kanteerava Stadium
- P15-Near City Market
- P16-Near Bakshi Gardens
- P17 - KSRTC Bus Depot

2. Commercial Street – To be designated as 'CLOSED FOR VEHICLES FROM 10 A.M TO 9 P.M.' and supported by parking P-2 near Kamaraj Road
3. Brigade Road – To be designated as 'CLOSED FOR VEHICLES FROM 10 A.M TO 9 P.M.' and supported by parking P-1 near M.G.Road

These proposals are indicated in **Figure 7.6.**

7.12 PARKING

7.12.1 The parking demand is growing with growth of vehicles in the city. The multistoried buildings in busy/commercial areas are major attractors. Though the building regulations specify a minimum provision of parking area, there can be many defaulters and some who later convert the spaces for other purposes. This results in the vehicle parking spilling to streets (main road or side streets). A practical solution is to provide off street multistoried parking lots in this areas. As funds will be constraint consultants suggest a policy in this regard. The Owner who fails to provide required parking spaces as per the regulations should be charged an annual levy equivalent to market rental value for the short fall in parking area provided. Subsequently the market value will rise every year. Amount so collected plus parking charges collected will be substantially enough to meet the repayment installments of loans which were taken to construct multistoried parking lots. Once such facility is provided it is possible to prevent the on Street parking of vehicles or otherwise road space can be utilized for traffic. The development control regulations and TCP act may be suitably amended to provide for such levies.

Figure 7.6

7.12.2 Parking demand can also be controlled by implementing transport management measures like staggering office and school working hours and banning on-Street parking of private vehicles in CBD and on major arterials.

However it must be realized that mere regulatory measures are not enough and positive steps are required to meet the parking demand and provide safe parking outside the congested areas. It is suggested that for proper parking management and control, to start with we may divide the city into three zones.

7.12.2.1 Zone A – Central areas inside the core ring road where only short term parking on hourly basis should be provided between 9 AM to 9PM with high telescopic charges increasing with every hour of parking. These areas will invariably be provided with automatic mechanical parking (AMPs). Beyond 9PM and upto 9AM they can offer lower tariff rates for long term night parking.

7.12.2.2 Zone B – between the CRR and ORR – in these areas a combination of AMPs and Conventional Multi level Parking (CMPs) can be provided at selected interchanges, especially at the TTMCs and other identified locations closer to public transport corridors. Parking in these areas will also be short term time based but at a slightly lower tariff as compared to Zone A.

7.12.2.3 Zone C – outside the ORR – large CMPs may be provided at the TTMC s and other locations adjoining the public transport stations of Metro, Monorail/LRT, BRT etc. these will be long term parking lots of 8 to 12 hour duration at a nominal tariff to encourage the vehicle owners to park at these facilities and ride the public transport system to their destination and back.

7.12.3 To begin with parking for about 10000 vehicles has been suggested at the following sites in **Table 7.13**.

Table 7.13 Proposed Parking Sites

S. No.	Location	Phase	Type
1	M G Road	P-1	AMP
2	Near Kamraj Road	P-1	AMP
3	Gandhi Nagar	P-1	AMP
4	Jayanagar Shopping Complex	P-1	CMP
5	Koramangala near Raheja Tower	P-1	CMP
6	Rajajinagar BDA Complex	P-1	CMP
7	Banashankari BDA Complex	P-1	CMP
8	Gandhi Bazaar	P-1	CMP
9	Malleshwaram	P-1	AMP
10	Fire Station, Residency Road	P-1	AMP
11	Dhobi Ghat, Cunningham Road	P-1	AMP

S. No.	Location	Phase	Type
12	SP Office, Miller Road, Cunningham Road crossing	P-1	AMP
13	Near Sagar & States	P-1	AMP
14	Kanteerava Stadium	P-1	AMP
15	City Market	P-1	AMP
16	Bakshi Gardens	P-1	AMP
17	KSRTC Bus Depot	P-1	AMP

Of these sites, where the availability of land is limited and the land values very high, automatic mechanical parking (AMP) which can provide 500 parking lots in approx. 1000 sqm of space have been suggested. In the outer areas, conventional multistory parking (CMP) has been proposed.

In addition, since most of the TTMC's are proposed to be adequately served by Public Transport like Metro, Mono Rail/LRT, BRT etc, substantial Park and ride facilities should be provided from where the commuters can switch over from private to public transport. These proposals are indicated in **Figure 7.2**.

Similarly at all the termini of Metro, Mono rail/LRT, BRT,CRS and their major stations out side the Core Ring Road should be provided with adequate park and ride facilities are to be provided.

Within the core area where the land is scarce and very expensive, mechanical automatic & semi automatic parking may be provided with heavy time based parking Charges.

In the long run, when the mass transport system is city-wide and adequate, parking demand will stabilize. Therefore it is important that adequate and convenient mass transport system as recommended above is provided.

7.13 FREIGHT MOVEMENT

7.13.1 The freight movement through the city particularly on some of the arterials is already restricted in CBD area. Many orbital corridors cannot be easily restrained till such time the wholesale activities are concentrated in the CBD. The strategy already followed is to decongest the CBD by shifting the wholesale market to outer areas or proposed IFCs along the PRR. In order to facilitate the shifting of the wholesale activity from the core areas, both harsh measures in terms of restriction on the activities at their present location and incentives for relocation in the new areas will have to be followed. The restrictions in the central areas could be in the form of banning the entry of HCVs completely and permitting only LCVs between 10 PM and 9 AM; treating these properties as engaged in misuse activities and charge a very hefty misuse charge on a daily basis and a substantial increase in the property tax. All private vehicles should be banned from entering these areas between 9 AM to 10PM. simultaneously well developed wholesale markets may be created along side the IFCs with modern transport, loading and unloading, parking and ancillary facilities. These sites can be allotted to the persons relocating their business on no profit no loss basis on priority.

The provision of PRR is itself going to help diversion of through freight traffic. Nearly 80% of the ORR has lost the sole identity of ring road, the PRR being thought of in this connection will be a boon to the city. Development of another orbital ring road as proposed by BMRDA would also help in diversion of the freight traffic. So far there is no though regarding the shifting of the goods shed. If a ring railway is formed over the outer ring road, shifting of the goods shed to the periphery of the city can also be thought of. But this will take longer time. However, future planning of the rail facilities in and around Bangalore will need to be kept this in mind. Such shifts will have some adverse effect i.e. HCV/LCV movement from the goods sheds on the periphery and any wholesale complexes, into the city will develop. By suitable management measures like restricting these movements during particular timings of the day, problem can be suitably managed.

7.13.2 Integrated Freight Complexes (IFC)

Near the junctions of the PRR with the following radial corridors, six IFC's are proposed as indicated in **Figure 7.4**:

1. Hosur Road
2. White Field Road
3. Old Madras Road
4. Bellary Road
5. Tumkur Road
6. Mysore Road

In addition to acting as nodes for handling the HCVs traffic and diverting it on the PRR they will also act as center for wholesale trade. Quite a few wholesale markets to be shifted outside the central area can be located as part of the IFC for efficient handling for bulk goods.

7.14 DEMAND CONTROL

7.14.1 Reducing Private Vehicle Use

There are two ways to restraint the growth of private vehicles on road to either by pricing policy or by providing better level of service on public transport. Road pricing is difficult to achieve in a city like Bangalore particularly since its enforcement would be very difficult. It should be possible to put constraints in some areas by restricting private vehicles entering into the congested roads particularly during the peak hours. Providing good public transport with feeder

IPT modes like Mini buses for facilitating the commuters to reach their destinations from Train/Bus stations would also induce many private vehicle users to shift from private vehicles. In fact with the coming up of the Core Ring Road, proposed improvements in the alignment of the ORR, Coming up of the various Mass Rapid Transit (MRT) Modes like Metro, Mono-Rail / LRT & BRT we can substantially achieve the objectives through the following measures:

- Enough parking lots be provided outside the ORR & CRR easily accessible from the radials reaching the ORR & CRR
- Proper park & ride facilities for long term parking at the stations / termini of the MRT modes out side the ORR.
- Providing comfortable, environmentally friendly transport (Electrically operated / CNG mini busses) between MRT stations and the core areas.
- The parking facilities provided / planned in side the CRR should only be for Short term parking with high hourly charges.
- Congestion Charges be imposed on slab-scale from private vehicles entering first the ORR and then the CRR.
- Private vehicles be completely banned from entering the pedestrian zones between the shopping hours i.e. 10 AM to 9 PM.

The above measures can help in reducing private vehicles in busy areas.

7.14.2 Land use for demand optimization

The land use and density component of the above strategy can be operationalized only through revisions in the Master Plan. High traffic generating activities and high density (high FSI) zones should be realigned around mass transport nodes and along major transportation corridors.

Such a reorganization of land use and density cannot be realized only through the modifications in the Master plan. In already developed areas, this needs to be translated into projects for planned redevelopment, ensuring that the high density and high intensity of activities are supported by appropriating land for improvements in the road network, street design and supporting infrastructure. The energy for redevelopment already exists in the real estate market in Bangalore, and will receive further impetus from the implementation of mass transport projects.

In new growth areas, a mechanism for micro-level planning (such as Town Planning Schemes in Gujarat) will need to be introduced to ensure that all new development is adequately served by primary, tertiary and secondary road network with provision for public transport facilities. These would also essentially have to be translated into land management projects.

7.14.3 Development of Integrated Facilities

As already pointed out, Bangalore has a good network of rail system, which can be converted by adding a few facilities like parallel lines, electrification, additional stations etc to serve as a commuter rail system also. Detailed studies have been completed already. CRS along with the Metro system under construction and the Bus transport can be integrated with good interchange and parking facilities at stations to form an Integrated Transport System.

7.15 TRANSPORT SYSTEM MANAGEMENT – B-TRAC 2010

7.15.1 Background

Bangalore City, has witnessed a phenomenal growth in vehicle population. As a result, many of the arterial roads and intersections are operation over the capacity (i.e., v/c is more than 1) and average Journey speeds on some of the key roads in the Central Area are lower than 10 Kmph in the peak hour. Therefore, it has become necessary to establish plans for efficient traffic management in Bangalore. In this regard, Bangalore City Police have envisaged the "Bangalore Traffic Improvement Project – B- TRAC 2010"

7.15.2 Goal and Objectives

The objectives of B-TRAC 2010 would be two-fold:

1. Operational Objectives: (a) Reduce traffic congestion by 30% in the Central Area of Bangalore City; (b) Reduce accidents by 30% in the city of Bangalore; (c) Achieve significant reduction in pollution; (d) Achieve substantial compliance of Traffic Laws and Rules; and (e) Set up an effective Trauma Care System.

2. Institutional Objectives: (a) Coordinated traffic management by developing mechanisms for the same, like institutionalizing Traffic Task Force, Road Safety Committee, Traffic Action Committee etc; (b) Robust Revenue Model (traffic funds to pay for traffic management infrastructure and maintenance); (c) Legal and Institutional reforms; (d) Capacity Building (Modernization and up gradation of Traffic Training Institute etc.); and (e) Strengthening of Traffic police by augmenting officers and staff; construction of buildings and provision of modern communication and mobility.

7.15.3 Approach

The city of Bangalore needs a traffic management that addresses not just supply aspects, but also demand and B-TRAC – 2010 adopts this very same approach.

7.15.4 Strategy

B-TRAC-2010 framework would be as follows: (a) Land use development controls; (b) Primacy to Public Transport; (c) Parking controls and management; (d) Automated Control and Enforcement (ITS/ATC); (e) Entry Restriction to the Central Area; and (F) Road safety plan for accident reduction. Specific components of the strategy are: (a) Central Area – Area Traffic Control System; One way systems; dedicated bys lance and signal priority for buses; Parking controls; creation of no-auto zones; restricted entry of traffic in to the core area

(b) Core ring road development for unhindered movement of traffic thereby avoiding the central area (c) Corridor Traffic Control System (as in ATC) for the several radial roads (d) up gradation of intermediate and outer ring roads and development of the peripheral ring road (e) Traffic police modernization with improved communication, computerization, mobility, capacity building and automated enforcement systems.

7.15.5 Components

The various components of B-TRAC are as under:

- Junction Improvements
- Street Furniture and Road Marking
- Intelligent Transport System including. ATC, VMS etc for 250 intersections
- Surveillance / monitoring and enforcement cameras etc
- Education and Training / Others

7.15.6 Benefits

(a) Traffic congestion will be reduced by 30% in the Central Area of Bangalore City
(b) Accidents will be reduced by 30% in the city of Bangalore
(c) There will be significant reduction in pollution
(d) Substantial compliance of Traffic Laws and Rules will be achieved
(e) Effective Trauma Care System will be set up
(f) Coordinated traffic management will be achieved
(g) Level of traffic and road safety awareness will be enhanced and
(h) State of the art traffic policing and regulation will lead to substantial compliance.

7.15.7 Summary

B-TRAC 2010 will be first of its kind project in the country to address the issues of traffic congestion, safety etc by utilizing the latest traffic management technology and techniques, which are appropriate to our context. This will give the much-needed scope for larger infrastructure projects to be planned and implemented for improving the transportation system in Bangalore city.

CHAPTER – 8

TRANSPORT INTEGRATION

8. 1 NEED

A multi-modal public transport network for the BMA has been proposed to be developed to meet expected commuter's travel needs. Integration of various modes of transport is vital to evolution of a least-cost and viable transport system. Objective of an integrated transport system is to offer maximum advantage from economic, traffic and planning considerations. Various transport modes are to be integrated in such a way that each mode supplements the other. For effective integration, total transport system has to be planned, implemented and operated under common policies. Depending upon the forecast transport demand and other parameters along various corridors, an appropriate transport system giving least-cost option has been proposed.

8.2 INTEGRATION OF MODES

8.2.1 It is not possible to provide direct origin to destination service and vice a versa for all commuters. The need to interchange modes and or corridors is an essential feature of any public transport system. The planning objective as stated earlier is to minimize the need to change and when change is essential to make it as convenient as possible and with minimum time loss.

8.2.2 The proposed network includes corridors that are collector routes to serve areas at some distance from the mass transport routes. Another corridors are radial that normally would be direct origin to destination routes and hence will meet the objective of minimum interchanges. There are circular routes that will interchange with the radial routes. On these routes, one interchange should meet the needs of most commuters. The overall network of radials and circular corridors has formed a grid and hence most commuters should not need more than one or two interchanges.

8.3 FEEDER SERVICES

Feeder services to the proposed network will also be important in order to provide convenient and quick transfer of passengers from one mode of transport to other. As all commuters will not be living within walking distance of the proposed network, proper planning for feeder services will be necessary to ensure the forecast passenger demand on the system. For catchment area of about 0.5-1 km from the proposed network, commuter can easily access it by walk. People residing in next 1-km can reach station by cycles, scooters, auto-rickshaws and mini-buses. Areas outside the 2-km catchment area will require regular feeder bus services to important terminals/stations. Feeder services can also be provided by Para-transit modes. However, choice of a particular mode will depend upon passenger demand, road cross-section, road gradient, etc.

8.4 INTER-CHANGE FACILITIES

8.4.1 One of the most important elements of transport integration is the provision of inter-change facilities. Required inter-changes will be between the proposed mass transit systems such Metro, CRS, LRT/Monorail, BRTS and with other feeder services. Integration facilities at stations would depend upon expected station load to ensure proper system utilization. This will also include approach roads to stations, circulation facilities, pedestrian ways and adequate parking areas for various modes that are likely to come to important stations including feeder, bus/mini-bus routes. The provision will have to be made for peak demand at each station. At either stations, proper road based integration is to be ensured.

8.4.2 **Figure 7.1** shows the interchange points in the mass transport network. There are 49 locations of interchange with high capacity mass transport modes.

8.4.3 The main issue is to make these interchanges convenient with minimum time penalty. Facilitates for interchange between modes/corridors should be planned for convenience and minimum loss of time. Side by side or vertical interchange that involves minimum walking is the best and hence has to be the norm in planning. It is proposed that planning and design of convenient interchanges and safe access from the area up to stations and stops forms the subject of a special study devoted to achieve the objective.

8.5 OPERATIONAL INTEGRATION

Integration at operational level will be required to synchronize the timings of mass transit and feeder services. For efficient inter-change, walking/waiting time at these stations will need to be minimized. Introduction of common ticketing and their availability at convenient places will be necessary to ensure forecast patronage of the system. An integrated passenger information system covering all modes through publication of common route guides, time-table, information boards at terminals for providing up-to-date information for the system users will also be important.

CHAPTER – 9

COST ESTIMATES, PHASING AND FINANCING PLAN

9.1 UNIT RATES

9.1.1 The Traffic and Transportation Plan comprising proposals for public/mass transport system, inter-city bus terminals, pedestrian facilities, parking facilities, road infrastructure, integrated freight complexes, transport system management measures etc has been prepared for the BMA to cater to travel demand up to the year 2025 at an acceptable level of service as explained in Chapter 7. In order to know the financial implications of these proposals, block cost estimates have been worked out in this chapter. Unit rates adopted for items at 2007 prices are given in **Table 9.1**.

Table 9.1 Unit Rates

S.No.	Item	Unit	Rate (Rs Cr.)
1	Metro Elevated Section	per Km	130
2	Metro Underground Section	per Km	250
3	Mono Rail/ Light Rail Transport System	per Km	85
4	Commuter Rail System inc. dedicated line, signalling systems, improvement of stations etc.	per Km	15
5	BRT	per Km	12
6	Low floor urban commuter buses	Each	0.4
7	Bus terminal cum Traffic & Transit Management Centres (TTMC)	Each	45
8	Bus station	Each	12
9	Bus depot	Each	6
10	Bus shelter	Each	0.03
11	Inter-city bus terminal	Each	45
12	Elevated Road	per lane/ Km	10.0
13	New dual carriage way road	per lane / Km	1.66
14	Widening of roads	per lane/Km	0.5
15	Grade separators 6 lane dual CW 700 mts long	each	30
16	Improvements of Foot paths	per Km	0.2
17	Sky walks	Each	2
18	Automatic Mechanical Parking	per parking space	0.05
19	Conventional Multi Storey Parking	per parking space	0.02
20	Integrated Freight Complex	Each	45

9.2 COST ESTIMATES OF PROPOSALS AND PHASING OF IMPLEMENTATION

9.2.1 Considering the various proposed schemes and unit rates, cost estimates of these schemes have been worked out at 2007 prices and are given for Proposed Mass Transport Corridors, City Bus System, Road Infrastructure, Grade Separators, Pedestrian Facilities, Parking Facilities, Integrated Freight Complexes and Transport System Management Measures in **Tables 9.2 to 9.9** respectively. The entire transport development plan is not required to be implemented in one go. Considering the existing problems, expected traffic demand levels and schemes already under implementation/ active consideration of the Government, phasing of implementation of various projects has been suggested in three phases (2007-12, 2013-18 and 2019-24) and is also given in these tables. Cost estimates for each project to be implemented in the three phases have also been given in the tables.

Table 9.2 Cost Estimates of Proposed Mass Transport Corridors (Rs Crore)

S.No.	Corridor	Length km	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
Metro System							
1	Baiyyappanahalli to Mysore Road East-West Corridor	18		5605	5605		
2	Peenya to R.V terminal North-South Corridor	18.8					
3	R.V .Terminal to PRR	10.2	130	1326	1326		
4	Baiyyappanahalli to Benniganahalli along Old Madras Road	1.5	130	195	195		
5	Yelahanka R.S. to PRR via Nagavara , Electronic City	36	175	6300		6300	
6	Indiranagar Metro Stn. to White field Railway Station via 100ft Indiranagar Road	19.5	130	2535		2535	
7	Proposed Devanahalli Airport to M.G.Road via Bellary Road	33	120	3960	3960		
	Total	**137**		**19921**	**11086**	**8835**	

S.No.	Corridor	Length km	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
Mono Rail / LRT System							
1	Hebbal to J.P.Nagar (Bannerghatta Road) along the western crescent of outer ring road	31	85	2635	2635		
2	PRR to Toll gate along Magadi Road	9	85	765	765		
3	Kathriguppe Road / Ring Road Junction to National College	5	85	425	425		
4	Hosur Road - Bannerghatta Road Junction to PRR along Bannerghatta Road	15	85	1275		1275	
	Total	**60**		**5100**	**3825**	**1275**	
Commuter Rail System							
1	Kengeri - Bangalore City Station.	13	15	195	195		
2	Bangalore City Station - Whitefield	24	15	360	360		
3	Bangalore City Station - Baiyyappanahalli Via Lottegollahalli	23	15	345		345	
4	Lottegollahalli to Yelahanka	7	15	105		105	
5	Banaswadi upto BMA Boundary	29	15	435		435	
6	Kengeri- BMA Boundary	9	15	135	135		
7	Yeshwantpur to BMA Boundary	14	15	210		210	
8	BMA Boundary - Hosur	12	15	180		180	
9	BMA Boundary-Ramanagaram	23	15	345		345	
10	BMA Boundary to Tumkur	50	15	750			750
	Total	**204**		**3060**	**690**	**1620**	**750**
BRT System							
1	Hebbal to Bannerghatta Road along Eastern portion of the ORR	33	12	396	396		

S.No.	Corridor	Length km	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
2	Benniganahalli (ORR) to PRR along Old Madras Rd.	7	12	84	84		
3	From ORR to Hosur Road along Hitech Corridor	8	12	96	96		
4	Hosur Rd. to Tumkur Road along PRR (western part)	41	12	492		492	
5	Tumkur Road-PRR Junction to Hosur Road along PRR via Tirumanahalli, Old Madras Road, Whitefield	76	12	912		912	
6	Along Core Ring Road	30	12	360	360		
7	Vidyaranyapura to Nagavarapalya via Hebbal, Jayamahal Road, Queens Road, M.G. Road, Ulsoor, Ind1ranagar, CV Raman Nagar	29	12	348	348		
8	Kengeri Sattelite Town to J.P. Nagar along Uttarahalli Road, Kodipur	13	12	156		156	
9	Banashankari III stage to Banashankari VI stage Ext. along Ittumadu Road, Turahalli, Thalaghattapura	6	12	72		72	
10	Domlur Ext. to Koramangala along inner ring road	5	12	60	60		
11	Mulur to Maruti Nagar (up to Hitech corridor) along Sarjapur Road	7	12	84	84		
12	Peenya to PRR along Tumkur Road	6	12	72	72		
13	Old Madras Road near Indiranagar to ORR near Banaswadi along Baiyyappanahalli Road – Banaswadi Road	5.5	12	66	66		
14	Hebbal to Devanahalli Airport along Bellary Road	25.0	12	300	300		
	Total	**291.5**		**3498**	**1866**	**1632**	

Table 9.3 Cost Estimates for Proposed Improvement in City Bus System and Intercity Bus terminals / IMTCs (Rs Crore)

SNo.	Proposals	Phase	Units	Qty/Nos.	Unit Cost (Rs Cr)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
City Bus System									
1	New Buses to be added by 2010	P-1		2500	0.4	1000	1000		
	Addl. Buses to be added by 2018	P-2	1500	3000	0.4	1200		600	
	Addl. Buses to be added by 2025	P-3	1500		0.4				600
2	Bus Terminal cum Traffic & Transit Management Centres (TTMC)	P-1	45	45	45	2025	2025		
3	New Bus Stations	P-1	23	23	12	276	276		
4	New Bus Shelters	P-1		300	0.03	10	10		
5	New Depots								
	Upto 2010	P-1	27	27	6	162	162		
	Addl. Depots required by 2018	P-2	10	20	6	120.00		60	
	Addl. Depots required by 2024	P-3	10						60
6	Improvement of IT Infrastructure	P-1				184.00	184		
7	Multimodal Transit Centre at Subhashnagar	P-1	1	1	350	350	350		
8	Development of HRD Infrastructure	P-1				150	150		
9	Environment Protection Projects	P-1				49	49		
Intercity Bus Terminals / IMTCs									
10	Intermodal Transit Centres cum Intercity Bus Terminal-Peenya	P-1	1	1	60	60	60		
11	Intermodal Transit Centres cum intercity Bus terminals- Hosur Rd, Bellary Rd, NGEF at Old Madras Road	P-1	3	3	45	135	135		
	Total					**5721.0**	**4401**	**660**	**660**

Table 9.4 Cost Estimates for Proposed Road Infrastructure Development Plan (Rs Crore)

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
New Roads							
1	Core Ring Road (CRR) (elevated)	30	40	1200	1200		
2	Arterial Roads crossing CRR	30	1	30	30		
3	Peenya Industrial Area To Bangalore Mysore Expressway	2.2	10	22	22		
4	Peripheral Ring Road (PRR)	114	30	3420	3420		
5	Air Port Link Road (Expressway)	26	20	520	520		
6	Link from Tigalarapalaya main road to Nelagadaranahalli (Cost included in Item 42 of parallel ring road)	1.23					
7	Link from Hesarghatta main road to Shettihalli and Madarahelli to Mohammed Sabi Palya (Cost included in Item 43 of parallel ring road)	4.02					
8	Link from Sampigehalli to CRPF parade ground (Cost included in Item 25 of parallel ring road)	1.72					
	Total	**209.17**		**5192**	**5192**		
Outer Ring Road Re Alignment							
1	Elevated road along Bang. University Road (excluding cost of Construction of ORR connecting Mysore Road to Magadi Road including underpass across Bangalore Mysore Rly Line accounted for at item no. 9 of RUB/ROB List)	2.5	20	50	50		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
2	Realigning ORR between Magadi Rd. and Pipe Line Rd	1.9	10	19	19		
3	Realigning ORR at Tumkur Rd through CMTI	1.2	10	12	12		
4	Realigning ORR from Kasturi Nagar to Mahadevapura along Salem railway line	5	10	50	50		
5	Elevating ORR along common portion with Sarjapur Rd (excluding cost of grade separators at Agara & Ibbalur at item no. 6 & 7 of list of Grade separators)	2	10	20	20		
6	Elevating ORR along common portion with Bannerghatta Road	1	40	40	40		
7	PESIT to Janabharti Enterance Banglore University	3	40	120	120		
	Total	**16.6**		**311**	**311**		
Road Improvements (Inside ORR)							
1	Bellary Rd	7.60	1	7.6	7.6		
2	Palace Road	1.75	1	1.75	1.75		
3	Seshadri Road	0.50	1	0.5	0.5		
4	Nrupatunga Road	1.10	1	1.1	1.1		
5	Vidhana Veedhi	0.20	1	0.2	0.2		
6	Mission Road	1.00	1	1	1		
7	Devanga Hostel Road	0.50	1	0.5	0.5		
8	Sankey Road	3.40	1	3.4	3.4		
9	Lalbagh Road	0.41	1	0.41	0.41		
10	Jaymahal Road	2.80	1	2.8	2.8		
11	Hosur Road	1.60	1	1.6	1.6		
12	Hosur Laskar Road	4.30	1	4.3	4.3		
13	Victoria Road	1.60	1	1.6	1.6		
14	Lower Agaram Road	2.40	1	2.4	2.4		
15	Sarjapur Road	3.35	1	3.35	3.35		
16	Hosur Road	4.30	1	4.3	4.3		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
17	Bannerghatta Road	4.11	1	4.11	4.11		
18	80' Koramangala	4.00	1	4	4		
19	Dickenson Road	0.30	1	0.3	0.3		
20	Ulsoor Road	0.60	1	0.6	0.6		
21	Kensington Road	0.32	1	0.32	0.32		
22	Murphy Road	1.70	1	1.7	1.7		
23	Old madras Road	1.70	1	1.7	1.7		
24	Richmond Road	5.20	1	5.2	5.2		
25	Airport Road	5.20	1	5.2	5.2		
26	Goods shed Road	1.35	1	1.35	1.35		
27	Cottonpet main Road	1.20	1	1.2	1.2		
28	17th main J CNagar in ward13	1.50	1	1.5	1.5		
29	5th cross Malleshwaram	1.00	1	1	1		
30	Commissariat Road	0.74	1	0.74	0.74		
31	A M Road	0.75	1	0.75	0.75		
32	Lalbagh fort Road	1.35	1	1.35	1.35		
33	Race Course Road	1.66	1	1.66	1.66		
34	Kasturba Road	0.77	1	0.77	0.77		
35	A S char street & BVK Iyengar Road	1.21	1	1.21	1.21		
36	Vanivilas Road	0.85	1	0.85	0.85		
37	Suranjan Das Road	3.85	1	3.85	3.85		
38	Mysore Road	3.90	1	3.9	3.9		
39	Mt joy Road & Kattriguppe main Road via vidyapeeta Circle	3.00	1	3	3		
40	Mahalakshmi layout & Nandini Layout road via Ayyappa temple & Singapore layout	2.70	1	2.7	2.7		
41	Dinnur main Road and kavalbyrasandra Road (via ganganagar sulthan palya)	4.50	1	4.5	4.5		
42	Hoskerehalli main Road(via girinagar)	2.05	1	2.05	2.05		
43	Vasanth nagar main Road	0.62	1	0.62	0.62		
44	K R Road	1.16	1	1.16	1.16		
45	Sulthan Road	0.42	1	0.42	0.42		
46	1st main Chamarajpet	0.15	1	0.15	0.15		
47	3rd cross Chamarajpet & Bull temple Road	1.00	1	1	1		
48	Link Road	0.63	1	0.63	0.63		
49	Padarayanapura main Road	1.86	1	1.86	1.86		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
50	Bull temple Road via N R Colony, Chennamma tank bed & 30th main BSK 3rd stage	1.10	1	1.1	1.1		
51	Infantry Road	1.83	1	1.83	1.83		
52	Park Road	0.50	1	0.5	0.5		
53	Hospital Road	1.10	1	1.1	1.1		
54	Dispensary Road	0.50	1	0.5	0.5		
55	K Kamaraj Road	1.25	1	1.25	1.25		
56	Dharmaraj Road	0.40	1	0.4	0.4		
57	Chandini chowk	0.45	1	0.45	0.45		
58	Meenakshi koil street	0.60	1	0.6	0.6		
59	Thimmaih Road	2.10	1	2.1	2.1		
60	Old poor house Road- Haine's Road	1.00	1	1	1		
61	Millers tank bund Road	0.52	1	0.52	0.52		
62	Station Road	1.30	1	1.3	1.3		
63	Queen's Road	0.95	1	0.95	0.95		
64	Millers Road	1.42	1	1.42	1.42		
65	Cunningham Road	0.80	1	0.8	0.8		
66	Road in front of Russel market	0.25	1	0.25	0.25		
67	Dr. Ambedkar Road (tannery Road)	4.43	1	4.43	4.43		
68	Hennur Road	3.62	1	3.62	3.62		
69	Banaswadi Road & Wheelers Road (via Banaswadi)	6.35	1	6.35	6.35		
70	Hare Krishna Road	0.70	1	0.7	0.7		
71	HMT main Road	2.10	1	2.1	2.1		
72	Magadi Road	2.40	1	2.4	2.4		
73	Baiyyappanahalli main Road	3.35	1	3.35	3.35		
74	Bapujinagar cross Road	0.80	1	0.8	0.8		
75	Kumaraswamy layout main Road	1.75	1	1.75	1.75		
76	South link Road	0.50	1	0.5	0.5		
77	MTB Road	0.50	1	0.5	0.5		
78	Kurubarahalli main Road in ward 16	1.00	1	1	1		
	Total	141.73		**141.73**	141.73		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
Road Improvements (Outside ORR)							
Radial Roads							
1	From Peenya II Stage to Andrahalli (via Peenya II Stage, Industrial area, Andrahalli)	4.00	0.75	3.00	3.00		
2	Tumkur Road-NH4	8.80	0.75	6.60	6.60		
3	New BEL Road	3.40	0.75	2.55	2.55		
4	Jalahalli Main Road to Attur via Yelahanka	28.00	0.75	21.00	21.00		
5	Yeshwantpur to Yelahanka	20.00	0.75	15.00	15.00		
6	Doddaballapur Road.	6.00	0.75	4.50	4.50		
7	Devanahalli - Hebbal Bellary Road	25.00	3.0	75.0	75.00		
8	NH-7 Kogilu Junction to Nagavara Main Road	8.00	0.75	6.00	6.00		
9	Dasarahalli Main Road	16.00	0.75	12.00	12.00		
10	HBR Ring Road to Nagavara Main Road leading to Jakkur	20.00	0.75	15.00	15.00		
11	HBR Ring Road to Hennur Main Road	16.00	0.75	12.00	12.00		
12	Old Madras Road	5.25	0.75	3.94	3.94		
13	ITPL Road from Ring Road to Hope farm	8.50	0.75	6.38	6.38		
14	Varthur Road from Marathalli to Varthur Kodi	5.00	0.75	3.75	3.75		
15	Varthur to Outer Ring Road via Belegere and Panathur	6.50	0.75	4.88	4.88		
16	Kaigondanahalli to Sarjapur	10.00	0.75	7.50	7.50		
17	Bannerghatta Road - ORR to National Park	8.60	0.75	6.45	6.45		
18	Bannerghatta Road - National Park to PRR	2.40	0.75	1.80	1.80		
19	Begur Road from Hosur Road to Begur	7.00	0.75	5.25	5.25		
20	Kanakapura Road.	10.40	0.75	7.80	7.80		
21	Ring Road to Kanakapura Road (via Ittumadu)	7.00	0.75	5.25	5.25		
22	Rajarajeshwari Nagar Arch to PRR	10.00	0.75	7.50	7.50		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
Connector Roads							
23	From Magadi Road to NH 4(Via Sunkadakatte, Hegganahalli Main Road, Peenya II Stage, NTTF circle, KIADB Main Road)	6.00	0.75	4.50	4.50		
24	Peenya II Stage to Ring Road (via Peeya II Stage Bus stop, Rajgopal Nagar Main Road, Peenya Industrial Area)	3.00	0.75	2.25	2.25		
25	NH-7 to Nagavara Main Road through Jakkur	16.00	0.75	12.00	12.00		
26	NH-7 to Nagavara Main Road	12.00	0.75	9.00	9.00		
27	Hennur Main Road to Hoskote Ring Road	10.00	0.75	7.50	7.50		
28	Horamavu-Agara to HBR Ring Road	4.00	0.75	3.00	3.00		
29	Horamavu Road from Outer Ring Road to Kalkere	4.20	0.75	3.15	3.15		
30	T C Palya main Road from ORR to Anandapura	5.50	0.75	4.13	4.13		
31	Devasandra main road from NH 4 to Basavanapura Road	1.70	0.75	1.28	1.28		
32	Kundalahalli Road from Devasandra main Road to Kundalahalli gate via Hoodi	7.00	0.75	5.25	5.25		
33	ITPL Road to Varthur Road via Pattanadur Agrahara & Nellurahalli	4.00	0.75	3.00	3.00		
34	Sarjapur Road to Ring Road(near Devarabisanahalli)	7.00	0.75	5.25	5.25		
35	Nagarthapura to Matha Amruthamayee College	5.00	0.75	3.75	3.75		
36	Hosur Road to Nagarthapura (Hosur Road)	4.00	0.75	3.00	3.00		
37	Begur to Hosur Road (via Begur tank Bund, Chikkabegur and Manipal County)	7.00	0.75	5.25	5.25		
38	Bannerghatta Road to Begur (via DoddaKammanahalli, Yelenahalli)	8.00	0.75	6.00	6.00		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
39	Kottur Dinne to Bannerghatta Road	5.00	0.75	3.75	3.75		
40	Harinagar to Kottanur Dinne	4.00	0.75	3.00	3.00		
41	Corporation Bank to Ring Road via Javaraiana doddi	4.00	0.75	3.00	3.00		
Parallel Ring Road							
42	From Magadi Road to NH 4(Via Herohalli, karivobanahalli, Andrahalli, Tigalarapalya, Nelagadaranahalli, Nagasandra)	8.00	0.75	6.00	6.00		
43	Hesaraghatta Main Road to SM Road (via Mallasandra, Shetty halli, Abbigere, Kammagondanahalli main Road, Gangammagudi Circle)	6.00	0.75	4.50	4.50		
44	Vidyaranyapura Main Road to Hennur main Road	35.00	0.75	26.25	26.25		
45	Nagavara Main Road to Kalkere Junction	8.00	0.75	6.00	6.00		
46	Sarjapura Road to Kalkere via chikkaballapur,Gujurpalya, Varthur, Hope farm, Kadugodi, Sadaramangala, Kodigehalli, Basavanapura, T.C.Palya	31.00	0.75	23.25	23.25		
47	Matha Amruthamayee to Sarjapura Road(Kaigondanahalli)	5.00	0.75	3.75	3.75		
48	Kanakapura Road- Amruthnagar to Harinagar	4.50	0.75	3.38	3.38		
49	Kengeri to Konanakunte via Uttarahalli(end of Kanakapura Road)	13.50	0.75	10.13	10.13		
50	Kengeri 80' Ring Road to Ullalu Main Road via Matha Mata	10.50	0.75	7.88	7.88		
51	Begur Road to Hosur Road and Kudlu	6.00	0.75	4.50	4.50		

S. No.	Corridor	Length km	Unit Cost per Km (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
52	B G Road to Begur Road(via BTM Layout, Kodichikkanahalli	5.00	0.75	3.75	3.75		
53	Chunchaghatta Road to B G Road	6.00	0.75	4.50	4.50		
54	GnanaBharati Circle to Magadi Road	11.00	0.75	8.25	8.25		
	Total	**502.75**		**433.31**	**433.31**		

Table 9.5 Cost Estimates for Proposed Grade Separators (Rs Crore)

SNo	Location / Road	Nos.	Unit Cost per G.S (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
Grade Seperators-Roads							
1	Hudson Circle-N.R.Road Under pass	1	30	30	30		
2	Cauvery Theatre Junction-Bellary Road Grade separator	1	10	10	10		
3	Minerva circle-J.C.Road Fly over	1	25	25	25		
4	Nagavara Junction Along ORR Flyover	1	22	22	22		
5	Hennur Banasvadi along ORR underpass	1	25	25	25		
6	Sarjapur Road & ORR Jn. Along ORR flyover near Ibbalur	1	23	23	23		
7	On ORR Jn. Along ORR near Agara flyover	1	40	40	40		
8	Flyover along Hosur Road near Check post	1	25	25	25		
9	Hosur Road-Inner Ring Road along Hosur Road fly over	1	25	25	25		
10	Additional slip road at CSB intersection	1	25	25	25		
11	Hosur Road Grade separator @ Attibelle	1	25	25	25		

SNo	Location / Road	Nos.	Unit Cost per G.S (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
12	Along 16 main BTM Layout underpass	1	25	25	25		
13	Puttenahalli along ORR underpass	1	23	23	23		
14	Kanakapura Road & ORR Jn. Along ORR flyover	1	30	30	30		
15	Kadirenahalli Road & ORR Jn. along ORR flyover	1	30	30	30		
16	Flyover on RV road near RV Teacher College	1	14	14	14		
17	Tagore Circle underpass on Gandhi Bazaar Main Road	1	25	25	25		
18	Tumkur Road & ORR Junction along ORR Grade separator	1	40	40	40		
19	Flyover along NH 4 at Jalahalli Cross	1	25	25	25		
20	Underpass along pipeline road near Ayyappa Temple	1	25	25	25		
21	Grade separator along Guttahalli Main Road near Guttahalli Circle	1	25	25	25		
22	Grade separator at Yeshwantpur Circle near Bus Station	1	22	22	22		
23	Bridge at Gali Anjaneya Junction	1	32	32	32		
24	Grade separator at Malleshwaram Circle	1	12.5	12.5	12.5		
25	Underpass at Prof. CN Rao Circle	1	27.5	27.5	27.5		
26	Underpass along Chord Road at Magadi Road & Chord Road Junction	1	31.5	31.5	31.5		

SNo	Location / Road	Nos.	Unit Cost per G.S (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
27	Underpass along ORR at ORR and Banaswadi Ramamurthy Nagar Road Junction	1	21.5	21.5	21.5		
28	Grade separator at ORR & Magadi Road Junction	1	29	29	29		
	Total	**28**		**713**	**713**		
Road Over Bridges / RUBs-Rail							
29	ROB along MES Road near Jalahalli	1	20	20	20		
30	Underpass along Link Road Connecting D Rajagopal Road & Kodigehalli Road	1	20	20	20		
31	Ashoka Theatre - Pottery Road	1	20	20	20		
32	Nagavara-Arabic College Road	1	20	20	20		
33	Kasturinagar-Chikka-Banaswadi Road	1	20	20	20		
34	Baiyyappanahalli Road	1	20	20	20		
35	Kadugondanahalli Railway line along Nagavara Main Road	1	20	20	20		
36	Hudi Main Road near Whitefield Railway Station	1	20	20	20		
37	Construction of ORR connecting Mysore Road to Magadi Road including underpass across Bangalore Mysore Rly Line	1	87	87	87		
38	along Settihalli main Rd.	1	20	20	20		
39	along S M Road near Gurudwara	1	20	20	20		
40	Along Koigehalli Main Road near Kodigehalli Rly Stn	1	20	20	20		
41	Along Hesaraghatta Main Road	1	20	20	20		
42	Near Tanisandra Rly Stn	1	20	20	20		
43	Along Kundalahalli Road at Kundalahalli gate.	1	20	20	20		

SNo	Location / Road	Nos.	Unit Cost per G.S (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
44	Along Varthur Road near Lakshmi Layout	1	20	20	20		
45	Along Panathur Main Road near Bellandur Rly Stn	1	20	20	20		
46	Along Sarjapur Road	1	25	25	25		
	Total	**18**		**432**	**432**		
Elevated Roads							
47	Elevated Road From Sirsi Circle to ORR on Mysore Road	6	60	360	360		
48	Elevated Road on Hosur Road	10.5	60	630	630		
	Total	**16.5**		**990**	**990**		

Table 9.6 Cost Estimates for Proposed Pedestrian Facilities (Rs Crore)

Sl No	Name of Road	Length (km)/No.	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
1	Improvement & augmentation of foot paths	350	0.2	70	70		
Skywalks/subways							
2	Cauvery Bhavan to KG circle crossing across KG Road and Distt. Office Road	1	10	10	10		
3	Opposite NTI connecting Guttahalli Road and Palace (opposite Bus Stop) on Sankey Road.	1	3	3	3		
4	Arya Bhavan Sweets to Kanthi Sweet to Himalaya Theatre, crossing KG Road	1	3	3	3		
5	Lalbagh Main Gate (Javaraiah Circle)	1	3	3	3		
6	Bannergatta Road near Jayadeva Hospital	1	3	3	3		
7	BMTC Main Bus Stand to Amar Lodge Building in Majestic Area	1	3	3	3		

Sl No	Name of Road	Length (km)/No.	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
8	KSRTC Kempegowda Bus Station to BMTC Main Bus Station.	1	3	3	3		
9	At Kengeri Bus Stand, Mysore Road	1	3	3	3		
10	At Byatarayanapura on Bellary Road (near Junction of BBMP office complex).	1	3	3	3		
11	BMTC Main Bus Station to Railway Station Premises	1	3	3	3		
12	Shanthala Silk House to KSRTC Main Bus Station and to Good-Shed Road	1	3	3	3		
13	RNS Motors, Tumkur road	1	3	3	3		
14	Jalahalli Circle, Tumkur Road	1	3	3	3		
15	Near Webb junction	1	3	3	3		
16	Near Kamakhya, Kathriguppe Ring Road	1	3	3	3		
17	Gandhi Bazaar Main Road	1	3	3	3		
18	On Vittal Mallya Road near Mallya Hospital	1	3	3	3		
19	Seshadri Road near Maharani College	1	3	3	3		
20	On JC Road near Ravindra Kala Kshetra	1	3	3	3		
21	On Hosur Main Road near Madivala Check post	1	3	3	3		
22	On Raja Ram Mohan Roy Road, near Pallavi theatre	1	3	3	3		
23	On Richmond Road near D'Souza Circle.	1	3	3	3		
24	On Race Course Road near Chalukya Hotel	1	3	3	3		
25	On Commissariat Street near Garuda Mall	1	3	3	3		
26	On Residency Road near Mayo Hall.	1	3	3	3		
27	On Kamaraj Road near Commercial Street	1	3	3	3		

Sl No	Name of Road	Length (km)/No.	Unit Cost per Km	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
28	Near Indira Nagar 100 feet Road & Water Tank junction on Airport Road	1	3	3	3		
29.	On Hosur Road (Near Forum)	1	3	3	3		
30.	On Tumkur Road, near SMS Railway Junction	1	3	3	3		
31.	On Air Port Road, Marath Halli at Village Road	1	3	3	3		
32.	On Air Port Road, Marath Halli at Junction of ORR Under Pass	1	3	3	3		
33.	K.R. Pura Bus Stand	1	3	3	3		
34.	Bharatiya Vidya Bhavan, Devaraj Urs Road	1	3	3	3		
35.	On Hosur Road "T" Junction with Tavarekere Main Road (Opposite Sai Sadan & Prestige Acropolis) (High Rise Apartments Condominium)	1	3	3	3		
36.	Mission Road at the foot of Fly over	1	3	3	3		
37.	Vidhana Veedhi near M S Building	1	3	3	3		
38.	Tumkur Road near Yeshwantpur Circle	1	3	3	3		
39.	At South End Circle	1	3	3	3		
40.	30 no. Sky -walks / Sub-Ways along the eastern crescent of the ORR	30	3	90	90		
	Sub-Total	68		211	211		
	TOTAL			**281**	**281**		

Table 9.7 Cost Estimates for Proposed Parking Facilities (Rs Crore)

S.No	Location	Type	Capacity	Cost per Parking Space (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013-18	Phase-III 2019-24
1	M G Road	AMP	500	0.05	25	25		
2	Kamraj Road	AMP	500	0.05	25	25		

S.No	Location	Type	Capacity	Cost per Parking Space (Rs. Cr.)	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013-18	Phase-III 2019-24
3	Gandhi Nagar	AMP	500	0.05	25	25		
4	Jayanagar Shopping Complex	CMP	1000	0.02	20	20		
5	Koramangala near Raheja Tower	CMP	1000	0.02	20	20		
6	Rajaji nagar BDA Complex	CMP	500	0.02	10	10		
7	Banashankari BDA Complex	CMP	1000	0.02	20	20		
8	Gandhi Bazaar	CMP	500	0.02	10	10		
9	Malleshwaram	AMP	500	0.05	25	25		
10	Fire Station, Residency Road	AMP	500	0.05	25	25		
11	Dhobi Ghat, Cunningham Road	AMP	500	0.05	25	25		
12	SP Office, Miller Road, Cunningham Road crossing	AMP	500	0.05	25	25		
13	Near Sagar & States	AMP	500	0.05	25	25		
14	Kanteerava Stadium	AMP	500	0.05	25	25		
15	City Market	AMP	500	0.05	25	25		
16	Bakshi Garden	AMP	500	0.05	25	25		
17	Majestic	AMP	500	0.05	25	25		
	Total		**10000**		**380**	**380**		

Table 9.8 Cost Estimates for Proposed Integrated Freight Complexes (Rs Crore)

S.No.	Location	No.	Cost per Unit	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
1	Hosur Road	1	45	45	45		
2	White Field Road	1	45	45		45	
3	Old Madras Road	1	45	45		45	
4	Bellary Road	1	45	45		45	
5	Tumkur Road	1	45	45	45		
6	Mysore Road	1	45	45	45		
	Total	**6**		**270**	**135**	**135**	

Table 9.9 Cost Estimates for Transport System Management Measures (B-TRAC) (Rs Crore)

SNo	Component	Nos	Unit Cost Crs	Total Cost (Rs. Cr.)	Phase-I 2007-12
1	Junction Improvements	250	0.7	175	175
2	Street Furniture and Road Marking			100	100
3	Intelligent Transport System including. ATC, VMS etc for 250 intersections			150	150
4	Surveillance / monitoring and enforcement cameras etc			50	50
5	Education and Training / Others			25	25
	Total			**500**	**500**

9.2.2 Summary of the cost estimates for various projects is given in **Table 9.10.** Overall cost of the entire plan is estimated as Rs 46,944 crore of which Rs 31,377 crore is proposed for Phase I (2007-12). Cost of the projects proposed in Phase II is Rs 14,157 crore.

Table 9.10 Summary of Cost Estimates for the Entire T&T Plan (2007 prices)(Rs Crore)

ITEM	Length kms/Nos	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
MASS TRANSPORT CORRIDORS					
Metro System	137	19921	11086	8835	0
Mono Rail / LRT System	60	5100	3825	1275	0
Commutor Rail System	204	3060	690	1620	750
BRT System	291.5	3498	1866	1632	0
IMPROVEMENT IN CITY BUS SYSTEM					
Improvement in City Bus System		5721	4401	660	660
ROAD INFRASTRUCTURE					
New Roads	209.2	5192	5192	0	0
Outer Ring Road Realignment	17	311	311	0	0
Road Improvements (Inside ORR)	142	142	142	0	0
Road Improvements (Outside ORR)	503	433	433	0.00	0.00
GRADE SEPARATORS					
Grade Separators-Road (Nos.)	28	713.0	713.0	0.0	0.0
Rail Over Bridges / RUBs-Rail (Nos)	18	432	432	0	0
Elavated Roads (Kms)	16.5	990	990	0	0

ITEM	Length kms/Nos	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
PEDESTRIAN FACILITIES		**281**	**281**	**0**	**0**
PARKING FACILITIES (No. of car spaces)	10000	380	380	0	0
Integrated Freight Complexes (IFC):	6	270	135	135	0
B-TRAC		**500**	**500**	**0**	**0**
GRAND TOTAL		**46944**	**31377**	**14157**	**1410**

9.3 BROAD FINANCING OF TRANSPORTATION PROJECTS

9.3.1 The estimated investment for the entire T &T Plan based on public transport oriented system for the period till 2025 is estimated to be Rs 46944 crore at 2007 prices as given in **Table 9.10**. More than two-thirds of this investment is proposed during the period 2007-12 which coincides with the JNNURM mission period. The proposed Implementing Agency (given in **Table 9.11**) and tentative financing structure for each of the major investments proposed is dealt with briefly below:

Table 9.11 Implementing Agencies for Various Projects

S.No	ITEM	Implementing Agency
1.	Metro	BMRCL
2.	Mono Rail / LRT	BMRCL/New Company
3.	Commuter Rail System	Railways/Govt of Karnataka /BMRDA
4.	BRT	BMTC / BBMP/BDA
5.	City Bus System (including Inter City Bus Terminals)	BMTC/KSRTC
6.	New Roads	BBMP/BDA
7.	Road Improvements (Inside ORR)	BBMP
8.	Road Improvements (ORR & Outside ORR)	BBMP,BDA/NHAI
9.	Grade Seperators	BBMP/NHAI/ BDA
10.	Rail Over Bridges / RUBs	Railways / BBMP
11.	Improvement & augmentation of foot paths	BBMP
12.	Pedestrian Sky Walks / Sub-Ways	BBMP
13	Parking Facilities	BBMP
14	Integrated Freight Complexes (IFC)	BDA
15	B-TRAC	BBMP/Traffic Police

9.3.2 Metro

Out of Rs 19,921 crore of investment for the 137 km of Metro, financing for Rs 5605 crore corresponding to the present phase I corridors under implementation now (about 34 km) has already been arranged and the project is implemented by BMRCL, a company incorporated for the purpose. Balance investment for Metro would also be mobilized by the company through a combination of contributions from Government of India, Government of Karnataka and debt financing. It is also recommended that JNNURM funding from Government of India to an extent of Rs 532 crores be sought to finance the balance Rs 1521 crores for the Phase I. The recommended funding pattern for Rs 1521 crores for Phase I is as follows:

- Government of India (JNNURM) funding: Rs 532 Cr
- Government of Karnataka (JNNURM) funding: Rs 228 Cr
- BMRCL / Debt funding: Rs 761 Cr

The Airport Metro Project may be implemented on BOT basis with viability gap funding from the Government.

9.3.3 Mono Rail / LRT

The implementing agency for mono rail / LRT could either be BMRCL or a new special purpose company to be incorporated. It is recommended that funding for this project be on similar lines as Metro. The viability of the scheme should be established at the time of preparation of the detailed project report.

9.3.4 Commuter Rail System

This project involves the active participation of three principal stake holder's viz. Railways, State Government and the implementing agency. The implementing agency for the project could be BMRDA / BDA or a special purpose company. Since the proposed rail system extends beyond BBMP area it is recommended that the project promoter is BMRDA. The funding pattern is recommended to be:

- Railways – Railway related infrastructure including rolling stock and O&M approx one third of the project cost
- Government of Karnataka – One third of the project cost to cover the cost of expansion of stations, and additional tracks
- BMRDA – Access roads, parking facilities and passenger facilities to cover one third of the project cost

9.3.5 BRT System

Implementing agency for BRT system may be BMTC or a new special purpose company to be incorporated with representative from BBMP, BDA and BMRDA. The project may be implemented on PPP model.

9.3.6 All Road Improvements and New Roads

Investments to the extent of Rs 8154 crore proposed till 2012 for road related infrastructure would be implemented by Bruhat Bangalore Mahanagara Palike (BBMP), BDA etc. It is recommended that the funding for these projects be arranged under the JNNURM scheme seeking 35% grant from GOI, 15% from GOK and balance to be arranged by BBMP/BDA through debt financing and internal resources. Since this represents the core infrastructure for decongesting the city traffic system the funding should be routed through the JNNURM.

9.3.7 City Bus System/Inter-city Bus System

Out of estimated investment of Rs 5,721 crore, the cost of rolling stock requirement by the city bus transport corporation is Rs 2200 crore. This amount is proposed to be funded through internal resources and project financing structure of the corporation. The balance amount of Rs 3,521 crore represent the infrastructure support required by the transport corporations. An amount of Rs 3,401 crore is proposed to be incurred during the period 2007-12 and it is recommended that the same be funded under the JNNURM funding pattern viz:

- GOI: 35% - Rs 1,190 Crore
- GOK: 15% - Rs 510 Crore
- BMTC/KSRTC: 50% - Rs 1,701 Crore (IMTCs / Inter-city Bus Terminals could also undertaken by KSRTC on PPP model)

For the phases II and III the funding will have to be arranged by the company based on the strength of its balance sheet.

9.3.8 Footpaths/Pedestrian Sky Walks/subways and Parking facilities

An amount of Rs 661 crore is estimated towards improving and strengthening the pedestrian facilities and establishing parking facilities at identified locations across the city. The funding for the same shall be arranged though a PPP model where revenue sharing models could be explored. Viability gaps if any could be funded by BBMP the implementing agency.

9.3.9 Integrated Freight terminals

An amount of Rs 270 crore for establishing freight complexes at six locations is recommended to be funded through a PPP model involving oil companies, freight operators, industries' associations and BDA as the implementing agency.

9.3.10 Transport System Management Measures (B-TRAC)

This component represents the intelligent road system including traffic management systems to be introduced in the city to reduce the number of accidents and regulate the traffic using technological interventions. It is proposed that the amount of Rs 500 crore estimated under this head is posed under JNNURM with 50% contribution of the ULB allocated by BBMP (balance 50% from GOI and GOK as per JNNURM norms).

9.4 FUNDING OF INFRASTRUCTURE THROUGH DEVELOPMENT, CONVERSION & INFRASTRUCTURE DEVELOPMENT CHARGES

Alternatively Government can also partly finance the CTTP by imposing External Development Charges (EDC), Licence Fee, Conversion Charges of land-use and Infrastructure Development Charges (IDC) on the lines of Haryana Government for the new developing areas (about 320 sq km) in Bangalore. The estimated revenue that can be generated through these sources is given in **Table 9.12** below:

Table 9.12 Expected Recoverable Charges through Development of External Areas as per Master /Zonal Plans 2015

Landuse	Net Extension Area Sq. Kms	Rates prevalent per Sq Mts in Haryana	Suggested Avg.Rates of EDC, IDC, Conv. Charges, License Fee per Sq Km	Expected Returns Rs. Cr
Residential	255			
Plotted Dev. (60%)	153	1227	125	19125
Gr. Housing (40%)	102	3328	350	35700
Commercial	38	11297	1150	43700
Industrial	6.5	1250	125	812.5
I.T	20	2271	250	5000
Total	**319.5**			**104337.5**
Assuming 75 % of the above Returns to be used for Town Level Public Health Services (Water Supply, Sewerage, Storm Water Drainage), Power, Community Facilities etc.				Rs. 78253.125 Cr.
Balance amount that should be used for financing CTTP				Rs. 26084.375 Cr.

Thus about Rs 100,000 crore can be generated through the above charges for the planned new areas for development as per the Master Plan 2015. Out of this about Rs 20000 to 25000 crore may be used for financing transportation projects.

CHAPTER – 10

INSTITUTIONAL STRENGTHENING

10.1 REGIONAL PLANNING

10.1.1 Though the Study covers the transportation problems in the BMA, the impact of the traffic from the neighboring towns has also to be taken into consideration. The description of the BMR has already been given in Chapter 1. These towns lie in outer belt and the traffic which emanates from or bound for these come into or exit the city mostly though the major radials like Mysore Road, Magadi Road, NH-7, NH-4 and NH-209. The traffic to and from these areas have been accounted for through the outer cordon survey. Planning for these townships is being carried out independently by Bangalore Metropolitan Regional Development Authority (BMRDA). The data available individually for these towns as at present is meager. Hence, for the purpose of this study, the traffic which is passing through the outer cordon as determined by traffic counts at cordon points has been considered as the basis. The BMRDA is also involved in the development of the satellite towns and BIAPPA area.

10.1.2 As such it is presumed that any future planning in these areas will be directly controlled by the BMRDA or the BMRDA will be more actively involved in their development plans. According to the present structure, the overall planning in the BMRDA in respect of land use and transportation facilities is looked after and controlled by the BMRDA which forms the nodal agency. However the planning in respect of industries, education, commerce etc., for areas outside the city, are done by the respective Departments of the State Government at District level. They are coordinated by the District Commissioners. Within the city, it is partly coordinated by BDA and the City Corporation. The implementation of the various plans / proposals in the region is thus under different agencies as discussed below.

10.2 AGENCIES INVOLVED IN CIVIC WORKS

10.2.1 Presently day-to-day land use control and maintenance of services like drainage, roads etc., are done by Bruhut Bangalore Mahanagara Palike, BDA, TMCs and CMCs, while BDA prepares the Master Plan and development control regulations. The road infrastructure connecting the different municipalities, towns and also the National Highways and the State Highways passing through the city and these are maintained, improved and expanded by the Public Works Department/NHAI. The water supply within the city is looked after by the Bangalore Water Supply & Sewerage Board (BWSSB) and by respective municipalities in TMCs and CMCs.

10.2.2 Progress of works and flow of funds in respect of any aided projects, is watched and monitored by a Project Management Department/ Division of KUIDFC.

10.3 ROLE OF VARIOUS TRANSPORTATION AGENCIES

10.3.1 Transport Department

10.3.1.1 The Commissioner for Transport is in-charge of the licensing of the motor vehicles, issue of route permits/area of operation and monitoring condition of the vehicles by having them periodically examined and also maintaining the various statistics with regard to the transportation in the whole city. There are nine Regional Transport Officers who control the licensing and monitoring of the vehicle operations in and around BMA. While the commercial vehicles and larger passenger vehicle operations are licensed for statewide operation, the licensing for IPT modes like auto-rickshaws are confined to respective districts. There are certain constraints on their operations outside their respective areas, particularly from the district into the city, which sometimes cause problems. Even collection of the data on the vehicles operating in the metropolitan region becomes difficult in view of this.

10.3.2 Traffic Engineering & Transport Management

10.3.2.1 The traffic engineering works, design and implementation within the city is looked after by a separate division under the Engineering Department in BBMP and BDA. In parallel, the Commissioner of Police under whom there is a Traffic Division also initiates and implements certain traffic engineering proposals as part of traffic management.

10.3.2.2 The Traffic Management is considered an enforcement function and the Traffic Division under the Commissioner of Police does all the planning and implementation within the city as mentioned earlier. There is a coordinating body which is of a recommendatory nature functioning in the under Home Secretary.

10.3.3 Public Transport consisting of Road and Rail within BMA

10.3.3.1 The road transport is looked after by Bangalore Metropolitan Transport Corporations (BMTC) working under the direct control of the Secretary / Transport of the State Government. In addition, there is Karnataka State Road Transport Corporation serving peripheral areas and regional towns around BMA.

10.3.3.2 Bangalore Metro Rail Corporation Limited (BMRCL) has been entrusting with the implementation of Bangalore Metro.

10.3.3.3 The Railway transport is under the South Western Railway, which works under the Ministry of Railways of the Central Government. There is very little coordination between these agencies. The fare policies are dictated by the State Government for bus and by the Central Government under the authority of the Parliament for the Railways. The expansion of facilities and utilisation of the available facilities are done by the respective agencies depending upon the availability of funds. Their routing and services are also run, keeping in view need for maximizing their use of assets and revenues. This naturally results in development of very little inter-modal services for the benefit of the commuters.

10.3.3.4 Existing institutional arrangement for transportation in Bangalore is given in **Table 10.1**.

Table 10.1- Existing Institutional Arrangement for Transport in Bangalore

S.No.	Functions	Institution
1.	Policies and framework affecting transport sector	Departments of Urban Development and Transport
2.	Road building, road maintenance, street lighting, Construction of select ring roads and grade separators Construction of bus shelters Construction of traffic islands Issue of permission for road cutting	Bruhat Bangalore Mahanagara Palike (BBMP) the urban local body of the Bangalore City
3.	Enforcement of traffic laws and regulations, management of traffic junctions and corridors, regulation of right of ways, parking and right of ways	Bangalore City Traffic Police
4.	Public transport system - bus based - construction and maintenance of bus depots, stations and passenger centres	Bangalore Metropolitan Transport Corporation (BMTC)
5.	Public transport system - Metro Rail	Bangalore Metro Rail Corporation Limited (BMRCL)
6.	Preparation of Comprehensive Development plan (CDP) (primarily land use and zoning), formulating of regulations, construction of select ring roads and grade separators	Bangalore Development Authority (BDA)
7.	Planning of transport System in BMR	BMRDA
8.	Registration of motor vehicles, issue of licenses and enforcement of regulations	Regional Transport Office and Department of Transport, Government

S.No.	Functions	Institution
	of motor vehicle act	of Karnataka
9.	Monitoring of air quality and noise levels	Karnataka State Pollution Control Board (KSPCB)
10.	Infrastructure and finance	Karnataka Urban Infrastructure and Finance Corporation Limited (KUIDFC)
11.	Construction and Operation of rail system	Indian Railways
12.	Construction and maintenance of NH	NHAI

10.4. NEED FOR UNIFIED METROPOLITAN TRANSPORT AUTHORITY

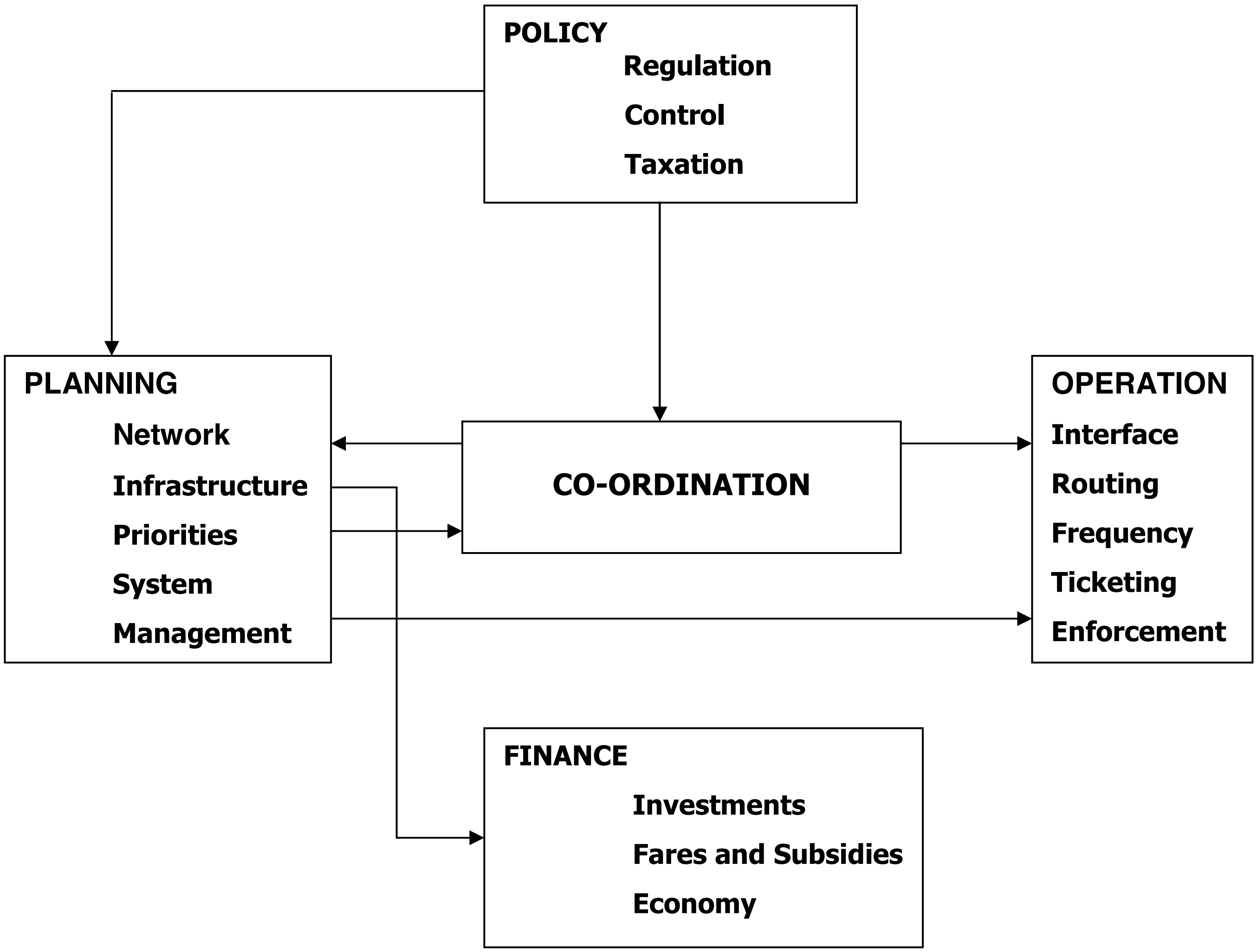
10.4.1 The above discussion suggests that there are many agencies involved in the urban transport in Bangalore. As such there is nothing wrong in multiplicity of authorities. However currently there is no mechanism to ensure coordination among various institutions which is one of the key road block affecting formulation and implementation of major schemes and initiatives to improve the traffic situation and mobility plans in the city. Close co-ordination is needed on number of factors as indicated in **Figure 10.1**.

10.4.2 Since early 1990s planners in India have been suggesting need for a unified metropolitan transport authority (UMTA)in order to ensure co-ordination, co-operation and continuity. In view of the fact that both central and state government agencies are involved in providing urban transport, such an authority will need to be created by an act in Parliament, even though the city and state governments are primarily responsible for urban planning including transport. Alternatively, it can be one of the existing authorities with full powers of planning, implementation and control. Such an authority could be an urban development authority at the third level. All departments of the authority should be manned by skilled personnel in technical jobs. The authority should ensure planning, development, co-ordination and implementation.

10.4.3 The National Urban Transport Policy has recommended setting up of Unified Urban Transport Authorities (UMTA's) in million plus cities. In the policy document it is observed as follows:

'*The current structure of governance for the transport sector is not equipped to deal with the problems of urban transport. These structures were put in place well before the problems of urban transport began to surface in India and hence do not provide for the right coordination mechanisms to deal with urban transport. The central government will, therefore, recommend the setting up of Unified Metropolitan Transport Authorities (UMTA's) in all million cities to facilitate more co-ordinated planning and implementation of urban transport programmes & projects and integrated management of urban transport systems. Such Metropolitan Transport Authorities would need statutory backing in order to be meaningful*'.

Figure 10.1 Unified Metropolitan Transport Authority



10.5 DIRECTORATE OF URBAN LAND TRANSPORT

10.5.1 Bearing in mind the National Urban Transport Policy, the Government of Karnataka felt that there is a strong case for reorganization of the administration structure dealing with urban land transport in the State by creation of a State Directorate of Urban Land Transport (DULT) under the administrative control of the Urban Development Department. Considering this, DULT has now been sanctioned by the State Government. The functions of the DULT are as follows.

1. Periodic assessment of travel demand in a given area through CTTS and other studies
2. Determination of level of public transport required on different corridors and the type of transport system required.
3. Assessment and recommendation of the new investments needed for creation of transport infrastructure
4. Apart from State owned service providers devising a system of procurem,ent of public transport services from private operators nad ensuring compliance
5. Setting policy guidelines for development of total network
6. Actively liaising with the municipal bodies/UDAs in designing and developing integrated policies and plans

10.5.2 The Directorate of Urban Land Transport (DULT) shall initially cover jurisdiction of seven Municipal Corporatioons in the State viz, Banagalore, Msore, Mangalore, Hubli-Dharwar, Belgaum Gulburga and Bellary. The integrated transport plans for these cities may extend to the local planning areas (LPAs) also. It will be gradually extended in stages to all towns / cities and urban settlements with a population of over one lakh.

10.5.3 The newly created directorate of Urban land Transport (DULT) shall take up comprehensive traffic and transportation studies (CTTS) for the six Municipal Corporations (excluding Bangalore). These studies would help assess the urban transport needs over a medium term perspective (say 25 years), identify technological and cost options, intensity of local urban economic activity and paying capacity of the average population and in short help arrive at an optimal urban transport solution. On completion of the CTTS, the existing master plan for the LPAs of these cities will be updated / revised to incorporate the necessary land use changes so that the transport and land use plan are totally integrated. A city level investment plan for creation of transport infrastructure together with sources of financing will also have to be created so as to enable posing of the projects for financing under different schemes including multilateral / bilateral assistance as also on PPP basis.

10.5.4 Other functions of the State Directorate of Urban Land Transport would include (i) road network planning in the urban areas, (ii) setting of technical standards for construction of the maintenance of urban roads, (iii) planning execution of infrastructure for pedestrians/cyclists, (iv) comprehensive drainage network to ensure road quality, (v) parking infrastructure ets. All of them will be part of the Intergrated Transport Plan at the city level and would be developed in close coordination with the local bodies who will eventually need to adopt the plan.

10.5.5 An important aspect with respect to the adopted functions of the State Directorate for Urban Land Transport is capacity building. It is necessary to develop a manpower base for good and sustainable urban transport planning and execution by creating a pool of skilled manpower. There is a need to:

1) Strengthen academic programme in the State in urban transport
2) Create systems for accreditation of specialists in urban transport
3) Ensure mechanism for continuous training at all levels.

A multi disciplinary team of experts will be constituted as an advisory board for the State Directorate of Urban Land Transport to provided inputs for:

1) Capacity building
2) Academic and educational programmes
3) Preparation of standards/manuals/codes
4) Development for Intelligent Transport System (ITS)
5) Other technical issues related to urban transport

10.5.6 The Organisation for DULT is supposed to have Commissioner (Urban Land Transport), Special Officer (Urban Planning), Traffic & Transportation Planners, Traffic Engineer etc. It is necessary that DULT is staffed with adequate numbers of transportation personnel as it will cover urban transport for all cities of Karnataka.

10.6 BANGALORE METROPOLITAN LAND TRANSPORT AUTHORITY

10.6.1 Bearing in mind the National Urban Transport Policy, the State Government considered it also necessary to create an Unified Metropolitan Transport Authority for the Bangalore Metropolitan Region (BMR) which will function as an umbrella organization to coordinate planning and implementation of urban transport programmes and projects and provide an integrated management structure. All land transport systems (excluding Railways) in the BMR may be brought under all purview of the Bangalore Metropolitan Land Transport Authority (BMLTA). The BMLTA will be created initially under an executive order and later with statutory backing.

10.6.2 Under the circumstances explained above, Government has already sanctioned creation of Bangalore Metropolitan Land Transport Authority (BMLTA) for Bangalore metropolitan Region (BMR) as per Government Order No. UDD 134BMR 2006 (2),Bangalore dated 09.03.2007. This shall be taken up as a part of the Greater Bangalore reorganization exercise so as to make it operational by 2007-08. Initially as an interim arrangement, the Government has set up this as a Committee of the BMRDA with the Chief Secretary as Chairman with the following composition.

1.	Chief Secretary to Government	Chairman
2.	Principal Secretary, Finance Department	Member
3.	Principal Secretary, UDD	Member
4.	Principal Secretary, Transport Department	Member
5.	Principal Secretary, Forest Ecology & Environment Department	Member
6.	Principal Secretary, Public Works Department	Member
7.	Commissioner, Urban Land Transport (DULT)	Member
8.	Commissioner, BMP	Member
9.	Commissioner, BDA	Member
10.	Managing Director, BMTC	Member
11	VC & Managing Director, KSRTC	Member
12	Commissioner, BMRC	Member
13.	Commissioner of Police	Member
14.	Managing Director, KUIDFC	Member
15.	Representatives from Railways, AAI etc	Member
16.	Any other experts connected with the Urban Transport found necessary	Member
17.	Commissioner, BMRDA	Member Secretary

10.6.3 The Functions of BMLTA / committee shall be as follows:

(1) To coordinate all land transport matters in the BMR

(2) To prepare detailed Master Plan for Transport Infrastructure based on the Comprehensive Traffic and Transport Study for Bangalore.

(3) To oversee implementation of all transportation projects

(4) To appraise and recommend transportation and infrastructure projects for bilateral / bilateral Central assistance.

(5) To function as empowered Committee for all Urban Transportation Projects

(6) To initiate action for a regulatory frame work for all land transport systems in BMR.

(7) To initiate steps, where feasible for common ticketing system.

(8) Take any other decision for the integrated urban transport and land use planning and implementation of the projects.

(9) Any other functions entrusted from time to time.

10.6.4 BMLTA / committee will function as an umbrella organization to coordinate planning and implementation of urban transport programmes and projects and provide an integrated management structure. All land transport systems (excluding Railways) in the Bangalore Metropolitan Region shall be brought under the purview of BMLTA / Committee.

10.6.5 It is seen from the above that the GOK has already taken the lead and has initiated steps to strengthen the institutions for urban transport. Therefore it is important that BMLTA is established at the earliest with statutory backing and adequate technical staff provided for this organization. It is also important that BMLTA is also given with the power to assign various projects to various organizations. All the finances for transportation projects to the concerned organizations should also be routed through BMLTA in order to make BMLTA effective and to ensure timely completion of projects.

10.6.6 Shifting of utilities, a key function encountered in most of the road improvement works as well construction of new roads requires very effective coordination among institutions to ensure timely completion of projects. This key function is reported to be the major contributor for project delays and cost over runs. Revamping of institutional arrangements with assignment of authority to single entity to accord approvals and sanction would enhance the efficiency of implementation of major projects proposed under the CTTS. The study recommends that this be vested with BMLTA.

10.7 TRANSPORT PLANNING UNIT (TPU)

10.7.1 The role of BDA with regard to town planning is defined within the BDA act as follows:

- i) To prepare a structure plan for the development of BMA
- ii) To formulate schemes for implementation the structure plan
- iii) To secure and coordinate the execution of the town planning schemes for development of transport infrastructure and management of transport system in accordance with the plan.
- iv) To entrust to any local authority the work of execution of the development plan and schemes
- v) To coordinate the activities of the various bodies which are concerned with developmental activities.

10.7.2 Transport planning is essential ingredient of the town planning. Presently there is no proper technical body for the required transport planning inputs. It is necessary that technical expertise is created not only within BDA to undertake this task but also in BMRDA to carry out similar jobs at Bangalore Metropolitan Region Level.

10.7.3 The proposed Transport Planning Unit (TPU) will perform the following specific functions:

i) To prepare a strategic plan for long term development and utilisation of transport facilities
ii) To formulate schemes for implementing the strategic transport plan
iii) To secure and coordinate the execution of schemes for development of transport infrastructure and management of transport system in accordance with the plan.
iv) To entrust to appropriate local authorities the work of execution of transport schemes
v) To coordinate activities of the various bodies concerned with transport with BDA
vi) To define a strategic transport network for BDA / BMRDA
vii) To define a metropolitan transport policy based on strategic network demand and plan.

10.7.4 The other important responsibilities of Transport Planning Unit will include the establishment of criteria for capital investment and methods for fixing the priorities for road and transport schemes and feasibility studies. The TPU will also be responsible to prepare definite policies related to public transport, road safety, environmental protection and goods movement pattern with related agencies dealing with road planning, railways, traffic engineering, enforcement and regulation will be imperative.

10.7.5 The TPU will be headed by a Senior Transport Planner, who will be of rank of superintending Engineer. The head will be overall in charge and will give the necessary direction to the unit apart from the high level coordination with the concerned departments. He will be assisted by two transport planners, one for policy planning and other for the co-ordination and monitoring. An economist at a senior level is also proposed to be associated with the unit on a part time basis depending upon the requirements.

10.8 TRAFFIC ENGINEERING CELLS (TEC)

A large number of agencies deal with roads such as BBMP, BDA, Traffic Police, PWD, NHAI, BMRDA, Transport Department, KUIDFC, BMRCL, BMTC, BMLTA etc. There are numerous issues of proper road geometrics, traffic circulation, junction design, traffic signals, road signs/markings, street furniture etc which are properly attended to by these agencies due to lack of traffic engineering expertise. Traffic planning is a continuous affair. It is therefore important that Traffic Engineering Cells are established in these organizations with qualified and adequate staff such as traffic engineers. This will ensure that the traffic schemes are properly implemented with better results and fine tuned later, if necessary. This will go a long way to improve traffic flow in Bangalore.

EXECUTIVE SUMMARY

COMPREHENSIVE TRAFFIC AND TRANSPORTATION PLAN FOR BANGALORE

1. PROBLEMS AND ISSUES

1.1 Bangalore population has been growing at a rate of 3.25% per year in the last decade. There has been a phenomenal growth in the population of vehicles as well especially the two and four wheelers in this period due to rising household incomes. The number of motor vehicles registered has already crossed 28 lakhs. In the absence of adequate public transport system, people are using the personalized modes which is not only leading to congestion on limited road network but also increasing environmental pollution. An average Bangalorean spends more than 240 hours stuck in traffic every year. Such delays result in loss of productivity, reduced air quality, reduced quality of life, and increased costs for services and goods

1.2 The analysis of collected data from primary and secondary sources has brought the following major issues regarding the transport system of Bangalore.

1. Road network capacity is inadequate. Most of the major roads are with four lane or less with limited scope of their widening. This indicates the need for judicious use of available road space. The junctions are closely spaced on many roads. Many junctions in core area are with 5 legs. This makes traffic circulation difficult. There is need to optimise the available capacity by adopting transport system management measures and by making use of intelligent transportation systems.
2. Traffic composition on roads indicates very high share of two wheelers. The share of cars is also growing. This indicates inadequate public transport system. V/C ratios on most of the roads are more than 1. Overall average traffic speed is about 13.5 kmph in peak hour. This not only indicates the need of augmenting road capacity but the also to plan high capacity mass transport systems on many corridors.
3. Outer cordon surveys indicate high through traffic to the city. This points to the need of road bypasses not only for Bangalore Metropolitan Area (BMA) but also for Bangalore Metropolitan Region (BMR). High goods traffic also indicates the need of freight terminals at the periphery of the city.
4. The household travel surveys indicate high share of work trips. This segment of travel demand needs to be mostly satisfied by public transport system. Considering the large employment centres being planned in the BMA, the public/mass transport system needs to be upgraded/extended substantially.

5 At present, modal split in favour of public transport is about 46% (exclusive of walk trips). The trends show a decline in this share over the last two decades. This is further expected to fall unless adequate and quality public transport system is provided to the people of Bangalore. Share of two wheelers and cars in travel demand is disturbingly high. This trend needs to be arrested.

6 There is high pedestrian traffic in core area and some other areas in Bangalore. Footpath facilities are generally not adequate and their condition is deteriorating. Therefore up gradation of their facilities is very important. Share of cycle traffic has declined over the years. This mode of transport needs to be promoted by providing cycle tracks along the roads.

7 Parking is assuming critical dimensions in Bangalore. Parking facilities need to be augmented substantially. In the long run, city-wide public transport system needs to provide not only to reduce congestion on roads but also to reduce parking demand.

8 Area of the BMA has been increased as per Revised Master Plan-2015. This plan has provided for densification of existing areas, Mutation corridors, hi-tech areas etc in various parts of the city. This likely to have a major impact on traffic demand. The transport network including mass transport system needs to be planned taking the proposed development in to consideration.

9 Major developments have been proposed in the suburban towns of Bangalore by BMRDA in the BMR. This is likely to increase interaction between Bangalore and these suburban towns. There will be need to provide commuter rail services to these towns from Bangalore.

1.3 Thus while planning for the transport system of Bangalore, the above problems and issues need to be kept in consideration. The issues relating to traffic and transportation in a large and growing city like Bangalore need to be viewed in the larger perspective of urban planning and development. Issues relating to land use planning and development control, public-private transportation policy and industrial location would need to be integrated at the perspective planning level. With Metro Rail under implementation there is the need to coordinate inter modal transport issues.

2. THE PREFERRED STRATEGY FOR TRANSPORT DEVELOPMENT

In order to prepare the Comprehensive Transport Plan the following policy measures have been considered.

1 Extension of mass transport system to provide wide coverage and transport integration with other modes of transport.

2 Provide substantially large network of medium level mass transport system such as BRT to cover the areas beyond the Metro network and on over loaded corridors.
3 Landuse adjustments and densification of corridors along mass transport corridors where possible.
4 Extension of commuter rail system upto the BMRDA's New Townships & beyond upto Tumkur, Hosur etc. to act as sub-urban services.
5 Rationalisation of local bus system and its augmentation.
6 Improvement in traffic management through TSM measures.
7 Special facilities for pedestrians within the entire network specially in the core areas; pedestrianisation of selected shopping streets in side the core area going to be served by Metro. Provision of pedestrian sky walks/subways, footpaths and road furniture along the roads where necessary.
8 Diverting through traffic on Peripheral Ring Road. Providing transport hubs at the junctions of Peripheral Ring Road with important radials such as; the National Highways and other heavily loaded roads.
9 Improving primary, arterial and other important roads (particularly radial and ring roads) by providing grade separation, junction improvements, adding missing links, widening and other road side facilities wherever necessary.

3. TRANSPORT DEMAND ANALYSIS

3.1 Population of the BMA is expected to increase from 61 lakh in 2001 to 88 lakh in 2015 and 122 lakh in 2025. Considering proposed land use, transport sector requirements upto 2025 have been assessed using travel demand modeling. The transport sector recommendations contained in the Master Plan for BMA, city development plan proposed by Bruhat Bangalore Mahanagara Palike (BBMP) under the auspices of Jawaharlal Nehru National Urban Renewal Mission (JNNURM), region development plan prepared by Bangalore Metropolitan Regional Development Authority (BMRDA), development plans of Bangalore International Airport Area Planning Authority (BIAAPA) and Bangalore-Mysore Infrastructure Corridor Area Planning Authority (BMICAPA) have been examined.

3.2 For the purpose of transport demand analysis, various scenarios have been considered as follows.

Scenario 1: This scenario considers a 'do minimum' situation wherein Improvement & augmentation in existing system for the bus network and roads already proposed. The purpose of the scenario is to capture the intensity of the problem if no measures are taken to overhaul the transport system in the city
Scenario 2: in addition to what has been considered in scenario 1, scenario 2 considers the implementation of metro project as planned, a mono rail system

covering 50 km, a BRT system covering 30km, commuter rail system covering 62 km, elevated core ring road of 30 km, a peripheral ring road of 114 km and intermediate ring road of 188 km as proposed IN Master Plan.

Scenario 3: this scenario is developed to address the anticipated demand with extensive public transport system as the focus for development. It is developed upon scenario 2 with additional lines of mass transport systems (about 650 km).

3.3 127 lakh person trips by mechanical modes are estimated to be generated in 2025 against 56 lakh in 2006. Present modal split of 46% in favour of public transport is estimated to fall to 29% by 2025 for scenario 1. Thus most of the trips would be undertaken by personalised modes creating unbearable congested conditions. For scenario 2, modal split in favour of public transport is expected to improve to 50% by 2025. However, this is also not enough for the city of size of Bangalore and many roads would still be overloaded. For scenario 3, the modal split in favour of public transport is estimated as 73%. This modal split is in conformity with the desirable modal split for the city of size of Bangalore as recommended by a Study Group of Government of India. The study, thus, recommends scenario 3 that would fulfill the objectives of the transport sector development integrated with the proposed land use and giving predominance to the public transport system.

4. THE PROPOSED TRAFFIC AND TRANSPORTATION PLAN

4.1 On the basis of projected traffic, an integrated multi-modal mass transport system plan on various corridors has been suggested in order to cater to traffic up to the year 2025. The mass transport systems have been proposed on various corridors considering expected traffic demand by 2025, available road right-of-ways and system capacity. The balance traffic should be carried by road system in order to satisfy the needs of normal bus system and other modes such as two wheelers, cars, bicycles, trucks, pedestrians etc. The proposed Traffic and Transportation Plan for Bangalore contains the following types of proposals, which will cater to requirements of the projected travel demand up to the year 2025.

- Mass Transport System
  - Metro System
  - Monorail/LRT System
  - Bus Rapid Transport (BRT) System
  - Commuter Rail Services
- City Bus System
  - Augmentation of Bus Fleet
  - Grid Routes

- Bus Terminal cum Traffic & Transit Management Centres (TTMC)
- Volvo Depot cum Traffic & Transit centre
- New Bus Stations/bus shelters
- Additional Depots
- IT Infrastructure
- HRD Infrastructure
- Environment Protection Projects

▪ Inter-city Bus Terminals

▪ Transport Integration

▪ Transport System Management Measures

▪ Pedestrian/NMT Facilities

- Footpaths
- Skywalks/Subways
- Pedestrian zones
- Cycle Tracks

▪ Road Development Plan

- New Roads/Missing Links (Peripheral Ring Road, Core Ring Road, New Airport Expressway etc).
- Road Widenings
- Grade Separators
- Re-alignment of Outer Ring Road

▪ Parking Facilities

▪ Integrated Freight Complexes

4.2 Integrated multi modal transport system has been recommended in order to ensure seamless travel. For the balance travel demand, road improvement proposals have been formulated. While making road proposals, entire corridor has been proposed to be improved instead of isolated improvements.

4.3 The proposed mass transport corridors are shown in **Table 1** and **Figure 1**. Proposals pertaining to city bus system (other than BRT), parking, pedestrian and road improvement proposals are shown in **Figures 2 -4**. Summary of proposals is given in **Table 2**.

4.4 Summary of the cost estimates for various projects is also given in Table 2. Overall cost of the entire plan is estimated as Rs 44,029 crore of which Rs 25,872 crore is proposed for Phase I (2007-12). Cost of the projects proposed in Phase II (2013-18) is Rs 17,017 crore.

Table1. Proposed Mass Transport Corridors

S.No	Corridor	Length (km)
	Metro Corridors	
1	Baiyyappanahalli to Mysore Road East-West Corridor	18.0
2	Peenya to R.V terminal North-South Corridor	18.8
3	Extension of North -South corridor from R.V. Terminal upto PRR	10.2
4	Baiyyappanahalli to Benniganahalli along Old Madras Road.	1.5
5	Yelahanka R.S to PRR via Nagavara , Electronic City	36.0
6	Indira Nagar Metro Stn to White field Railway Station via 100ft Indira Nagar Road	19.5
7	Proposed Devanhalli Airport to M.G.Road via Bellary Road	33.0
	Total length	**137.0**
	Monorail/LRT Corridors	
1	Hebbal to J.P. Nagar (Bannerghatta Road) along the western portion of outer ring road	31.0
2	PRR to Toll Gate along Magadi Road	9.0
3	Kathriguppe Road / Ring Road Junction to National College	5.0
4	Hosur Road - Bannerghatta Road Junction to PRR along Bannerghatta Road	15.0
	Total Length	**60.0**
	Commuter Rail Corridors	
1.	Kengeri - Bangalore City Station	13.0
2.	Bangalore City Station - Whitefield	24.0
3.	Bangalore City Station - Baiyyappanahalli Via Lottegollahalli	23.0
4.	Lottegollahalli to Yelahanka	7.0
5.	Banaswadi upto BMA Boundary	29.0
6.	Kengeri- BMA Boundary	9.0
7.	Yeshwantpur to BMA Boundary	14.0
8.	BMA Boundary - Hosur	12.0
9.	BMA Boundary- Ramanagaram	23.0
10	BMA Boundary to Tumkur	50.0
	Total Length	**204.0**
	Bus Rapid Transit (BRT) Corridors	
1	Hebbal to Bannerghatta Road along eastern crescent of outer ring road	33.0
2	Benniganahalli (ORR) to PRR along old Madras Road	7.0
3	From ORR to Hosur Rd along Hi-tech Corridor	8.0
4	Hosur Road to Tumkur Road along PRR (western part)	41.0
5	Tumkur Road-PRR Junction to Hosur Road along PRR via Tirumanahalli, Old Madras Road, Whitefield	76.0

S.No	Corridor	Length (km)
6	Along Core Ring Road	30.0
7	Vidyaranyapura to Nagavarapalya via Hebbal, Jayamahal Road, Queens Road, M.G. Road, Ulsoor, Indiranagar, CV Raman Nagar	29.0
8	Kengeri Sattelite Town to J.P. Nagar along Uttarahalli Road, Kodipur	13.0
9	Banashankari III stage to Banashankari VI stage Ext. along Ittumadu Road, Turahalli, Thalaghattapura	6.0
10	Domlur Ext. to Koramangala along inner ring road	5.0
11	PRR (Mulur) to Maruti Ngr. (up to Hitech corridor) along Sarjapur Road	7.0
12	Peenya to PRR along Tumkur Road	6.0
13	Old Madras Road near Indiranagar to ORR near Banaswadi along Baiyyappanahalli Road –Banaswadi Road	5.5
14	Hebbal to Devanahalli Airport along Bellary Road	25
	Total Length	**291.5**

Table 2. Summary of Proposed Projects and Cost Estimates (2007 prices) (Rs Crore)

ITEM	Length kms/Nos	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
MASS TRANSPORT CORRIDORS					
Metro System	137	19921	11086	8835	0
Mono Rail / LRT System	60	5100	3825	1275	0
Commuter Rail System	204	3060	690	1620	750
BRT System	291.5	3498	1866	1632	0
IMPROVEMENT IN CITY BUS SYSTEM					
Improvement in City Bus System		5721	4401	660	660
ROAD INFRASTRUCTURE					
New Roads	209.2	5192	5192	0	0
Outer Ring Road Realignment	17	311	311	0	0
Road Improvements (Inside ORR)	142	142	142	0	0
Road Improvements (Outside ORR)	503	433	433	0.00	0.00
GRADE SEPARATORS					
Grade Separators-Road (Nos.)	28	713.0	713.0	0.0	0.0
Rail Over Bridges / RUBs-Rail (Nos)	18	432	432	0	0
Elevated Roads (Kms)	16.5	990	990	0	0
PEDESTRIAN FACILITIES		**281**	**281**	**0**	**0**
PARKING FACILITIES (No. of car spaces)	10000	380	380	0	0
Integrated Freight Complexes (IFC):	6	270	135	135	0
B-TRAC		**500**	**500**	**0**	**0**

ITEM	Length kms/Nos	Total Cost (Rs. Cr.)	Phase-I 2007-12	Phase-II 2013- 18	Phase-III 2019- 24
GRAND TOTAL		46944	31377	14157	1410

5. INSTITUTIONAL STRENGTHENING

5.1 The current structure of governance for the transport sector is not adequately equipped to deal with the problems of urban transport. Multiplicity of organizations, independent legislations and inherent conflict in the roles and responsibilities of stakeholders actually impede in the process of planning and implementation of major schemes aimed at development. Government of Karnataka has recently accorded sanction for the creation of State Directorate of Urban Land Transport (DULT) under the Urban Development Department with the intended objective of ensuring integration of transport planning and development of transport infrastructure in urban areas. The government has also sanctioned setting up of Bangalore Metropolitan Land Transport Authority (BMLTA) for BMR. BMLTA will function as an umbrella organization to coordinate planning and implementation of urban transport programmes and projects. All land transport systems (excluding Railways) in the BMR will be brought under the purview of BMLTA. Therefore it is important that BMLTA is established at the earliest with statutory backing and adequate technical staff provided for this organization. It is also important that BMLTA is also given with the power to assign various projects to various organizations. All the finances to the concerned organizations should also be routed through BMLTA in order to make BMLTA effective and to ensure timely completion of projects.

5.2 Transport Planning is an essential component of town planning. Presently there is no proper technical body for required transport planning inputs. It is necessary that technical expertise is created within BDA and BMRDA to undertake this task. For the purpose Transport Planning Unit (TPU) is proposed to be established in BDA and BMRDA.

5.3 A large number of agencies deal with road system such as BBMP, BDA, Traffic Police, PWD, NHAI, BMRDA, Transport Department, KUIDFC, BMRCL, BMTC, BMLTA etc. There are numerous issues of proper road geometrics, traffic circulation, junction design, traffic signals, road signs/markings, street furniture etc which are not properly attended to by these agencies due to lack of traffic engineering expertise. Traffic planning is a continuous affair. It is therefore important that Traffic Engineering Cells are established in these organizations with qualified and adequate staff such as traffic engineers and transport planners. This will ensure that the traffic schemes are properly implemented with better results and fine-tuned later, if necessary. This will go a long way to improve traffic flow in Bangalore. As bus system will continue to be an important sub-system in future also, it is also important that BMTC is adequately strengthened through its HRD initiatives.

 ANNEXURE-R2

Congestion costs incurred on Indian Roads: A case study for New Delhi

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***Abstract*—We conduct a preliminary investigation into the levels of congestion in New Delhi, motivated by concerns due to rapidly growing vehicular congestion in Indian cities. First, we provide statistical evidence for the rising congestion levels on the roads of New Delhi from taxi GPS traces. Then, we estimate the economic costs of congestion in New Delhi. In particular, we estimate the marginal and the total costs of congestion. In calculating the marginal costs, we consider the following factors: (i) productivity loss, (ii) air pollution costs, and (iii) costs due to accidents. In calculating the total costs, in addition to the above factors, we also estimate the costs due to the wastage of fuel. We also project the associated costs due to productivity loss and air pollution till 2030. The projected traffic congestion costs for New Delhi comes around 14658 million US$/yr for the year 2030. The key takeaway from our current study is that costs due to productivity loss, particularly from buses, dominates the overall economic costs. Additionally, the expected increase in fuel wastage makes a strong case for intelligent traffic management systems.**

***Index Terms*—road congestion, marginal cost, total cost, projections**

I. Introduction

Traffic congestion in Indian cities is visibly on the rise. This has a detrimental effect on productivity, air pollution, fuel wastage, health, and quality of life. In the developed world, traffic congestion has long been recognized as an economic as well as a social impediment, and detailed studies on the economic aspects of congestion have been conducted. Such studies have been successful in sparking numerous policy deliberations, and have generated interest in devising novel traffic management systems.

A brief overview of road congestion statistics in some developed economies is given below.

- Annual congestion cost in the United Kingdom (UK) will reach 33.4 billion US$ by 2030, rising by over 50% from the 2014 levels of 20.5 billion US$ [2].
- Annual cost of congestion in the United States (US) as of 2014, has been pegged at 124 billion US$; this is projected to increase to 186 billion US$ by 2030 [2].
- In Australia, annual congestion cost levels are expected to rise from Australian Dollars (AUD) 3.5 billion (2005) to AUD 7.8 billion (2020) for Sydney, and AUD 3.0 billion (2005) to AUD 6.1 billion (2020) for Melbourne [8].

Such extensive studies have not been conducted for Indian cities as yet. However, it is being recognised that as India develops, congestion in cities is going to increase sharply, with numerous negative implications. The following statistics provide some insights into the congestion scenario in New Delhi:

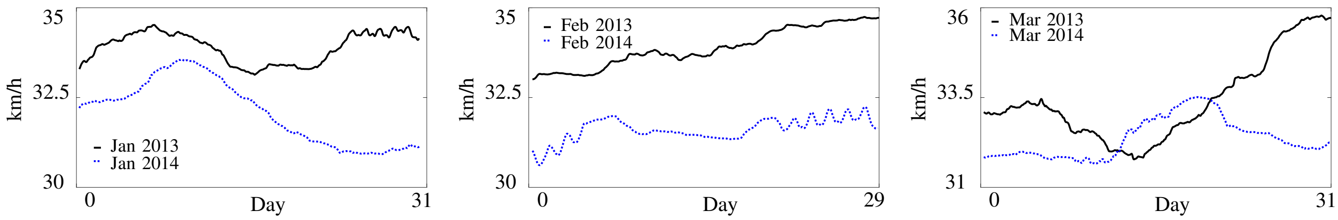
- New Delhi's vehicular population is projected to rise to 10 million by 2020, leading to a marked increase in congestion, which will severely impede economic activity [8].
- In New Delhi, at least about 300,000 US$ worth of fuel was being wasted everyday, by vehicles idling at traffic signals as early as in 1998 [27]. This figure jumped to approximately 1.6 million US$ per day as of 2010 [23].
- New Delhi has been named the world's most polluted city among 1600 cities by the World Health Organisation (WHO), and vehicular emissions are a major contributor to this situation [31].

Most of the research in the literature studying economic aspects of congestion, uses the link-flow approach. An example of this is [23], which uses analytical models to establish congestion costs against a baseline scenario. Another related paper [14] uses a similar approach to estimate total traffic congestion costs. The approach followed by most of these researchers is to use an exponential congestion function, which relates the minutes needed to drive a kilometer in terms of the Passenger Car Units (PCU) in the city. We note that previous studies have not explicitly considered the effect of two-wheelers on the congestion costs. This may undermine the congestion estimates, as two-wheelers already outnumber cars, and will also increase in the future. The impact of two-wheelers has been incorporated in our study.

The main contributions of this paper are twofold. First, by analysing the average speed of GPS enabled taxis over a period of one year, we provide statistical evidence for the increasing congestion levels in New Delhi. Second, we quantify the macroeconomic cost of traffic congestion in New Delhi, due to a variety of factors. [1]

We begin with an analysis of the GPS traces from taxis to empirically show a downward trend in the average vehicular speed over the year 2013. Specifically, we employ a statistical test, known as the Kolmogorov–Smirnov test, which indicates that the average vehicular speed is statistically lower in the first quarter of 2014, as compared to the first quarter of 2013. We posit that this reduction in average speed of taxis

[1]The conference version of this paper has appeared in the proceedings of the 2015 7th International Conference on Communication Systems and Networks (COMSNETS), held at Bangaluru, India in the year 2015.



(a) January 2013 versus January 2014 (b) February 2013 versus February 2014 (c) March 2013 versus March 2014

Figure 1: Comparison of average taxi speed in the first 3 months of 2013 and 2014. There is a visible reduction in the speeds in 2014 as compared to 2013.

is primarily due to an increase in congestion levels over the year of study. The major detrimental effects arising due to increasing congestion levels include the following.

- People spend more time in traffic, leading to productivity losses.
- Vehicles spend more time idling, releasing more pollutants into the air.
- Increasing fuel wastages due to frequent traffic jams, and stalling at signals.

In order to quantify these losses, we conduct a macroeconomic analysis of road congestion. To that end, we first aim to understand the marginal external costs of congestion, which measures the additional cost incurred due to an additional PCU worth of traffic. This is estimated for three factors; namely, productivity losses, air pollution costs, and road accidents. We have also included some key inferences obtained by analysing the major air pollutants on the roads of New Delhi. Next, we derive estimates for the total costs of congestion. In addition to the previous factors considered, we also incorporate fuel wastage due to traffic delays in our computations.

Once the congestion costs are estimated, it is then reasonable to consider some cost projections based on historical trends. To that end, we project costs due to productivity losses and air pollution till the year 2030. A key finding of our study is to identify that productivity losses incurred by bus commuters is the main contributing factor. This finding, coupled with the expected increase in fuel wastage, highlights the need for a combination of government policy and technology adoption. This work is an extended version of [18]. In addition to the work presented in [18], we have analysed taxi traces for the city of Delhi to provide evidence for the rising congestion levels. The marginal and the total costs are also elaborated on in this paper.

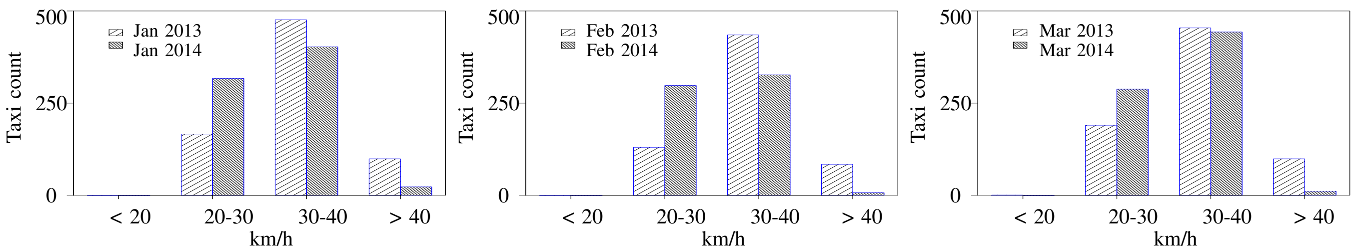
The rest of the paper is organised as follows. In Section II, the motivation for estimating the economic costs of congestion is provided, by analysing data. In Section III we compute the marginal costs of congestion, followed by Section IV, in which we compute the total costs of congestion. In Section V, we make projections on some of these costs based on vehicular growth projections. Finally, in Section VI, we present our conclusions and a few recommendations.

II. Analysis of Taxi Traces

In this section, we provide statistical evidence for the rising congestion levels. In particular, we perform an analysis of vehicle speed, using taxi GPS traces. The GPS traces used here are provided by a leading mobile application based taxi service provider. The data contain the vehicular position in terms of latitude and longitude, the current speed, the taxi ID and the direction in which it is heading. These GPS traces are available for a period of over one year, from January 2013 to March 2014.

A prominent indicator of congestion in any city is the variation in average speed of vehicles over time. Observations show that for 78% of the time in January 2014, the taxis exhibited a lower speed compared to January 2013. Similarly for February 2014 and March 2014, the corresponding percentages were 86% and 71% respectively. In fact, in January 2013, around 22% of time, the speed was higher than the speed in January 2014 by 10%. See Table 1 for similar inferences regarding the three months of interest. The data was also plotted for visual clarity. A basic moving average filter was used to smoothen the data. Figure 1 compares the average smoothed speed of taxis over the first 3 months of 2013 and 2014, *i.e*, over the months of January, February and March. We observe that there is a visible reduction in speed in 2014, as compared to 2013. While this effect is clearly visible in Figures 1a and 1b, for a brief period in mid-March (see 1c), taxis travelled with better speeds in 2014. After aggregating the speed over each hour in the year of 2013, we used a linear regression model to fit the data. The fit resulted in a negative slope, indicating that the average speed reduced from 34.2 km/h to 33.6 km/h in the year 2013. When similar procedure was repeated for the number of taxis, we observed a fit with a positive slope. It shows an increase in the number of taxis by roughly 200 units. Even though not conclusive, we can safely assume that other vehicles such as two wheelers and buses will follow a qualitatively similar reduction in the average speed. The negative trend for average speed and the positive trend for the vehicle count suggest an increase in road congestion over the period of study.

Over the year 2013, vehicular speed on weekends was slightly lower than the speed on weekdays. This observation suggests that the roads in New Delhi suffer from more traffic jams on weekends than on weekdays. Apart from monitoring the average speed of vehicles, a similar congestion indicator



(a) January 2013 versus January 2014 (b) February 2013 versus February 2014 (c) March 2013 versus March 2014

Figure 2: Number of taxis in various ranges of speed for the first 3 months of 2013 and 2014. There is a pronounced shift towards the lower speed ranges in 2014 compared to 2013.

Fraction of time (%)			Reduction in speed (%)
Jan	Feb	Mar	
48.7	62.3	48.2	>5%
22.6	30.4	24.2	>10%
03.1	03.6	04.2	>20%
00.9	01.3	01.1	>25%

Table 1: Percentage reduction in speed in 2014 compared to 2013

is the count of vehicles in different ranges of speed. In figure 2, we observe a shift in the count of vehicles towards lower speed ranges in 2014. This is evident in all the 3 months that we analysed. The number of vehicles having average speed > 40 has reduced marginally in an year. In the year 2014, the number of vehicles in the lower speed range (20-30 km/h) has increased, and in the higher speed range (30-40 km/h) has decreased as compared to 2013.

A. *Kolmogorov-Smirnov test*

In order to provide statistical evidence for the observations made by visual inspections, we conduct a statistical test known as the Kolmogorov-Smirnov test (K-S test) [**?**]. In the one sample variant of the K-S test, we test whether a specified test distribution could have generated the set of samples at hand. We are interested in the two-sample variant of the K-S test, which determines whether the two sets of samples differ significantly. The null hypothesis of the test states that the two sets of samples are drawn from the same distribution. We can reject the null hypothesis with high confidence if its p-value is close to zero. On the other hand, a larger p-value indicates that the two sets of samples are statistically more similar. The K-S statistic D captures the distance between the empirical distribution functions of two samples.

We run the K-S test for the speed data obtained from taxi GPS traces. The samples are drawn from the first 3 months of the years 2013 and 2014. We first consider the null hypothesis that the Cumulative Distribution Function (CDF) of samples from 2013 is equal to the distribution function of samples from 2014. When the K-S test was performed for this null hypothesis, it resulted in a p-value of 2.2e-15 and a D statistic of 0.2088. This gives us overwhelming confidence to reject the null hypothesis, and suggests that the samples from 2013 and 2014 are statistically quite different. Similarly, we could reject with high confidence that the underlying distribution corresponding to the 2013 samples lies above that of the 2014 samples. Finally, we obtained a p-value greater than 0.9 for the hypothesis that the underlying distribution corresponding to the 2013 samples lies below that of the 2014 samples. This provides statistical evidence that the average speeds in 2013 were indeed greater than those in 2014. The empirical distribution of the average speeds, plotted in Figure 3, is also consistent with the findings of the K-S test.

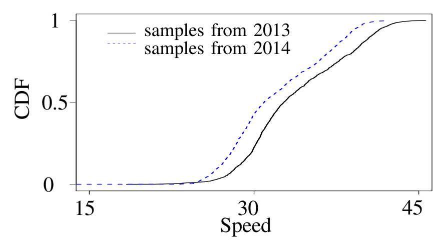


Figure 3: Empirical Cumulative Distribution function of samples from 2013 and 2014, where the population is the hourly taxi speed.

Thus, the preliminary data analysis using taxi GPS traces suggest that there is a downward trend in the vehicular speed for the period we analysed. The statistical test further suggests that there is a high probability that the two speed distributions from 2013 and 2014 are dissimilar, and that 2013 has a higher speed distribution compared to 2014 for the same observation period. These inferences point to a visible increase in traffic congestion in 2014, when compared to 2013.

We will now compute the losses due to congestion in terms of costs. For this, first, we calculate the marginal external costs of congestion and then, the total costs of congestion in the following sections.

III. Marginal External Costs of Congestion

The notion of marginal costs relates to the change in a dependent variable corresponding to a unit change in an underlying independent variable. In the case of transportation systems, marginal costs of congestion refer to the costs incurred due to the addition of one vkm (vehicle kilometer) in an existing transportation network. Marginal costs indicate sensitivity of the transportation network to changes in demand. This in turn indicates the resilience of the transportation network [2].

An important distinction of marginal costs from similar measures is that marginal costs, in the case of road travel, almost always increase with the addition of a unit of demand. On the contrary, cost measures such as the average costs may reduce with increased demand due to economies of scale, scope or density in the supply of transport services [23]. Marginal costs are of great practical importance especially in congestion pricing schemes that are gaining widespread acceptance in several cities around the world [14]. For instance, [25] emphasizes the importance of marginal costs due to the close estimation of real transportation costs accrued.

Several approaches have been followed to compute the marginal costs of congestion. One of the earliest works, [39], computes the marginal costs by multiplying the per unit cost with the elasticity of the unit cost increased by one. The work makes use of traffic flow and velocity data collected by highway engineers, and lays emphasis on highway congestion. An important development in the computation of marginal costs is the inclusion of peak and off-peak loading as in [10]. Another important milestone in the study of marginal costs is [24] - it brings into purview the costs due to road damage and the subsequent increased costs due to vehicles operating on these damaged roads. A more recent work in the area of marginal costs is [20], in which the authors carry out an extensive study of the components making up marginal costs and their implications for policy purposes. The work closest to this section is [32], which computes the marginal costs in New Delhi with an elaborate methodology. However the work leaves out two important effects: two-wheelers and the effect of new legislation in New Delhi that has considerably reduced marginal costs due to air pollution [9].

To compute marginal costs, the first step is to understand the different components that contribute to the marginal costs. A non-exhaustive list of components considered so far is given in Table 2. The second step in computing marginal costs is to identify the components that are actually relevant. Ascertaining relevance of the components includes considering the geographical, legal and regional particulars, unique to the transportation network. For the purpose of computing the marginal costs in New Delhi, we consider only the following three components: productivity losses, environmental costs and accidents. The other costs are neglected for the following reasons:

- Infrastructure and maintenance costs are marginal in the case of New Delhi. Due to the developing nature of the Indian economy skilled labour is relatively cheaper [36], and hence implies reduced infrastructure costs.
- Operation and usage costs of vehicles, have been increasing globally. In the case of India, the effect of increasing operation and usage costs has been very gradual due to the increasing quality of infrastructure, and customer-facing technology [15].
- Additional service costs and Mohring effect can be neglected in the case of New Delhi, since state transportation schedules are not dynamic, and often times do not reflect the demand. Despite several studies highlighting the importance of a dynamic scheduling system for Indian cities, progress in its implementation is scarce and the schedules are more or less fixed [38].
- Fuel wastage is a relevant component for computing marginal costs in New Delhi. However, due to restricted availability of information, fuel wastage can only be considered as a component while computing total costs of congestion. It will be taken up in the next section.

Category	Basis
Infrastructure maintenance	Maintenance costs due to road usage
Operation and usage	Cost of an additional vkm
Productivity losses	Cost due to delays
Additional service	Cost due to providing remedial services
Mohring effect	Benefits due to increased demand
Accidents	Expected increase due to additional road travel
Emission and pollution	Increased noise and emission costs
Fuel wastage	Increased consumption costs

Table 2: Components making up marginal costs [23]

The third step, is to examine the selected components individually and compute the marginal costs due to each of these components. The computational approach is similar to that found in [32], but with a few important modifications. The modifications include considering two-wheelers and taking into account the post legislation CNG bus policy.

From a total costs perspective, if T_i is the total cost of congestion function, due to the i^{th} contributing component. ν_C, ν_f are the average vehicle speeds under congested and free-flow conditions respectively. Then, a plausible form for T_i is:

$$T_i = F_i(\nu_C) - F_i(\nu_f). \quad (1)$$

Here, $F_i(\nu)$ is a function that represents total costs due to the i^{th} contributing component when the average network speed is ν. The derivative of total costs with respect to vkm is expected to directly give us the marginal costs. Note that the derivative of the second term in Equation (1) vanishes or leaves a very small contribution, depending on the network characteristics, since the average free-flow speed is constant. Hence, the marginal costs due to air pollution and accidents may be approximated to be the marginal costs of congestion due to air pollution and accidents. The following subsections compute the marginal costs due to each of the corresponding components. In the end, the total marginal costs due to all these contributions are computed.

A. *Productivity Losses*

Productivity losses are costs incurred due to delays experienced by commuters. The losses can be categorized into two dimensions:

- A personal dimension that covers losses arising out of personal time forgone while stuck in traffic delays. It includes time, that could be used towards employment, rest or any personally gainful activity.
- A commercial dimension, especially in the freight and cargo industry. Productivity losses may stem out of canceled orders or refused shipments due to late delivery.

While the first aspect that covers productivity losses has been widely studied, fewer works have taken up business impact caused by congestion [3]. We will stick with losses on a personal scale, since business impact of traffic congestion is difficult to be modeled for New Delhi.

To compute the productivity losses for an additional vkm, the first step is to specify a speed-flow relationship for a given mode, i at time j. We use the Passenger Car Units (PCU) metric in the speed-flow relationship as used in most works to capture the vehicle characteristics [32]. PCU is the impact that a transport mode has on traffic variables such as speed and it is compared against a car. For example, a motorcycle is considered as 0.5 PCU. A difference in our methodology is that we use PCUs for two-wheelers on Indian roads as investigated in [6]. The commonly used speed-flow relationship is given by:

$$t_{ij} = A_{1j}\big[A_2 + A_3\exp(A_4 q_i)\big]. \quad (2)$$

Here, t_{ij} is the time (in minutes) needed to travel 1 km on mode i during time interval j. A_{1j}, A_2, A_3 and A_4 are constants that depend on the characteristics of the transportation network under consideration. A_{1j} also depends on the period of travel j, and q_i represents the PCU of mode i. Note that this approach is justified at least in the case of New Delhi, since the speed-flow fit has a high R^2 measure [32].

The Marginal Economic Costs of Congestion due to Productivity loss (MECCP$_i$) is thus given by:

$$\text{MECCP}_i = \sum_j \frac{\partial t_{ij}}{\partial q_i} x_{ij}\text{VOT}_{ij}. \quad (3)$$

In the above equation, x_{ij} is the number of passenger kilometers (pkm) travelled in period j by mode i. VOT$_{ij}$ is the Value Of Time for a user travelling in mode i, during period j. $\frac{\partial t_{ij}}{\partial q_i}$ is the increase in delay suffered in mode i during period j, due to a unit increase in the PCU of mode i. Across modes, the value of time for commuters estimated in [32] is corrected to reflect present day price-levels by using:

$$P_{new} = P_{old}\frac{\Gamma_{2013}}{\Gamma_{2001}}\frac{1}{[1+\frac{i_{2013}-i_{2001}}{100}]}, \quad (4)$$

where, P_{old} is the original 2001 price (in Rupees per hour) used in [32] for the value of time for different modes of transport. Γ_t is the price-level in New Delhi during the year t, and i_t is the national inflation rate during year t. A textbook definition of price-level describes it as the sum of the prevailing prices of a standard basket of goods and services consumed indicating the prevailing value of money. Table 3 lists the value of time for passengers using different modes of transport. Comparing 2001 to 2013 levels (Table 4), a near doubling in the marginal costs due to productivity is observed.

Mode of Transport	2001 (in INR/h)	2013 (in INR/h)
Car	50.84	99.12
Bus	17.11	33.36
Two-wheeler	25.74	50.18

Table 3: Value of time for passenger transport [32]

Mode of Transport	2001 (inINR/vkm)	2013 (inINR/vkm)
Car	4.91	9.57
Bus	9.83	19.16
Two-wheeler	0.98	1.91

Table 4: Marginal costs of congestion due to productivity losses

B. 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 on-road time, which in turn considerably increases vehicular emissions. Computing marginal costs of congestion due to air pollution entails considerations such as emission per vehicle kilometer (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 (MECCE$_i$) for a transport mode i, summed over all emitted pollutants indexed by k, is given by:

$$\text{MECCE}_i = \sum_k \rho_i^k \delta^k. \quad (5)$$

In the above equation, ρ_i^k is the age-division-corrected emission structure for the i^{th} mode, and δ^k is the cost per kilogram of pollutant k emitted, computed in [33]. Further, ρ_i^k is computed using:

$$\rho_i^k = \sum_j E_{ij}^k \gamma_{ij}, \quad (6)$$

where, E_{ij}^k is the coefficient of emission per vkm for the i^{th} mode of transport, belonging to the j^{th} age-division, for the k^{th} pollutant.

The emission coefficients are listed in Tables 5, 6 and 7. Though vehicular emissions consist of a large variety of GHGs (Green House Gases) as well as harmful pollutants, in this study we only consider pollutants that are emitted in significant amounts, such as: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_X), and Particulate Matter (PM). In Table 6 two differing sets of emission coefficients for PM are provided. The ‘Business As Usual’ (BAU) type corresponds to the PM emission coefficients, if the ruling to convert all buses to Compressed Natural Gas (CNG) had not been enforced in New Delhi. The next column in the table provides the most recent PM emission coefficients, following the ruling. Though the vehicle fleet-age structures differ, the PM emission

Age Group	CO	HC	NO_X	PM
1991-1995	4.75	0.84	0.95	0.06
1996-2000	4.53	0.66	0.75	0.06
2001-2005	3.01	0.19	0.12	0.05
2006-2010	0.84	0.12	0.09	0.03

Table 5: Emission coefficient E_{ij}^k for cars in New Delhi (in gm/km) [32], [1]

Age Group	CO	HC	NO_X	PM (BAU)	PM (Actual)
1991-1995	13.06	2.40	11.24	2.013	0.032
1996-2000	4.48	1.46	15.25	1.213	0.032
2001-2005	3.97	0.26	6.77	1.075	0.032
2006-2010	3.92	0.16	6.53	0.300	0.032

Table 6: Emission coefficient E_{ij}^k for buses in New Delhi (in gm/km) [1], [30]

coefficients remain the same, since most older vehicles have been refit to comply with the existing standards.

The coefficient γ_{ij}, representing the distribution of vehicle fleet age structure, is given in Table 9 for New Delhi. Hence, using (4), (5) and (6), the marginal external costs of congestion due to air pollution can be readily computed; see Table 10.

We note that even for the newer buses from the 2006-2010 age group, there is an order of magnitude difference between the actual and BAU values for PM emission coefficients. For the older buses, the improvement in PM emissions can be as large as two orders of magnitude. This highlights the pivotal role and potential of government policy and enforcement in this area.

C. Accidents

Accident costs arise mainly from factors such as manpower losses, vehicular damages, insurance and other exigency costs. Accident statistics for the year 2013 is as given in Table 11. The economic value of damages due to accidents has been assessed in [35]. In computing the cost due to accidents, the same prices are used, but these prices are corrected to 2013 levels using (4). The corrected prices are given in Table 12. The Marginal Economic Costs of Congestion due to Accidents involving the i^{th} mode (MECCA_i) is given by:

Age Group	CO	HC	NO_X	PM
1991-1995	3.12	0.78	0.23	0.010
1996-2000	1.58	0.74	0.30	0.015
2001-2005	1.65	0.61	0.27	0.035
2006-2010	0.72	0.52	0.15	0.013

Table 7: Emission coefficient E_{ij}^k for two-wheelers in New Delhi (in gm/km) [1]

Pollutant	High Estimate	Low Estimate
CO	0.46	0.05
HC	6.73	0.60
NO_X	108.26	7.37
PM	869.57	63.73

Table 8: High and Low cost estimates of δ^k (in INR/kg) for New Delhi [33]

Age Group	Cars	Buses	Two-wheelers
1991-1995	0.154	0.374	0.398
1996-2000	0.200	0.593	0.252
2001-2005	0.323	0.016	0.235
2006-2010	0.323	0.016	0.115

Table 9: Vehicle fleet age structure γ_{ij} for vehicles operating in New Delhi [1]

Mode of Transport	Cost (INR/vkm)
Car	0.26
Bus	1.78
Two-wheeler	0.12

Table 10: Marginal external costs of congestion due to air pollution

$$\text{MECCA}_i = \frac{\sum_l \epsilon_{il} H_l}{365 \psi_i \mu_i}. \quad (7)$$

In the above equation, ϵ_{il} is the number of accidents in the l^{th} seriousness category for the i^{th} mode as in Table 11. Table 12 gives H_l, the average cost of the accident corresponding to the particular mode and the seriousness category. Ψ_i is the average total number of trips in a day as given in Table 18 and μ_i is the average length of a trip for mode i as in [29]. Following this computation, the marginal costs due to accidents are tabulated in Table 14.

D. Total Marginal Costs

Total marginal costs of congestion due to the three factors considered (productivity losses, air pollution, and accidents) are summed in Table 15. In Table 16, the contribution due to the air pollution component to the total marginal costs are compared against the results obtained by [32]. The key findings from these marginal cost estimates are as follows:

- The most significant increase in marginal costs is for cars, estimated at nearly 57%. In contrast, the corresponding figure for buses is only 10.4%.
- A striking observation is the decrease in the marginal costs due to air pollution in 2013. The contribution of the air pollution component has reduced despite the increased cost per gram of emissions corrected to the 2010 prices. This appears to be a direct consequence of government

Accident Classification	Events	Bus	Cars	Two-wheelers
Minor Accidents	169	25	44	27
Major Injury Accidents	5619	843	1461	899
Fatal Accidents	1778	338	213	124
Persons Injured	7098	N / A	N / A	N / A
Persons Killed	1820	N / A	N / A	N / A

Table 11: Accident statistics for New Delhi, ϵ_{il} [8]

Accident Classification	Cost (INR in 2013-14 prices)
Fatality	1745600
Major Accident	311430
Minor Accident / Non Injury	40917

Table 12: Economic costs of accidents, H_l [35]

Mode of Transport	Distance
Bus	77571669
Car	32735914
Two-wheeler	32605073

Table 13: Average vkm perday commuted in New Delhi, $\psi_i \mu_i$ (in km/day) [29]

Mode of Transport	Marginal Cost (in INR/vkm)
Bus	1.578
Car	0.042
Two-wheeler	0.113

Table 14: Marginal external costs of congestion due to accidents

policy: (i) the switch to CNG buses, and (ii) the complete phasing out of vehicles purchased before 1990.

IV. Total Costs of Congestion

The total costs of congestion are the sum of all costs accrued due to the delays experienced arising out of stalled speeds caused by road traffic congestion. In most cases, the total costs of congestion are defined with respect to a baseline scenario where congestion is minimal. The excess costs over and above the operating points of this scenario are considered as the total costs of congestion [23]. This popular approach highlights the dependence of total costs of congestion on not only the number of vehicles, but also the transportation network aspects such as capacity.

Table 17 provides estimates of total costs of congestion made by several works for several transportation networks around the world. One aspect is clear, the cost has been consistently rising. Note that the costs of congestion computed by these works, correspond to the price levels when the research was actually published.

As we compute the total costs of congestion in the proceeding sections, it is also important to understand some issues regarding the total costs of congestion. Several authors have in the past questioned the meaning of the total costs of congestion. Some of the criticisms are:

- The 'total cost of congestion' is rather a misnomer. If the total costs of congestion are incurred due to congestion, does alleviating congestion guarantee that the economy will be better off by an amount equal to the total costs of congestion? Certainly not. Alleviating congestion implies infrastructural spending, which has to be meted out by the state [12].
- Several paradoxes relating to transportation networks have proved that reducing congestion implies reducing travel impedance and hence increasing travel demand. Increased travel will only increase the total costs of congestion [12].
- The total costs of congestion measures are also criticized because the baseline scenario is rather arbitrary. Accuracy of measures of average free-flow speeds have been questioned [12].

Mode	Lost Time	Pollution	Accidents	Total	Total [32]
Bus	19.16	1.78	1.58	22.52	26.23
Car	9.57	0.26	0.04	9.87	6.29
Two-wheeler	1.91	0.12	0.11	2.14	N / A

Table 15: Marginal costs of congestion in New Delhi (in INR/vkm)

Mode	Marginal costs	Marginal costs from [32]
Car	0.26	0.27 - 2.74
Bus	1.78	9.12 - 14.14
Two-wheeler	0.12	N / A

Table 16: Air pollution component contribution to the total marginal costs of congestion

Work	Estimate
Glanville, 1958	GBP 170 million in the UK
Newbery, 1995	GBP 19.1 billion in the UK
Dodgson and Lane, 1997	GBP 7 billion in the UK
Mumford, 2000	GBP 18 billion in the UK
Tweedle, et al., 2003	GBP 24 billion in the UK
Scottish Executive, 2005	GBP 71 million in 10 areas of Scotland
DoTRS - Canberra, 2007	AUD 6.1 billion in Melbourne
CEBR, 2014	US$ 20.5 billion in the UK
CEBR, 2014	US$ 124 billion in the US

Table 17: Estimates of total congestion costs [23]

Despite questions raised on the utility and accuracy of total costs of congestion, such a measure is important in the case of a developing country like India. Some of the reasons for this are:

- India does not have an established system of basic infrastructure. For instance, metro transportation is yet to be opened in most of the cities. Expenditure on these facilities will considerably debunk congestion, while in the case of developed countries with already existing transportation facilities, increased expenditure may only marginally provide relief.
- Total costs provide an excellent direction for a country like India which is still in the planning phases. Cities are still being built - not the case in developed countries.

Total costs of congestion have been well-studied in the past. Though there are several variations in the computation process, the basic framework remains the same in all past works: compare the congestion scenario with a reference baseline scenario with minimal congestion. The earliest work, perhaps, on the total costs of congestion is [11]. The approach followed in the computation makes use of the basic delay aspect. However, [11] neglects the value of non-work time. In [24], the authors provide a different approach by categorizing road users and then computing a nationwide total cost figure for the UK. This approach has been criticized in [7] on dimensional counts, for multiplying marginal costs with a total volume. In [7], the authors use a link-based methodology to estimate time and operating costs, and then compare costs at free-flow and current speeds. In our approach, we study total costs of congestion by aggregating costs for the three factors considered: productivity losses, air pollution costs and accidents. An additional cost considered in the case of total costs is the fuel wastage costs. All these costs are computed by comparing against a baseline scenario, mainly in terms of average speeds.

Though by definition a simple numerical integration of the marginal cost function seems to intuitively provide the total costs of congestion, the computation of the marginal cost function throughout the range of the integral is cumbersome due to changes in parameters A_{1j}, A_2, A_3 and A_4 in (2) as the number of vehicles change. Therefore, a data driven approach is adopted, that considers the prevailing averages of the various parameters that have been considered in the previous section.

The following subsections delve into the computational details of the total costs of congestion. We will first consider the contribution by productivity losses to the total costs, and followed by this, air pollution costs will be studied. Costs due to accidents follow, finally ending with the contribution of fuel wastage to the total costs.

A. Productivity Losses

Here, 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 point worth mentioning here is that, the productivity losses in this case will depend on the average vehicle occupancy. The reason for dependency on occupancy is that the costs in this case are not with respect to a vehicular parameter (such as vkm), but necessitate the inclusion of an aggregate passenger number to compute losses.

Computing the total costs of congestion due to productivity losses involves considering several factors. These include: Value of time, average occupancy, trip length by mode, number of trips by mode, free-flow speed and average speed in congested conditions. Computing most of these factors at an individual micro-level is a formidable task. So for the purpose of these computations, averaged values of these factors are available, and are expected to produce similar results. Considering these factors, the Total Costs of Congestion due to Productivity Losses (TCCPL) is then given by:

$$\text{TCCPL} = 365 \sum_i \text{VOT}_i \Psi_i \mu_i \Lambda_i \left(\frac{1}{\nu_C} - \frac{1}{\nu_f} \right). \qquad (8)$$

In the above equation, Ψ_i is the average total number of trips in a day for mode i, μ_i (in kilometres) is the average length of a trip for mode i, and Λ_i is the average occupancy for mode i. VOT_i (in Rupees per hour) is the value of time for the commuter travelling in mode i, ν_C is the average speed in New Delhi under congested conditions, and ν_f is the free-flow speed of traffic. Both Ψ_i and μ_i are provided in Table 18. Notice that, in New Delhi, the number of trips by buses is more than twice that for cars and two-wheelers. This is intuitive, since most cars and two-wheelers serve individual travel needs, and may be used just for commuting from home to work. However in the case of buses, they are in use almost throughout the day because of the scheduled public transportation trips. Just by looking at this table, one can come to the conclusion that whatever legislation is to be passed, favoring buses might have an overwhelming positive effect.

Mode	Trips per day	Occupancy	Trip Size (km)
Car	2902120	2.2	11.28
Bus	7276892	20.0	10.66
Two-wheeler	3250755	1.2	10.03

Table 18: Trips per day in New Delhi [29]

Mode	Cost (in million US$/Yr)
Car	869
Bus	6310
Two-wheeler	239
Total	7410

Table 19: Total costs of congestion in New Delhi due to productivity losses

The average trip size, μ_i remains almost the same for all the three categories at around 10-11 km/trip. Fewer number of trips for cars and two-wheelers outlines the enormous potential that ride-sharing and similar initiatives can have, especially in the case of cars, where average occupancy is mostly less than 50%. While potentials for improvement and reducing costs exist in all the three categories, it must be observed that bringing about improvements in bus systems is considerably easier since most buses are state-owned. In the case of two-wheelers and cars, coordination among a large number of commuters may be essential, before being able to bring about considerable improvements.

In equation (8), Λ_i represents the average occupancy for mode i. The average occupancy for buses is among the lowest in several similar works. For instance, [34] uses an occupancy rate as high as 85%, which translates to roughly an average occupancy of 34 in a 40-seater bus. This is an important point to note since taking higher average occupancies may considerably increase productivity loss costs. The free-flow speed (ν_f) is taken to be 40 km/h as in [37], and ν_C is taken to be 22.2 km/h as in [29].

With (8) and Table 18, the total costs of congestion due to productivity losses are readily computed, and are listed in Table 19. Throughout this study we have used the exchange rate of 1 US$ = 60 INR (Indian Rupee). From the Table 20, cars contribute more than 10% of the total productivity loss. As the number of cars is projected to grow rapidly, there could be a severe detrimental effect not only on the car passengers, but on all the other road users as well. Also note that the productivity losses for buses are the highest, because of its higher occupancy compared to other modes of transport. This is a good area for policy-makers to focus.

B. Air Pollution Costs

The computation of total congestion costs due to air pollution follows a comparison approach against the free-flow scenario. The factors considered to compute air pollution costs are similar to those introduced in the previous section. An important factor to be considered is the correction factor, that must provide an appropriate comparison with the baseline scenario. The correction factor must preferably be in terms of ν_C and ν_f, since these are already available.

Keeping these in mind, the Total Cost of Congestion due to vehicular Emission of air pollutants, TCCE is given by:

$$\text{TCCE} = 365\left(\frac{\nu_f}{\nu_C} - 1\right)\sum_i\left(\Psi_i\mu_i\left(\sum_k \rho_i^k\delta^k\right)\right). \tag{9}$$

In the above equation, the inner summation with respect to the k^{th} pollutant provides cost due to pollutants (CO, HC, NO_X and PM) emitted per vkm for the i^{th} mode. This data is obtained from Tables 5, 6, 7, 8 and 9. Once this cost has been computed for the i^{th} mode for all pollutants, the outer summation seeks to compute the total costs for all modes, throughout the year. Product of the cost of emissions per vkm with the average total vkm traversed per day ($\Psi_i\mu_i$) will give cost of emissions per day, for the i^{th} mode. The outer summation over all modes, gives the Total Cost of Congestion due to Emissions (TCCE).

Note that in expression (9), we introduce a correction factor, which was not present in (8). This factor accounts for the reduced speed due to congestion. The basic assumption underlying the correction factor is that the pollutants emitted increase proportionally with the increase in travel time. This is only an approximation since in most cases, the emission characteristics and constituents change as the vehicle speeds change. The changes are cumbersome and difficult to model. Keeping the assumption, the fractional change in time on road due to congestion is:

$$\text{Correction Factor} = \frac{\text{T}_C - \text{T}_f}{\text{T}_f}, \tag{10}$$

where T_C is the time taken by a commuter to travel a given distance in congested conditions and T_f is the time taken to travel the same distance in free-flow conditions. Since distances are the same in both congested and free-flow conditions, we have:

$$\text{T}_C\nu_C = \text{T}_f\nu_f. \tag{11}$$

Using the above and simplifying, we have:

$$\text{Correction Factor} = \frac{\nu_f}{\nu_C} - 1. \tag{12}$$

This is a rather simplified approach to computing the correction factor. More accuracy may be obtained by including travel demand elasticities [13], since increased congestion increases travel impedance, reducing demand for travel. Then, the following must hold:

$$\text{T}_C\nu_C = \Pi_{TD}\text{T}_f\nu_f, \tag{13}$$

where $\Pi_{TD} < 1$ is a factor to account for the reduced travel demand. Due to data unavailability and complexity in computing elasticities, we will use (11) instead of the slightly more accurate (13). The correction factor is hence equal to the fractional increase in travel time due to congestion. Using (11), the total costs of congestion due to air pollution is given in Table 20.

Mode	Cost (in million US$/Yr)
Car	41
Bus	670
Two-wheeler	19
Total	730

Table 20: Total costs of congestion in New Delhi due to emission of air pollutants

C. Accidents

As in the previous section, in which we compute the marginal costs due to accidents, we see in this section that accidents contribute a less significant component to total costs. However, in this case, the total costs due to accidents includes an aggregate total cost incurred due to accidental events involving a range of seriousness levels. Computing the total costs of congestion is slightly more direct than computing the marginal costs of congestion due to accidents because the data available is already in an aggregate form. In the previous section we found the cost per vkm only after finding the total costs. Then, the Total Cost of Congestion due to Accidents (TCCA) is given by:

$$\text{TCCA} = \left(\frac{\nu_f}{\nu_C} - 1\right)\sum_i\sum_l \epsilon_{il}H_l. \tag{14}$$

We also include the correction factor introduced in (9). The form of the correction factor, follows the underlying assumption that increased road-time increases the probability of meeting with an accident. However, note that in this case the elasticities of travel demand will not come into play. We assume, and with reason, that travel time does not have elastic dependencies - a commuter who can complete his travel sooner, will not stay on road, just to ensure that the entire time he expected to be on the road elapses. The treatment of elasticities is far more complex in this case. Additionally, some studies have also found that commuters prefer constant travel time over varying travel times, where commuters may actually end up saving time on some days [17].

The total cost due to accidents is provided in Table 21. The year-wise breakup of the number of accidents, as obtained from [8], is enumerated in Table 22. Note that the number of accidents is largely stable in the years 2008 through 2013. Accidents do not seem to follow any increasing or decreasing trend with observable parameters. Also, we notice that fatal accidents contribute to most of the costs. Thus, there is a compelling case to formulate and enforce very strict safety norms, that reduce fatalities in road accidents.

D. Fuel Wastage

Fuel wastage due to traffic delays leads to losses that can be traced directly to traffic congestion. Some of the reasons for this fuel wastage due to congestion include:

- Stalling at traffic signals.

Severity	Events	Cost per Accident (INR)	Total (million US$/Yr)
Fatal	1778	1745600	41.48
Major	5619	311430	23.38
Minor	169	40916	0.09
Total	7566	-	64.95

Table 21: Total costs due to accidents in New Delhi [35], [24]

Year	Number of Accidents
2008	8435
2009	7516
2010	7260
2011	7280
2012	6937
2013	7566

Table 22: Total number of accidents in New Delhi (New Delhi traffic police)

- Stalling and reduced speeds in traffic jams and diversions.
- Reduced speeds at narrowing and tapering roads.
- Reduced speeds at junctions, intersections and flyover extremes.

The basic approach to computing total fuel wastage costs includes computing reduced speeds at congested intersections and finding the equivalent fuel consumption at these stalling points. The next step is to assign the wasted fuel monetary costs. We do not compute the costs due to fuel wastage in New Delhi as this has already been widely researched by several governmental policy think-tanks. The earliest known estimate of fuel-wastage in New Delhi was provided by the Central Road Research Institute, back in 1996. The wastage was estimated at 300,000 US$/day [5].

In [26], a survey based approach is followed, by earmarking 12 intersections in New Delhi catering to varying traffic densities. The study estimates that the waste fuel cost is as high as 994.45 crores of Rupees per annum according to the 2008 price levels. Later in 2010, an independent study conducted by the Center for Transforming India has pegged this cost at approximately 10 crores of Rupees per day [4]. This figure will be used in our computations.

E. Summary of Total Costs

In this subsection, we present the total costs of congestion, having considered the various components that contribute to the total costs of congestion. Table 23 shows the total cost of congestion in New Delhi per year, with most of the data used to compute the contributions of the underlying factors falling in the range of 2008-2010. In INR terms, traffic congestion costed New Delhi close to 54,000 crores of Rupees in the year 2013. There are a few important points that are to be emphasised as evident from Table 23:

- Buses are the largest contributors to the total costs of congestion. But, considering the number of trips per day that buses in New Delhi undertake and the number of commuters whose travel demands they satisfy, buses are probably the most efficient transportation means, in terms of total costs.

Mode	Total Cost (in million US$/yr)
Car	911
Bus	6980
Two-wheeler	258
Accidents	64
Fuel Wastage	699
Total	8912

Table 23: Total costs of congestion in New Delhi

- Costs due to productivity losses are the largest contributor to the total costs of congestion. All other factors fall within 10% of the contribution made by costs due to productivity losses.
- The contributions by cars to congestion costs is almost a billion US$/yr and given the occupancy of less than 50% these costs are likely to have the most potential for reduction.

V. Cost Projections for Productivity Losses and Air Pollution

In Section II, we computed the marginal costs of congestion, followed by total costs of congestion in Section III. An important requirement now is to be able to approximately tell how these costs are expected to change with time. This is an essential requirement since it justifies recommended infrastructural spending to ease congestion.

This section provides the cost projections for the marginal and total costs until 2030. The closest work relating to the results in this section is [19], which uses projections to determine the optimal transportation mix. In our case, we use the projected vehicle population growth to determine both marginal and total costs of congestion and in turn, make projections on these costs.

Of the four underlying factors that have been considered as contributors to total costs of congestion, we argue that two of the factors - fuel wastage costs and accident costs may be neglected. Projections will then be made for the productivity losses and air pollution costs.

Accident costs are neglected in making the projections because:

- The number of accidents are difficult to be modelled and predicted. The number of accidents does not seem to show any strong dependence on the number of vehicles [8].
- Even if a method to accurately determine number of accidents was perfected, the contribution from such costs would be dwarfed by the total costs of congestion. For instance, in the present scenario, the contribution to the total costs from accidents is just about 0.72% of the total. A similar situation is encountered in the case of marginal costs.

The fuel wastage costs are also neglected for the following reasons:

- The magnitude of fuel wastage costs is distorted due to changes in global oil prices. Projecting fuel wastage

requires being able to project oil prices many years hence, which is an impossible task [28].
- The dependence of fuel quantity wasted with the number of vehicles is non-trivial and may strongly depend on several factors such as infrastructure and other network characteristics of the transportation network.
- This is another minor contributor to the total costs, presently contributing less than 8% of the total costs and can hence be neglected.

Projections of marginal and total costs of congestion are made by obtaining the growth projections of the two underlying factors affecting these costs - productivity losses and air pollution costs. However, making projections directly based on these two factors is non-trivial. A good approach would be to find a common dependence on which both these two factors depend, and for which plenty of past data is available so as to make the statistical projections meaningful. Vehicular population is one such common dependence and it satisfies the past data availability criteria also.

There are advantages in making projections for productivity losses and vehicular emissions indirectly based on the projections for vehicle population, rather than directly making projections based on the individual factors:

- In the indirect approach, the projections are independent of the model used to arrive at the contributions made by productivity loss and vehicular emissions based costs.
- Another inherent advantage is that projections on the vehicular population of New Delhi have been widely studied; however, this is not true of the individual factors.

Note that this approach lacks accuracy, as with increasing vehicular populations, network parameters describing the network characteristics may well change. Though the approach underestimates the projected costs, it will serve to justify minimal infrastructural spending. The projections for vehicular population in New Delhi is completed using a spreadsheet model. This completes the first step of the projection process.

The next task is to model the dependence between vehicular population and the two most relevant underlying factors making up marginal and total costs. The equations below capture the dependence of these two factors on vehicle population. From (2), the dependence of Productivity Loss Costs (PLC) on the vehicle population, N, is:

$$\text{PLC} \propto e^{A_4 N}. \tag{15}$$

Similarly, since the Vehicular Emission Costs (VEC) depend on the number of vehicles, assuming an equal distribution and a similar modal share throughout the projected years, we have:

$$\text{VEC} \propto N. \tag{16}$$

The projections for vehicular population in New Delhi obtained from the simple spreadsheet model are provided in Table 24. Using Table 24 and equations (15,16), the projections for the marginal costs of congestion are as in Table 25. Similarly, projections for the total costs of congestion are given in Table 26.

Year	Two-wheeler	Car	Bus
2015	4918777	2512234	64748
2018	5608980	2885110	74713
2020	6033646	3127639	84643
2023	6634911	3461118	89259
2025	7013511	3693622	93971
2027	7402890	3908506	99580
2030	8056069	4236245	109330

Table 24: Vehicular population projections in New Delhi

Year	Car	Bus	Two-wheeler
2015	11.16	21.69	2.61
2018	13.93	23.20	3.89
2020	16.08	24.79	4.99
2023	19.61	25.55	7.11
2025	22.51	26.35	8.88
2027	25.57	27.32	11.18
2030	31.07	29.08	16.47

Table 25: Cost projections - marginal costs of congestion (INR/vkm)

An assumption regarding the projection for buses is that the government will continue sanctioning buses in line with the demands of the population, and will not look to increase bus frequencies so as to lower average occupancies. This is only a slight underestimation, since with increasing living standards in India, it is highly likely that buses will be sanctioned at an higher rate than predicted. Though this effect will not affect the productivity loss costs (which depends only on the number of passengers), it will increase the environmental costs due to the lower average occupancies, and hence increased vkm per day. This will once again underestimate the cost projections.

An alarming observation based on the projections is the nearly 70% increase in the number of cars. Clearly, this will not be sustainable, and will have a damaging impact, particularly on productivity losses, environmental costs, and fuel wastage.

VI. Conclusions and Recommendations

The key takeaways from our study are summarised below.

- After monitoring the taxi GPS traces on the roads of New Delhi for a period of over an year, we noticed that there is a negative trend in the average taxi speed. We also observed a positive trend in the number of taxis during the same period of study. These patterns point towards the increasing levels of congestion in the city.

Year	Car	Bus	Two-wheeler	Total
2015	1033	7233	331	8597
2018	1288	7746	493	9527
2020	1486	8282	630	10398
2023	1809	8540	896	11245
2025	2074	8809	1120	12003
2027	2354	9138	1410	12902
2030	2857	9731	2070	14658

Table 26: Cost projections - total costs of congestion (million US$/yr)

- The results from the K-S test suggest that the speed distributions for the years 2013 and 2014 are dissimilar, and that the taxi speeds are statistically higher in 2013. The reduction in speed in 2014 may lead to more productivity losses, pollution losses and fuel wastages, compared to 2013. Hence, it is very likely that the total congestion costs in 2014, and the subsequent years, will be higher than that in 2013. This supports the cost projections in Table 26.
- Even 15 years after the authors' claim in [19], buses still are the most popular means of road transport catering to about 60% of New Delhi's total demand. The state-owned New Delhi Transport Corporation buses are in fact the largest CNG-driven fleet in the world [27]. It is clear from our study that buses are contributing a substantial portion of the total costs, primarily due to productivity losses. The productivity loss due to congestion delays of commuters who use buses accounts for about 75% of total costs of congestion.
- Idling at traffic lights, signalised intersections and busy junctions due to congestion causes fuel wastage, which is another source of substantial costs. With the number of cars projected to increase sharply, this component is expected to play an increasingly significant role.
- From Table 25, we see that the projected marginal congestion costs of cars approach that of buses. This means that in the year 2030, according to our projections, the cost of adding a vkm of car travel to the existing traffic network is very similar to the cost of adding a vkm of bus travel to the same network, despite the enormous differences in size and hence in road space occupancy. This goes to show that the New Delhi traffic network will be so saturated that the addition of one vkm of bus or car will be viewed similarly.
- Another important conclusion is that cars have the most potential for cost savings, due to two important reasons: average occupancies not exceeding 50% and a low number of average trips per day. Ride-sharing and similar arrangements in New Delhi will have tremendous potential in terms of cost saving as well as easing congestion.
- The economic costs arising from accidents is not a significant proportion of the total costs. Though accidents entail significant and irrevocable personal losses, their contribution is less significant from a macroeconomic perspective.

Based on the results obtained so far and the conclusions above, we provide some key recommendations to address the issues identified.

- The Government should look into setting up dedicated bus lanes. This would considerably reduce the productivity losses for commuters who use buses, encouraging other private transport users to commute by buses due to the reduced transit time. Our study also adds strong credibility to various works in literature that make a case for dedicated lanes for buses in New Delhi [16], [31]. In order to make dedicated bus lanes effective, it would be important to have more frequent, and more comfortable buses. This could also help in shifting a fraction of the motorists to buses.
- Employ state-of-the-art scheduling policies for buses. There is also a case to be made for equipping public buses with GPS and making the data publicly available. This would enable real-time solutions and innovation to flourish. Though these recommendations entail additional spending on the part of the Government, public transport investments by the Government in New Delhi have had high returns, as is evident in the case of the New Delhi metro [22].
- As fuel wastage is expected to increase, it would be important to employ intelligent traffic management systems, including smart traffic lights. Such solutions could be extremely valuable in future smart cities, where it may be possible to install the required infrastructure in advance.
- Car pooling and other similar measures must be promoted, and the Government should help facilitate and incentivise such practices where ever possible.

Policy Recommendation	*Cost Impact*
Dedicated Bus Lanes	6300 million US$/yr
Strict Vehicular Emission Control Norms	730 million US$/yr
Safety and Accident Prevention Features	65 million US$/yr

Table 27: Policy recommendations and likely impact cost

With regards to future work, a more comprehensive study on all the aspects that impact costs of congestion in New Delhi is certainly required. There are several aspects of this study, especially in the computational modelling aspects that can be extended. Some of these among several others are:

- Include travel demand elasticities to obtain a more accurate correction factor in (11).
- Compute the new δ^k costs for New Delhi. The existing costs are fairly outdated, last computed for the year 1998 using the transfer of benefit method as used in [33].
- Projections can be made more accurately, by considering parametric changes that are influenced by the vehicular population. The present approach makes projections based on vehicular growth projections, but assumes all else to be constant, hence underestimating the cost projections.
- Recompute the fitting parameters A_{1j}, A_2, A_3 and A_4 obtained from [32]. The parameters are expected to have slightly changed now, due to the passage of time since they were first computed using curve-fitting methods in 2010.

The advantages of replicating similar systematic study in other major Indian cities can be clearly seen. Such studies would better inform cost-benefit considerations for the numerous possible solutions that may be considered, towards providing a smarter transportation infrastructure in various cities, which is an important requirement in the developing world.

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ANNEXURE-R3

The Welfare Effect of Road Congestion Pricing: Experimental Evidence and Equilibrium Implications*

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Abstract

The textbook policy response to traffic externalities is congestion pricing. However, quantifying the welfare consequences of pricing policies requires detailed knowledge of commuter preferences and of the road technology. I study the peak-hour traffic congestion equilibrium using rich travel behavior data and a field experiment grounded in theory. Using a newly developed smartphone app, I collected a panel data set with precise GPS coordinates for over 100,000 commuter trips in Bangalore, India. To identify the key preference parameters in my model – the value of time spent driving and schedule flexibility – I designed and implemented a randomized experiment with two realistic congestion charge policies. The policies penalize peak-hour departure times and driving through a small charged area, respectively. Structural estimates based on the experiment show that commuters exhibit moderate schedule flexibility and high value of time. In a separate analysis of the road technology, I find a moderate and linear effect of traffic volume on travel time. I combine the preference parameters and road technology using policy simulations of the equilibrium optimal congestion charge, which reveal notable travel time benefits, yet negligible welfare gains. Intuitively, the social value of the travel time saved by removing commuters from the peak-hour is not significantly larger than the costs to those commuters of traveling at different, inconvenient times.

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1 Introduction

Traffic congestion is a significant urban disamenity, especially in developing countries, where urban population and private vehicle ownership are growing rapidly.[1] Even holding fixed the number of vehicles in use, peak-hour traffic jams may be particularly inefficient, as large numbers of commuters driving at the same time cause longer travel times for everyone. Reflecting this concern, various urban traffic policies focus on reducing peak-hour congestion, either through pricing or quantity restrictions.[2]

However, it is challenging to evaluate the welfare impact of such policies or, more generally, to quantify the inefficiency in a decentralized unpriced equilibrium. These calculations depend critically on how drivers value the time they spend driving, as well as on their flexibility of changing the *timing* of their trips. Intuitively, the inefficiency may be small if commuters have sufficient schedule flexibility so as to eliminate congestion peaks in the decentralized equilibrium to begin with. Alternatively, if everyone is very inflexible, the distribution of departure times under the social optimum will look similar to the unpriced equilibrium. Apart from these preference parameters, the road technology mediates the externalities that drivers impose on each other. Engineering studies at the road or highway segment level, typically in developed countries, regularly find a convex impact of vehicular volume on travel time (Small et al., 2007), which suggests large social marginal costs when congestion is already high. However, we know little about this relationship at the commuter-trip level and in large cities in developing countries, where the infrastructure, types of vehicles driven, and driving styles differ considerably from the settings of existing studies.[3]

This paper analyzes the peak-hour traffic congestion equilibrium using a rich data set of travel behavior and a theory-grounded field experiment on congestion charge policies. The backbone of the study is a fine-grained panel data set of trips from a sample of around 2,000 car and motorcycle commuters from Bangalore, India. I collected this data using a novel smartphone app that passively logs precise GPS location data, which I helped design for this purpose. The data covers over 100,000 individual trips and almost one million kilometers of travel inside the city.

I outline the key preference parameters of interest in this setting using a simple model of commuting trip scheduling and route choice, building on classic models in transportation economics (Arnott et al., 1993; Noland and Small, 1995). In the model, commuters choose between two route options and decide their trip

[1] Between 2005 and 2015, new private vehicle registrations have grown at 15% and 43% per year in India and China, compared to 0% in the United States and Europe (OICA, 2016).

[2] The congestion charge policy in Stockholm and Singapore's Electronic Road Pricing (ERP) policy have higher fees during the morning and evening peak hours. Jakarta's former "3-in-1" and the current "odd-even" policies are in effect during morning and evening peak hours only. Similarly, Manila's Unified Vehicular Volume Reduction Program (UVVRP) only applies during peak hours in certain parts of the city.

[3] A notable exception is Akbar and Duranton (2017), who use a household travel survey in Bogotá together with Google Maps data collected several years later. They find a small elasticity and hypothesize that drivers are more likely to use side roads during peak hours.

departure time, taking into account the expectation and uncertainty in travel times for different departure times and for the two routes, their ideal arrival time (unobserved to the researcher), and their schedule flexibility.[4] The key parameters for welfare are the value of time spent driving, and the schedule costs of arriving earlier or later than desired. Intuitively, these parameters respectively measure the benefits and the costs of policies that aim to reduce peak-hour congestion by inducing commuters to travel before or after the peak. In an ideal experiment, we would observe choices for various vectors of prices over departure times and drive times. By contrast, observational data does not have sufficient independent variation in costs over these two dimensions. For example, an earlier departure time typically affects both the probability of arriving late and the mean driving time.

In order to identify the model parameters, I designed and implemented two realistic congestion charge policies as part of a field experiment with 497 commuters. The two policies introduce exogenous price variation in departure times and driving times, which identifies the value of time and schedule cost parameters. Under the "departure time" policy, trips are charged according to a pay-per-km rate that is higher during peak-hour departures. Under the "area" policy, commuters face a flat fee for driving through a small area, chosen such that there exists an alternate, untolled route with a longer driving time. Participants were randomized into treatment and control groups for the "departure time" policy. For the "area" policy, the timing of the treatment was randomized among participants. For both treatments, charges were calculated automatically on a daily basis, using the smartphone app travel data, and subtracted from a prepaid virtual account. In order to separate the effect of price incentives from that of information, daily SMS updates, and experimenter demand effects, participants in a separate "information" sub-treatment received daily SMS information notifications and flat weekly bank transfers.

Experimental results show that commuters have moderate flexibility to adjust trips away from typical work hours in order to save money. Under "departure time" charges, commuters leave earlier in the morning and later in the evening. These findings are consistent with working hours acting as constraints, at least in the short run. During the morning interval, participants advance their trips by around 4-6 minutes on average, an effect driven by a subset of commuters that responds more strongly. Responses in the low rate sub-treatment are roughly half of those in the high rate sub-treatment, although imprecisely estimated, and I do not find any impact of the information treatment, which suggests that commuters are responding to prices rather than to other aspects of the intervention. Under "area" charges, participants cross the congestion area around 20% less frequently, and switch to longer routes. Neither randomly doubling the congestion charge nor shortening the detour affects this fraction. These findings are consistent with considerable preference

[4]The model abstracts from the extensive margin travel decision to focus on the within-day distribution of travel.

heterogeneity, and the implied value of time for the marginal commuter is large relative to the average hourly wage for this sample.

I next use the experimental price variation to structurally estimate a model of route and departure time choice for the morning home to work commute. The model includes random utility shocks over routes and departure times, leading to a nested logit specification, and it accounts for the non-linear structure of incentives in the experiment. I construct individual-level choice sets using Google Maps driving time data collected for each driver's typical route and detour route, at all departure times, and I calibrate the driving time uncertainty. I simulate the model to compute choice probabilities, and perform an additional step to invert the individual-specific distribution of ideal arrival times from observed departure times in the pre-experimental period. I estimate the model using two-step GMM and moments chosen to exploit the variation induced by the congestion charge experiments. The estimated schedule cost of early arrival, at around Rs. 320 per hour (approximately $5), is roughly a quarter of the value of time spent driving, at Rs. 1,120 per hour. Late arrival schedule costs are large but imprecisely estimated. I also estimate the probability that a participant responds to the experiment, by matching the distributions of individual effects in the departure time and area treatments. Around half of participants respond to the experiment.[5]

The structural demand estimates show that commuters are moderately schedule flexible relative to how much they value time spent driving. However, to understand the equilibrium welfare costs of congestion, we need to combine these demand estimates with knowledge about the shape and size of the technological part of the externality.

I document a moderate and linear impact of traffic volumes on travel times. I use all the GPS trips data collected using the smartphone app to measure volumes, and Google Maps data on travel delay collected daily to measure driving times.[6] The average travel delay for trips starting at a certain time of the day is linearly increasing in the average volume of departures at that time. In particular, I do not find any convexity for high levels of traffic, unlike previous empirical estimates for highway road segments. Quantitatively, making an average length trip during peak hours increases aggregate driving time for everyone else by approximately 15 minutes, which is roughly half of the private trip duration.[7]

Finally, I compute the optimal equilibrium congestion charge profile, which implements the social optimum. I simulate the city-wide traffic equilibrium in an environment where agents have preferences drawn from those estimated from the data, and aggregate travel volumes determine the travel delay profile through

[5] The experimental results show stark heterogeneity in individual responses, which is not well explained by models with random coefficients. The binary "response probability" does a much better job at replicating this pattern.

[6] I validate the Google Maps driving time data using median driving times from the GPS data. The two measures co-vary with a slope close to 1.

[7] I show that such calculations depend on a semi-elasticity and do not require knowledge of the *total* number of vehicles.

the estimated road technology. This approach has the benefit of relying entirely on estimated parameters. However, I ignore extensive margin responses, and results may differ if long-term responses to congestion charges differ significantly, for example if in the long run firms can accommodate more flexible schedules. I compute the social optimal allocation by finding a Nash equilibrium with congestion charges with the following fixed point property: the charge for departure time h is equal to the marginal social cost of driving at time h.

The social optimum has notable travel time savings relative to the decentralized unpriced equilibrium. Travel is one minute faster from a base of 39 minutes, which is 7% of the travel time above free-flow speeds. However, welfare gains are negligible. This is due to the fact that the social benefits of travel time savings are almost fully offset by the scheduling costs incurred by drivers who now avoid the peak-hour. I conduct counterfactual simulations with alternate policy parameters and road technologies and show that the linear road technology is important for driving these findings.

This result implies that peak-hour congestion pricing and similar quantity-based restrictions are not warranted in Bangalore for the sole purpose of flattening peak-hour congestion by re-allocating drivers across departure times.

This project builds on and contributes to several literatures.

First, transportation economists have developed a rich theoretical literature that models traffic equilibria. Vickrey (1969) and Henderson (1974) introduced the inefficiency due to trip scheduling and their ideas were further formalized by Arnott et al. (1993) and Chu (1995).[8] I build on these early models and adapt them to make it easier to apply them to data on real travel behavior.

Second, the vast majority of transportation research uses survey methods (such as trip diaries) to measure travel behavior. In this project, I collected precise travel behavior data based on detailed GPS traces from around 2,000 participants using their own smartphones. This method circumvents misreporting and recall bias issues that affect survey methods, and makes it easier to collect longitudinal data. Early studies that collected GPS travel behavior data were typically limited to small samples and used special GPS devices that participants carried with them during the study (see, for example, Papinski et al., 2009). Zhao et al. (2015) use a smartphone app and a respondent-supervised machine learning trip classification algorithm to measure travel behavior in Singapore. In this project, I designed and calibrated an entirely automatic trip detection algorithm, which makes it easier to collect large quantities of travel behavior data.[9]

[8] Later on, this literature evolved towards more sophisticated models, for example the joint analysis of departure time and network routing models (Yang and Meng, 1998), and studies of the distributional impacts of pricing (van den Berg and Verhoef, 2011; Hall, 2016).

[9] The app used in this study is also more battery efficient – an important requirement in this setting – due to not collecting accelerometer data.

Third, most estimates of travel preferences in transportation research and planning are based on "stated preferences," whereby survey respondents make hypothetical choices between alternatives that involve trade-offs (Ben-Akiva et al., 2016). Despite their flexibility, stated preferences may bias results if respondents do not properly anticipate their own behavior, a problem the literature has attempted to minimize through careful survey design. In this paper, I measure revealed preferences (real behavior) after experimentally introducing congestion charges for some commuters.

There are relatively few studies that estimate commuter preferences using a revealed-preference approach. Small et al. (2005) analyze real-world driver decisions to use a faster tolled lane to estimate the value of time and of reliability, and Bento et al. (2017) estimate the value of urgency in a similar setting. Estimates of scheduling preferences are even rarer (Small, 1982). A separate group of papers analyzes reduced form impacts of road pricing experiments. Tillema et al. (2013) study a pilot offering rewards for avoiding peak-hour driving. In a contemporaneous study, Martin and Thornton (2017) analyze a randomized experiment that implemented several types of congestion charges in Melbourne, Australia. They report reduced-form effects and implied elasticities, and document that peak-hour distance charges reduced peak-hour travel, cordon charges reduced cordon entries, especially for commuters moderately close to public transit, while commuting to work was not affected. In this paper, I bring these two strands of the literature together by designing a randomized experiment in order to be able to recover the key commuter preference parameters in the model, value of time and scheduling preferences.

Fourth, a growing empirical literature documents the impact of traffic policies on traffic volumes, travel times and air pollution. Several papers analyze the aggregate impact of real-world congestion pricing policies, in London (TfL, 2006; Prud'homme and Bocarejo, 2005; Raux, 2005), Milan (Gibson and Carnovale, 2015) and Stockholm (Karlström and Franklin, 2009), while another strand studies non-price, vehicle quantity restrictions (Davis, 2008; Kreindler, 2016; Hanna et al., 2017; Gu et al., 2017). These papers measure impacts on aggregate outcomes, and either do not address the welfare implications of these policies, or, in a few cases, perform basic welfare calculations treating travel at any time of the day as a single good. Here, I combine estimated preferences with road technology estimates to run equilibrium policy simulations, which allows me to assess policy welfare impacts.

Fifth, empirical studies of the relationship between traffic density, speed and flows mostly focus on small road segments (Small et al., 2007). Geroliminis and Daganzo (2008) used data from fixed-loop detectors and taxi GPS data over a large area in Yokohama, Japan, to document that speed decreases strongly with vehicle density. We do not have similar estimates for cities in developing countries. Akbar and Duranton (2017) use trip data from a household travel survey in Bogotá, Colombia and travel times collected from Google Maps several years later, to estimate both the demand for travel and supply (or road technology). They find a small elasticity of travel time with respect to volume of travel, and I show that the results in Bangalore and Bogotá are very similar. In this paper, I use a large GPS data set with precise information on traffic volumes and driving times, as well as contemporaneous driving time data from Google Maps, and document a linear, moderate relationship between volume and travel times, both within day and across days.

I organize the rest of the paper as follows. Section 2 describes traffic congestion and travel behavior in Bangalore. Section 3 sets up a theoretical model of travel preferences and analyzes the experiment within the model. Section 4 describes the data collection and study sample, and section 5 describes the experimental design and reduced form results. Section 6 describes the structural estimation, section 7 quantifies the traffic congestion technology, section 8 reports the policy counterfactual simulations and quantifies the inefficiency in the decentralized equilibrium, and section 9 concludes.

2 Setting

Traffic Congestion and Travel Behavior in Bangalore, India

Similar to other large cities in developing countries, Bangalore's fast-growing population and economy put stress on its transportation network, which suffers from severe road traffic congestion. In Bangalore, commuters essentially depend on the road in order to reach their destinations. Nearly all motorized transport, both private and public, travels on urban roads, so, to a first approximation, congestion affects all commuters.[10]

Traffic congestion in Bangalore is extreme, and shows significant and predictable within-day variation. Figure 1 shows average predicted travel delay in minutes per kilometer, collected from the Google Maps API on 28 routes in the study area.[11] On average between 7 am and 10 pm on weekdays and across all routes, it takes 3.41 minutes to advance one kilometer. Travel delay is the inverse of speed, so this is equivalent to a speed of 10.9 miles per hour. This is extremely slow, but broadly in line with speeds in other heavily congested large cities in developing countries, such as downtown Jakarta, Indonesia (Hanna, Kreindler and Olken 2017) and Delhi (Kreindler, 2016). Bangalore is much slower compared to cities in the U.S. For example, Anderson (2014) finds an average travel delay of 0.7 minutes per kilometer on urban highways in Los Angeles.

Figure 1 also shows strong predictable within day variation in traffic congestion. Between 7 am and 9 am, travel delay increases by 0.75 minutes per kilometer, or 30%. In other words, a trip that would take

[10] The 2011 census reports that roads are used by 97% of all commuters – excluding those who do not travel, walk or use the bicycle. The main modal split is 33% using motorcycles, 15% cars, and 44% bus. Ridership on the Bangalore metro was below 100,000 per day in 2016, accounting for no more than 4% of all commuters.

[11] Results from 178 routes across Bangalore show a very similar shape and slightly lower travel delay levels.

an hour starting at 7 am would take 80 minutes starting at 9 am. Similarly large changes in average travel delay occur around the evening peak. Here we are taking an average over many different routes that cover all directions and that may have different temporal patterns. In smaller areas, the within-day variation in expected travel time is likely larger. In addition, these results ignore travel time uncertainty, which increases alongside expected travel time.

Assuming that commuters have some flexibility in their schedules, these results suggest that it may be more efficient if some people traveled at earlier or later times, in order to avoid the peak hours. The individual-level GPS data collected for this study using the smartphone app shows that commuters do indeed vary their departure times significantly from day to day. Table 1 reports descriptive statistics about travel behavior in the study sample. Panel C shows the within-person departure time variability in the morning and evening. For the first trip in the morning, the standard deviation for the median person is 1.3 hours, which implies a 95% confidence interval of five hours for the departure time! Even restricting to trips between home and work, the median commuter's departure time is covered by a 95% confidence interval of almost two hours for the morning and three and a half hours in the evening.

However, the daily variation in how commuters travel does not automatically mean that commuters have flexible schedules and that they would respond strongly to policies that give incentives for off-peak travel. It is possible that desired travel times change from day to day (based on changes in work or other constraints), yet commuters may be inflexible around those times on any particular day. Similarly, the existence of large, predictable travel time differentials between different times of the day is not by itself enough to understand the externality imposed by an additional commuter on the road at a given time. Overall, the facts discussed in this section suggest that peak-hour inefficiency is a possibility, yet they are not enough to quantify the welfare impact of policies that aim to reduce peak-hour traffic. In order to study these issues formally, I next introduce and analyze a model of within-day travel behavior and traffic congestion.

3 Theoretical Framework

The profile of traffic congestion within a day cannot be summarized effectively by a single aggregate statistic. Instead, commuters choose when to travel taking into consideration congestion at each time of the day, among other factors. Moreover, a commuter's impact on driving times experienced by others will also depend on their departure time. This is a departure from classic models, where externalities operate through a single aggregate measure (Beckmann et al., 1956; Diamond, 1973).

The model introduced here and elaborated in section 6 puts a specific structure on the demand substitution pattern between travel at different times of the day. I also use the model to explain why the key parameters cannot be identified from observational data alone, and to show that two specific congestion charge policies help solve this problem.

The model is based on the classic formulation of preferences over scheduling and time spent driving from (Arnott et al., 1993), modified to include travel time uncertainty and ideal arrival time variation. It abstracts from the extensive margin decision to travel. I first set up the model for a single route, then introduce the route choice problem briefly in section 3.2 and formally in section 6.

3.1 Model Setup

An atomistic commuter decides when to travel from a stable origin (home) to a stable destination (work), taking into account traffic conditions at different departure times. Define $u(h_D, T)$ the utility from departure time h_D and travel time T, and assume it is quasi-linear in money. This general formulation can include preferences to depart and arrive at specific times, the distaste for time spent traveling, and variations in travel times based on departure time. The commuter maximizes expected utility, namely solves $\max_{h_D} \mathrm{E}_T u(h_D, T(h_D))$, where travel time $T(h_D)$ is stochastic and realized only after departure.

I assume utility takes the following form:

$$u(h_D, T) = -\alpha T + -\beta_E \left| h_D + T - h_A^* \right|_- - \beta_L \left| h_D + T - h_A^* \right|_+$$

The commuter cares about travel time and the arrival time $h_A = h_D + T$. Travel time cost is linear, and α measures the value of time. The second and third terms measure scheduling preferences over arrival time (Arnott et al., 1993). The commuter has an ideal arrival time h_A^*, and constant per-unit of time costs of arriving early (β_E) and of arriving late (β_L). Here, $|x|_-$ and $|x|_+$ respectively denote the negative and positive parts of x (both defined as non-negative numbers). I assume that the ideal arrival time is known in advance but it can change from day to day.

The key parameters of interest in this model are α, β_E, and β_L. The first measures the benefits of any policy that improves expected travel times. The other two parameters capture the costs of a policy that attempts to push commuters away from the peak-hour, namely the costs of traveling at inconvenient times.

Under these assumptions, the commuter's problem becomes

$$\max_{h_D} -\mathrm{E}_T \left[\alpha T(h_D) + \beta_E \left| h_D + T(h_D) - h_A^* \right|_- + \beta_L \left| h_D + T(h_D) - h_A^* \right|_+ \right] \tag{1}$$

While the commuter preferences over arrival times have a kink at the ideal arrival time, the uncertainty in travel time smoothes out the utility. The first order condition can be re-written as the following identity:

$$\pi(h_D^*) = \frac{\alpha \cdot d\mathrm{E}_T T / dh_D + \beta_L}{\beta_E + \beta_L} \tag{2}$$

Here $\pi(h_D) = \Pr\left(h_D + T\left(h_D\right) < h_A^*\right)$ is the probability of arriving early when departing at h_D, which depends on the distribution of travel time shock $T\left(h_D\right) - \mathrm{E}_T T\left(h_D\right)$. At the optimum departure time, the probability to arrive early depends on the following factors. If the slope of expected travel time with respect to departure time is positive, the commuter has an incentive to leave earlier to take advantage of faster travel, and this effect is increasing in the value of time, α. This is captured in the first term in the numerator. The commuter also chooses departure time to balance the costs of arriving early and arriving late. The more costly it is to arrive late, the earlier the optimal departure time will be. This effect is captured by the $\frac{\beta_L}{\beta_E+\beta_L}$ term.

3.2 Identifying preferences using congestion charges

The key parameters α (value of time spent driving) and β_E and β_L (schedule costs of arriving early and late) are not typically identified from observational data. There are two problems. First, a change in departure time leads to a change in the distribution of arrival times, and it may also lead to a change in expected travel time. This makes it difficult to disentangle the relative importance of schedule costs from the value of time, as shown in expression (2). For example, assuming we know h_A^*, if we observe someone leave early, we do not know if they do so in order to take advantage of faster travel times (assuming $d\mathrm{E}_T T/dh_D > 0$) or because the cost of arriving late is very high. The second problem is that it is difficult to learn anything from day to day variation in departure times. If we allow the ideal arrival time h_{At}^* to vary by day (t) – for example because the commuter needs to arrive earlier or later to work on some days – then the individual optimal departure time will for the most part track h_{At}^*. To see this, assume the travel time distribution is independent of departure time, then this relationship is exactly linear. In other words, in this model, day-to-day changes in observed departure time are not informative about the underlying parameters α, β_E, β_L.

I now introduce two congestion charge policies that create price variation that will help identify the required parameters. This procedure has the added benefit of providing monetized estimates of α, β_E and β_L. The first policy imposes a marginal cost of departure time, $m = p \cdot h_D$. Intuitively, this creates an independent incentive to change departure time and leave earlier. The first order condition with pricing changes to

$$\pi(h_D^*) = \frac{\alpha \cdot d\mathrm{E}_T T/dh_D + \beta_L + p}{\beta_E + \beta_L}$$

By observing the commuter's departure time behavior for various values of p, and given knowledge of the shape of the function π, we are able to identify the denominator and numerator in (2). However, β_L and β_E are not identified separately without knowing α, how the commuter values time spent commuting, except in the case when $d\mathrm{E}_T T/dh_D = 0$, that is when expected travel time does not depend on departure time.

Now consider a different congestion charge scheme to help identify the marginal value of time α. First, consider an extension of the model where the commuter also chooses one of two routes $j \in \{0, 1\}$. The route $j = 0$ is the shorter, direct route from home to work, while the $j = 1$ (detour) route takes more time. Travel time on route j at departure time h_D is denoted by $T_j(h_D)$, and satisfies $\mathrm{E}T_1(h_D) > \mathrm{E}T_0(h_D)$ for all h_D. Under the second congestion charge policy, the commuter has a choice between using the short route $j = 0$ and paying a flat fee m, or taking the detour route $j = 1$ for free. The fee m that makes the commuter indifferent between the two options is informative about the value of time α, although β_E and β_L also play a role by determining the optimal departure time for each route.

Taken together, the two congestion charge schemes jointly identify the value of time and schedule flexibility parameters, assuming we know the distributions of travel time and shape of idiosyncratic shocks. The field experiment is designed based on these insights.

3.3 Closing the model: road technology, equilibrium, and social optimum

To close the model, we need to specify how the distribution of travel time at each departure time depends on the volume of traffic at that and other departure times. I consider a simple relationship between the rate of departures at a given time h, and the expected travel time starting at that time. Assume $\mathrm{E}T(h) = F(Q(h))$, where Q is quantity or volume of traffic departing at time h, and $F(\cdot)$ is a function that describes the road technology. (In section 7 I will show that a linear F provides a very good fit to the data.[12]) I further assume that the travel time distribution at a given departure time is fully determined by the expected travel time. (In the empirical application, I show that a log-normal distribution with standard deviation following a quadratic function in the mean offers a good fit to the data.)

A Bayesian Nash equilibrium of this model is described by a pair of travel decisions $(h_{Di})_i$ for all commuters i in the population, and a travel profile $(T(h))_h$ such that commuters respond optimally to traffic conditions, and the travel profile is determined by the aggregate pattern of departures. It is also possible to compute a Nash equilibrium in the presence of departure time monetary charges $\tau(h)$. Simulations in section 8 identify a unique and stable equilibrium. Intuitively, commuters have well-defined desired arrival times, and congestion makes traveling at a given time strategic substitutes.

The social optimum can be implemented as a Nash equilibrium with "Pigou" charges, where the charge $\tau(h)$ at departure time h is exactly the marginal social cost of a commuter traveling at h. We can compute

[12]The bottleneck model is a classic alternative with useful theoretical characteristics (Arnott et al., 1993). In that model, traffic is modeled as a bottleneck with fixed flow capacity. If vehicles arrive at the bottleneck at a rate below capacity, they pass through without delay. As soon as the incoming flow exceeds capacity, a queue forms. The queue is cleared in a first-come-first-served order, at the bottleneck capacity rate per unit of time. The wait time (and queue length) depends on the entire distribution of departure times in the past. Unfortunately, this type of model does not fit the data in this setting.

the marginal social cost of a commuter i traveling at a given departure time h by computing the two equilibria when i leaves at h and when i does not travel at all, and comparing the (utilitarian) welfare for the other commuters.

Having estimated the demand parameters and equipped with a model of road technology, it is possible to compute the equilibrium, evaluate welfare under counterfactual congestion charge policies, compute the externalities imposed in the unpriced equilibrium, and compute the optimal charges.

4 Data Sources and Study Sample

The data backbone of the project is a data set of trips with precise GPS coordinates, collected using a newly developed smartphone app. This data was used both for measuring detailed travel behavior and for implementing the congestion charge policies in the experiment. This section describes how the app was designed, how the data was collected, and how it was automatically cleaned and classified. I also briefly describe several other data sources. The section ends with a description of the study participant recruitment procedure.

4.1 GPS trip-level data from smartphone app

GPS traces. Travel behavior data was collected using a smartphone app that works in the background of any GPS-enabled Android smartphone and passively collects phone location data, without requiring any user input. To conserve battery power, updates were collected at variable time intervals, between every 30 seconds while traveling and every 6 min when in stationary mode.[13] The phone location is identified by the phone operating system using GPS information, as well as cell phone network and WiFi information. (Henceforth, I will refer to this data simply as *GPS data*.) The app uploads data to a server at regular intervals using the phone's data connection. The app has a simple interface that shows a map with the user's current location, and users can receive notifications in the phone notification panel.

Measuring travel behavior using a smartphone-based app has several major advantages over previous data collection techniques. Most often, surveys collect self-reported behavior, which is affected by recall bias, rounding of departure times and trip duration, and tends to underestimate within-person temporal and route variation Zhao et al. (2015). The study app solved these issues by collecting the relevant information completely automatically, without any user input at the beginning or end of a trip, and without requiring participants to later review and validate their trips. Using a smartphone as sensing device also improves

[13] The app, called "Bangalore Traffic Research," was available from Play Store during the study period,. I worked together with GridLocate Ltd, a GPS tracking solutions company, to adapt one of their products to the specific needs of this project.

over previous studies that required participants to carry a separate GPS device.[14]

Trip Data Processing. The raw GPS data for each user-day was automatically cleaned and classified into *trips* and *locations*. I designed and implemented a sequence of algorithms that eliminates outliers and imprecise GPS data points, and segments each day into a sequence of trips and locations, as well as segments corresponding to missing data. Consecutive trips with short stops (at most 15 minutes) between them are linked together into *chains*, which is the unit of analysis. There is no direct way to distinguish the travel mode, including walking or public transport. However, short walking trips are automatically excluded from the sample of trips. The algorithm tags trips outside Bangalore, defined as more than 18km away from the city center. This algorithm was used during the experiment to compute congestion charges for participants in the treatment groups.

Missing GPS data was caused by technical as well as human factors. The app does not record location data if the phone or the location services are switched off, if app permissions are revoked, or if the phone is unable to determine its own location. The last situation may arise, for example, when the phone's 3G internet connection is switched off, because an active connection helps achieve a faster first GPS location. I classify data into three quality categories based on the total duration without location data, and the total distance traveled without precise route information: good quality data, insufficient data, and no data. During the experiment, around 75% of days are good quality, which is the category used for analysis.

Common Destinations and Regular Commuters. Travel behavior and preferences may differ on regular and non-regular trips. In order to be able to control for this important regularity in travel behavior, I identify common, recurring destinations at the commuter level (such as a workplace or school) using a clustering algorithm to group locations into groups, followed by manual review of the location groups most frequently visited.[15] The home location is easy to identify as the most common location group. I then classify one or at most two location groups as "work" destinations. Next, I compute the fraction of distance traveled between home and work, as well as the fraction of days present at work. Using these two variables, I classify participants into regular and variable commuters. Around 75% of study participants have a regular destination, and the median regular commuter visits work on 91% of weekdays (Table 1 Panel B).

Google Maps data. I collected two types of Google Maps data on travel times that include information on traffic congestion. The first data set collected "live" or real-time travel time on 178 routes across Bangalore, including 28 routes in the study area of South Bangalore, every 20 minutes throughout the day,

[14] In a phone survey performed after the experiment ended, only 2.5% of respondents said they left their phone at home "sometimes, for usual destinations."

[15] For grouping locations, I used the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm implemented in the `sklearn` package in python. I then define the top two groups as home and work candidates, respectively, and classify all trips based on whether they connect one or both of these locations.

for 207 days in 2017. This data will be used to calibrate the distribution of travel times, holding route and departure time fixed, and in order to measure the road technology impact of traffic volume on speeds. The second data set is individual-level data on typical travel times between their home and work locations, at all departure times during the day. This data will be used to understand the choice set faced by individual commuters.

4.2 Study sample and survey data

Study participants were recruited in a random sample of gas stations in South Bangalore.[16] Surveyors approached private vehicle drivers (commuters) who were using a car, motorcycle or scooter, excluding taxis and professional drivers, and invited them to participate in a study about understanding traffic congestion in Bangalore. Respondents first answered a short eligibility filter,[17] and if eligible the surveyor explained in broad terms the study purpose, mentioning monetary rewards for participation and the possibility to receive monetary incentives tied to changes in travel behavior. Respondents were invited to install the study smartphone app and answer a very short survey on the spot. All respondents received a study kit including a branded study flyer and consent form.[18] The recruitment survey collected basic contact data, demographic variables (age category, gender, self-reported income, occupation) as well as information on the vehicle (car, motorcycle or scooter, brand and model, odometer reading).[19]

In the weeks after recruitment, we collected travel data from the participant smartphone app.[20]

5 Congestion Charge Policies Experimental Design

I designed and implemented two congestion charge policies that capture the main dimensions of traffic congestion: time and location. The first policy, called "departure time" congestion charges, imposed a pay-

[16] Gas stations are ideal locations to meet commuters who regularly use their private vehicle. (During piloting our team attempted household visits, which suffered from a very low probability of finding respondents at home.) In gas stations, surveyors worked Monday–Saturday in one of two shifts, 8 am – 1 pm or 3 pm – 8 pm.

[17] A respondent was eligible if they reported being the owner or regular user of the private vehicle used on that day, traveling with it or another private vehicle at least 20 Km in total per day, at least three days per week, owning a smartphone and not planing to leave Bangalore for more than two weeks over the following two months. Smartphone usage is very high: 76% of participants eligible based on other conditions owned a GPS Android smartphone (an additional 12% owned an iphone and were not included).

[18] Out of 16,912 persons approached, 43% refused to be interviewed. A further 28% were ineligible. Out of eligible respondents, 27% or 2,300 accepted to install the app. This is calculated assuming the same fraction of ineligibles between those who answered the initial filter and those who refused.

[19] A few variables were collected for all respondents, including refusals: age category, vehicle type, brand and model. I also scraped vehicle prices from an online marketplace, and merged this data with the recruitment survey data for all respondents who were approached.

[20] The study team monitored quality and contacted respondents in case data quality problems arose. Participants were also offered an incentive worth Rs. 300 in phone recharge for providing one week of quality data.

per-kilometer congestion rate that was higher during morning and evening peak hours. Peak hours are a natural target for traffic policies, and congestion charge policies in Stockholm and Singapore have the same feature of higher fees for peak-hour travel. The second policy, called "area" congestion charges, imposed a flat fee for crossing or driving through a specific circular area. This is modeled after flat fee cordon pricing policies (such as those in London and Milan), with an additional special focus on detour route decisions.[21] In addition to emulating common congestion pricing policies, the two policies were designed such that commuter responses to these charges identify the key parameters of the travel demand model described in section 3.

The experimental sample was selected based on app data quality and a second eligibility check.[22] Participants were invited to meet with a surveyor to discuss the second part of the study (the experimental phase). Overall, 497 or 22% of all app participants were enrolled in the experiment on a rolling basis. After the meeting was scheduled and before it took place, participants were randomized into treatments; all participants (including the control group) met in person with a surveyor at a location convenient for the respondent. During the meeting, surveyors explained the treatment and (if applicable) how congestion charges function. Participants were told that the purpose of the study is to understand how commuters in Bangalore would react to the presence of charges, and the surveyors emphasized that there are no correct or incorrect behaviors in response to congestion charges.

During the experiment, charges were deducted from a pre-paid virtual account that was set up for each participant. The outstanding balance at the end of each week during the experiment was transferred to the participant's bank account. In addition to any charges due to their travel behavior, participants were charged a flat fee for no or severely incomplete GPS data, and in case they did not make any trips on a given weekday.[23] A maximum daily total charge and minimum account balance of Rs. 250 also applied. Account opening balances were chosen independently for each participant, based on a model that predicted expected charges given baseline travel behavior and a hypothesis of responsiveness to treatment. (The target final account balance was randomized to either Rs. 500 or Rs. 1,000 per week.) Charges were calculated automatically and participants received daily account balance updates through SMS and app notifications. In addition, weekly phone calls reminded participants about their treatment group details. Participants also received support materials such as a laminated rate card with information about congestion charges (see Appendix Figure A3). To establish trust, participants received a welcome bank transfer soon after the first meeting, and/or an external smartphone battery (power bank) as a gift during the meeting. A study call

[21] The diameters of the congestion areas in London and Milan are 6.5 and 3.5 kilometers, respectively, whereas in this experiment they range between 0.5 and 2 kilometers. Study participants never have a stable destination inside the congestion area, and always have a detour route that takes at most 14 minutes more than their usual route.

[22] Commuters with less than 5km of travel per day, and those who actually lived or spent considerable amount of time outside Bangalore, were dropped.

[23] The "no trip" fee was designed to dissuade incentive gaming by leaving one's smartphone at home for the entire day.

center was available if study participants had questions or complaints.

Experimenter demand effects are an important concern in this setting. Commuters in Bangalore generally care deeply about traffic congestion, and study participants may be motivated to avoid congested times or areas by a sense of civic duty. While these responses may in principle be real, it is also possible that they are specific to this (short-term) experiment, where their participation was voluntary and compensated. I took several steps to guard the experimental results against this possibility. First, during the meeting surveyors were trained to present the options in a neutral light, and to emphasize at least twice that the study does not have a preference over whether participants change or do not change their behavior. Importantly, the experimental design includes a departure time "information" treatment, where participants received flat payments as well as SMS and app notifications that concerned how they can change departure times to avoid traffic. Finally, both types of congestion charges had sub-treatments with price variation, in principle allowing the estimate price responsiveness controlling for overall responsiveness.[24]

Participants were added to the experiment on a rolling basis, and the allocation to treatments was pre-randomized for each stratum. There were eight strata in the experiment, all combinations of participants eligible or ineligible for the area charge, car or non-car (motorcycle or scooter) users, and participants with high or low daily travel distance in the baseline period. The strata, sub-treatments for each of the departure time and area treatments, and timing, is described in Appendix Tables A11 and A12. All departure time and area sub-treatments were cross-randomized within each stratum, and the sub-treatments in each main treatment were stratified in time, across blocks of 8 consecutive slots.

5.1 Congestion Charges

Departure Time Pay-per-Km Congestion Charge

Participants in this treatment were charged for each trip based on a per-km rate and the length of their trip. The rate was positive during a 3-hour interval during the morning and a 3-hour interval during the evening. Each charged interval had the same structure: a one hour increasing "shoulder" ramp when the rate grew linearly from zero to the peak rate, one hour of peak rate, and a one hour decreasing "shoulder" ramp when the rate fell linearly to 0. Appendix Figure A3 shows an example rate card (given to study participants) that illustrates the charges for the morning interval.[25]

[24] In addition, as argued in section 3, we are mainly interested in *relative* preferences over time spent driving and schedule costs, and these measures are more robust to experimenter effects than the absolute values, as there is no obvious reason for these effects to disproportionally affect one treatment over the other.

[25] The start time of the charged interval differed by at most ±30 minutes between commuters, and was designed to maximize the overlap between the shoulder periods and typical departure times for that commuter based on baseline data. This procedure was implemented for *all* commuters before randomizing them between the treatment groups.

Four sub-treatments were designed to separate the impact of prices from other features of the intervention. The sub-treatments were: control, information, low rate, and high rate (see Appendix Table A11). Participants in the control group were monitored for 5 weeks, received regular updates about their data quality, and received a flat Rs. 300 payment per week for participation. I included an information group in order to measure the bundle of experimenter demand, information and reminder provision, and other non-price features. Participants in the information group received daily messages about the trips they had completed the previous day, together with advice about quicker travel times outside the morning and evening peak hours. They also participated for 5 weeks. The low and high rate groups had a maximum (peak) congestion rate of Rs. 12/Km and Rs. 24/Km, respectively. These participants received this treatment for three consecutive weeks out of four in total, either the first three or the last three. (During the remaining week, they received the information group treatment.) Before the start of the congestion charge phase, participants underwent a three-day *trial phase* where they received congestion charge messages to understand how charging works. In total, low rate and high rate participants also were in the experiment for approximately 5 weeks.

Area Congestion Charge

Participants in this treatment were charged for driving through a congestion area that was chosen individually for each participant. The area was a disc with radius 250m, 500m or 1000m positioned along a route used frequently by the participant during the pre- period. The area induced an alternate non-intersecting detour route, which was between 3 and 14 minutes longer than the original route. If no area charge with this property was found, the participant was ineligible for the area congestion charge. (Roughly half of the experiment participants were are eligible.) The charge was in effect between 7 am and 9 pm, and applied at most once for the morning interval (7 am – 2 pm) and at most once for the evening interval (2 pm – 9 pm). The area congestion charge was implemented for one week (five weekdays). The area location, radius, boundaries, and induced detour were emphasized by the surveyor during the meeting before the experiment, and this information was repeated in each daily reminder SMS sent to study participants.[26]

The area treatment did not include a pure control group, due to the smaller size of participant pool. However, participants were randomized between being treated early (in the first week after the meeting) or late (in the last or forth week of the study), which is the basis for the experimental comparison.

The area sub-treatments were designed to identify the effect of price and detour time variation on choices. On two randomly chosen days, the congestion charge was 50% higher. The following sub-treatments were cross-randomized (see Appendix Table A11). Low rate participants were charged a baseline charge of Rs. 80

[26]The area location did not specifically target congested areas. Surveyor were instructed to not convey this idea to the participant during the in-person meeting, and if they were asked to reply that the area was selected by an algorithm.

(and Rs. 120 on the two days per week when the charge was higher), while High Rate participants were charged Rs. 160 (and Rs. 240 respectively). Long detour participants had an area location and radius that induced a predicted detour between 7 and 14 minutes above the usual route, if such an area existed. Short detour participants had an area that induced a predicted detour between 3 and 7 minutes above the usual route, if such an area existed.

5.2 Reduced-Form Responses to Congestion Charges

Reduced-Form Specification

The congestion charges described above may affect the number as well as the temporal and spatial distribution of trips. In order to capture unconditional effects, I first aggregate outcomes at the day level and run the following difference-in-difference specification:

$$y_{it} = \delta^I T_i^I + \delta^L T_i^L + \delta^H T_i^H + \gamma^I T_i^I \times Post_t + \gamma^L T_i^L \times Post_t + \gamma^H T_i^H \times Post_t + \mu_t + \alpha_i + \varepsilon_{it}, \qquad (3)$$

where y_{it} is an outcome of interest for commuter i on day t, such as the number of trips that day, $Post_t$ is a dummy for the period of the experiment, T_i^I, T_i^L and T_i^H are dummies for the information, low rate and high rate departure time sub-treatments, and α_i is a commuter fixed effect, μ_t is a study cycle fixed effect whose categories are the period before the experiment, and each week in the experiment. The coefficients of interest, γ^I, γ^L and γ^H, respectively measure the impact of information, low congestion rates and high rates relative to control, during the experiment relative to the period before.

The sample is all non-holiday weekdays when the respondent does not travel outside Bangalore. During the experiment, I include the three weeks when charges are in effect; in the control and information groups I also keep three weeks to make the timing in each sub-treatment comparable. Where necessary for the construction of the y_{it} variable, the sample is restricted to days with "good quality" GPS data, as defined above. Standard errors are clustered at the commuter level. For trip level outcomes, I use the same specification with outcome y_{jit} corresponding to trip j of commuter i on day t.

For the Area treatment, there is no pure control group. Instead, the empirical strategy is based on comparing commuters randomly assigned to be treated early or late. Specifically, in the first week I compare commuters treated early (treated group) to those treated late (control group). In the fourth week, these roles are reversed. The period before the experiment and the second and third week during the experiment are included to gain precision when estimating individual fixed effects. Specifically, define $Treated_{it} = (1 - T_i^{Late}) \times \mathbb{1}(t \in W_1) + T_i^{Late} \times \mathbb{1}(t \in W_4)$ where T_i^{Late} is an indicator for being treated late, and W_s is an indicator for week s. I run the following specification:

$$y_{it} = \gamma^A \cdot Treated_{it} + \mu_t + \alpha_i + \varepsilon_{it} \tag{4}$$

The coefficient of interest is γ^A, which measures how the outcome y_{it} differs as a result of being exposed to area congestion charges, relative to similar commuters who are not treated that week.

Experimental Integrity Checks

Table A2 reports the experimental balance check. The different treatment groups are similar along demographic and pre- period travel behavior variables. All coefficients are small, and join significance tests cannot reject the null of no effect.

Given that smartphone app data was used to implement the congestion charges, it is especially important to ensure that treated participants did not differentially tamper with their smartphones by switching the phone or the GPS sensor off during certain trips or on certain days. During the experiment, participants provided good quality GPS data on approximately 75% of weekdays. Appendix Table A1 shows that the departure time and area sub-treatments did not have any detectable differential impact on GPS data quality. This suggests that missing GPS data was mostly due to technical and human factors unrelated to gaming incentives.[27]

The Impact of Departure Time Pay-per-Km Charges

Commuters may respond to charges by canceling trips with departure times during the charged period, as well as by rescheduling these trips to departure times with lower charges. Figure 2 shows the causal impact of congestion charges on the distribution of trip departure times, for the morning and evening charges. It plots a locally linear difference-in-difference by departure bin. To construct Figure 2, for each commuter, day and departure time *relative* to the midpoint of the congestion charge for the commuter,[28] I compute the number of trips that start around that time, using an Epanechnikov kernel. Then, for each departure time I run a regression similar to (3) except that I compare the low rate and high rate charge groups (identified by T_i^{LH}) to the control and information groups combined. Figure 2 plots the coefficients on $T_i^{LH} \times Post_t$ as well as pointwise 95% confidence intervals.

Commuters substitute away from departure times with high charges towards departure times with lower charges. In the morning (panel A) there is strong substitution within the early ramp interval, when the

[27]The experiment was generally successful in terms of *retaining* study participants: around 5% of participants dropped out right after the meeting, and this figure rose to 10% on the last day of the study. Drop outs are 2 percentage point more frequent in the treatment group, yet this difference is not statistically significant (p-value 0.20).

[28]Recall that the congestion charge has the same shape for everyone, but its location varies by commuter, including for those in the information and control groups.

charge is linearly increasing. In this interval, there is a marginal incentive to advance one's departure time. The results suggest that study participants understood this feature and decided to leave earlier and take advantage of lower charges. There is suggestive evidence of an increase in the number of trips starting right after the end of the charged period; note that the exact position of this increase does not map cleanly to the predicted response given incentives, in the way that the early AM change does.

The results for the evening period are broadly mirrored, namely commuters substitute towards later departure times on the decreasing ramp of the congestion charge profile. However, the results are slightly weaker and less precise. In sum, Figure 2 shows that commuters responded to charges by advancing their departure times in the morning when this leads to lower charges, and delaying their departure times in the evening.

Table 2 shows results on daily outcomes. Panel A of Table 2 shows impacts on trip shadow rates. This outcome is computed in the same way for every trip in the data given its departure time and the commuter's own congestion charge rate profile (which is defined for everyone irrespective of treatment group) and using a normalized peak rate of 100. The rates are then summed over all trips in the day. This outcome is a summary statistic for whether the commuter changed their travel behavior to avoid charges, and includes intensive and extensive margin responses. The results show that the High Rate sub-treatment leads to a decrease of around 14 from a base of 97 in the control group. The Low Rate treatment also appears to lead to a decrease in rates, of roughly half the size of that of the High Rate group, yet these results are not significant. The information group does not seem to have any effect on charges. In panel B, the outcome is the total number of trips in the first column, and the total number of trips during the morning and evening in the other columns. The point estimates are negative, small, and far from statistical significance.

Running the same specification at the trip level leads to similar results. Daily charges are mechanically related to the number of trips per day that occur in the charged interval. Even in the absence of a treatment effect on the number of trips, chance variation in the number of trips per day between treatment groups reduces the precision of the estimates in panel A. Table 3 explores the impact of charges at the *trip* level instead of daily level. Panel A covers the entire sample of commuters and trips, panel B covers only regular commuters and trips between home and work or vice-versa, and panel C covers all trips belonging to the approximately 25% variable commuters. In addition to full day results in column (1) and results in the morning and evening in columns (2) and (4), the table also reports results restricted to the *early* morning interval (all departure times before the midpoint of the peak of the rate profile) in column (3), and restricted to the *late* evening interval in column (5).

Trips in the High Rate have on average lower rates by around $13 - 15\%$ relative to the control group (panel A), with a larger and precisely estimated effect in the morning. The coefficients for the Low Rate treatment are also negative, of roughly half the size, yet not statistically significant. The effects are more precisely estimated for regular commuters in panel B. In particular, the coefficients for early morning and late evening are negative and larger than for the entire day period, as suggested in Figure 2. In panel C there is no evidence that congestion charges changed the distribution of trip departure times for variable commuters. In the entire table, no discernible pattern emerges for the information group, suggesting that information alone did not shift travel behavior.

In Appendix Figure A1 panel A, I investigate the heterogeneity in individual responses to the departure time treatments. Pooling together the Low Rate and High Rate (as in Figure 2), the figure shows that treatment group respondents have a bi-modal distribution in the within-person change in shadow trip rates. This suggests that a certain group of commuters decided to change their behavior to take advantage of lower charges, while others did not make any changes.

The Impact of Area Charges

Following the discussion of the model in section 3, we are interested in the impact of Area charges on the choice probability of alternate routes that avoid the congestion area. Tables 4 and 5 report the results at the day and trip level, respectively.

Panel A of Table 4 reports the impact on total shadow charges due to crossings of the congestion area. These are calculated for every trip in the sample, and the charge for a crossing is normalized to 100. The results show a large, precisely estimated decrease in the probability to cross the congestion area. The decrease is around 23% of the control mean, significant at the 1% level. The impact is similar in the morning and evening intervals, and roughly similar for participants treated in the first or the last week (columns 4-6). Panel B shows the impact of being treated on the number of trips in the day. Being treated results in around $6-10\%$ more trips per day, with the effect concentrated in the morning and for participants treated in the last week. The increase in number of trips seems related to a small increase in data quality in the treatment group (both effects are concentrated in the 4th week). Note that a larger number of trips will tend to mechanically increase the coefficient on shadow rates, so the treatment impact may in reality be slightly more negative than the result in column (1).

Table 5 investigates whether the area charge induced commuters to take a longer detour, and the choice probability of alternate routes that avoid the congestion area. The table shows results at the trip level and restricts the sample to regular commuters and trips from home to work or vice-versa.[29] Panel A reports the impact on whether the trip intersects the congestion area, and shows a large reduction of 23 percentage

[29] 93% of Area treatment participants are regular commuters.

points on a base of 83%, or equivalently a 29% reduction in area crossings. The effect is very precisely estimated, and of similar magnitude in the morning and evening intervals.

Panel B uses trip duration as outcome variable and reports the experimental effect of being treated on trip duration. The point estimates are positive on average, yet small and not significant. This result is likely due to lack of power to detect a reduced-form effect on trip duration. Indeed, multiplying the treatment effect in panel A by the average difference in duration (4 minutes) we find an average increase of 1.45 minutes for Treated respondent. The point estimates are most often smaller, but we cannot reject this value either.

One concern would be that study participants identified alternate routes that avoided the congestion area that are quicker than what I estimated using Google Maps. To explore this hypothesis, Appendix Table A5 shows the non-experimental correlation between trip duration and whether a trip is charged, including commuter-level, directed route fixed effects. Charged trips are significantly shorter, by about 5 minutes. Moreover, this effect is significantly larger for respondents in the Long Detour Area sub-treatment (column 2), and the extra duration for avoiding trips closely tracks the Google Maps predicted detour of the quickest non-intersecting alternative (column 3). These results show that the Google Maps data accurately predicts the extra time detour incurred in real trips that avoid the congestion area.

Randomly varying the crossing charge and the detour length does not affect the response to the area treatment. Indeed, Table 6 shows that neither doubling the congestion charge (randomized across participants), nor having a 50% higher charge on a random day (randomized within participant), has any significant effect on shadow charges (columns 2 and 3). The last column shows that participants randomly assigned to a short detour ranging between 3 and 7 minutes (as opposed to the long detour, between 7 and 14 minutes) do not reduce their shadow charges more. These results are consistent with high levels of heterogeneity in the population, whereby some participants are easy to sway to change their routes (low values of time), while the others are much more difficult to convince (high values of time).

Individual level response heterogeneity is consistent with this story (Appendix Figure A1 panel B). For each area participant, I count the fraction of days crossing the congestion area, separately when treated and when in the control group. The distribution in the control group is concentrated near 1, as most commuters select the shortest route in the absence of charges (solid, gray bars). In the presence of charges, the distribution becomes bi-modal, with around 20 per cent of the population in the lowest bin, implying that some participants stopped crossing the congestion area at all (outline, red bars).

On the other hand, results on observable sources of heterogeneity are somewhat imprecise (Appendix Table A6). Regular commuters and self-employed commuters appear to respond more to the departure time treatment (columns 1 and 2, panel A), although these differences are not quite statistically significant. Surprisingly, commuters with more expensive vehicles seem to respond more to the departure time treatment, and there is also evidence that they reduce their number of trips (column 4, panels A and B). There is also suggestive evidence that older respondents respond more to both treatments (column 5). There is no evidence that stated preferences predict responses in the experiment (columns 6 and 7).

In summary, departure time pay-per-km charges caused commuters to change their departure times towards departure times with lower charges, especially towards earlier departures in the morning and later departures in the evening. This means that commuters have some flexibility to move trips away from typical work hours in order to save money. These results are driven by a subset of commuters who responds more strongly. Responses in the low rate sub-treatment are roughly half of those in the high rate sub-treatment, although imprecisely estimated, and I do not find any impact of the information and nudges treatment.

Area congestion charges lead to a precisely estimated shift to routes that avoid the congestion area. Participants intersect the congestion area around 20% fewer times when "area" charges are in effect. Doubling the congestion charge or shortening the implied detour experimentally do not affect this fraction. (Routes that do not intersect the congestion area are on average 5 minutes longer.) Consequently, the naive implied value of time for the marginal participant lies between Rs. 1,152 and Rs. 2,304 per hour, both of which are large. These findings are consistent with considerable preference heterogeneity.

However, in order to better quantify these results – especially in terms of interpreting and comparing the responses to the two treatments – I will next estimate a structural model where agents choose departure times and routes.

6 Structural Travel Demand Estimation

I now estimate the key parameters in a model of travel demand over routes and departure times, using experimental variation from the congestion charge treatments. This procedure will provide monetary measures of individual preferences over schedule inflexibility and mean driving time.

I first augment the model set up in section 3 with route choice, commuter heterogeneity and random utility shocks, and derive the choice probabilities. I then describe the Google Maps data used to construct individual-level choice sets, discuss the experimental moments, and finally I present discuss the results and robustness exercises.

Nested Logit Model over Routes and Departure Times

To make the model of the morning home to work commute introduced in section 3 easier to fit to real data, I add route choice, commuter heterogeneity and random utility shocks. On day t, a commuter i chooses a route type $j \in \{0, 1\}$, where $j = 0$ represents any route from home to work that intersects the congestion area, and departure time h_D, chosen from a discrete grid of departure times H_D. Utility is given by:

$$\begin{aligned} U_{it}\left(h_D, j, h^*_{Ait}\right) = & -\alpha \mathrm{E} T_i\left(j, h_D\right) - \beta_E \,\mathrm{E}\left|h_D + T_i\left(j, h_D\right) - h^*_{Ait}\right|_{-} - \beta_L \,\mathrm{E}\left|h_D + T_i\left(j, h_D\right) - h^*_{Ait}\right|_{+} \\ & - m^{DT}_{it}\left(h_D\right) - m^{A}_{it}\left(j\right) + \varepsilon_{it}\left(j, h_D\right), \end{aligned} \tag{5}$$

where h^*_{Ait} is the ideal arrival time on day t, $T_i\left(j, h_D\right)$ is the (random) driving time on route j, $m^{DT}_{it}\left(h_D\right)$ represents the departure time congestion charge that may apply to the current trip, $m^{A}_{it}\left(j\right)$ is the area congestion charge for route j, and $\varepsilon_{it}\left(j, h_D\right)$ is a random utility shock for route j and departure time h_D on day t.[30] Both h^*_{Ait} and $\varepsilon_{it}\left(j, h_D\right)$ are drawn i.i.d. each day. Expectations are with respect to the random driving time T_i. The key preference parameters of interest are α, β_E and β_L, respectively the value of mean travel time, and the schedule costs of arriving early and late. Commuter heterogeneity is captured by different distributions of ideal arrival times h^*_{Ait} and different driving time profiles T_i.

In order to allow different patterns of substitution between departure times and between routes, I assume that the random utility shocks $\varepsilon_{it}\left(j, h_D\right)$ follow an extreme value distribution with correlation within each route. This leads to a nested logit structure over routes and departure times. The two route choices constitute the upper nest, while the choice over departure times is the within-nest component.[31,32]

The distribution of the random utility shocks depends on two parameters, σ and μ, which will be estimated from the data.[33] The probability to choose a given departure time and route can be decomposed as $\Pr\left(j, h_D \mid h^*_{Ait}\right) = \Pr\left(h_D \mid j, h^*_{Ait}\right) \Pr\left(j \mid h^*_{Ait}\right)$. Denote by $V_{it}\left(h_D, j, h^*_{Ait}\right)$ the constant part of utility in (5) (without the utility shock $\varepsilon_{it}\left(j, h_D\right)$), then the departure time choice conditional on route is

$$\Pr\left(h_D \mid j, h^*_{Ait}\right) = \frac{\exp\left(\frac{1}{\sigma_i} V_{it}\left(h_D, j, h^*_{Ai}\right)\right)}{\sum_h \exp\left(\frac{1}{\sigma_i} V_{it}\left(h, j, h^*_{Ai}\right)\right)} \tag{6}$$

Costs scale approximately linearly with route length, so I normalize the logit parameter for commuter i by i's route length, namely $\sigma_i = \frac{KM_i}{\overline{KM}}\sigma$ where $\overline{KM}$ is the sample average of KM_i. This means that all commuters have similar probabilities to choose non-optimal departure times, instead of commuters who

[30] When calculating departure time congestion charges, I ignore the trip distance dependence on route j. In the experiment, the area and departure time treatments never apply at the same time; trip distance still matters, by making route $j = 1$ relatively less attractive when departure time charges are in effect. However, this effect is of secondary importance.

[31] The assumption of independent utility shocks at several minute intervals along the departure time grid may not seem particularly attractive. However, the resulting choice probabilities have a familiar form. To see this, assume that utility is quadratic – which always holds as an approximation around the optimum h^*_D – then as the grid becomes finer the multinomial logit model becomes equivalent to choosing the optimum h^*_D plus a random noise term, with the standard deviation of the noise term related to the inverse curvature of the utility function at the optimum.

[32] It is possible to set up more detailed models over departure times and routes. For example, transportation researchers have developed route choice models that are considerably more sophisticated than the one used here (Ben-Akiva M., 2003). However, this model serves the primary purpose of understanding the margin of route choice highlighted in the experiment, namely the trade-off between taking a longer route and paying a higher congestion charge.

[33] The normalization used here is that utility is expressed in Rupees.

travel far having more precise choices, as would be implied by a constant $\sigma_i = \sigma$.

The route choice probability is given by

$$\Pr\left(j \mid h^*_{Ait}\right) = \frac{\exp\left(\frac{1}{\mu} V_{it}(j)\right)}{\exp\left(\frac{1}{\mu} V_{it}(0)\right) + \exp\left(\frac{1}{\mu} V_{it}(1)\right)} \tag{7}$$

where $V_{it}(j) = \sigma_i \log\left(\sum_h \exp\left(\frac{1}{\sigma_i} V_{it}\left(h, j, h^*_{Ait}\right)\right)\right)$ is the expected utility assuming i chooses route j, called the "logsum" term for route j. The parameters σ and μ measure the importance of utility shocks for departure time choice and route choice, respectively. Higher values correspond to more importance given to utility shocks (less precise choices).[34] Overall choice probabilities are obtained by integrating over the (individual-specific) distribution of ideal arrival times h^*_{Ait}.

To capture the stark heterogeneity documented in the reduced form experimental results, I assume that each participant responds to experimental congestion charges with some probability p, while with probability $1 - p$ they behave as if there were no charges. This assumption has two possible interpretations: either this behavior reflects real preferences, that is, a fraction $1-p$ of the population is infra-marginal to the incentives offered in the experiment, or for other reasons these participants decided to ignore the experiment, in which case we do not know their true preferences.[35]

To summarize, agents choose routes and departure times according to nested logit, and they ignore monetary charges with some probability. The full vector of parameters to be estimated is $\theta = (\alpha, \beta_E, \beta_L, \sigma, \mu, p)$ as well as the individual specific distributions of ideal arrival times h^*_{Ait}.

Data Sources and Model Simulation

In addition to behavior data collected using the smartphone as part of the experiment, fitting this model requires knowledge of the counterfactual distribution of driving times. For average driving times $\mathrm{E}T_i(0, h_D)$ and the short route length KM_i, for each person I collected Google Maps predicted driving times on their home to work route at all departure times throughout the day. To calibrate the distribution of driving times conditional on route and departure time, I use live Google Maps data collected on a set of 178 routes across Bangalore. Conditional on route and departure time, driving time is approximately log-linearly distributed across the 146 weekdays in the data, with the standard deviation well explained by a quadratic in the average driving time (Appendix Figures A5 and A6). Thus, for each commuter and departure time, I assume that

[34] Commuters not in the area treatment only choose departure time, according to multinomial logit (there is no route choice). Their choice probabilities are given by $\Pr\left(h_D \mid h^*_{Ait}\right) \propto \exp\left(\frac{1}{\sigma_i} V_{it}\left(h_D, h^*_{Ait}\right)\right)$.

[35] A more traditional way to capture preference heterogeneity is by assuming random coefficients, that is that parameters α, β_E and β_L vary at the individual level according to some distribution (such as log normal). In this setting, estimating models with random coefficients fails to fully capture the heterogeneity documented in section 5.2 and Appendix Figure A1.

driving time follows such a distribution given the measured Google Maps average driving time. I calibrate driving times on the alternate route ($j = 1$) as an individual-specific constant multiple of driving times on the shortest route ($j = 1$).[36] I assume that the relevant variation in commuter beliefs is captured by the Google Maps travel time. In particular, if commuters systematically over- or under-estimate travel time differences, then the structural estimates from these procedure should be adjusted based on those beliefs.

The estimation sample covers the morning interval, covers all trips between home and work, and restricts to 308 regular commuters with at least two observed trips between home and work in the morning interval during the experiment.

To compute choice probabilities, I use formulas (6) and (7) given individual preference parameters α, β_E, β_L, the nested logit parameters σ and μ, the ideal arrival time h^*_{Ait}, and the travel time distributions for each route and departure time, denoted $\tau_i \equiv (T_i(j, h_D))_{j,h_D}$. During estimation, I assume candidate values for the first five preference parameters, while the travel times are taken from the Google Maps data together with the log-normal distribution assumption. The remaining difficulty is that the distribution of h^*_{Ait} is neither observed nor known *a priori*. To overcome this, I use the observed distribution of departure times in the pre period (before the experiment) to obtain the distribution of ideal arrival times conditional on other parameters. I then use this distribution for h^*_{Ait} to compute choice probabilities both before and during the experiment.[37] During the experiment, the terms $m^{DT}_{it}(h_D)$ and $m^A_{it}(j)$ are either zero or the congestion charges experienced by commuter i in that period, denoted by M^{DT}_{it} and M^A_{it}.

GMM Estimation and Moment Choice

To estimate the model parameters, I use the generalized method of moments (GMM).[38] I use four sets of moments: (1) difference in difference changes in departure time "market shares," (2) the variance of individual-level changes in shadow charges in the departure time treatment and control groups, (3) route choice "market shares" when treated and not treated with area charges, and (4) the 3-bin histograms for

[36]For area treatment participants, before the experiment, I obtained from Google Maps the driving time for the quickest route that does not intersect the congestion area, for a departure time of 9 am for all participants. I assume that the driving times on the detour route ($j = 1$) are a constant multiple of the driving times on the main (intersecting) route, namely $T_i(1, h_D) = \lambda_i T_i(0, h_D)$. The constant λ_i is chosen to match the alternate route travel time at 9 am for person i, as queried before the experiment.

[37]Specifically, I first fit a normal distribution on departure times during the pre period. This is done before estimation, and confidence intervals in Table 7 do not take into account that the departure time distributions are themselves estimated. Then, for given parameter values, I find the distribution of ideal arrival times that, under optimal behavior, would give rise to the normal fit on departure times. This inversion is computationally expensive to do precisely. Instead, I make the following approximations: (1) for each ideal arrival time h^*_{Ait} the optimal departure time is normally distributed around the utility maximizing departure time, with the standard deviation given by the curvature of the utility around the optimum (see footnote (31)), and (2) I assume that the standard deviation is constant for all h^*_{Ait} which allows me to obtain the distribution of optimal departure times by shrinking the distribution of departure times. I then invert the optimal departure time relationship to obtain the distribution of ideal arrival times.

[38]Nested logit has a closed form likelihood function, recommending maximum likelihood on efficiency grounds. Nevertheless, with GMM it is possible to choose moments such that parameters are essentially identified from experimental variation.

individual sample frequency of choosing the short route when treated and not treated with area charges.

The first 61 moments match the difference in difference in departure time market shares, between the departure time treatment and control groups, during the experiment relative to before. Formally, for each 5-minute departure time bin h^k between -2.5 and 2.5 hours relative to the rate profile peak, and for each participant i, I compute the probability that i leaves during h^k, conditional on a trip being made. In the model, for a day t, let $P_{itk}^{DT}\left(\theta, \tau_i, m_{it}^{DT}\right) = \Pr\left(h_i\left(\theta, \tau_i, m_{it}^{DT}\right) \in h^k\right)$ where the random departure time (relative to i's peak) h_i depends on preference parameters, the travel time profile τ_i and charges m_{it}^{DT}. In the data, define $\tilde{P}_{ik}^{DT}(pre)$ and $\tilde{P}_{ik}^{DT}(post)$ the fractions of trips starting in bin h^k for individual i in pre- and post- periods, respectively. Recall that M_{it}^{DT} denotes the charges assigned to i in the experiment, and for convenience make the dependence on θ and τ_i implicit. For $k \in \{1, \ldots, 61\}$, the k-th moment is:

$$
\begin{aligned}
g_i^k(\theta) = {} & \left(\left(\tilde{P}_{ik}^{DT}(post) - \tilde{P}_{ik}^{DT}(pre)\right) \cdot T_i^{LH} - \left(\tilde{P}_{ik}^{DT}(post) - \tilde{P}_{ik}^{DT}(pre)\right) \cdot \left(1 - T_i^{LH}\right)\right) \\
& - p \cdot \left(\left(P_{itk}^{DT}\left(M_{it}^{DT}\right) - P_{itk}^{DT}(0)\right) \cdot T_i^{LH} - \left(P_{itk}^{DT}\left(M_{it}^{DT}\right) - P_{itk}^{DT}(0)\right) \cdot \left(1 - T_i^{LH}\right)\right)
\end{aligned}
$$

where T_i^{LH} is an indicator for being in any of the departure time treatment groups (low or high rate), t is a day during the experiment, and the heterogeneity parameter p enters by attenuating the model term. Intuitively, for given p these moments help identify the schedule costs β_E and β_L, as well as the logit parameter σ. The magnitude of responses on the early and late ramps of the congestion rate profile identify the first two parameters, while the precision of these responses helps identify σ.

The departure time heterogeneity moments target the variance of the individual-level change in shadow charges for trips in the early morning, between the pre and post periods. For these moments, it is important to take sampling variation into account when simulating the model, so denote N_i^{pre} and N_i^{post} the number of days in the pre and post periods for i. Assume h_{it} for $t = \left\{1, \ldots, N_i^{pre} + N_i^{post}\right\}$ are independent random variables, the first N_i^{pre} distributed according to $h_i(\theta, \tau_i, 0)$, and the rest according to $h_i\left(\theta, \tau_i, M_{it}^{DT}\right)$, in both cases conditional on departure times in the two hours before the rate profile peak, namely $h_i \in [-2, 0]$. Define $ch(h)$ to the be the shadow charge of departure time h, and the random individual effect as

$$
ch_i^{DT} = \frac{1}{N_i^{post}} \sum_{t=N_i^{pre}+1}^{N_i^{pre}+N_i^{post}} ch(h_{it}) - \frac{1}{N_i^{pre}} \sum_{t=1}^{N_i^{pre}} ch(h_{it})
$$

Denote the individual effect in the data by $\tilde{ch}_i^{DT}$. The two departure time heterogeneity moments match the variance of ch_i^{DT} in the treatment and control groups. The expressions for full response ($p = 1$) are:[39]

$$g_i^{62} = \left(var\left(ch_i^{DT}\right) - \widehat{var}\left(\tilde{ch}_i^{DT}\right)\right) \cdot T_i^{DT}$$
$$g_i^{63} = \left(var\left(ch_i^{DT}\right) - \widehat{var}\left(\tilde{ch}_i^{DT}\right)\right) \cdot \left(1 - T_i^{DT}\right)$$

The first moment helps identify the probability p that a study participant responds to the treatment. Indeed, given other parameter values, p affects the variance of the individual effect, by splitting the sample between participants who respond and those who do not respond. The second moment helps ensure that the model is able to replicate the sampling variation in individual effects.

The next two moments match route choice market shares, namely the probability to intersect the congestion area when treated and when not treated for commuters in the area congestion charge treatment. Formally, define $P_i^A\left(\theta, \tau_i, m_{it}^A\right) = \Pr\left(j\left(\theta, \tau_i, m_{it}^A\right) = 0\right)$ the probability to take the short route (intersect the congestion area), where the random route choice j depends on preference parameters, the travel time profile τ_i and charges m_{it}^A. In the data, define $\tilde{P}_i^A\left(treat\right)$ and $\tilde{P}_i^A\left(control\right)$ the fraction of days (mornings) when the commuter intersects the congestion area, when treated and when not treated, respectively. Recall that M_{it}^A denotes the area charge assigned to i in the experiment, and for convenience make the dependence on θ and τ_i implicit. The area moments are:

$$g_i^{64}\left(\theta\right) = \left(p \cdot P_i^A\left(M_{it}^A\right) - (1-p) \cdot P_i^A\left(0\right) - \tilde{P}_i^A\left(treat\right)\right) \cdot T_i^A$$
$$g_i^{65}\left(\theta\right) = \left(P_i^A\left(0\right) - \tilde{P}_i^A\left(control\right)\right) \cdot T_i^A$$

where T_i^A is an indicator for being in the area treatment. Without area charges, a commuter will only choose the detour route ($j = 1$) due to large utility shocks that offsets the driving time penalty. For a given value of time α, this helps identify the outer nest logit parameter μ. With area charges, there is an additional monetary benefit to choosing the detour, and for given p these moments together help identify α.

The area heterogeneity moments target the distribution of individual-level sample frequency of intersecting the area. Once again, it is important to take sampling variation into account, so define N_i^{treat} and $N_i^{control}$ the number of days when i is treated and not treated, respectively. Assume j_{it} for $t = \left\{1, ..., N_i^{control} + N_i^{treat}\right\}$ are independent random variables, the first $N_i^{control}$ distributed according to $j\left(\theta, \tau_i, 0\right)$, and the rest according to $j\left(\theta, \tau_i, M_i^A\right)$. Define the (random) sample average of intersecting

[39] Note that ch_i^{DT} is random for a given commuter i, and its distribution also differs between commuters. We are interested in the overall variance, both between commuters and within commuter, as this is what we see in the data. Hence, I use the following shorthand notation: $var\left(ch_i^{DT}\right) \equiv \mathrm{E}\left(ch_i^{DT} - \mathrm{E}\frac{1}{N}\sum_{j=1}^{N} ch_j^{DT}\right)^2$ and $\widehat{var}\left(\tilde{ch}_i^{DT}\right) \equiv \left(\tilde{ch}_i^{DT} - \frac{1}{N}\sum_{j=1}^{N} \tilde{ch}_j^{DT}\right)^2$.

the area in control and treatment as

$$ch_i^{A,control} = \frac{1}{N_i^{control}} \sum_{t=1}^{N_i^{control}} j_{it} \quad \text{and} \quad ch_i^{A,treat} = \frac{1}{N_i^{treat}} \sum_{t=N_i^{control}+1}^{N_i^{control}+N_i^{treat}} j_{it}$$

In the data, denote the corresponding quantities by $\tilde{ch}_i^{A,control}$ and $\tilde{ch}_i^{A,treat}$, respectively. We are interested in the distribution of these variables. The four area heterogeneity moments match the probability that these variables are the middle or top third of the unit interval (the moment for the bottom third is omitted because it is colinear with the others), when treated and not treated. The expressions for full response ($p = 1$) are:

$$g_i^{66} = \left(\Pr\left(ch_i^{A,treat} \in [1/3, 2/3)\right) - \mathbb{1}\left(\tilde{ch}_i^{A,treat} \in [1/3, 2/3)\right)\right) \cdot T_i^A$$
$$g_i^{67} = \left(\Pr\left(ch_i^{A,treat} \in [2/3, 1]\right) - \mathbb{1}\left(\tilde{ch}_i^{A,treat} \in [2/3, 1]\right)\right) \cdot T_i^A$$
$$g_i^{68} = \left(\Pr\left(ch_i^{A,control} \in [1/3, 2/3)\right) - \mathbb{1}\left(\tilde{ch}_i^{A,control} \in [1/3, 2/3)\right)\right) \cdot T_i^A$$
$$g_i^{69} = \left(\Pr\left(ch_i^{A,control} \in [2/3, 1]\right) - \mathbb{1}\left(\tilde{ch}_i^{A,control} \in [2/3, 1]\right)\right) \cdot T_i^A$$

Intuitively, the first set of moments will help identify the probability p that a study participant responds to the treatment, by matching the empirical histogram in the treated group with an average between the model treated and the model control histograms.

6.1 Structural Estimation Results

Table 7 shows the estimation results from two-step GMM, using 100 random parameter starting values to ensure convergence to the global minimum of the objective function.

Commuters value time spent driving at Rs. 1,122, and the estimated schedule cost of arriving earlier than ideal is Rs. 320. Commuters are thus relatively schedule flexible to leave earlier in the morning. To put these values in context, a commuter with these preferences would be indifferent between leaving one hour earlier if the driving time from leaving early was 15 minutes lower (this back of the envelope example ignores uncertainty). In particular, this means that commuters have some ability to "self-insure" against congestion, in the sense that commuters will tend to change departure times in response to a *localized* increase in congestion, which will reduce the welfare impact of the shock. It is important to note that the estimated value of time is significantly larger than the average self-reported monthly income of Rs. 270 per hour (Rs. 39,000 per month).[40]

[40] It is possible that this estimate of α also includes a fixed cost of switching routes. The field experiment was designed to separate the fixed cost of route change and marginal costs of travel time, through the low and high rate sub-treatments in the area treatment. Given that I do not find any reduced form effect of increasing the area congestion charge, I model the route

The late arrival cost β_L cannot be estimated precisely from the data. The underlying reason is that in Figure 2 there is no reduced form impact on late departures. This tells us that β_L is large; however, it is not clear how large. For the estimation in Table 7, this parameter is fixed at $\beta_L =$ Rs. $4,000$. Appendix Figure A8 (Panel A) shows that the GMM objective function is mostly flat above this value. In Appendix Table A7, I show that using $\beta_L =$ Rs. $1,000$ or $\beta_L =$ Rs. $8,000$ instead has no detectable effect on the other estimated parameters. This inflexibility of leaving later is consistent with work requirements acting as a firm constraint.

Around half of all study participants responded to congestion charges ($\hat{p} = 0.46$). Intuitively, this value maximizes the variance of individual responses, emphasizing the stark response heterogeneity in the data.

Both logit parameters are estimated to be approximately Rs. 37, indicating a small or moderate amount of noise in choices. The fact that these terms are equal means that I cannot reject the multinomial logit model over the entire decision space. The inner nest logit parameter σ, corresponding to departure time choice, is estimated with significantly more noise than the outer nest parameter μ, which corresponds to route choice. This is related to commuter heterogeneity in terms of ideal arrival time. In principle, both a wide distribution of h^*_{Ait} and a large σ will imply a wide observed distribution of departure times. The logit parameter is separately identified from the shape of the *experimental* response to departure time congestion charges. As σ becomes smaller, the impact concentrates around the kinks of the congestion ramp. In practice, and with the available data, I can only estimate σ somewhat imprecisely.

Appendix Figure A7 shows the model fit graphically by plotting the data and model prediction for the moments used in estimation. The model generally fits the data well, and in particular it does a good job of replicating the variance in individual effects for departure times and in route choices (panels B, C, and E).

I use two empirical methods to shed light on how model parameters are identified. The first is to show numerically that the estimation procedure can recover the parameters using simulated data for various sets of random parameter. Appendix Table A8 shows that estimated parameters track the true parameters closely. The estimated slope between the underlying parameter and the GMM estimate is close to 1, and the R^2 is very high, in all cases except for the inner nest (departure time) logit parameter σ, for which the slope is above 1 and statistically significantly different from zero, yet noisier.

The second exercise is to compute the sensitivity measure from Andrews et al. (2017). The (scaled) sensitivity matrix Λ captures how estimated parameters depend on the different moments of the data. Specifically, each entry $\Lambda_{\gamma k}$ measures the impact of a standard deviation increase in moment g^k, $1 \leq k \leq 69$, on estimated parameter $\gamma \in \{\alpha, \beta_E, \beta_L, \sigma, \mu, p\}$. The results generally confirm the intuitions described earlier,

choice decision in this parsimonious way.

while also emphasizing that parameters are jointly estimated, with contributions from several moments. As expected, the early schedule cost β_E depends most strongly on departure time moments in the early ramp part of the departure time problem (departure times between -1.5 and -0.5 in Appendix Figure A8, Panel B). However, the area moments also have important contributions (column 2 in Appendix Table A9). As expected, the value of time driving α is most strongly identified by the area moments (column 1 in Appendix Table A9). The probability to respond, p, is affected more strongly by the area moments than by the departure time heterogeneity moments (column 5 in Appendix Table A9).

Overall, the structural model offers a good fit to how commuters responded to the congestion charge experiments. The results indicate that commuters are fairly flexible to change their schedules by leaving earlier locally around their ideal departure time, relative to how much they value time spent driving. However, in order to quantify the externalities involved in peak-hour traffic congestion, and the welfare impacts of congestion mitigating policies, it is also necessary to know how traffic responds to aggregate changes in driving patterns.

7 The Road Traffic Congestion Technology

Each additional vehicle on the road leads to slower road speeds. I now quantify this external cost using all the GPS trip data collected during the study, and real-time Google Maps driving time data collected during the same period on a set of routes in Bangalore.[41]

The traditional approach to studying this relationship in transportation engineering has been to analyze road or highway segments in developed countries. Empirical estimates vary considerably, in part due to the variation in the specific roads considered.[42] From an economic perspective, we are interested in full trips, not only road segments or small areas. Indeed, commuters make decisions over trips, and trips cover large areas and different types of roads. There are few empirical studies that measure travel time costs and external costs at the trip level. Geroliminis and Daganzo (2008) use GPS taxi trip data from 140 taxis for one month in Yokohama, Japan, and show that average trip speed declines strongly at times of the day when many trips are taking place. Akbar and Duranton (2017) measure road traffic volume from around 20,000 motorized trips recorded in a household transportation survey in Bogotá, Colombia, and travel times from

[41] Driving also imposes other external costs, such as increases in pollution emissions, pollution exposure (which is related to traffic speeds), and accidents. Here I am only considering the impact on higher (and less reliable) driving times.

[42] A commonly used functional form to describe travel time T as a function of incoming flow V is given by $T = T_f \cdot \left(1 + a \cdot (V/V_k)^b\right)$, where T_f is time under free-flow, and V_k is the maximum road capacity. The parameter values for a and b vary considerably. For example, the Bureau of Public Roads (BPR) and the updated BPR functions use $a = 0.15$, $b = 4$ and $a \in [0.05, 0.2]$, $b = 10$, respectively. See section 3.3.2 in Small et al. (2007) for a review of estimated and postulated functional forms.

real-time Google Maps data collected several years later. They establish a much smaller elasticity of travel time with respect to the volume of traffic. Their results suggest that there are fundamental differences in city-wide road technology in Bogotá relative to cities in richer countries. One potential concern with their approach is attenuation bias due to survey survey recall bias, which can lead to mis-measurement in the traffic volume measure. For example, survey respondents may omit trips or only report imprecise departure and arrival times. In this paper, I use precise GPS data, contemporaneous real-time Google Maps data, and a larger sample of trips than in the two previous papers. I show at the end of this section that the elasticity in Bogotá estimated by Akbar and Duranton (2017) is very similar and slightly smaller than what I find in Bangalore.

To measure the *quantity* of driving, I rely on 117,527 trips coded from GPS data from 1,747 app users, covering 185 calendar dates and 44,034 user-days with travel information.[43] (This sample includes the experimental sample, as well as other study participants who used the smartphone app for shorter periods of time and were not included in the experiment.)

For road *speeds*, I use two different data sources that give very similar results. My main data source is Google Maps travel delay data collected on 28 routes in the study area over the same calendar period, at 20 minute intervals.[44] I also compute trip-level travel delay directly from the GPS data.[45] The two measures track each other exceptionally well at the level of departure time (column 3 in Table 8 and panel A in Appendix Figure A9).

I use a simple empirical specification to measure the impact of traffic volumes on travel delay. (I discuss possible threats to causal inference below.) In order to reduce measurement error in the dependent variable, I summarize traffic volume and travel delay along two dimensions: trip departure time, and calendar date. In the first case, the average departure rate at a given time of the day measures *inflows* into the urban road network, so this approach is similar to classic transport engineering estimates, except that here I consider results for a large urban area.[46] The second approach considers the total travel on a given calendar date. In

[43]I restrict the sample to trips longer than 2 km. Shorter trips have higher travel delay, possibly because of higher likelihood of walking trips. Results are almost identical including all trips.

[44]Travel delay is the inverse of driving speed, measuring the number of minutes necessary to cover 1 kilometer, on average. To obtain it, for each route I divide driving time (in minutes) by the route path length (in kilometers).

[45]Trips in the GPS data may have considerably more noise, for example due to short stops along the way, or errors in trip classification. I use medians to summarize this data in order to limit the influence of outliers. The sample is all weekday trips shorter than 2km, without stops along the way. To avoid circuitous trips, I restrict to trips with diameter to total length ratio above 0.6 (the 25th percentile). For each departure time, I compute the median delay of all trips starting around that departure time (weighting each trip using an Epanechnikov kernel with bandwidth 20 minutes around the reference departure time). In addition, Appendix Table A10 reports results from quantile (median) regressions.

[46]It is plausible that travel conditions depend on the history of inflows, not only on contemporaneous inflow. One way to model this is to measure the number or *density* of vehicles on the road at any given time. This approach gives very similar results, see panel B in Appendix Figure A9. Intuitively, the two variables are strongly correlated, because trips are short relative to the scale of peak/off-peak fluctuation. In addition, models that includes lags will fit the data marginally better. Indeed, in panel A of Figure 3 the travel delay at 9 am – following a large inflow – is slightly lower than predicted by the

both cases, I normalize the dependent (volume) variable to mean 1, so the results are directly comparable. I am not able to distinguish between the impact of motorcycles and cars, and cannot account for vehicle occupancy.[47] Results should be interpreted as the average effect along these dimensions.

Travel delay is well explained by a linear function of traffic volume, and results are similar using variation within day and across calendar dates. Figure 3 shows the main results in graphical form. Panel A shows results at the departure time level (collapsing over all weekdays in the data), and plots the results for all departure times at 30 minute intervals, while panel B shows results by calendar date. Columns 1, 2 and 4 in Table 8 show the same results in regression format. For departure times, an increase in the number of vehicles equal to 10% of the mean is associated with an increase of 0.106 minutes per kilometer higher travel times (column 1). The relationship is close to linear, and I can reject at the 95% level an exponent of 1.18 (column 2). The relationship is similar and slightly shallower across calendar dates at 0.097 minutes per kilometer (column 2). The difference may partly reflect attenuation bias due to measurement error in traffic volumes along calendar dates.

These results imply that every additional (average length) trip departing increases the aggregate driving time of everyone else on average by approximately 4.2 minutes for a 7 am departure time, and by approximately 17 minutes for trips departing at the morning peak (9 am) or evening peak (7 pm). (For reference, the average trip duration is 33 minutes.) To derive this result, note that the impact on aggregate driving time is equal to the traffic volume, times the marginal impact on travel delay, and times the average trip length, namely $\tilde{Q}(h) \frac{\partial T(h)}{\partial \tilde{Q}(h)} \cdot \overline{KM}$. The first two terms form a semi-elasticity, so this social cost calculation does not depend on the scaling of traffic volume $\tilde{Q}$. In other words, for a representative sample the in-sample calculation is consistent for the population calculation. The empirical results show that $\frac{\partial T(h)}{\partial \tilde{Q}(h)} = 1.06\,\text{min/km}$ (for any h), and the average trip length is 8.0 kilometers, which gives an effect of $8.5 \cdot \tilde{Q}(h)$ minutes, where $\tilde{Q}(h)$ is the relative traffic volume at h. Figure 3 shows that $\tilde{Q}(7\,\text{am}) \approx 0.5$ and $\tilde{Q}(9\,\text{am}) \approx \tilde{Q}(7\,\text{pm}) \approx 2$, which gives the figures cited above.

One potential concern is whether the data used here is representative for Bangalore. It is reassuring that the results from two completely different data sets on speeds (GPS data and Google Maps data) give similar results: column 3 in Table 8 shows that the slope between the two variables is very close to one. The other concern is whether the traffic quantity measure is not representative in a way that is correlated with the pattern of congestion. In principle, it is possible that the survey team recruited disproportionately more (or fewer) respondents during peak hours, which may bias the results. However, the link between recruitment

linear relationship, yet delay continues to rise after 9 am despite slightly decreasing inflows. Here, I use the more parsimonious functional relationship.

[47] The share of trips made by car is roughly constant throughout the day, at around a third.

time and average departure time is very weak. Indeed, the R squared of a regression of trip departure time in the morning on morning recruiting time is below 4%, and below 2% for the evening.[48]

Interpreting these results as the causal impact of driving on external driving time costs raises several potential concerns. One issue arises if different types of drivers systematically travel at different times, for example if inherently slower drivers are more likely to travel during peak hours. A related concern is if peak-hour and off-peak trips differ in some dimension correlated with speed, such as trip length. In principle, these issues could even affect the Google Maps travel delay estimates, if Google's algorithms do not correct for such biases. To address these concerns, in Appendix Table A10 I run trip-level quantile (median) regressions of trip delay on the traffic volume at the trip departure time, where I control for trip length and commuter fixed effects. The results are broadly similar and somewhat smaller than those in Table 8. More generally, any factor correlated with the within-day or across-date distribution of traffic volume, which also directly impacts driving times, is a potential omitted variable. For example, anticipated weather and road network shocks (e.g. construction, closures) may bias the estimates downwards. These factors are unlikely to be a major concern in this setting. First, weather during the study period was very stable, and there were no major road network shocks. Secondly, the within-day results are less likely to be significantly biased by this type of factors, because weather and road network shocks tend to last longer. Higher pedestrians flows during peak hours may bias our results *upwards*, if pedestrians interact with and slow down incoming traffic. Anecdotally, drivers in Bangalore tend to not slow down considerably when pedestrians cross the road.

The results in Bangalore are very similar to those reported by Akbar and Duranton (2017) in Bogotá. Appendix Figure A9 panel D compares the log-log curves in the two cities. The curve for Bogotá is slightly lower and the maximum elasticities in Bangalore and Bogotá are 0.33 and 0.25, respectively. The curve in Bogotá also becomes flat for high values of traffic volume. There may be two reasons for this. First, note that the local linear fit in Bangalore also has a slightly lower slope for high volumes; this may be due to the linear contemporaneous road technology specification, which omits traffic volume lags. In particular, traffic volume rises quickly in the morning, and speed grows slightly slower (only to continue to grow even past the peak in traffic volume); this tends to attenuate the relationship between traffic volume and travel times. Another potential reason for the more pronounced flat region in Akbar and Duranton (2017) is that survey respondents are likely to give typical departure times that underestimate the variability in departure times, which tends to overestimate peak-hour volumes. Indeed, Zhao et al. (2015) document exactly this phenomenon by comparing survey data with precise GPS travel data collected with a smartphone app on the same sample in Singapore.

[48] Panel C in Appendix Figure A9 shows graphically that the recruit time and trip departure time distributions are very different.

Previous engineering studies on road segments show that travel time responds strongly and convexly to traffic inflows. Intuitively, one would expect this relationship to be even stronger in a high congested city, such as Bangalore. In fact, I provided evidence for a shallower and linear relationship. The slope is several times shallower than the slope identified based on taxi trips in Geroliminis and Daganzo (2008). There are several potential reasons why the road technology may be different in Bangalore. The high ratio of motorcycles may render traffic more fluid; however, using the GPS data I find that motorcycles are faster only during the night, and have a similar speed as cars during the day. Another hypothesis is that drivers switch to side streets during peak hours, thus avoiding traffic build-ups on main thoroughfares (Akbar and Duranton, 2017). Further, the driving style in cities like Bangalore, where anecdotally vehicles are driven close to each other, may attenuate traffic jams. (However, in principle this type of driving could also make jams worse.) Another structural difference is the smaller number of automatic traffic signals compared to cities like Yokohama, Japan, and potentially higher reliance on traffic police agents, which may also affect the bottleneck properties at certain key junctures. I consider average travel times over several months, which are likely the relevant measure to measure the expected externality. This is similar to Akbar and Duranton (2017) and unlike Geroliminis and Daganzo (2008), who use instantaneous relationships.[49]

In this section, I provided new evidence that despite high levels of traffic congestion in Bangalore, the shape of the road technology externality is moderate and linear throughout the distribution of traffic volume. Equipped with this estimate, we are now in a position to quantify the inefficiency involved in the peak-hour traffic equilibrium.

8 Policy Simulations

In this section I quantify welfare and the inefficiency in the no-toll equilibrium, and explore how these numbers depend on preferences and on the road technology.

Commuters make departure time decisions based on their own travel time and schedule costs, and have some flexibility to adjust departure times to avoid congestion, as shown in the experimental results. However, their decisions also affect the other traffic participants by increasing delays at the times when they travel, an effect mediated through the road technology that was quantified in the previous section. Moreover, other commuters adjust to the increase in congestion, and this has either positive or negative first order impacts on welfare, as the envelope theorem does not hold for welfare at an inefficient equilibrium. For example, for the same level of congestion, traveling after the peak-hour may have a higher externality because it induces

[49] In principle, it is possible that the instantaneous relationship is convex, and the peak-hour is realized at slightly different times on different days, which would smooth out the relationship. However, the relationship in Figure 3 looks similar when using a single day of data (not shown).

other commuters to switch to earlier (more congested) travel times.

I now study these interactions and their welfare consequences using a simulation model of the city-wide road traffic equilibrium. I use the model to solve for decentralized Nash equilibria without or with departure time charges, I then compute the marginal social cost of departing at a certain time around a given Nash equilibrium, and I finally solve for the social optimum and compare the improvement relative to the decentralized equilibrium using various benchmarks. In any equilibrium with charges, I assume that tax revenue is transferred back to commuters lump-sum.

The model parameters are derived entirely from demand and road technology estimates presented in previous sections. At the same time, there are several important limitations of this approach. I continue to abstract from the extensive margin decision of whether to travel using a private vehicle. Thus, the analysis here pertains specifically to the within-day inefficiency due to commuters wanting to travel at similar times. I also do not take into account longer term preferences and adjustments, which may be different from the short-term responses measured in the experiment. As in the road technology estimation, I do not distinguish between the externalities generated by motorcycles and cars, although in practice the latter is likely to be higher. Finally, this analysis ignores other traffic, including trips that are not between home and work, bus passengers (who would also benefit from reductions in travel times), taxis, bus and truck traffic (which may respond differently to similar congestion charges and may affect traffic differently). I also do not measure in these calculation other important social costs of congestion, such as pollution generation and pollution exposure.

The simulation environment is populated with N agents. Each agent has a single route and chooses a morning departure time according to multinomial logit probabilities, using $\hat{\sigma}$ as estimated previously. Each simulation agent is a copy of a real study participant, with the same route length and preferences as estimated in section 6, with a fixed ideal arrival time randomly drawn from the distribution estimated for that agent. In practice, I replicate each real commuter and draw 120 ideal arrival times for each copy, for a total of $N = 36,960$ simulation agents.

I use an asynchronous logit best-response dynamic to compute Nash equilibria. Given (fixed) congestion charges that depend on the departure time, and an initial travel time profile, each period a 1% random sample of agents re-compute their choice probabilities,[50] and then the travel time is updated given the aggregate volume at each departure time (integrated choice probability over all simulation agents). The simulation stops when every agent is close to best-responding, namely when the ℓ^2-norm of changes in choice probability, averaged over the entire population, is below a certain threshold. This procedure leads to fast convergence to

[50] Travel time uncertainty is parametrized based on the mean travel time, as was done for structural estimation. Travel time is log-normal distributed, and travel delay standard deviation is quadratic in the mean. See Appendix Figure A6.

equilibrium; indeed, the choice probability norm roughly halves after half of the population updates (every 50 periods), and it takes around 7 revisions per capita to reach equilibrium. Moreover, this dynamic has a natural interpretation in terms of commuters revising their actions periodically. In practice, the simulation finds a unique equilibrium independently of starting conditions, which is consistent with travel at various times being strategic substitutes due to congestion.

The marginal social cost imposed by a commuter leaving at a certain departure time h_D should be calculated allowing other commuters to adjust.[51] Indeed, other commuters may change their departure times in response to the increase in congestion, which will decrease their costs and may have either positive or negative spillovers.[52] This effect is quantitatively meaningful; for example, the partial equilibrium social welfare cost of an additional departure at 9:40 am, starting from the Nash equilibrium, is Rs. -408.6, compared to Rs. -352.0 after recomputing the equilibrium with the fixed departure at 9:40 am. Moreover, for the same level of congestion, the marginal social cost depends on the slope of congestion around that point. Figure 4 shows in blue (right axis) that the marginal social cost is higher after the peak. This happens because displaced commuters tend to leave earlier (because $\beta_E < \beta_L$) and when the additional commuter departs after the peak, this switching leads to even more congestion at earlier times.

The social optimum is a Nash equilibrium with departure time Pigou charges.[53] It has the following fixed point property: charges at departure time h_D equal the marginal social cost of an additional commuter at h_D. To find this fixed point, I use a lazy adjustment dynamic for charges. The starting point is the Nash equilibrium, and for each iteration I compute the marginal social cost and update charges at each departure time with a $1/3$ weight on the new marginal social cost and $2/3$ on the current charge. This procedure converges in around 15 iterations with precision Rs. 0.1 for welfare.

The social optimum leads to small but notable improvements in travel times. Figure 4 shows the travel delay under the decentralized unpriced equilibrium and under the social optimum. The social optimum has a lower peak, and more commuters departing early, between 5:30 am and 7:45 am. However, the distance between the two travel delay profiles is not very large; at the peak, travel delay improves by 0.14 minutes per kilometer, which translates to 0.9 and 2.3 minutes faster travel time for the commuters at the 25th and 75th percentile of route distance. One reason for this moderate difference is that moving some people away from the peak does not have an outsized effect on congestion under the linear road technology. The social marginal

[51] Arnott et al. (1993) make the same point in their model with identical agents, where the stark implication is that MSC does not depend on departure time (as in equilibrium all agents are indifferent). The more general point also applies in this setting, where agents differ.

[52] Computing the marginal social cost thus requires computing a new Nash equilibrium for each departure time.

[53] I assume that the social planner knows individual preferences but does not observe the exact realization of the random utility shocks. In this case, where also all commuters have the same externality conditional on departure time, the planner can implement the social optimum with departure time congestion charges.

cost function is also drawn (right Y axis). For the same level of congestion, social marginal cost is higher after the peak, and yet there is almost no aggregate difference between the Nash and social optimum on that side of the graph. This happens because the cost of departing later β_L is very high. Despite large congestion charges, individual changes under the social optimum are small. The average change in average departure time (conditional on ideal arrival time) is leaving 3 minutes earlier, and the 25th and 75th percentiles are 4.1 minutes earlier and half a minute later. These number are within the range of experimental responses to the departure time policy. Hence, these counterfactual results do not rely on extrapolating based on the functional form in preferences.

Table 9 quantifies the effects on travel time and on welfare. The social optimum leads to a reduction of 1.04 minutes in expected travel time, from a base under Nash of 38.7 minutes.[54] This represents a 2.7% improvement relative to the Nash equilibrium, or a 6.8% improvement when considering only travel time above free-flow. (Free-flow is defined as a speed of 2.14 minutes per kilometer, which is the intercept in Table 8.)

The improvement in welfare under the social optimum are an order of magnitude smaller. In other words, the travel time benefits are nearly offset by schedule costs incurred by commuters who are induced to travel at privately inconvenient times. Welfare is Rs. 4.5 per commuter per morning higher under the optimum (7 US cents), from a total trip cost of around Rs. 773, which represents a roughly half percentage improvement. Relative to free-flow, the improvement is only 1.3%. Moreover, to achieve the social optimum, commuters pay on average Rs. 267.3 in charges, or 35% of their average private cost. For this exercise, I assumed that charges are a costless transfer, whereas in reality policy enforcement and attention costs may be important. It is likely that real-world, more forceful policies that attempt to cap peak-hour congestion may lower welfare. This framework can be used to quantify these effects.

The road technology plays a key role for these results. Indeed, the welfare gain would be higher and would depend more on preferences if travel time was convex in traffic volume. Figure 5 shows this by plotting the improvement of going from the unpriced equilibrium to the social optimum, for travel times (panel A) and for welfare (panel B). The black and red lines denote the current (linear) and counterfactual (third power) road technology, while preferences vary along the X axis. The welfare gains are an order of magnitude higher with the power road technology, and range between 3.5% and 5.5%, relative to $0 - 0.5\%$ with the linear technology.

Overall, I have shown using policy simulations grounded in demand and road technology estimates

[54] Note that the average route length is not evenly distributed across departure time, with commuters who travel far slightly more likely to depart early. Moreover, under the social optimum this effect is slightly stronger, which contributes to lower average travel time than suggested by Figure 4 alone.

that the social inefficiency due to departure times is likely small. This result highlights the importance of measuring and considering the (schedule) costs of a policy that attempts to clear up the congestion peak-hour. An important reason for these findings is the size of the road externality, and especially its linearity, which implies that even for high levels of congestion the travel time benefit of removing a commuter from the peak is the same as for lower levels. By consequence, road traffic congestion does not warrant intervention through corrective taxation solely for the reason of departure time inefficiency.

9 Conclusion

Reducing traffic congestion has significant benefits in terms of the value that commuters put on the time they spend driving; it can also lead to improved subjective well-being (Anderson et al., 2016). This makes it tempting to only consider these benefits when thinking about traffic policies, and in particular about policies designed to reduce peak-hour congestion. However, it is also important to take into account the costs of disruption to commuter schedules.

In this paper, I collected new data on travel behavior and implemented a field experiment motivated by a model of travel demand to study both sides of the peak-hour traffic equilibrium. Estimating a model of the morning commute decision using experimental variation, I find that the cost of arriving earlier than ideally desired is around 4 times smaller than the value of time spend driving. To put this in context, as a first approximation this means that a commuter facing a one hour expected drive time would prefer to leave one hour earlier, if this reduced the expected drive time to less than 45 minutes.

Surprisingly, given high levels of traffic congestion in Bangalore, I find a moderate road traffic externality, and a *linear* effect of traffic volume of travel times, including for high values of traffic volume. This result is robust to using different data sources and analyzing this relationship across days or within day and across departure times. These estimates are smaller than a previous study in Yokohama, Japan (Geroliminis and Daganzo, 2008), and they rule out hyper-congestion. Differences in driving style and the density of traffic control measures (traffic lights) are possible explanations for the discrepancy between the two settings.

Putting demand and road technology estimates together, I calculate the equilibrium optimal congestion charge for the morning peak-hour. I find that relative to the decentralized equilibrium without charges, the social optimum allocation leads to notable travel time benefits of around 1.2 minutes per trip from a base of 36.5 minutes (which is 30% of the improvement that can be achieved by spreading all commuters evenly between 5 am and 12 pm). However, the welfare gains from optimal charging are small, as the travel time benefits are almost fully offset by the schedule costs of making commuters travel at inconvenient times.

The elasticities of travel at different times may differ from those estimated here in the long-run and in the presence of a city-wide policy. For example, firms may adjust by providing more flexible schedules, allowing commuters to more easily change their travel timings. As in other large cities marred by high congestion, some large companies in Bangalore are already implementing this type of flexible work-hours policies (Merugu et al., 2009). Moreover, around 20% of the sample in this study are self-employed and may already have higher autonomy in deciding their own schedules. Finally, it is worth noting that the welfare impacts of firm-level work-hours changes is ambiguous, due to complementarities *between* firms of having similar work hours (Henderson, 1981).

The cost and road technology estimates in this paper are also useful for thinking about the extensive margin of making trips with private vehicles, which was held constant throughout this analysis. Indeed, the same methods can be used to compute the social marginal cost of adding a commuter at a certain departure time,[55] and thus calculating the optimal congestion charge. The results will depend on the elasticity of making a trip with respect to generalized travel cost. Given the small share of metro travel in Bangalore, this effect would likely mostly go through canceling non-essential trips, working from home, or switching to bus travel.[56] Moreover, the same framework can be used to include additional externalities, such as the air pollution that drivers generate, and the impact that longer driving times have on exposure to air pollution, which is high on urban roads.

This paper argues that the peak-hour traffic congestion equilibrium is close to efficiency from the point of view of travel speed externalities. This does not imply that there are no welfare enhancing policies to ease traffic congestion. Pricing the extensive margin may be a viable policy, either done directly or through taxes on gasoline or private vehicle ownership. Road infrastructure investment – including investments to make road network flows more efficient – may currently be at an inefficient level. Of course, developing viable public transport options may also contribute to lower congestion and more convenient travel. However, the results in this paper do put into focus the welfare costs that well-intended traffic control policies may have on commuters affected by such charges or restrictions.

[55]The marginal social cost will not be exactly the same, because some commuters who are at the margin may cancel their trip in response to an increase in congestion.

[56]There are two reasons why this margin was not studied experimentally here. The first is a measurement issue, as commuters would have strong incentives to leave their smartphones at home given monetary incentives to reduce the number of trips. It is possible to solve this problem by installing a GPS device in the private vehicle – as Singapore plans to implement its next generation Electronic Road Pricing policy, and as in the experiment studied in Martin and Thornton (2017). The second reasons is that extensive margin changes will plausibly take longer, as commuters need to find alternate travel arrangements or substitutes for canceling unessential trips. Indeed, Martin and Thornton (2017) do not find any reduced-form impact of distance-based congestion charges on trip extensive margin, even after two months.

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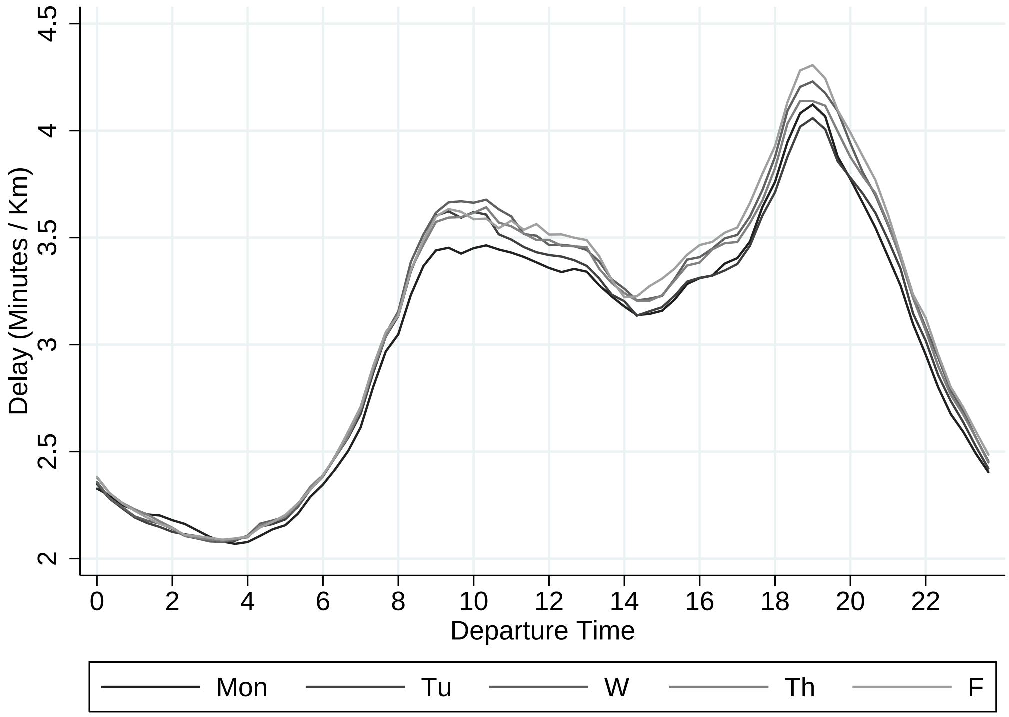
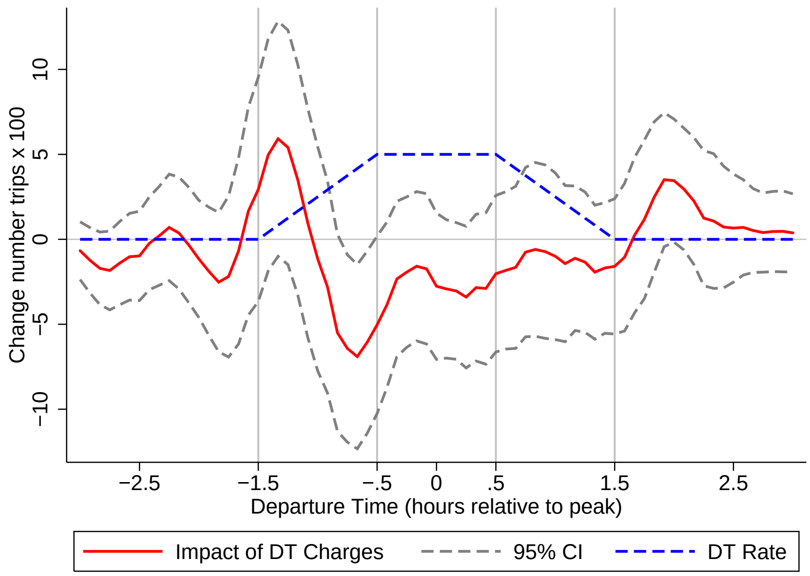
Figures

Figure 1: Average Predicted Travel Delay in the Study Region in Bangalore

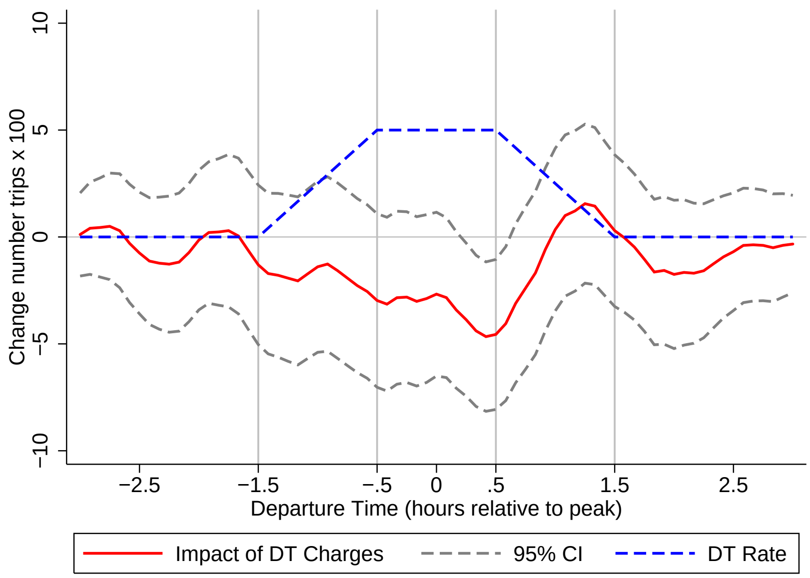


Notes: This graphs plots the average predicted travel delay on 28 major routes across the study area of South Bangalore, by day of the week. *Travel delay* is defined as the number of minutes to cover one kilometer, i.e. the inverse of speed. (A travel delay of 2 minutes per kilometer corresponds to 18.6 miles per hour.) The travel time and route length data is obtained from the Google Maps API. For each route, weekday and departure time (at 20 minute frequency) I queried the typical travel time under normal conditions, as predicted by Google.

Figure 2: Impact of Departure Time Charges on the Distribution of Departure Times



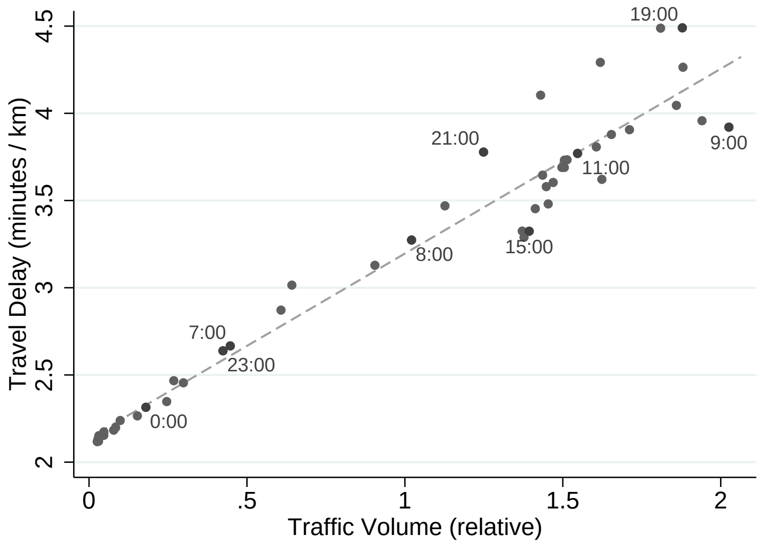
Panel (A) Morning Peak



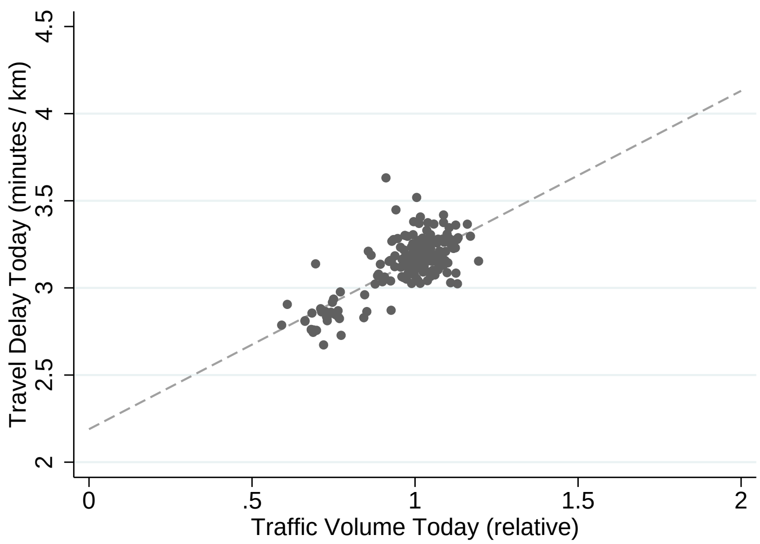
Panel (B) Evening Peak

Notes: These graphs plot the impact of departure time charges on the distribution of departure times, in the morning and evening. To construct this figure, for each commuter, day and departure time relative to the commuter's mid-point of the congestion charge rate profile, I compute the number of trips that start approximately at that time, using an Epanechnikov kernel with bandwidth 20 or 30 minutes for AM and PM, respectively. Then, for each relative departure time I run a difference-in-difference regression that identifies the impact of being in any of the charged sub-treatments (either High Rate or Low Rate) relative to being in the control or information sub-treatments. Each figure plots the charged sub-treatment times *Post* interaction coefficients, as well as pointwise 95% confidence intervals clustered at the individual level. The dimension of the Y axis is the number of trips at a given departure time, divided by 100. The sample is all non-holiday weekdays with good quality GPS data, excluding days outside Bangalore. In the post period, only the first or the last three weeks are included.

Figure 3: Road Technology: Travel Delay Linear in Traffic Volume



Panel (A) By Trip Departure Time



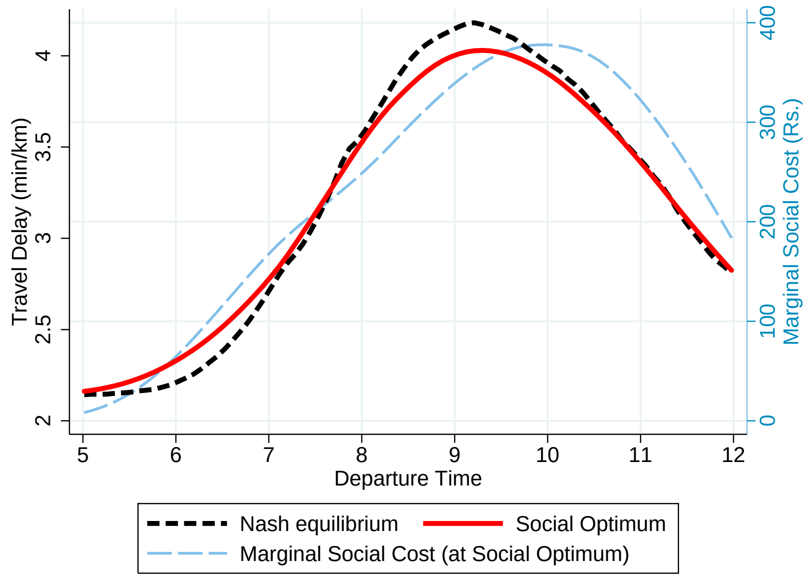
Panel (B) By Trip Calendar Date

Notes: These graphs show that travel delay is approximately linear in the volume of traffic.

Data. The volume measures are based on GPS data covering 117,527 trips from 1,747 app users across 185 days (including weekends). In panel A, all weekday trip departure times are aggregated at the departure time minute level, then smoothed using a local linear regression with Epanechnikov kernel with 10 minutes bandwidth, and finally normalized to have mean 1. In panel B, for each date I compute the number of trips per capita (using the number of app users that day), and again normalize this variable to have mean 1. The travel delay measures use Google Maps data collected over 28 routes in South Bangalore, every 20 minutes daily for 185 weekdays. In panel A, I compute the average delay over all weekdays and routes for each departure time, interpolating at the minute level. In panel B, I compute the average delay over all routes and departure times, for each day in the data.

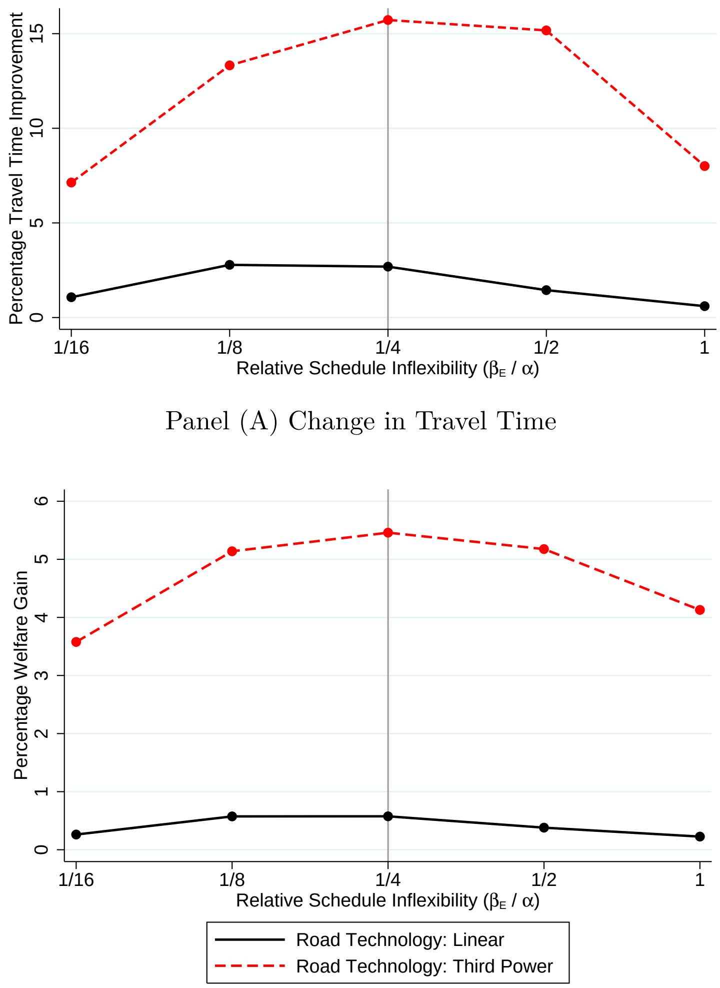
The OLS slopes for the two panels are 1.06 (0.06) and 0.97 (0.04), respectively. Table 8 reports the regression version of these relationships.

Figure 4: Unpriced Nash Equilibrium and Social Optimum (Policy Simulation)



Notes: This graph shows the profile of travel delay under the simulated Nash equilibrium for morning departures (black, dashed line, left axis) and under the social optimum (red, solid line, left axis). The social optimum is a Nash equilibrium implemented with (equilibrium-consistent) social marginal charges in Rupees (blue, long dashed line, right axis). Under the Nash equilibrium, departure time choice probabilities are given by multinomial logit based on the travel time profile, and the profile itself is determined based on the road technology formula and aggregate traffic volume at each departure time. It is the end point of an asynchronous logit "best-response" dynamic whereby 1% of the population updates their choices each period (and travel delay updates in response). To compute the marginal social cost of adding a commuter at departure time h_D, I compute the new Nash equilibrium with that (fixed) addition and compute the change in total expected utility. The social optimum is a Nash equilibrium with the following fixed point property: departure time charges are exactly the marginal social cost of adding a commuter at that departure time. I compute the social optimum by updating departure time charges towards the marginal social costs until convergence.

Figure 5: Policy Simulations with other Preference and Road Technology Parameters



Panel (A) Change in Travel Time

Panel (B) Change in Welfare

Notes: This graph plots the improvement in average travel times and welfare of going from the no-toll equilibrium to the social optimum (as a percentage of the value in the no-toll equilibrium), for various assumptions on preference parameters and road technology. The black solid line corresponds to the linear road technology from Table 8 ($Delay = \lambda_0 + \lambda_1 Volume$ where $Volume$ is relative volume), while the red dashed line corresponds to road technology given by a thrid power ($Delay = \lambda_0 + \lambda_1 Volume^3$). The X axis reports the approximate ratio of early schedule cost (β_E) to value of time spent driving (α); at the center I report results using the estimated value of $\hat{\beta}_E/\hat{\alpha} = 0.28 \approx 1/4$; the other estimates vary this by a factor of 1/4, 1/2, 2 and 4. For each point, I compute the Nash (to toll) equilibrium and the social optimum for that road technology and preference parameters as described in Table 4, and plot the percentage imporvement in the social optimum relative to the Nash.

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Tables

Table 1: Descriptive Statistics about Travel Behavior

	Median	Mean	Std. Dev.	10 Perc.	90 Perc.	Obs.
Panel A. Trip Characteristics						
Total Number of Trips						51,164
Number of Trips per Day	2.85	3.15	[1.16]	1.90	4.85	497
Median trip duration (minutes)	24.50	27.38	[12.77]	15.05	42.60	497
Median trip length (Km.)	5.91	7.17	[4.66]	2.90	13.36	497
Panel B. Commute Destination Variability						
Regular Commuter		0.76				497
Frac. trips Home-Work, Work-Home	0.38	0.39	[0.21]	0.13	0.67	378
Frac. of trips Work-Work	0.03	0.06	[0.08]	0.00	0.15	378
Frac. of days present at Work	0.91	0.86	[0.16]	0.61	1.00	378
Panel C. Departure Time Variability (Standard Deviation of the Departure Time in hours)						
First Trip (AM)	1.27	1.24	[0.50]	0.52	1.85	496
Last Trip (PM)	1.72	1.71	[0.50]	1.06	2.34	497
First Home to Work Trip (AM)	0.48	0.62	[0.52]	0.15	1.28	332
Last Work to Home Trip (PM)	0.80	0.94	[0.62]	0.28	1.78	321

Notes: This table reports summary travel behavior statistics for the experimental sample of 497 commuters and 51,164 trips. For panel B, I classify each commuter as "regular" or "variable" based on a hybrid automatic and manual algorithm to identify common destinations (home or nighttime and work or daytime). In panel C, I compute the within-commuter variation in departure times for different classes of trips.

Table 2: Impact of Departure Time Charges on Daily Outcomes

	(1)	(2)	(3)
Time of Day	AM & PM	AM	PM
Commuter FE	X	X	X
Panel A. Total Shadow Rates Today			
High Rate × Post	-13.9**	-7.8**	-6.1*
	(6.1)	(3.8)	(3.4)
Low Rate × Post	-7.4	-2.8	-4.6
	(6.3)	(3.7)	(3.8)
Information × Post	-0.3	-0.2	-0.0
	(5.4)	(3.3)	(3.3)
Post	1.1	-0.9	2.1
	(4.9)	(2.9)	(3.1)
Observations	15,610	15,610	15,610
Control Mean	96.5	48.3	48.2
Panel B. Number of Trips Today			
High Rate × Post	-0.11	-0.04	-0.06
	(0.14)	(0.07)	(0.07)
Low Rate × Post	-0.06	-0.00	-0.07
	(0.14)	(0.07)	(0.07)
Information × Post	0.08	0.05	0.03
	(0.13)	(0.06)	(0.07)
Post	0.04	-0.01	0.06
	(0.11)	(0.06)	(0.06)
Observations	15,610	15,610	15,610
Control Mean	3.05	1.16	1.30

Notes: This table reports difference-in-difference impacts of the departure time sub-treatments on daily total shadow (per-Km) rates and total number of trips. In panel A, the outcome is the sum over all trips that day of the trip shadow rate. The shadow rate for a given trip is between 0 and 100 and is computed based on the trip departure time, the respondent's rate profile, and a peak rate of 100 for all respondents. (See Appendix Figure A3 for an example of rate profile.) In panel B, the outcome is the number of trips that day. The sample is all non-holiday weekdays with good quality GPS data, excluding days outside Bangalore. In the post period, only the first or the last three weeks are included. Column (2) and (3) restrict to the morning interval (7am-1pm) and to the evening interval (4-10pm), respectively. All specifications include respondent and study cycle fixed effects, and *Post* is an indicator for days during the experiment. The mean of the outcome variable in the control group during the experiment is reported for each specification. Standard errors in parentheses are clustered at the respondent level. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table 3: Impact of Departure Time Charges on Trip Shadow Rate

	(1)	(2)	(3)	(4)	(5)
Time of Day	AM & PM	AM	AM pre peak	PM	PM post peak
Commuter FE	X	X	X	X	X
Panel A. Full Sample					
High Rate × Post	-3.99***	-6.23***	-5.60	-3.12*	-5.40*
	(1.34)	(2.25)	(3.50)	(1.84)	(2.80)
Low Rate × Post	-1.85	-2.71	-3.59	-1.33	1.07
	(1.41)	(2.24)	(3.49)	(1.96)	(3.20)
Information × Post	-1.00	-2.32	-0.13	-0.41	0.40
	(1.06)	(1.81)	(2.70)	(1.63)	(2.53)
Post	-0.36	-0.81	-0.95	-0.35	-3.28
	(1.09)	(1.70)	(2.38)	(1.76)	(2.45)
Observations	43,776	16,764	7,592	18,468	7,899
Control Mean	31.64	41.81	46.98	37.21	44.29
Panel B. Regular Commuters, Home-Work and Work-Home Trips					
High Rate × Post	-4.97*	-7.48**	-10.12**	-1.54	-8.97
	(2.68)	(3.38)	(4.50)	(3.85)	(6.15)
Low Rate × Post	-4.02	-2.97	-9.12**	-5.38	-9.67
	(3.18)	(3.98)	(4.46)	(4.90)	(7.07)
Information × Post	-0.25	0.85	-2.73	-1.15	-1.97
	(2.06)	(2.96)	(3.32)	(3.42)	(4.60)
Post	-2.07	-2.73	-0.94	-3.86	-4.79
	(1.97)	(2.73)	(3.17)	(3.40)	(5.05)
Observations	11,895	5,789	3,782	4,862	2,113
Control Mean	37.08	44.59	44.91	38.16	42.28
Panel C. Variable Commuters, All Trips					
High Rate × Post	-1.99	-1.00	-4.41	-4.73	-2.10
	(2.90)	(5.05)	(10.32)	(4.26)	(7.64)
Low Rate × Post	0.47	-4.28	-6.15	-0.19	11.16
	(2.30)	(5.35)	(9.83)	(4.68)	(8.67)
Information × Post	-1.37	-3.38	-1.07	-1.22	-0.99
	(2.21)	(4.10)	(8.51)	(3.41)	(6.18)
Post	-1.05	-1.27	-0.17	-1.33	-2.45
	(2.22)	(3.72)	(8.07)	(3.55)	(5.81)
Observations	8,177	2,826	961	3,432	1,439
Control Mean	27.37	34.91	41.51	36.18	41.67

Notes: This table reports difference-in-difference impacts of the departure time sub-treatments on (per-Km) trip shadow rates. The shadow rate for a given trip is between 0 and 100 and is computed based on the trip departure time, the respondent's rate profile, and a peak rate of 100 for all respondents. The sample of users and days, and the specifications, are the same as in Table 2. In addition, columns (3) and (5) respectively restrict to trips before the morning peak (between 7 am and the mid-point of the AM rate profile), and after the evening peak (between the mid-point of the PM rate profile and 10 pm). Panel B restricts to regular commuters and direct trips between their home and work locations, and panel C restricts to variable commuters. Standard errors in parentheses are clustered at the respondent level . $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table 4: Impact of Area Charges on Daily Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
Time of Day	AM & PM	AM	PM	AM & PM	AM	PM
Commuter FE	X	X	X	X	X	X
Panel A. Total Shadow Charges Today						
Treated	-22.8***	-13.2***	-9.6***			
	(5.5)	(3.4)	(3.3)			
Treated in Week 1				-26.2***	-16.3***	-9.9*
				(8.3)	(5.0)	(5.3)
Treated in Week 4				-19.2*	-9.9*	-9.3*
				(10.1)	(6.0)	(5.5)
Observations	8,878	8,878	8,878	8,878	8,878	8,878
Control Mean	107.7	54.4	53.3	107.7	54.4	53.3
Panel B. Number of Trips Today						
Treated	0.17**	0.12**	0.06			
	(0.08)	(0.05)	(0.05)			
Treated in Week 1				0.06	0.04	0.01
				(0.13)	(0.07)	(0.09)
Treated in Week 4				0.30*	0.20**	0.10
				(0.16)	(0.08)	(0.10)
Observations	8,878	8,878	8,878	8,878	8,878	8,878
Control Mean	2.50	1.13	1.37	2.50	1.13	1.37

Notes: This table reports difference-in-difference impacts of the Area treatment on daily total shadow charges and total number of trips. In panel A, the outcome is the sum over all trips that day of the trip shadow charge. The shadow charge of a trip is equal to 100 if the trip intersects the respondent's congestion area, and 0 otherwise. In panel B, the outcome is the number of trips that day. The sample is all non-holiday weekdays with good quality GPS data, excluding days outside Bangalore. In the post period, all days except trial days are included. Column (2) and (5) restrict to the morning interval (7am-2pm), and columns (3) and (6) to the evening interval (2-10pm). The sample is restricted to the 243 participants in the Area treatment. The Treated dummy is equal to one in the week when the individual is treated (first and fourth week of the experiment for "early area" and "late are" sub-treatment commuters, respectively) and zero otherwise. All specifications include respondent and study cycle fixed effects. The mean of the outcome variable in the control group in weeks one and four of the experiment is reported for each specification. Standard errors in parentheses are clustered at the respondent level. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table 5: Impact of Area Charges on Trip Duration and Trip Shadow Charge

	(1)	(2)	(3)	(4)	(5)	(6)
Time of Day	AM & PM	AM	PM	AM & PM	AM	PM
Route FE	X	X	X	X	X	X
Panel A. Trip Shadow Charge						
Treated	-22.5***	-25.9***	-19.0***			
	(3.4)	(3.8)	(4.1)			
Treated in Week 1				-23.6***	-26.1***	-21.5***
				(4.9)	(5.0)	(6.3)
Treated in Week 4				-21.3***	-25.6***	-16.1**
				(6.4)	(7.4)	(7.0)
Observations	7,455	4,108	3,347	7,455	4,108	3,347
Control Mean	83.4	85.1	81.3	83.4	85.1	81.3
Panel B. Trip Duration (minutes)						
Treated	0.52	0.66	0.40			
	(0.72)	(0.74)	(1.29)			
Treated in Week 1				-1.14	-0.53	-1.55
				(0.97)	(1.04)	(1.74)
Treated in Week 4				2.49**	2.05	2.72
				(1.09)	(1.25)	(1.80)
Observations	7,455	4,108	3,347	7,455	4,108	3,347
Control Mean	40.81	39.15	42.73	40.81	39.15	42.73

Notes: This table reports difference-in-difference impacts of the Area treatment on trip shadow charge (panel A) and on trip duration (panel B). The shadow charge of a trip is equal to 100 if the trip intersects the respondent's congestion area, and 0 otherwise. The sample of users and days are the same as in Table 4, except that we restrict to regular commuters and direct home to work or work to home trips. All specifications include route fixed effects. Standard errors in parentheses are clustered at the respondent level . $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table 6: Impact of Area Charge Sub-Treatments on Daily Outcomes

	(1)	(2)	(3)	(4)
Commuter FE	X	X	X	X
Panel A. Total Shadow Charges Today				
Treated	-22.8***	-21.4***	-25.0***	-23.6**
	(5.5)	(7.4)	(5.9)	(11.1)
Treated × High Rate		-3.0		
		(9.6)		
Treated × High Rate Day			5.4	
			(5.4)	
Treated × Short Detour				3.2
				(12.0)
Observations	8,878	8,878	8,878	5,417
Control Mean	107.7	107.7	107.7	110.6
Panel B. Number of Trips Today				
Treated	0.17**	0.09	0.24**	0.19
	(0.08)	(0.09)	(0.10)	(0.13)
Treated × High Rate		0.17		
		(0.14)		
Treated × High Rate Day			-0.16*	
			(0.10)	
Treated × Short Detour				-0.07
				(0.16)
Observations	8,878	8,878	8,878	5,417
Control Mean	2.50	2.50	2.50	2.53

Notes: This table reports difference-in-difference impacts of Area sub-treatments on daily total shadow charges and total number of trips. For outcome definitions and specifications see the notes for Table 4. The sample is the same as in Column (1) in Table 4. In column (4) the sample consists of the 148 Area participants for whom candidate areas included at least one with short detour (3-7 minutes) and at least one with long detour (7-14 minutes). (See section 4 for more details.) The specification in column (4) includes fixed effects for each day in the experiment. Standard errors in parentheses are clustered at the respondent level. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table 7: Structural Parameter Estimates

(1)	(2)	(3)	(4)	(5)	(6)
Value of time α (Rs/hr)	Schedule cost early β_E (Rs/hr)	Logit inner σ (dep. time.)	Logit outer μ (route)	Probability to respond p	Ratio α/β_E
1,121.9	319.4	36.5	36.9	0.46	3.51
(318.7)	(134.5)	(65.4)	(9.3)	(0.13)	(1.11)

Notes: This table reports structural estimates of model parameters using two-step GMM with 69 moments. The first set of moments match the difference in difference average number of trips in each of 61 departure time bins (between -2.5 and $+2.5$ hours around the peak-hour, in 5 minute increments). Two moments match the variances of individual changes in shadow charges for trips between the morning rate profile peak and two hours earlier, in treatment and control. Two moments match the probability to intersect the congestion area with and without area charges. Four moments match the fraction of commuters whose sample frequency to intersect the congestion area lies in the middle third and top third of the unit interval, with and without area charges. Data on the distributions of travel times at different departure times and routes was collected from Google Maps. Model simulation details are described in Section 6. The two-step GMM is estimated with 100 random initial conditions. The cost of late arrival is held fixed at $\beta_L = \text{Rs. } 4,000$ (Appendix Figure A8 shows that the objective function is mostly flat for $\beta_L \geq \text{Rs. } 4,000$. Appendix Table A7 shows that results are essentially unchanged by using $\beta_L = \text{Rs. } 1,000$ or $\beta_L = \text{Rs. } 8,000$). Standard errors from 100 bootstrap runs are shown in parentheses.

Table 8: Road Technology: Travel Delay Linear in Traffic Volume

	(1)	(2)	(3)	(4)
Dependent Variable:	Google Maps Travel Delay (min/km)			
Sample:	Departure Time			Dates
Traffic Volume	1.06***	1.15***		0.97***
	(0.06)	(0.12)		(0.04)
Traffic Volume Exponent γ		0.89***		
		(0.15)		
GPS Travel Delay (min/km)			1.00***	
			(0.04)	
Constant	2.14***	2.08***	-0.10	2.19***
	(0.03)	(0.06)	(0.12)	(0.04)
Observations	1,440	1,440	1,440	185
Traffic Volume Std.Dev.	0.69	0.69		0.16
R^2	0.94	0.94	0.95	0.56

Notes: Table version of Figure 3 and Appendix Figure A9. This table shows that travel delay – measured either using Google Maps or GPS data – is approximately linear in the volume of traffic.

Data. The volume measures are based on 117,527 trips from 1,747 app users across 185 days (including weekends). Google Maps travel delay was collected over 28 routes in South Bangalore, every 20 minutes daily for 207 days (including weekends).

Variables and Sample. In the first and second columns, all weekday trip departure times are aggregated at the departure time minute level, then smoothed using a local linear regression with Epanechnikov kernel with 10 minutes bandwidth, and finally normalized to have mean 1; I compute the average delay over all weekdays and routes for each departure time, interpolating at the minute level. In the last column, for each date I compute the number of trips per capita (using the number of app users that day), and again normalize this variable to have mean 1; I compute the average delay over all routes and departure times, for each day in the data. GPS travel delay in column 3 is computed based on the GPS trips data. The sample is all weekday trips without any stops along the way, and with a trip diameter to total length ratio above 0.6 (the 25th percentile). For each departure time that is a multiple of 20 minutes, I compute the *median* delay of all trips starting around that departure time (weighting each trip using an Epanechnikov kernel with bandwidth 20 minutes around the reference departure time), then interpolate the result at the minute level.

Specifications. Columns 1, 3, and 4 report OLS regression with Google Maps Delay as outcome, with Newey-West standard errors, with three-hour lag in columns (1) and (3), and 10 day lag in column (4). Column 2 reports results from a nonlinear regression $Delay_h = \lambda_0 + \lambda_1 Volume_h^{\gamma}$ with HAC standard errors with Newey-West kernel and three-hour lag.$^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

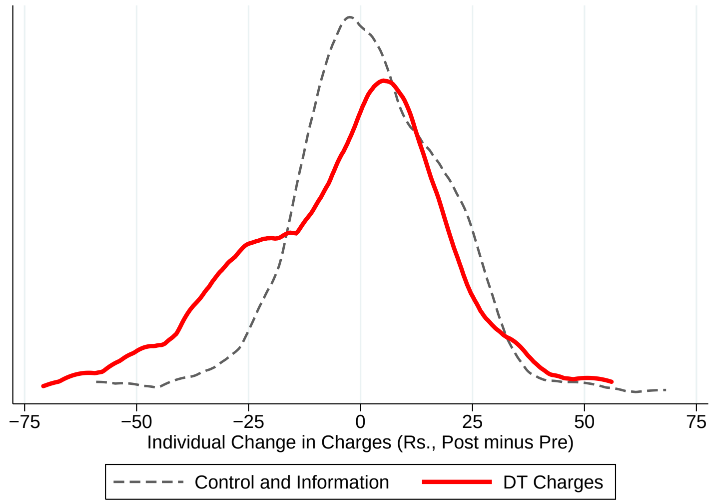
Table 9: Travel Times and Welfare in the Unpriced Nash Equilibrium and in the Social Optimum

	(1) Nash	(2) Social Optimum	(3) Improvement	(4) Improvement (% of Nash)
Panel A. Benefits and Welfare				
Travel Time (minutes)	38.7	37.7	-1.04	-2.69%
Welfare (Rupees)	-773.4	-769.0	4.46	-0.58%
Panel B. Benefits and Welfare Relative to Free-flow				
Travel Time (minutes)	15.4	14.4	-1.04	-6.77%
Welfare (Rupees)	-337.8	-333.3	4.46	-1.32%

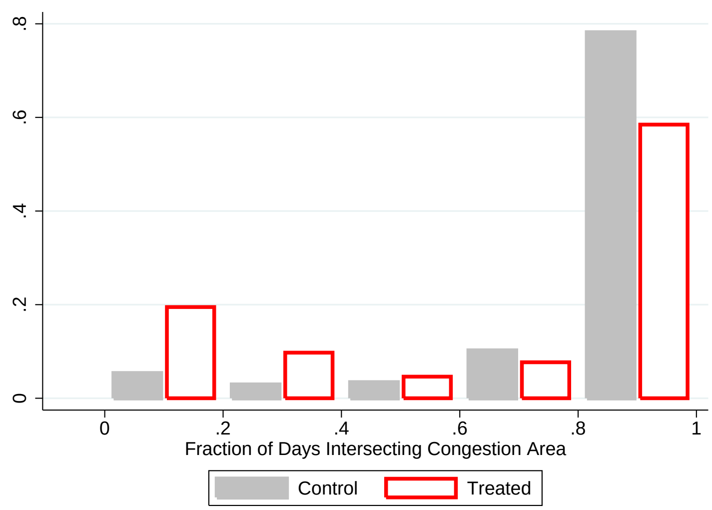
Notes: This table reports average travel times and welfare under the decentralized unpriced Nash equilibrium and under the social optimum. In panel B travel times and welfare are computed relative to the "free-flow" benchmark, where delay is constant at 2.14 minutes per kilometer regardless of traffic volume. (The average trip length is 10.9 Km.) Travel times are calculated taking individual route length into account, and welfare is the sum over all simulation agents of expected utility, including travel time and scheduling costs, and assuming charges are transferred lump-sum back to commuters. Columns 3 and 4 report the improvement from the unpriced Nash to the social optimum, in levels and as a fraction of the baseline (Nash) value.

A Appendix Figures

Figure A1: Treatment Heterogeneity for Departure Time and Area Treatments



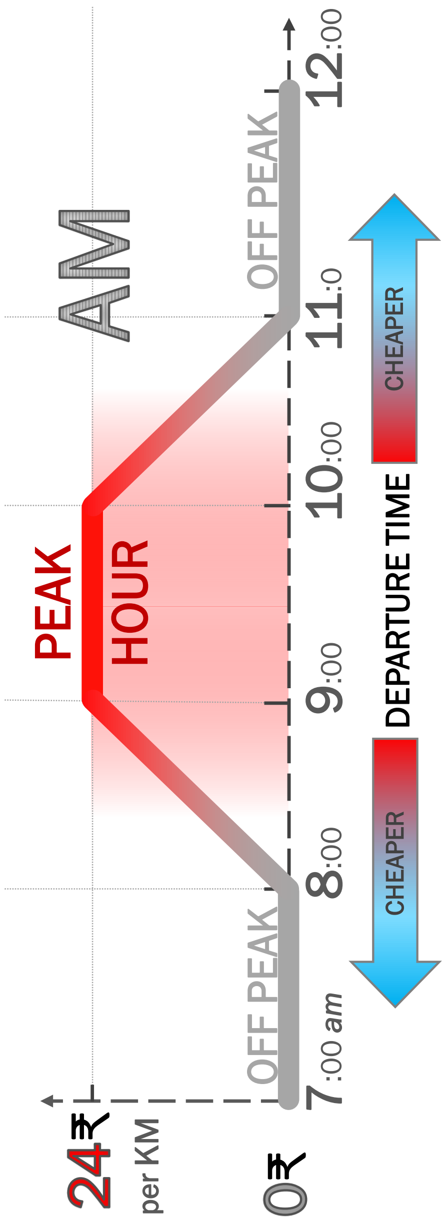
Panel (A) Individual-Level Change in Shadow Trip Rate, by Departure Time Treatment



Panel (B) Frequency of Avoiding the Congestion Area, by Area Treatment Status

Notes. These figures show the distribution of individual changes in shadow charges in the departure time treatment and control (panel A) and the distribution of individual frequency of intersecting the area when treated and not treated in the area treatment (panel B). In panel A, the sample is all regular commuters and all trips between the morning profile peak and 2 hours earlier. The graph plots the pre-post change in shadow trip rates for each participant, separately for participants with charges (Low Rate and High Rate treatments) versus those without charges (the control and information treatments). (The graph with shrunk distributions using empirical Bayes shows a similar pattern.) The sample for panel B is all days with trips in the morning between home and work for regular commuters (see Table 5 column 2). The graph shows the histogram of the fraction of days when a participant intersects the congestion area, separately for treated and not treated participants. Both graphs suggest a stark form of heterogeneity in how commuters respond to charges.

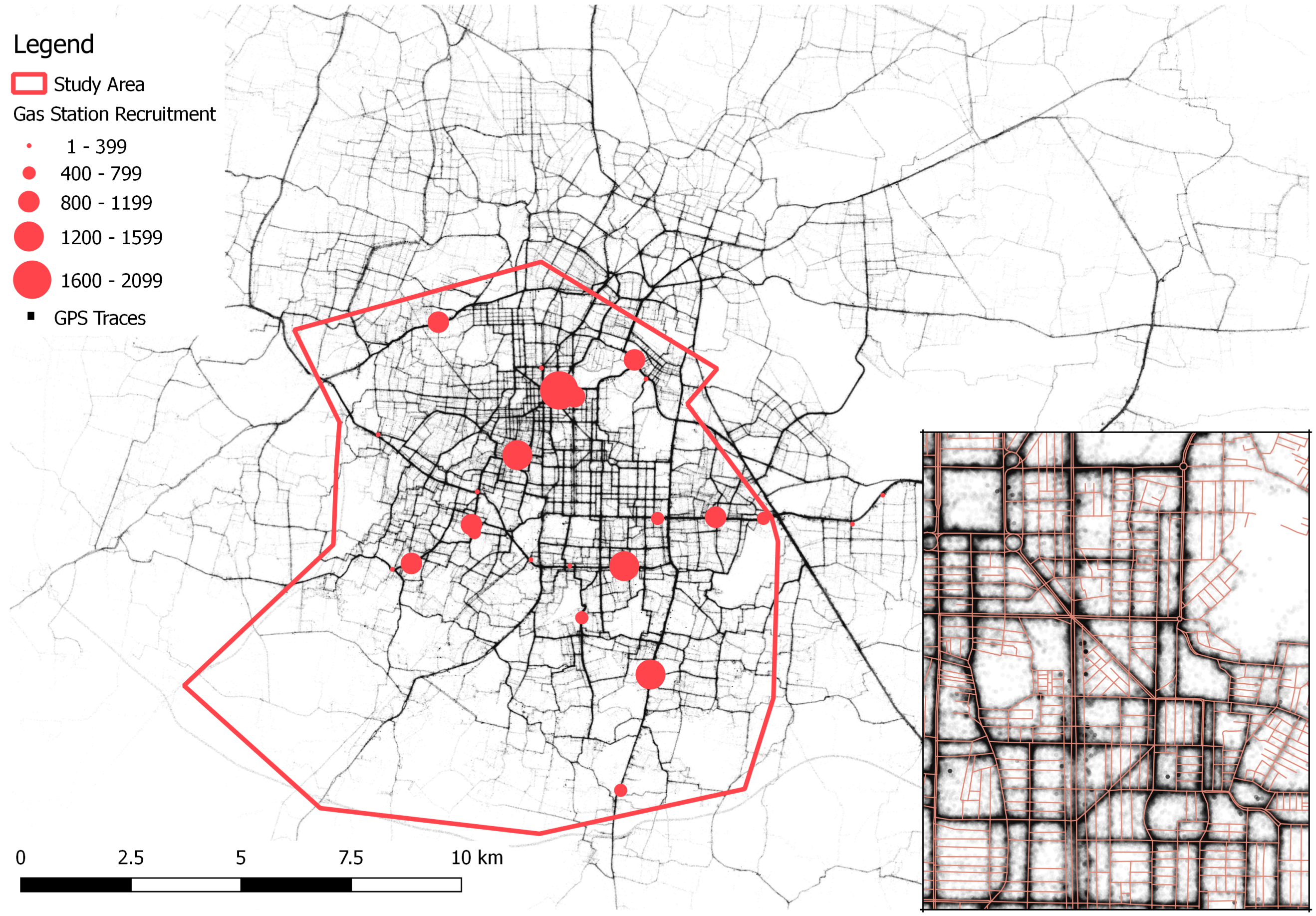
Figure A3: Departure Time Congestion Charge (AM) Rate Profile Card Example



	MORNING AM	
	Departure time	**₹perKM**
OFF-PEAK	7:00	**0₹** per **KM**
	7:10	
	7:20	
	7:30	
	7:40	
	7:50	
SHOULDER	8:00	**0**
	8:10	**4**
	8:20	**8**
	8:30	**12**
	8:40	**16**
	8:50	**20**
PEAK	**9:00**	**24₹** per **KM**
	9:10	
	9:20	
	9:30	
	9:40	
	9:50	
	10:00	
SHOULDER	10:10	**20**
	10:20	**16**
	10:30	**12**
	10:40	**8**
	10:50	**4**
	11:00	**0**
OFF-PEAK	11:10	**0₹** per **KM**
	11:20	
	11:30	
	11:40	
	11:50	
	12:00	

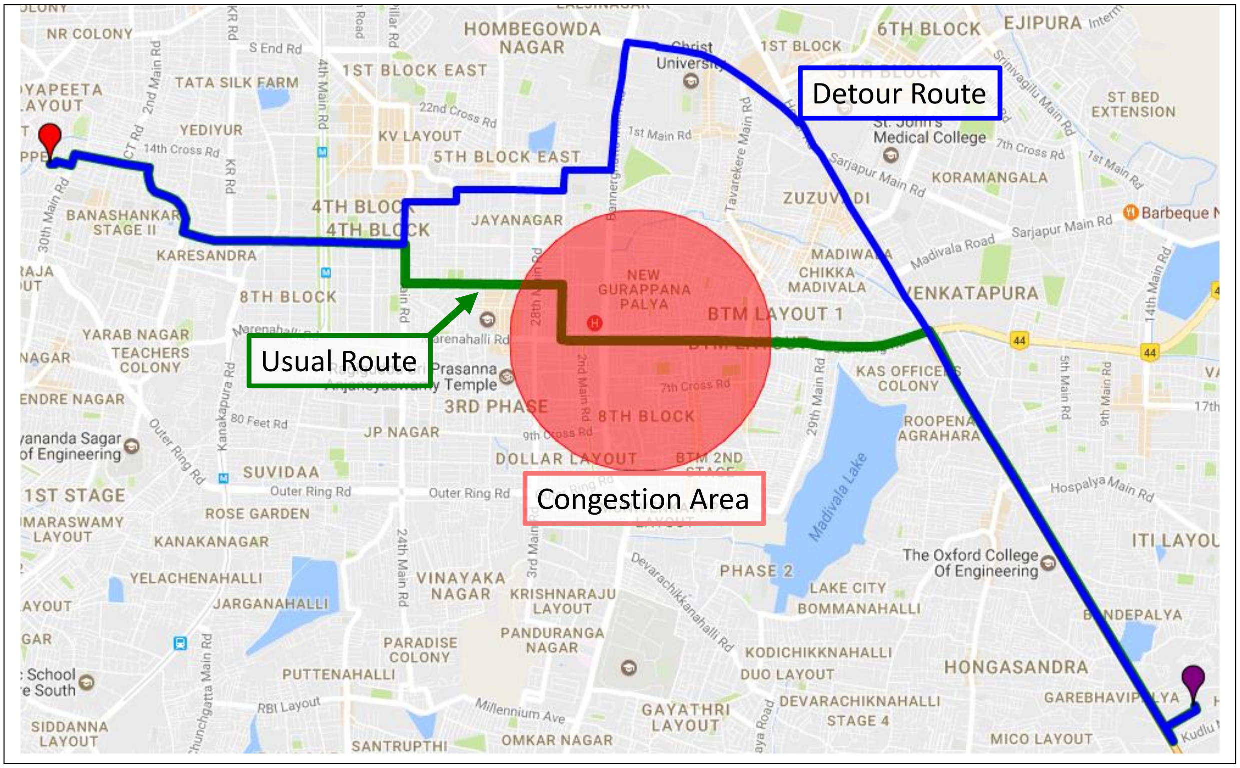
Notes: This figure shows an example of Rate Profile card that study participants in the departure time charge sub-treatments received. The cards for different participants differed in the value of the *peak rate* (Rs. 12/Km and Rs. 24/Km in the Low Rate and High Rate sub-treatments, respectively), and in the starting time of the profile (between 8 am and 9 am for the morning profile, and between 5 pm and 6 pm for the evening profile).

Figure A2: Study Area and Recruitment Locations



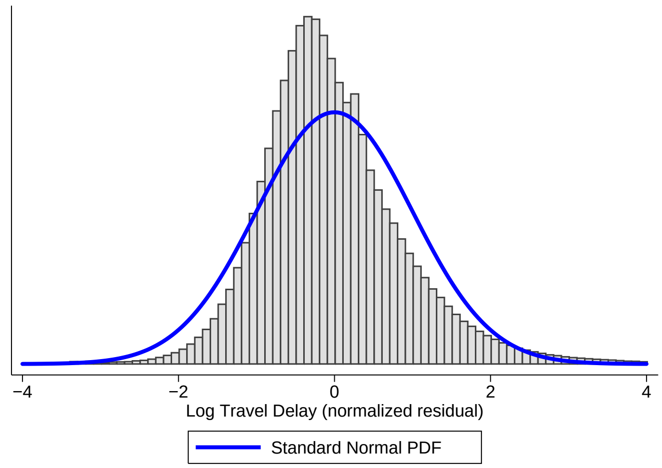
Notes. This figure shows the area of South Bangalore where the study was conducted. The red discs represent the randomly chosen gas stations where study participants were recruited (the diameter indicates the number of commuters approached). The black points represent all the GPS data collected during the study. (In the inset the Bangalore Open Street Map road network is overimposed for comparison.)

Figure A4: Area Congestion Charge Example



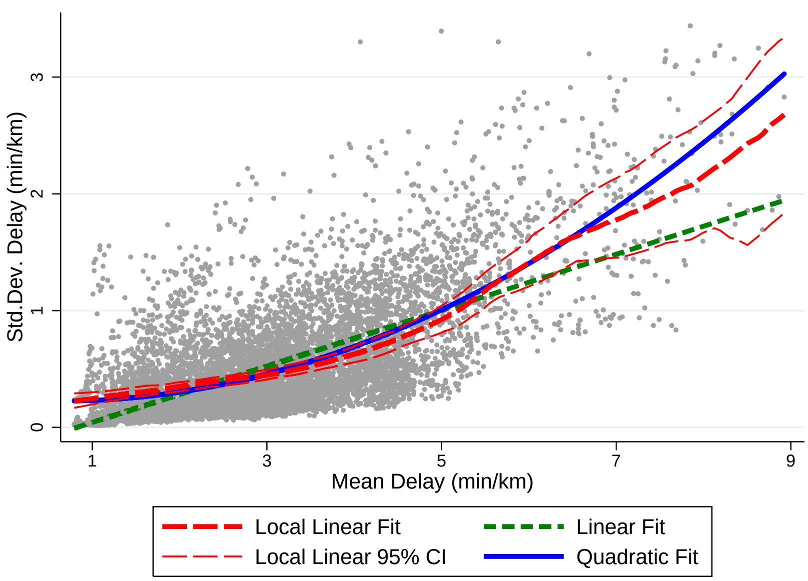
Notes: This figure shows an example of congestion area. Congestion areas were selected as follows. Given a regular route between home and work for a participant (in green), several "candidate" areas were selected along the route, with a radius of 250m, 500m or 1000m. For each candidate area, I found the quickest detour route that avoids the congestion area, based on a custom algorithm using multiple queries to the Google Maps API. Candidate areas with detours between 3 and 14 minutes longer were manually reviewed, and the final area was randomly selected from within this group.

Figure A5: Google Maps Travel Time is Approximately Log-Linear Distributed



Notes: This figure shows the shape of the day-to-day variation of log normalized travel time. For each route and departure time cell, I consider the distribution of travel times over 147 weekdays. Within each cell, I compute the normalized residual by subtracting the mean and dividing by the standard deviation for that cell. The graph shows the distribution of the log residuals for all cells, and a standard normal (solid blue line).

Figure A6: Travel Time Standard Deviation is Approximately Quadratic in Travel Time Mean



Notes: This figure shows the relationship between the mean and standard deviation of travel time. Each dot represents a route and departure time cell, and the two axes measure the mean and standard deviation in that cell over over 147 weekdays. The local linear, linear and quadratic fits are respectively shown in red (long dash), green (dash) and blue (solid). The local linear fit uses and Epanechnikov kernel with 0.5 minute per kilometer bandwidth, and 95% confidence intervals, bootstrapped by route, are also shown (thin red dashed line). The estimated quadratic equation is:

$$\text{StdDevDelay} = \underset{(0.02)}{0.24} - \underset{(0.01)}{0.05} \cdot \text{MeanDelay} + \underset{(0.002)}{0.04} \cdot \text{MeanDelay}^2$$