Figure A7: Structural Model Fit

Panel (A) Departure Time

Panel (B) DT Individual (Control)

Panel (C) DT Individual (Treatment)
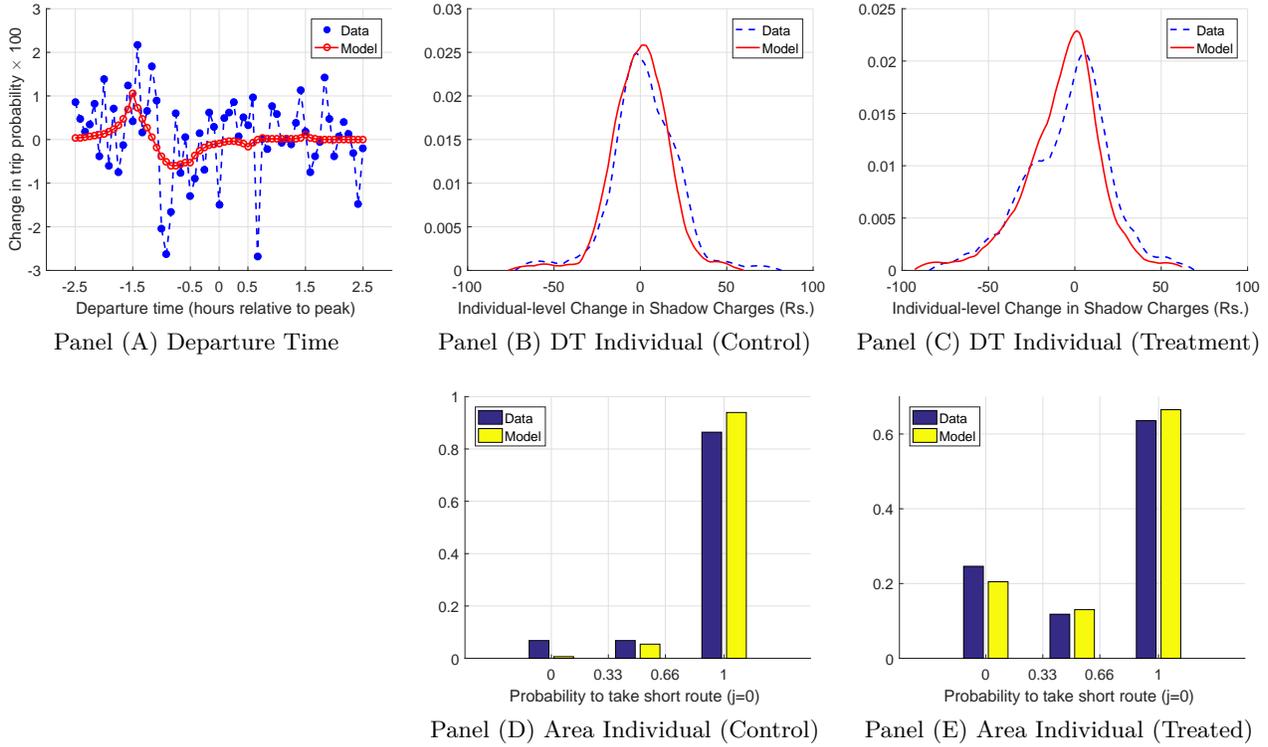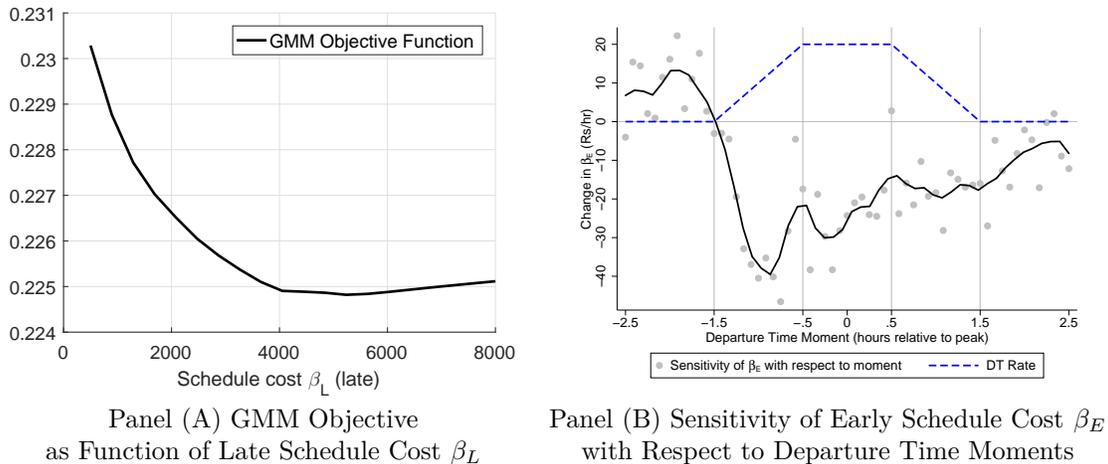
Panel (D) Area Individual (Control)

Panel (E) Area Individual (Treated)

Notes: This figure shows the fit of the estimated structural model. Panel A shows the 61 moments that target the difference in difference in number of trips by departure time bin. Panels B and C show the distributions of individual effects in the departure time treatments (changes in shadow charges between pre- and post-). Panels D and E show the distributions of individual effects in the area treatment (fraction of days intersecting the congestion area when treated and not treated).

Figure A8: Structural Model Diagnostics

Panel (A) GMM Objective
as Function of Late Schedule Cost β_L

Panel (B) Sensitivity of Early Schedule Cost β_E
with Respect to Departure Time Moments

Notes: Panel A shows that the objective function is mostly flat for values of the late schedule cost β_L above Rs. $4,000$. It is evaluated at the estimated parameters, using the optimal weighting matrix. Panel B plots the scaled sensitivity measure from Andrews et al. (2017), quantifying the change in the estimated early schedule cost parameter β_E given by one standard deviation change in each of the 61 departure time moments (see Appendix Table A9 for the full definition of the sensitivity measure).
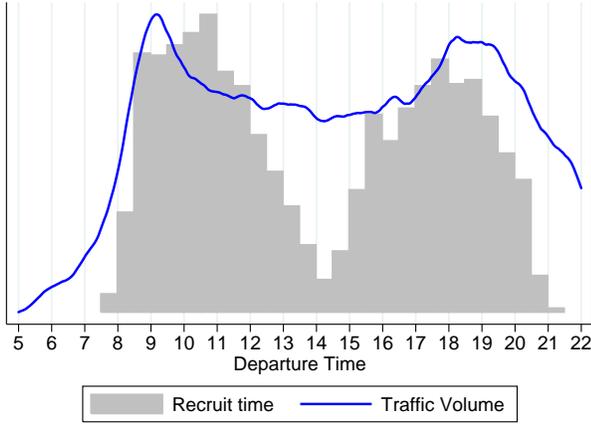
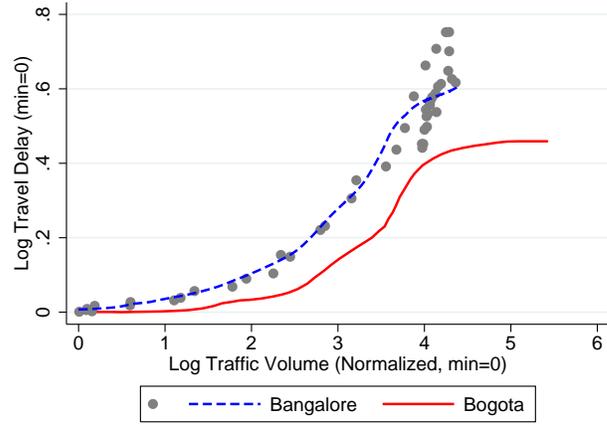Figure A9: Road Technology Estimation Robustness Checks
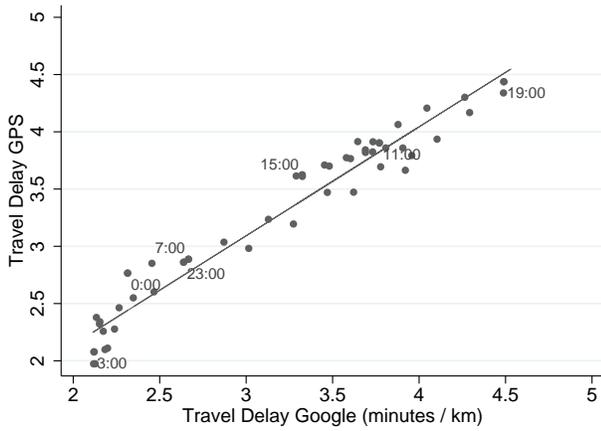
Panel (A) Travel Delay from GPS Data and Google Maps
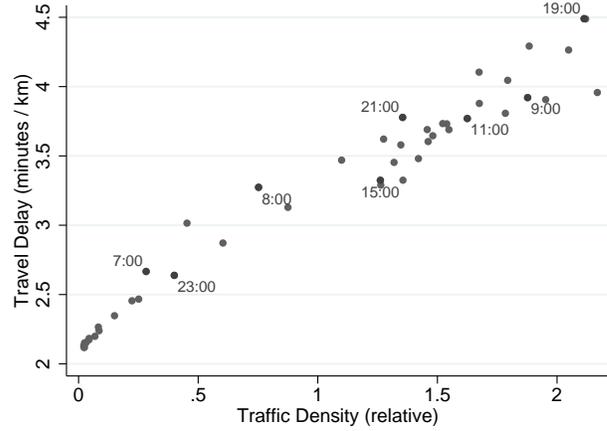
Panel (B) Travel Delay and Traffic Density

Panel (C) Recruitment Time and Trip Time Distributions

Panel (D) Comparison with (Akbar and Duranton, 2017)

Notes: Panel A shows the relationship between travel delay measured using Google Maps and travel delay measured using GPS trips from smartphone app users, at the level of departure time. The notes for Table 8 describe the samples and variable construction. Each dot represents the average delay from Google Maps (X axis) over all weekdays in the sample, and median delay from GPS data (Y axis) over all weekday trips in the sample. The OLS fit with slope 1.00 (0.04) is also shown.

Panel B replicates Figure 3 with traffic density instead of volume of departures on the X axis. Road density at a certain time is defined as the number of ongoing trips.

Panel C plots the distribution of participant recruitment times (histogram in solid gray) and the distribution of trip departure times (kernel density plot in solid blue line). Both Y axes start at zero.

Panel D compares log-log road technology estimates from this paper (gray dots, dashed blue line) with those from Akbar and Duranton (2017) in Bogotá (red solid line). (Their estimate is computed from Figure 4 panel C.) Akbar and Duranton (2017) use a transportation survey to measure traffic volume at different times of the day. Zhao et al. (2015) document that in Singapore survey respondents report more concentrated departure times in the morning and evening, compared to real departure times as measured with a GPS smartphone app; this leads to overestimating peak-hour volumes. A similar effect may explain the slightly flatter region for high traffic volumes in Bogotá.

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B Appendix Tables

Table A1: GPS Data Quality at Daily Level (Attrition Check)

	(1)	(2)	(3)	(4)
Commuter FE	X	X	X	X

Panel A. Departure Time Treatment

High Rate × Post	0.01			
	(0.05)			
Low Rate × Post	-0.01			
	(0.05)			
Information × Post	-0.01			
	(0.04)			
Post	0.09***			
	(0.04)			
Observations	24,827			
Control Mean	0.76			

Panel B. Area Treatment and Sub-treatments

Treated	0.05**	0.04	0.05**	0.05
	(0.02)	(0.03)	(0.02)	(0.03)
Post	0.06*	0.06*	0.03	0.07**
	(0.03)	(0.03)	(0.03)	(0.04)
Treated × High Rate		0.01		
		(0.04)		
Treated × High Rate Day			-0.00	
			(0.02)	
Treated × Short Detour				-0.05
				(0.05)
Observations	13,479	13,479	13,479	8,032
Control Mean	0.73	0.73	0.73	0.76

Notes. This table shows experimental impacts on the quality of the GPS data received from study participants. The outcome is a dummy for good quality GPS data on a given day. The sample covers all non-holiday weekdays for all experiment participants, excluding days outside Bangalore. In the post period, in panel A only the first or the last three weeks are included, and in panel B only the first and the last week are included. Panel B restricts to 243 participants in the Area treatment, except in column (4) where 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 on the candidate area selection process.) All specifications include respondent and study cycle fixed effects; column (4) includes fixed effects for each day in 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. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

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Table A3: Impact of Departure Time Charges on Daily Shadow Charges

	(1)	(2)	(3)
Time of Day	AM & PM	AM	PM
Commuter FE	X	X	X

Panel A. Total Shadow Charges Today

High Rate × Post	-22.7**	-16.5**	-6.2
	(11.1)	(7.4)	(6.3)
Low Rate × Post	-11.7	-3.5	-8.2
	(13.5)	(8.5)	(7.9)
Information × Post	9.5	2.9	6.6
	(10.2)	(6.7)	(6.2)
Post	0.6	-1.2	1.9
	(9.1)	(5.6)	(6.0)
Observations	15,610	15,610	15,610
Control Mean	151.0	81.7	69.3

Notes: This table replicates panel A in Table 2 using shadow *charges* instead of shadow *rates*. The shadow charge for a trip is equal to the shadow rate multiplied by the trip length in kilometers. Shadow charges are expressed in Rupees and are calculated based on a peak rate of Rs. 24/Km for for all respondents.

Table A2: Experimental Balance Checks

		Departure Time Treatments						Area Treatment			
		Information	(S.E.)	Low rate	(S.E.)	High rate	(S.E.)	Control Mean	Obs.	Area Early	(S.E.)	Obs.	Control Mean
(1)	Car user	0.01	(0.02)	0.01	(0.01)	0.01	(0.02)	0.28	497	-0.01	(0.01)	254	0.28
(2)	Regular destination	-0.05	(0.05)	0.00	(0.05)	-0.09*	(0.05)	0.77	497	-0.05	(0.03)	254	0.95
(3)	Age	-0.85	(0.93)	1.34	(1.01)	-0.03	(1.07)	33.13	497	-1.35	(0.94)	254	34.30
(4)	Log vehicle price	0.11**	(0.05)	0.09	(0.05)	0.03	(0.06)	11.06	453	0.00	(0.05)	231	11.17
(5)	Log income	-0.00	(0.10)	-0.03	(0.14)	-0.08	(0.14)	10.13	410	-0.09	(0.12)	211	10.24
(6)	Frac days with good GPS data	0.00	(0.03)	0.01	(0.04)	-0.02	(0.04)	0.62	497	0.02	(0.03)	254	0.64
(7)	Frac days present at work	0.01	(0.03)	0.00	(0.03)	-0.03	(0.04)	0.70	497	-0.03	(0.03)	254	0.79
(8)	Number of trips per day	-0.19	(0.14)	-0.01	(0.16)	-0.15	(0.15)	1.91	497	-0.00	(0.13)	254	1.69
(9)	Total distance per day (Km.)	-0.95	(0.86)	0.49	(1.14)	-0.50	(1.04)	12.95	497	0.43	(0.98)	254	13.19
(10)	Total duration per day (min)	-5.09	(3.71)	0.48	(4.50)	-2.36	(4.33)	54.82	497	1.59	(3.96)	254	52.48
(11)	Total D.T. shadow rate per day	-1.25	(4.68)	1.18	(5.00)	-3.82	(4.88)	59.07	497	-1.81	(4.59)	254	57.23
(12)	Total Area shadow rate per day	-3.35	(4.05)	-1.85	(5.22)	-4.29	(5.51)	36.07	497	-0.09	(6.79)	254	76.83
(13)	Joint Significance Test F stat	0.61		0.13		0.68				0.00			
(14)	Joint Significance Test P-value	0.44		0.72		0.41				0.99			

Notes. This table shows experimental balance checks for the departure time and area treatments. Variables 1,3,4, and 5 are from the recruitment survey, while the remaining eight variables are calculated from the GPS trips data before the experiment. Each row and group of columns combination reports coefficients from a regressions with the row header as outcome. In the "Area Treatment" columns, the sample is restricted to 254 participants who receive the area treatment, and the dependent variable is whether the respondent was assigned to the "early area" sub-treatment (to receive the area charges in week 1 as opposed to week 4). All regressions include randomization strata dummies. Rows 13 and 14 report the F-statistic and p-value from column-wise joint significance tests. The joint significance test for the all the "Departure Time" regressions has F-statistic of 0.32 and a p-value of 0.81. Robust standard errors are shown in parentheses.
$^* p \leq 0.10$, $^{**} p \leq 0.05$, $^{***} p \leq 0.01$

Table A4: Impact of Departure Time Charges on Trip Shadow Charge

	(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	-6.00*	-12.98**	-19.60*	-2.39	-10.55
	(3.10)	(5.44)	(10.07)	(4.53)	(6.60)
Low Rate × Post	-3.43	-4.86	-13.31	-4.68	-4.29
	(3.93)	(6.92)	(11.39)	(5.55)	(8.55)
Information × Post	1.66	-2.55	-5.92	4.19	6.28
	(2.67)	(4.59)	(7.07)	(4.06)	(6.40)
Observations	43,776	16,764	7,592	18,468	7,899
Control Mean	49.49	70.74	83.87	53.44	59.88

Panel B. Regular Commuters, Home-Work and Work-Home Trips

High Rate × Post	-14.29*	-27.00**	-44.46**	2.67	-10.17
	(8.07)	(11.22)	(17.39)	(10.71)	(13.40)
Low Rate × Post	-10.56	-10.71	-30.68*	-10.76	-34.80
	(10.53)	(12.66)	(16.20)	(16.79)	(26.84)
Information × Post	1.34	-0.63	-7.17	8.43	3.16
	(5.32)	(7.30)	(8.59)	(9.82)	(11.43)
Observations	11,895	5,789	3,782	4,862	2,113
Control Mean	68.87	83.39	85.20	70.19	76.48

Panel C. Variable Commuters, All Trips

High Rate × Post	-7.98	-5.25	1.04	-16.16*	-25.36*
	(6.05)	(11.06)	(20.67)	(8.58)	(14.65)
Low Rate × Post	0.69	-5.54	10.28	-4.08	27.66
	(8.22)	(17.12)	(27.75)	(11.76)	(19.59)
Information × Post	-1.73	-3.96	-1.10	-3.13	-3.07
	(5.92)	(9.42)	(19.31)	(7.40)	(11.17)
Observations	8,177	2,826	961	3,432	1,439
Control Mean	37.09	49.88	61.41	46.82	49.64

Notes: This table replicates Table 3 using shadow *charges* instead of shadow *rates*. The shadow charge for a trip is equal to the shadow rate multiplied by the trip length in kilometers. Shadow charges are expressed in Rupees and are calculated based on a peak rate of Rs. 24/Km for for all respondents.

Table A5: Trip Duration for Trips that Intersect or Do Not Intersect the Congestion Area

	(1)	(2)	(3)
	Trip Duration (minutes)		
Route FE	X	X	X
Trip Charged	-4.81***	-3.16**	-0.28
	(0.98)	(1.34)	(1.79)
Trip Charged × Long Detour		-3.66*	
		(1.91)	
Trip Charged × Predicted Detour			-0.83***
			(0.29)
Observations	7,455	7,455	7,455
Control Mean	38.51	38.51	38.51

Notes: This table compares the trip duration (in minutes) of trips that intersect and trips that do not intersect the congestion area. The sample is home to work or work to home trips of area participants on non-holiday weekdays. Each specification includes route fixed effects. "Trip Charged" is a dummy for whether the trip intersects the congestion area. Column (2) includes the interaction with the "Long Detour" Area sub-treatment. Column (3) includes the interaction with detour duration (in minutes) as predicted from Google Maps.

Table A6: Treatment Heterogeneity

Heterogeneity Dummy Variable K	(1) Regular Destination	(2) Self Employed	(3) Car Driver	(4) Small Log Vehicle Value	(5) Older	(6) Small Stated α	(7) Small Stated β	(8) Short Route	(9) Seldom Avoid Area
Panel A. *Departure Time Treatment: Trip Rate*									
Charges×Post×($K=0$)	-1.25	-2.74**	-2.89**	-5.81***	-1.06	-3.41**	-5.04***	-2.85*	
	(2.17)	(1.30)	(1.35)	(1.63)	(1.90)	(1.52)	(1.92)	(1.47)	
Charges×Post×($K=1$)	-4.11***	-7.01***	-4.69**	-0.85	-4.70***	-4.26**	-2.68	-3.95**	
	(1.37)	(2.68)	(2.26)	(1.59)	(1.47)	(1.96)	(1.66)	(1.77)	
Observations	43,776	43,170	43,776	43,776	43,776	40,783	39,639	43,776	
Participants $K=0$	119	407	350	280	175	252	218	249	
Participants $K=1$	378	82	147	217	322	205	228	248	
Control Mean $K=0$	29.71	32.34	32.16	32.57	30.90	32.25	32.43	30.73	
Control Mean $K=1$	33.34	32.73	33.06	32.24	33.32	33.11	32.68	34.59	
P-value interaction	0.27	0.15	0.50	0.03	0.13	0.73	0.35	0.63	
Panel B. *Departure Time Treatment: Number of Trips Today*									
Charges×Post×($K=0$)	-0.40*	-0.10	-0.14	-0.36**	-0.09	0.03	-0.15	-0.10	
	(0.24)	(0.13)	(0.15)	(0.15)	(0.20)	(0.19)	(0.15)	(0.20)	
Charges×Post×($K=1$)	-0.09	-0.34	-0.20	0.11	-0.19	-0.20	-0.16	-0.28*	
	(0.14)	(0.35)	(0.19)	(0.19)	(0.15)	(0.16)	(0.18)	(0.15)	
Observations	15,610	15,367	15,610	15,610	15,610	14,416	14,073	15,610	
Participants $K=0$	119	407	350	280	175	252	218	249	
Participants $K=1$	378	82	147	217	322	205	228	248	
Control Mean $K=0$	2.98	2.78	3.01	2.84	2.87	2.93	2.79	3.20	
Control Mean $K=1$	2.94	3.70	2.82	3.10	3.00	3.02	3.11	2.68	
P-value interaction	0.26	0.52	0.80	0.06	0.69	0.37	0.94	0.46	
Panel C. *Area Treatment: Trip Shadow Rate*									
Treated×($K=0$)		-11.91***	-11.54***	-11.29***	-7.04**	-12.92***	-9.65**	-11.46***	-9.43***
		(2.49)	(2.56)	(2.80)	(3.56)	(2.97)	(4.04)	(2.81)	(2.74)
Treated×($K=1$)		-7.94**	-12.73***	-12.54***	-14.18***	-10.19***	-13.07***	-12.66***	-14.19***
		(3.58)	(3.95)	(3.38)	(2.66)	(3.36)	(2.73)	(3.38)	(3.26)
Observations		20,367	20,594	20,594	20,594	18,741	18,260	20,594	20,594
Participants $K=0$		190	163	133	73	100	90	123	110
Participants $K=1$		32	63	93	153	104	109	103	116
Control Mean $K=0$		47.03	44.10	46.14	39.79	41.99	43.13	46.99	34.43
Control Mean $K=1$		37.31	46.75	42.84	47.35	46.56	45.21	42.07	53.00
P-value interaction		0.36	0.80	0.78	0.11	0.54	0.48	0.79	0.27
Panel D. *Area Treatment: Number of Trips Today*									
Treated×($K=0$)		0.21**	0.08	0.15	0.15	0.19	0.18	0.16	0.32**
		(0.09)	(0.10)	(0.10)	(0.15)	(0.13)	(0.12)	(0.13)	(0.13)
Treated×($K=1$)		-0.07	0.40**	0.20	0.18*	0.14	0.19	0.21*	-0.00
		(0.24)	(0.16)	(0.14)	(0.10)	(0.12)	(0.12)	(0.11)	(0.10)
Observations		8,745	8,878	8,878	8,878	8,056	7,874	8,878	8,878
Participants $K=0$		204	174	141	79	108	95	132	121
Participants $K=1$		35	69	102	164	110	118	111	122
Control Mean $K=0$		2.28	2.55	2.44	2.43	2.51	2.32	2.80	2.38
Control Mean $K=1$		3.80	2.37	2.58	2.53	2.45	2.58	2.17	2.61
P-value interaction		0.29	0.09	0.74	0.88	0.79	0.96	0.76	0.05

Notes: This table reports heterogeneous experimental response by observable characteristics. All heterogeneity variables K are dummy variables. They are: whether the commuter has a stable destination in column 1, whether the commuter's vehicle value is below median in column 4, whether the commuter is at least 35 years old in column 5, whether the stated preference value of time (α) is below median in column 6, whether the stated preference schedule cost (β) is below median in column 7, whether the daily average kilometers travelled pre-experiment is below median in column 8, and whether the frequency of intersecting the congestion area pre-experiment is below median in column 9.
Data. Vehicle values are scrapped from a global online marketplace and matched by vehicle type, brand and model. Stated preferences are from a phone survey. Value of time is measured by asking for the fee that would make commuters indifferent between their usual travel time plus the fee, or a longer travel time. The measure of schedule costs is computed asking by how much commuters would advance (or delay) their departure time if each minute leaving earlier (or later) was less expensive. A commuter has "small stated β" if the absolute change in departure time is above median. The stated preference values are residuals after controlling for morning or evening and cheaper earlier or cheapear later effects.
Specification. Each regression includes commuter fixed effects, study period fixed effects interacted with each group. The last line in each panel reports the p-value from the test of whether the two groups ($K=0$ and $K=1$) responded identically to the experiment.

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Table A7: Structural Estimation Robustness Checks

(1)	(2)	(3)	(4)	(5)	(6)
Value of time α (Rs/hr)	Schedule cost early β_E (Rs/hr)	Schedule cost late β_L (Rs/hr)	Logit inner σ (dep. time.)	Logit outer μ (route)	Probability to respond p
1,187.2	345.2	1,000	27.3	37.3	0.47
1,092.3	322.9	8,000	31.9	36.8	0.47

Notes: This table replicates Table 7 using different assumptions for the late schedule cost. In Table 7 the late cost is fixed at $\beta_L = $ Rs. $4,000$; here it is fixed at $\beta_L = $ Rs. $1,000$ and $\beta_L = $ Rs. $8,000$.

Table A8: Numerical Model Identification Check

	(1)	(2)	(3)	(4)	(5)
	$\hat{\alpha}$	$\hat{\beta}_E$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{p}$
Value of time α	1.12*** (0.04)				
Penalty early β_E		1.00*** (0.17)			
Logit inner σ			1.41** (0.55)		
Logit outer μ				1.08*** (0.03)	
Probability to respond p					1.05*** (0.03)
Observations	90	90	90	90	90
R^2	0.92	0.43	0.06	0.92	0.90

Notes: This table shows numerically that the GMM estimation is able to recover model parameters. To construct it, I drew 100 random sets of model parameters, and for each set I simulated the model to generate choice data corresponding to those parameters, and estimated the structural model on the simulated data. Each column in this table reports the results from a regression of the estimated parameter on the original parameter. Each random parameter $\theta_0 \in \{\alpha, \beta_E, \beta_L, \sigma, \mu, p\}$ was drawn independently from a uniform distribution $U\left(0.3 \cdot \hat{\theta}, 2 \cdot \hat{\theta}\right)$ where $\hat{\theta}$ is the GMM parameter estimate from Table 7. The simulated data covered five times more commuters than the real data. When running GMM, the random initial conditions did not depend on the original parameters, and the late schedule cost was fixed at $\beta_L = $ Rs. $4,000$ as in Table 7. Ten observations where the estimated parameters had extreme values were dropped; results are essentially unchanged with all 100 observations, except for column (3) where the coefficient becomes $0.53\,(0.78)$. Robust standard errors in parentheses. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table A10: Road Technology Trip Level Regressions

	(1)	(2)	(3)	(4)
Dependent Variable:		Trip Delay (min/km)		
Commuter FE			X	X
Traffic Volume at Trip Departure Time	0.87***	0.84***	0.70***	0.70***
	(0.04)	(0.03)	(0.04)	(0.04)
Trip Length (km)		-0.05***		-0.01**
		(0.00)		(0.00)
Constant	2.47***	2.97***	3.11***	3.17***
	(0.06)	(0.05)	(0.06)	(0.06)
Observations	61,234	61,234	61,234	61,234

Notes: This table reports trip-level quantile (median) regressions of the trip delay, defined as trip duration in minutes divided by trip length in kilometers, on the average traffic volume at the trip departure time and trip length. The sample is all weekday trips more than 2km in length, without any stops along the way, and with a trip diameter to total length ratio above 0.6 (the 25th percentile). Columns 3 and 4 first residualize the trip delay on commuter fixed effects. Standard errors in parentheses are clustered at the commuter level. $^{*}p \leq 0.10$, $^{**}p \leq 0.05$, $^{***}p \leq 0.01$

Table A11: Experimental Design (strata, sub-treatments, timing)

Strata	*Congestion Charge Treatments*		*Timing*
	Departure Time (DT) Sub-treatments	Area Sub-treatments	
$\begin{pmatrix} \text{Area eligible} \\ \text{Area ineligible} \end{pmatrix}$ $\times$ $\begin{pmatrix} \text{Car} \\ \text{Motorcycle} \end{pmatrix}$ $\times$ $\begin{pmatrix} \text{High Daily KM} \\ \text{Low Daily KM} \end{pmatrix}$	$\begin{pmatrix} \text{High Rate} \\ \text{Low Rate} \\ \text{Information} \\ \text{Control} \end{pmatrix}$	$\begin{pmatrix} \text{Low Rate} \\ \text{High Rate} \end{pmatrix}$ $\times$ $\begin{pmatrix} \text{Long Detour} \\ \text{Short Detour} \end{pmatrix}$	$\begin{pmatrix} \text{DT First} \\ \text{DT Last} \end{pmatrix}$

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Table A9: Structural Estimation Sensitivity Measure

	(1) Value of time α (Rs/hr)	(2) Schedule cost early β_E (Rs/hr)	(3) Logit inner σ (dep. time.)	(4) Logit outer μ (route)	(5) Probability to respond p
Panel A. Departure Time Moments					
(1-61) Average absolute value for departure time bin moments	28.7	17.3	6.32	0.32	0.005
(62) Variance individual effects departure time treatment	167.1	1.5	-5.16	0.59	-0.017
(63) Variance individual effects departure time control	61.7	9.1	9.88	0.08	-0.016
Panel B. Area moments					
(64) With charge: probability to intersect area	-170.8	-23.9	16.82	0.37	0.039
(66) With charge: sample frequency to intersect area $\in [1/3, 2/3]$	170.7	34.5	-4.41	3.47	0.029
(67) With charge: sample frequency to intersect area $\in [2/3, 1]$	238.9	26.4	-20.69	0.97	-0.060
(65) Without charge: probability to intersect area	187.2	49.2	2.38	-0.89	0.080
(68) Without charge: sample frequency to intersect area $\in [1/3, 2/3]$	-121.0	-23.3	3.70	1.16	-0.026
(69) Without charge: sample frequency to intersect area $\in [2/3, 1]$	-220.1	-48.0	1.51	0.60	-0.065

Notes: This table reports the estimated sensitivity measure Λ from Andrews et al. (2017), scaled by the (bootstrap) standard deviation of each moment. Each entry Λ_{pj} measures the change in estimated parameter θ_p due to a one standard deviation change in moment m_j. The matrix Λ is estimated by $\hat{\Lambda} = \left(\hat{S}'\hat{W}\hat{S}\right)^{-1}\hat{S}'\hat{W}\text{diag}\left(\hat{\sigma}_j\right)$ where $\hat{S}$ is the Jacobian of the moments with respect to parameters evaluated at the estimated parameters, $\hat{W}$ is the estimated optimal weighting matrix, and $\text{diag}(\hat{\sigma}_j)$ is the diagonal matrix with jth entry given by the (bootstrap) estimated standard error of moment j.

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Table A12: Subtreatment Probabilities by Stratum

	Strata			Departure Time (DT) Sub-treatments					Area Sub-treatments					Timing		
									High Rate		Low Rate					
No.	Area	Car or Moto	Daily KM	High Rate	Low Rate	Info	Control	Total	Short Detour	Long Detour	Short Detour	Long Detour	Total	DT Weeks 1-3	DT Weeks 2-4	Total
1	Eligible	Car	Low	3/8	1/8	2/8	2/8	1	1/4	1/4	1/4	1/4	1	1/2	1/2	1
2	Eligible	Car	High	1/8	3/8	2/8	2/8	1	1/4	1/4	1/4	1/4	1	1/2	1/2	1
3	Eligible	Moto	Low	3/8	1/8	2/8	2/8	1	1/4	1/4	1/4	1/4	1	1/2	1/2	1
4	Eligible	Moto	High	1/8	3/8	2/8	2/8	1	1/4	1/4	1/4	1/4	1	1/2	1/2	1
5	Ineligible	Car	Low	1/12	3/12	4/12	4/12	1					0	1/2	1/2	1
6	Ineligible	Car	High	3/12	1/12	4/12	4/12	1					0	1/2	1/2	1
7	Ineligible	Moto	Low	1/12	3/12	4/12	4/12	1					0	1/2	1/2	1
8	Ineligible	Moto	High	3/12	1/12	4/12	4/12	1					0	1/2	1/2	1

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Congestion pricing to solve traffic jams in Bangalore: Not so fast!

Articles

📅 Published 29.06.18

Photo credit: Jim/flickr

Gabriel Kreindler
Research Fellow, Becker Friedman Institute, University of Chicago

Congestion pricing is not as effective in reducing travel times as one might presume

Traffic congestion is a chronic problem in large citi... ...ons of urban co... ...y but aggressive traffic, no... ...on a daily basis. ... ...ous urban traffic ... s on reducing peak-hour congestion,

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users fees that scale in proportion to the amount of congestion. The idea is backed by common sense and economic theory. Drivers impose 'externalities', namely, a cost on society, notably by slowing down traffic. Typically, drivers do not take this into account, which leads to excessive congestion. Hence, it is presumed that judiciously chosen pricing can significantly improve traffic and commuter welfare.

The study

I investigate this hypothesis in a recent International Growth Centre (IGC) study in Bangalore, India, proceeding in three steps:

1. I organised an experimental pilot of peak-hour congestion pricing policies (to measure how commuters respond to pricing).
2. I measure the road traffic externality, that is how additional vehicles slow down traffic.
3. I compute (city-wide) optimal charges and their travel time benefits and schedule disruption costs.

In the study I focus on within-day commuting changes, and I do not quantify benefits from reduced exposure to pollution, nor longer term responses to pricing such as switching to public transport.

Th... ...are fine-grained co... ...mple of Bangalore ...o... ...rveyors stationed in a... ...in South Bangalore approached car

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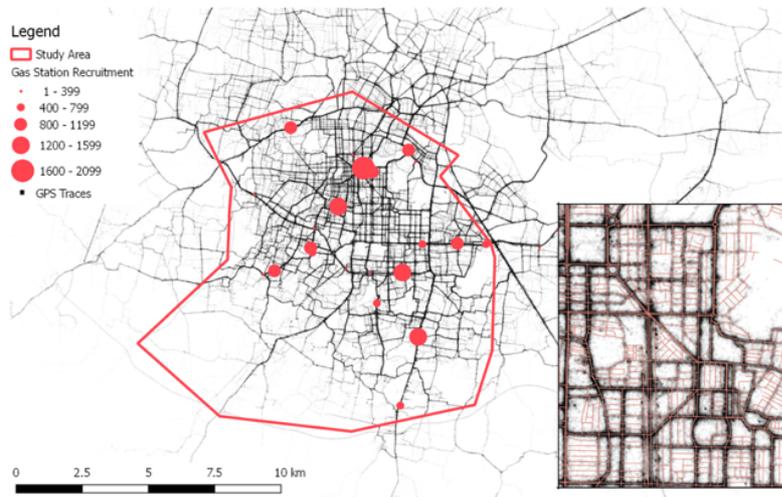| Browse by	Browse by content type
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of eligible drivers agreed to participate.) The resulting dataset covers over 100,000 individual weekday trips and almost one million kilometres of travel. The data confirm that Bangalore is one of the most congested cities in the world: commuters spend an average of 1.5 hours driving each weekday, with an average speed of only 14 km/h.I later use the same data to implement pricing policies. In a real-world policy, charges may be based on data from GPS responders installed in vehicles (Martin and Thornton 2017).

Figure 1 Study area, recruitment locations, and GPS data points (black)

Congestion pricing policies

I focus on policies to decongest the peak-hour by inducing commuters to change whenthey tra[...] [...]mented two broadly rea[...] [...]ample of 497 co[...]

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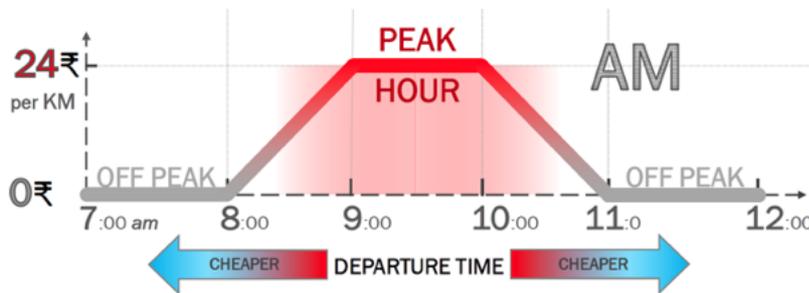This site uses cookies to store information on your computer.

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close to peak-hour.

- **The 'area' policy**: Commuters were charged a flat fee for driving through a small area along their usual route, giving them the option to drive along a longer but untolled alternate route.

Participants faced real monetary incentives to change their how they travel. In practice, charges were calculated automatically and subtracted from a prepaid virtual account that was set up for each participant. Each week during the experiment, the outstanding balance was transferred to the participant's bank account.

Figure 2 Illustration of the 'departure time' policy

The findings

In response to the 'departure time' policy, commuters demonstrated moderate flexibility in moving their trips away from their typical working hours in order to save money. They left earlier by around four to six minutes on average in the ~~morning~~ evening. In response to t~~he~~ ~~participa~~nts crossed the co~~ngestion~~ ~~rece~~ntly by switching to m~~~~

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For example, a typical commuter is roughly indifferent to leave one hour earlier than usual in the morning, as long as this results in 15 minutes faster travel time.

By themselves, the experimental results are moderately encouraging that congestion pricing could have an important beneficial impact on travel times and commuter welfare. However, to fully understand these consequences we also need to know how road speeds are determined.

Externalities: The social cost of peak hour travel

Optimal congestion pricing depends crucially on the cost that drivers impose on society. Here, I focus on the decrease in road speeds, using the large data set of GPS traces collected in the study and typical variation within the day. (I do not study costs related to pollution, which may also be important.) I find that each additional vehicle on the road has a roughly constant effect to increase average travel times (Figure 3). Quantitatively, making a half-hour trip during peak-hour leads to an increase inthe aggregatedriving time of everyone else of around 17 minutes.

This social cost is important, yet significantly smaller than indicated by previous engineering res~~~~~~~~~~~~~~~~y during peak-hours. Int~~~~~~~~~~~~anton (2017) document a s~~~~~~~~~~~~otá, Colombia. This ~~~~~~~~~~~~~~nology in developing ti~~~~~~~~~be fundamentally different from
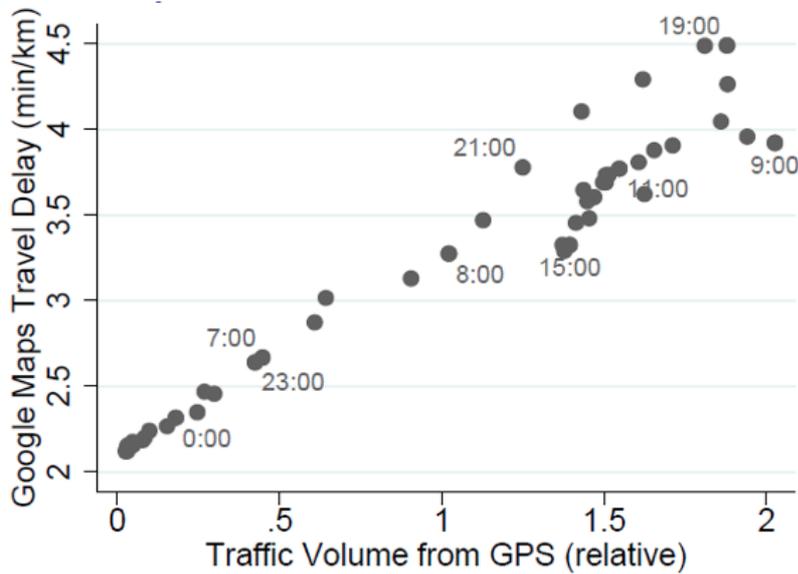
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times

The city-wide impact of congestion pricing

In the last step of the study, I put the first two parts together to simulate how a city-wide congestion pricing policy would play out. To make progress, I make several simplifying assumptions: in response to pricing, commuters in the model do not change home and work locations, nor their likelihood of using public transport or cancelling trips.

Peak-hour congestion pricing chosen optimally only delivers small benefits of 2-6% faster traffic. Furthermore, when also taking into account the schedule costs of commuters who avoid charges, the[se] [benefits are] [ne]gligible at 0.5% of the tot[al] [, or 8 US cents, per co[

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different, inconvenient times. In turn, this is mostly due to the small magnitude of the road speed externality.

Conclusion

The mere existence of severe traffic congestion does not, by itself, imply that the gains from congestion pricing would be substantial. Indeed, peak-hour pricing in Bangalore would only have a small benefit in terms of traffic speeds. It is of course possible that congestion pricing would still yield large welfare benefits in other cities, and in future research it is important to also measure how drivers switch to public transport and carpooling, and how home and work decisions depend on travel and monetary costs. In addition, pollution exposure due to traffic slow-downs, as well as motor vehicle accidents, also encompass externalities.

Even so, this study shows that arguments in favour of congestion pricing require careful measurement and understanding of driver responses and the determinants of road traffic congestion.

Editor's note: A version of this column was previously published by the IGC.

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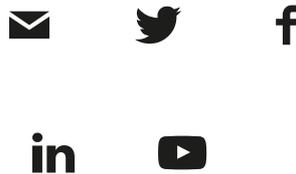
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THE TIMES OF INDIA

10 million Bengalureans lose 60 crore hours, Rs 3,700 crore a year to road congestion

TNN | Jan 6, 2017, 01.21 PM IST

BENGALURU: Here's a picture of Bengaluru, and it's not too pretty: a smoking, fuel-guzzling, congested metropolis where citizens spend many hours on the roads, which is hitting productivity and translating into huge losses. All because the city lacks a robust public transport system.
It is perhaps the most unnerving revelation made about economic impact due to congestion in Bengaluru.

The Revised Master Plan 2031 that the Bangalore Development Authority put out in the public domain on Wednesday, said 1.18 crore citizens waste 60 crore (600 million) man hours annually. And this translates to Rs 3,700 crore, including Rs 1,350 crore on fuel alone, and the rest on productivity (man hours) loss.

The lack of a public transport network has been dealt with in detail in the RMP. Over 90 lakh trips are made in a day by Bengalureans, which means every citizen in making one trip a day. But BMTC only caters to half of the load.

BDA admits that the shortage of public transport options has increased the number of private vehicles on the road, adding to congestion and reducing vehicle speed to 11kmph in 2015.

Fuel losses amount to Rs 50 crore annually by the citizen -almost 2.8 lakh litres are wasted per hour a day in the city.

A BDA source told TOI, "The RMP has also conducted origin and destination (OD) surveys across 500 zones in BBMP limits to

understand the traffic models in each zone, and where and how people move. Some data was gathered by manual collection of data and photographs and also from secondary sources like BMTC, BMRCL and DULT etc. This will help us come out with effective plans for transport like the Metro, light rail, suburban rail and buses."

BDA analysis says that traffic congestion will triple its effect on the business sector, and the share of public transport mode (mainly bus) will decrease to 36% from the existing 47% by 2031.

The RMP has focused on adopting various elements of `travel demand management' using the origin-destination studies from the Comprehensive Traffic and Transportation Study in 2008. And of course, on integrating with land

REVISED MASTER PLAN FORESEES SCARCITY, DEPENDENCE ON RENEWABLE RESOURCES

WATER | CONSERVE TO MEET DEMAND

Water scarcity is being reasoned as one of the major causes for the slipping livability quotient of Bengaluru.According to the RMP 2031 document, by 2051, water shortage will be around 69.45tmcft despite adopting shortand mid-term solutions to increase conservation and draw more from river basins.

BWSSB supplies 1470 MLD (million litres per day) of which 46% is lost through unaccounted water flow (illegal connections). But that still does not cater to all the outer areas of the city yet.

Water demand will be 5,340 MLD (50tmcft) for a population of over 20 million by 2031. This includes 3,920 MLD for domestic potable use and another 2,745 MLD for non-potable and commercial consumption.

"We have 29tmcft awarded from the Cauvery Water Tribunal but the distribution lines for entire Bengaluru city are not yet ready. That is why the crisis deepens. We've planned to increase our Local Planning Area jurisdiction to 1219 sqkm of Bengaluru, beyond the existing BBMP limits, to cap haphazard development in gram panchayat areas under the Bengaluru Metropolitan Area and also to ensure planned infrastructure for resource access to all in the 1219 sqkm area," a BDA official said. BWSSB is also to expand its coverage area for supply of drinking water and sewerage connections to the entire city. One

of the key concerns is to reduce unaccounted water flow which stands at 46% at present.

POWER | GRID DEPENDENCE FALLS, RENEWABLE ENERGY IS IN

Although the government analyzes the power distribution quality to be fairly good, citizens don't agree. Power cuts, power quality supply has moved many away from the grid and opt for rooftop solar power systems. However, RMP forecasts dependency on renewable energy and estimates Bengaluru can generate 14,880 Million Units of solar power by 2031 and 313 MU from biomass.

The power demand is growing at a flat rate of 9.5%, according to details from Bescom.Bengaluru draws 50% of the power generated and supplied in the entire state -12,455 MU per day and 2161 MW is the peak load during peak hours.

Staggering power, regularizing irrigational pump sets and various measures of capping waste has not met the demand. Thus, pushing the tariff remains the only option for the company but as it increases tariff, more big consumers reduce dependency on the grid, making it a vicious cycle in the sector.

An average Bengalurean already consumes 1,219 units of power a day (according to 2014 data) which was just 827 units a day in 2005. The city has 80% of domestic consumers, 11.8% of consumers include commercial, while the share of agricultural and industrial consumers is negligible. RMP estimates that energy demand will grow by 11.6% in the city by 2031.

SOLID WASTE MANAGEMENT | BIGGER PILES OF FILTH

Although this seems to be much under control for the state government, waste generation estimates for 2031 are shocking. Per capita waste generation is likely to grow by 1.3% a year -from 644gm per day to 905gm.

This means Bengaluru will generate 18,390 million tonnes of municipal waste by 2031, with a population of over 20 million. It generated 7,826MT in 2015. By 2020, the figure is likely to touch the 10,787MT mark. All this only pushes the requirement of

more land for landfills. But that is not the only alternative BDA proposes. Landfill requirement by 2031 is going to be 30%, says the RMP.

But a deeper look shows 58% of municipal waste is biodegradable, as per SWM Master Plan 2009. It is estimated that about 7,000MT waste will be dumped, despite processing which requires more land. Land will be identified jointly by BDA and BBMP to identify and use as landfills.

ANNEXURE-R6 (Colly)

SMARTCITIES**DIVE**

ARCHIVES: This is legacy content from before Sustainable Cities Collective was relaunched as Smart Cities Dive in early 2017. Some information, such as publication dates or images, may not have migrated over. For the latest in smart city news, check out the new Smart Cities Dive site or sign up for our daily newsletter.

To Reduce Traffic Congestion, India's Cities Can Learn from its Businesses

EMBARQ Network

The Indian city of Bangalore is engaging the private sector to shift how employees commute to work, reducing traffic congestion and costs for everyone. Photo by Miroslav ?uljat/Flickr.

*A century of car-centric urban development has left our cities polluted, congested, and searching for sustainable solutions. Transport Demand Management (TDM) strategies can provide these solutions by combining public policy and private sector innovation to reverse over-reliance on private cars. The **Moving Beyond Cars** series—exclusive to TheCityFix and WRI Insights—offers a global tour of TDM solutions in Brazil, China, India, and Mexico, providing lessons in how cities can curb car culture to make sustainable transport a reality.*

The number of cars on India's roads has been doubling every 8-10 years—and it's costing the country. A WHO study from 2014found that 13 of the world's 20 most polluted cities are in India. The country experiences 120,000 deaths per year due to traffic fatalities, more than any other country. And traffic congestion in Bangalore alone costs the city approximately 5 percent of its economic output.

City governments in India are still focused on investing in road expansions and overpass construction projects rather than curbing car dependence and improving public transport services. Instead of waiting for local governments to act, a handful of Indian businesses are taking the initiative to implement transport demand management (TDM) strategies, improving the productivity of their employees and reducing the social costs of car congestion.

TDM Initiatives Reduce Costs for Indian Businesses and Employees

Employer-initiated TDM strategies have been especially common in the information technology (IT) sector, because most IT employees in India use private cars to commute to and from work. These strategies have been relatively easy to implement given the availability of information—such as employees' origins and destinations, duration, and frequency of trips—for designing optimal transit and carpool routes.

Some initiatives have included providing employees with commuter subsidies for public transport or carpooling. Other businesses have experimented with company buses that transport workers from

nearby metro stations to offices, providing much-needed "last-mile connectivity." These programs have successfully shifted 30-50 percent of the targeted employees from cars to public transport, resulting in reduced travel times and significant cost savings for employers. Not only are employees more productive from shorter commutes, bus and other public transit subsidies are much cheaper compared to private company buses.

For example, Wipro—a major IT business in Bangalore—worked with the Bangalore Metropolitan Transport Corporation (BMTC) on specific routes designed to move workers more comfortably and efficiently. This collaboration improved employees' user experience, reduced costs, and shifted commuters from private company buses or cabs to public transit. BMTC introduced high quality bus services that were air-conditioned and convenient for WIPRO's employees and other transit riders. This initiative encouraged employees to commute by bus rather that private vehicle and is credited with reducing employee GHG footprint by almost 16 percent in the first year of implementation.

Another example is the "I-Travel Smart" initiative from GENPACT—a business operations and IT solutions provider in the city of Gurgaon. Demonstrating corporate social responsibility, Genpact has focused on innovating long term transport solutions for employees**.** The initiative has resulted in reducing travel distances by about 1.2 million km annually and has saved about 335 tons of CO_2 emissions. Their four step strategy includes:

- A free shuttle service from nearby metro stations to all Genpact sites, addressing the issue of last mile connectivity;

- A commuter guidebook for all employees containing comprehensive information about alternative transport options;

- Preferred parking locations for employees who choose to carpool; and

- Designated bus services for employees, in partnership with Haryana State Transport, Delhi Transport Corporation and Volvo.

Several other IT businesses have shown interest and are moving forward to implement TDM measures as well. For example, Infosys,

a major IT company with 180,000 employees, recently announced to roll out its own TDM program over the next four years to reduce its employees travel emissions.

Bringing TDM to a Citywide Level

Worldwide, TDM strategies have been shown to reduce traffic congestion as well as the costs of building, maintaining, and operating city roads. In India, cities like Bangalore, Mumbai and Delhi have proposed congestion charging initiatives like London's, but these plans have hit roadblocks. While several cities have drafted street parking policies, implementation seems unlikely, due to opposition from commercial business owners and car users.

City leaders need to recognize the value of TDM strategies—both to the private sector and local communities—and support these measures by improving the quality of public transit without compromising affordability. City governments need to implement appropriate parking policies as a precursor to TDM to ensure success. Furthermore, strong communication campaigns are necessary for educating the public about the harmful impacts of car dependence on health, safety, and quality of life.

Building on Past Success

To address mounting car ownership, city leaders and decision makers need to implement a diversity of TDM strategies. The successes of employer-initiated TDM measures demonstrate the potential for citywide TDM and signal to political leaders that cost-effective solutions exist. It's time that city leaders in India recognize the benefits of sustainable mobility and incorporate TDM strategies into their own public agendas. The future of their economies and their citizens depends on it.

Traffic congestion costs Bengaluru Rs 38,000 crore annually

New Delhi loses a maximum of Rs 63k crore as social cost of congestion; travel during peak hour takes an average of 162% more time in city.

Published: 19th April 2018 04:42 AM | Last Updated: 19th April 2018 04:42 AM

A+ A A-

By Express News Service

BENGALURU: The city loses a whopping Rs 38,000 crore (5.92 Billion USD) every year as the social cost of traffic congestion. Travel during peak hour traffic takes an average of 162% more time than the same distance travelled during off peak hours. This is second only to Kolkata among major Indian cities measured according to a study by the Boston Consulting Group commissioned by taxi aggregator Uber. Social costs of congestion include time delays, extra fuel spent, costs due to traffic accidents, vehicle loss, wear and tear as well as environmental issues.

In fact, Bengaluru's traffic places it below cities like Singapore, Hong Kong, Bangkok and Manila when it comes to time taken to travel during peak hours, the study has shown. In terms of costs, New Delhi loses the most with the social cost of congestion standing at D63,000 crore (9.60 Billion USD) annually. The report, which groups Bengaluru and Kolkata in similar groups owing to their smaller size in terms of population, states that these two cities have less modern and more road-based public transport networks.

"For Kolkata and Bangalore, congestion levels are relatively higher than in other cities, despite their smaller populations. This is driven by the limitation of their older public transport networks which are primarily road-based, along with a significant growth in private vehicles. Looking forward, a combination of infrastructure improvement, addition of more modern mass transit as well as efficient alternatives to vehicle ownership are likely to help curb congestion," the report states.

In Bengaluru's case, rail-based projects like Namma Metro or sub-urban rail, while effective, the capacity will not be sufficient to bring down congestion levels by the time they are fully operational. "We estimated that the added rail transport capacity still falls below the required level to maintain its congestion levels by 2022. According to our estimates, additional rail public transport adoption of close to 21% of total kilometres in the city is essential, in conjunction with public transport, to maintain today's congestion levels." A survey conducted by the group showed that Bengaluru and New Delhi respondents were less enthusiastic about buying a car in the next five years.

CARPOOLING, RIDESHARING CAN SOLVE TRAFFIC WOES

Bengaluru: Ridesharing and carpooling are some of the major solutions to the city's traffic woes. An estimated Rs 8,000 crore (1.30 Billion USD) in social costs could be saved annually with the widespread adoption of shared rides and carpooling solutions. This is from an estimated 17% drop in road congestion during peak hours if rideshare solutions are widely adopted, the report finds.

Discussing the benefits for the city by adoption of ridesharing, the report says that the availability of an affordable and dependable rideshare solution would mean that people would consider foregoing the option of purchasing a car entirely. Rideshares

could also help serve outlying areas which are not feasible for mega public transport projects.

Around 27% of those surveyed in the city also indicated that they would be willing to sign up to drive with a taxi aggregator to supplement their income. An estimated 40% of the city's cars and 8% of the total vehicles in the city could be taken off the roads if ridesharing options replace private vehicles as the preferred choice of transport, the report finds. The BCG report states that a large section of potential users found availability of cabs as a major deterrent to adopting rideshare options.

PERCENTAGE OF ADDITIONAL TIME TAKEN TO TRAVEL IN PEAK HRS

City	
DELHI	129
MUMBAI	135
BANGALORE	162
KOLKATA	171
SINGAPORE	57
HANOI	134
HONG KONG	63
BANGKOK	105

Lost due to congestion in major cities: (approximate)

Delhi: ₹63,000 crore (9.60 Billion USD)

Mumbai: ₹31,000 crore (4.80 Billion USD)

Bengaluru: ₹38,000 crore (5.92 Billion USD)

Kolkata: ₹12,000 crore (1.97 Billion USD)

OTHER FINDINGS

- Bengaluru's traffic places it below cities like Singapore, Hong Kong, Bangkok and Manila with reference to travel time during peak hours

- While around 90% of respondents in Mumbai and Kolkata said they wanted to purchase a four-wheeler, the response was lesser at 86% in Delhi and Bengaluru

- An estimated 40% of the city's cars and 8% of the total vehicles in the city could be taken off the roads if ridesharing options replace private vehicles as the preferred choice of transport

- Around 27% of those surveyed in the city indicated that they would be willing to sign up to drive with a taxi aggregator for extra income

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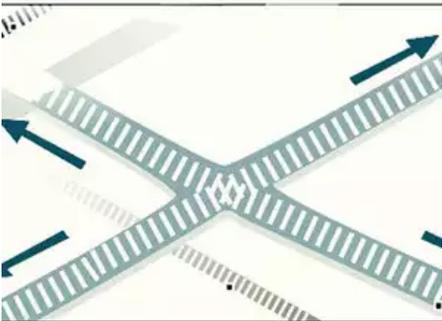Stock Analysis, IPO, Mutual Funds, Bonds & More
Market Watch

India incurs $21.3 billion loss due to delay on roads: Study

"According to estimates, the cost of delay was $6.6 bn per year and the cost of additional fuel consumption due to delay was $14.7 bn per year," the report said.

PTI | Updated: Jun 07, 2016, 06.39 PM IST

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"According to estimates, the cost of delay was $6.6 bn per year and the cost of additional fuel consumption due to delay was $14.7 bn per year," the report said.

NEW DELHI: India suffers a huge loss of $21.3 billion annually on account of delays and additional fuel consumption due to poor road conditions and frequent halts, says a study.

"According to the estimates, the cost of delay was $6.6 billion per year and the cost of additional fuel consumption due to delay was $14.7 billion per year," the study conducted jointly by logistics firm Transport Corporation of India [NSE -0.47 %] (TCI) and IIM-Kolkata said.

"In India, the scope of multi-modal transportation remained limited, given that most of the freight was carried by roads and the rest by railways," the study said.

The report, which was released by Road, Transport and Highways Minister Nitin Gadkari today, is based on joint survey of road freight transportation along 28 key routes in the country.

"The share of waterways and airways in carrying domestic freight was almost insignificant. Road transportation was door-to-door, reliable and efficient, with vehicles available almost in real-time. Railways, on the other hand, suffered from inefficiency, poor service, loading delays and the unavailability of rakes," the study said.

It said freight rate increased more than freight cost in the last three years with an increase in the contribution margin over the 2011-12 level on Delhi-Bangalore and Delhi-Mumbai routes.

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Among the remaining 26 routes, one common observation was that in routes covering the eastern and north-eastern parts of the country, average vehicle speeds were lower and average stoppage delays were higher than the corresponding national averages due to poor road conditions, more stops, long queues, delays at border check posts and on-road police intervention.

"If the average statistics for the 28 major routes surveyed approximately represent the national average, it may be inferred that while average stoppage delays per km have remained almost the same as in 2011-12, average stoppage expenses per tonne-km worsened during the same period. The average contribution margin improved in 2014-15," the study said.

The government should simplify and standardise the rules and regulations across different transportation modes to facilitate multi-modal transportation, it recommended.

Also it stressed that the government should remove all infrastructural bottlenecks to boost the movement of domestic freight by inland waterways.

"Despite India possessing a vast coastline and a significant inland waterways length, the share of waterways in carrying India's domestic freight is insignificant. Like railways, waterways are also an environment-friendly mode of transportation; sincere effort should be made to increase the share of inland waterways in domestic freight movement," the report recommended.

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Traffic jams in just four Indian cities cost $22 billion a year

REUTERS/VIVEK PRAKASH

Chaos.

By **Suneera Tandon**
Writer

April 19, 2018 · This article is more than 2 years old.

India's biggest cities may be losing up to $22 billion annually to traffic congestion, and its commuters are bearing the burden.

On average, travellers in Delhi, Mumbai, Bengaluru, and Kolkata spend 1.5 hours more on their daily commutes than their counterparts in other Asian cities during peak traffic times, according to an April 18 report released by The Boston Consulting Group (BCG) and commissioned by Uber.

In fact, peak-hour congestion, which implies the additional time taken during peak traffic to travel a given distance, in these four Indian cities is estimated at 149%, much higher than the Asian average of 67%.

The cost of congestion was calculated on the basis of fuel burned and productivity loss, which includes the man-hours and opportunity cost, pollution, and accidents (health costs) incurred on an annual basis.

Commuting woes

Indian commuters have struggled for years now.

Transport demand in India has increased by almost eight times since the 1980s as rapid economic development and increasing wealth among households has led to higher vehicle ownership. This is higher than anywhere else in the Asia-Pacific region, according to BCG.

"(Traffic congestion is) partly attributable to India's large population and high population density, as well as an under-developed public transportation network, especially rail-based transport," the BCG report says.

While public transport in cities like Delhi and Mumbai has been improving in relative terms over the years, particularly with an expanding metro network, this just hasn't been enough. "The reliance on cars is expected to increase, adding more pressure to road networks," the report said.

THE BOSTON CONSULTING GROUP

Matters are worse in Bengaluru and Kolkata which have witnessed a more recent population explosion.

Add to all this, a worsening pollution crisis which has often forced local governments to take dramatic measures.

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India wastes Rs 1.44 lakh crore due to traffic congestion, says Uber study

The congestion levels in Kolkata and Bangalore stand alarmingly higher at 171 per cent and 162 per cent respectively, while Delhi emerged as the least congested city (129 per cent).

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Rs 1.44 lakh crore. That is the avoidable social cost of traffic congestion in just four major Indian cities, Delhi, Mumbai, Bangalore and Kolkata. Incidentally, that amount is 50 per cent more than what the government allocated for updating India's education infrastructure in Budget 2018.

The Uber-commissioned report by the Boston Consulting Group, "Unlocking Cities: The impact of ridesharing across India", reveals more bad news. On an average, road congestion in peak hours among the Indian cities studied averaged 149 per cent, which is significantly higher than comparable metropolitan cities in South East and East Asia. This means that Indian commuters take 1.5 times longer to travel a given distance in peak hours compared to travel time during non-peak hours.

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The average peak hour congestion for 16 comparable Asian cities, including Bangkok, Manila, Singapore, Hong Kong and Hanoi, stood at 88.5 per cent. The congestion levels in Kolkata and Bangalore stand alarmingly higher at 171 per cent and 162 per cent respectively, while Delhi emerged as the least congested city (129 per cent).

How did this dismal state of affairs come to pass? The obvious reasons are India's high population density and our under-developed public transportation network. Since 1980, the country's population has nearly doubled (~90% growth) while the GPD per capita multiplied by over 5 times. In the bargain, the report claims that travel demand in India has grown eight-fold in the same period.

Given that the country's public transport infrastructure has lagged behind, private car usage is obviously high in the country - in fact, it is the most common mode of private transportation in the cities surveyed. "Among the commuters surveyed, on average, 87 per cent plan to buy a new car in the next 5 years," said the report, which aimed to assess how rideshare could help these cities to relieve congestion.

The silver lining is that "over 79 per cent of the above respondents also indicated that they would consider aborting their purchase plans should the availability and timeliness of ridesharing equal or exceed private car ownership". According to the study, substituting ridesharing for private cars could eliminate 46-68 per cent of the total cars on the road in these cities, reducing traffic congestion by 17-31 per cent - in the optimal scenario - and hence upping their 'liveability' quotient. Apart from reduced pollution, "this could significantly help these cities improve their amenity by saving approximately 760 acres (Kolkata) to 22,000 acres (Delhi) of unnecessary parking space in each city," added the report. This land could then be re-allocated to enhance living conditions, say, providing additional housing and social infrastructure. The possibilities are endless.

"We continue to be at the forefront when it comes to unlocking the true potential of ridesharing for India. Through this study, we are hoping to draw the attention of administrators and urban planners on how shared cars and mobility can be part of the solution vs individual car ownership," said Amit Jain, President, Uber India and South Asia, while releasing the study yesterday. Uber's Global COO Barney Harford had ominously added that "If car ownership trends continue, Indian cities risk coming to a complete standstill in only a few years." According to him, "ridesharing can be part of the solution to traffic congestion because it uses technology to get more people into

fewer cars. We can unlock our cities and their full potential, but we have to do it together."

According to the study, rideshare currently represents an average of 10 per cent of transport used in India. "In the majority of cities surveyed, two-thirds of current non-users state that they would be willing to adopt pooling if price, availability or speed worked out to be better than that of their most preferred mode of transportation."

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Construction of Proposed Elevated Corridors within Bengaluru Metropolitan Region,Bengaluru

Estimation of Saving in Man Hourand Travel Time

The Elevated Corridors project in Bangalore will yield tangible savings to the society at large due to various socio-economic benefits. This project will result in an increase the speed of road-based vehicles. This, in turn, will result in significant social benefits due to saving in man hour and travel time of passengers.

The methodology followed to work out the travel time saving is described below:

To understand the travel pattern of vehicles moving on the roads of Bengaluru city, Origin Destination surveys were conducted. To understand how these trips are geographically allocated, the study area was divided in to traffic analysis zone. A total of 166 zones were created and out of this 136 zones were within Bengaluru Metropolitan area and rest were external zones. Mode-wise trip matrices were created to understand the travel pattern of resident of Bengaluru city.

These matrices were taken to the traffic modelling software "VISUM" to assign these trips on the road network.

The base year matrices were further projected to different horizon year to see the congestion on the road network and the how this can be mitigated with the construction of elevated corridor.

To calculate the travel time saving, these matrices are further analysed

- The base and horizon year matrices are analysed to see the base year and horizon year travel pattern in different zones of the city
- Travel time matrices of base year and horizon year are analysed to understand the saving in travel time after the construction of elevated corridor
- Total time saving for each passenger mode has been recorded and presented in the table below;

Modes	Years	Total Vehicle on all the roads of Bengaluru (Daily)	Total Travel Time spent by vehicle on the road (min)	Saving in Travel Time (after opening of Elevated corridors) (2035-2016) (A)	Avg. Occupancy/ vehicle (B)	Total Man hour Saving (Daily) D= (A*B)	Total Man hour Saving (yearly) T = D*365
Car	2016	549334.51	2330929.47	-1053468.56	2	-2106937.12	-769032049
	2035	1757870.46	1277460.91				
2W	2016	419227.59	2330928.33	-1060286.28	1	-1060286.28	-387004493
	2035	1844601.4	1270642.04				
Bus	2016	100086.88	2330926.17	-1069704.36	30	-32091130.80	-11713262742
	2035	20017.37	1261221.8				

From the table above it is evident that

- There is a saving of 2 million man-hour daily in case of car and around 769 million man hour saving yearly
- In case of 2W there is around 1 million man hour saving daily and around 387 million man-hour saving annually

1

- In case of buses around 32 million man hour saving daily and around 11713 million man-hour saving annually

As per the latest Value of Time for Passenger mentioned in the IRC:SP:30 – 2019, Values for different categories of modes in mentioned in the Table Below:

S. No.	Transport Mode used by Passenger	Value of Time (□/hr)		
		Multilane Carriageways/ Expressways	Two Lane Roads	Single and Intermediate Lane Roads
1. (a)	Small Car	178.5	117.3	98.5
(b)	Big Car	258.0		
2	Two Wheeler	60.5	60.1	41.3
3. (a)	Ordinary Bus	73.2	74.1	27.2
(b)	Deluxe Bus	109.0	81.6	-

The Values calculated in the table above can be multiplied with the VOT to understand the monetary saving in Rs

Modes	Value (Rs/Hour)	Savings (Daily) (In Rs)	Savings (Yearly) (In Rs)
Car	178.5	2106937 * 178.5 =376088276	1060286.283 * 178.5 = 137272220886
2W	60.5	1060286 * 60.5 = 64147320	387004493.4*60.5 = 23413771851
Buses	73.20(OrdinaryBus Public transport)	32091130*73.20 =2349070775	11713262742*73.20 =857406240000

      The Table Shows that around 376 million rupees daily saving in car modes and 1,37,272 million rupees saving annually. Similarly for 2W category 64 million rupees saving daily and around 23,413 million rupees saving annually. Similarly, for Buses 2349 million rupees saving daily and around 8,57,406 million rupees saving annually.

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ORIGINAL ARTICLE

Urban CO$_2$ emissions in Xi'an and Bangalore by commuters: implications for controlling urban transportation carbon dioxide emissions in developing countries

Yuanqing Wang[1] · Liu Yang[1] · Sunsheng Han[2] · Chao Li[1] · T. V. Ramachandra[3]

Abstract China and India together have more than one third of the world population and are two emerging economic giants of the developing world now experiencing rapid economic growth, urbanization, and motorization. The urban transportation sector is a major source of carbon dioxide (CO$_2$) emissions in China and India. The goal of this study is to analyze the characteristics and factors of CO$_2$ emissions produced by commuters in Chinese and Indian cities and thus to identify strategies for reducing transportation CO$_2$ emissions and mitigating global climate change. Xi'an in China and Bangalore in India were chosen as two case study cities for their representativeness of major cities in China and India. The trends of CO$_2$ emissions produced by major traffic modes (electric motors, buses, and cars) in major cities of China and India were predicted and analyzed. The spatial distributions of CO$_2$ emissions

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produced by commuters in both cities were assessed using spatial analysis module in ArcGIS (Geographic Information System) software. Tobit models were then developed to investigate the impact factors of the emissions. The study has several findings. Firstly, in both cities, the increase of vehicle occupancy could reduce commuting CO_2 emissions by 20 to 50 % or conversely, if vehicle occupancy reduces, an increase by 33.33 to 66.67 %. It is estimated that, with the current increasing speed of CO_2 emissions in Xi'an, the total CO_2 emissions from electric motors, buses, and cars in major cities of China and India will be increased from 135×10^6 t in 2012 to 961×10^6 t in 2030, accounting for 0.37 to 2.67 % of the total global CO_2 emissions of 2013, which is significant for global climate change. Secondly, households and individuals in the outer areas of both cities produce higher emissions than those in the inner areas. Thirdly, the lower emissions in Xi'an are due to the higher density and more compact urban pattern, shorter commuting distances, higher transit shares, and more clean energy vehicles. The more dispersed and extensive urban sprawl and the prevalence of two-wheeler motorbikes (two-wheeler motorbike is abbreviated as "two-wheeler" in the following sections) fueled by gasoline cause higher emissions in Bangalore. Fourthly, car availability, higher household income, living outside the 2nd or Outer Ring Road, distance from the bus stop, and working in the foreign companies in Bangalore are significant and positive factors of commuting CO_2 emissions. Fifthly, "70-20" and "50-20" (this means that generally, 20 % of commuters and households produce 70 % of total emissions in Xi'an and 20 % of commuters and households produce 50 % of total emissions in Bangalore) emission patterns exist in Xi'an and Bangalore, respectively. Several strategies have been proposed to reduce urban CO_2 emissions produced by commuters and further to mitigate global climate change. Firstly, in the early stage of fast urbanization, enough monetary and land investment should be ensured to develop rail transit or rapid bus routes from outer areas to inner areas in the cities to avoid high dependency on cars, thus to implement the transit-oriented development (TOD), which is the key for Chinese and Indian cities to mitigate the impact on global climate change caused by CO_2 emissions. Secondly, in Bangalore, it is necessary to improve public transit service and increase the bus stop coverage combined with car demand controls along the ring roads, in the outer areas, and in the industry areas where Indian foreign companies and the governments are located. Thirdly, Indian should put more efforts to provide alternative cleaner transport modes while China should put more efforts to reduce CO_2 emissions from high emitters.

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report stated that recent global warming, sea level rising, and glacier melt were mainly caused by greenhouse gas (GHG) emissions generated by human activities (IPCC 2007). Among the GHG emissions, carbon dioxide (CO_2) is the single most important anthropogenic greenhouse gas which contributes about 65 % of total GHG emissions (WMO 2014). The transportation sector is a major source of CO_2 emissions and currently contributes 20–25 % of global CO_2 emissions. Its global share is projected to rise to 30–50 % by 2050 (Brand et al. 2013). It is estimated that the most targeted measure to reduce GHG emissions in an urban development context should be aimed at reducing transportation CO_2 emissions (Norman et al. 2006).

China and India together have more than one third of the world population and are two emerging economic giants of the developing world. There exist a group of cities in China (ranking between 5th and 65th; Beijing, Shanghai, Shenzhen, and Guangzhou not included) and in India, which are not the largest cities but are among the fastest growing cities in the world (Jones Lang LaSalle (JLL) 2015). The total population of these cities in China exceeds 300 million, larger than the total population of United States (US). The total economic output of these Chinese cities is ca. $8.6 trillion, accounting for 9 % of the global output, and is expected to reach $15 trillion (15 % of the global output) in 2025. Now, China and India are experiencing rapid urbanization and motorization (Pucher et al. 2007; Han 2010). CO_2 emissions from transportation sector account for a large percentage, about 8 % of total CO_2 emissions in China (Wang et al. 2011) and 32, 17, 13, 19, 43, 56, and 25 % of total CO_2 emissions in Delhi, Greater Mumbai, Kolkata, Chennai, Greater Bangalore, Hyderabad, and Ahmadabad of India, respectively (Ramachandra et al. 2015). Commuting traffic is a major part of urban traffic and has been viewed as the most important traffic in the urban transportation (Meyer and Miller 2001). Commuting trips account for 51.6 and 67 % of the urban passenger transportation in Xi'an and Bangalore, respectively (Mamatha and Madhu 2007; Xi'an City Traffic Management Committee and Chang'an University (XCTMCCU) 2012). The increase of CO_2 emissions produced from commuting trips will be huge in these Chinese and India cities during the fast urbanization and motorization and thus may cause severe impacts on the global climate change.

Xi'an and Bangalore were chosen as the two case study cities for their representativeness of major Chinese and Indian cities. Also, China and India are both rich in history and culture. Xi'an and Bangalore are typical cities with many heritages, rich cultures, and protected historical center districts. The two cities need to accommodate old traditions and modern development during the rapid urbanization and motorization (Ramachandra and Shwetmala 2009; Ramachandra et al. 2012; Wang et al. 2013, 2015).

Previous studies have found that socio-economic characteristics of individuals and households are related to transportation CO_2 emissions, including age, education level, car availability, occupation, and income (Carlsson-Kanyama and Lindén 1999; Brand and Boardman 2008; Weber and Matthews 2008; Susilo and Stead 2009; Brand and Preston 2010; Ko et al. 2011; Brand et al. 2013; Büchs and Schnepf 2013). Households in rural, suburb, and urban districts have different levels of transportation CO_2 emissions (Moriarty 2002; Troy et al. 2003; Nicolas and David 2009; Ko et al. 2011; Xiao et al. 2011; Liu et al. 2012; Büchs and Schnepf 2013). Furthermore, straight line distances from the household location to the city center have been found to be correlated with vehicle kilometer traveled (VKT) and the transportation CO_2 emissions (Miller and Ibrahim 1998). Previous research is short of comparative analysis between similar cities experiencing rapid economic growth, urbanization, and motorization in China and India, which are crucial for the global climate change. Also, the impacts of the urban spatial characteristics on the transportation CO_2 emissions in the previous studies focused on the scattered household locations, not on the entire city.

Therefore, the goal of this study is to analyze the characteristics and the changing trends of the commuting CO_2 emissions in Chinese and Indian cities during the process of the rapid economic growth, urbanization, and motorization. The study analyzes the characteristics, spatial distributions of commuting CO_2 emissions, and their relationships with individual/households' socio-economics, travel activities, and urban spatial characteristics in the entire urban area of Xi'an and Bangalore. Based on the analysis and the findings, several strategies are proposed for the reduction of transportation CO_2 emissions. This study will be useful for

the low-carbon transportation development in Chinese and Indian cities and will also be a good reference for other similar cities in the developing world. Therefore, it is important for the global climate change mitigations.

2 Related work

Based on the previous studies, this section sets out the methodologies for transportation CO_2 emission calculation, the relationship expected between socio-economic status, household spatial distribution, urban form, and transportation CO_2 emissions. These highlight the factors and characteristics which affect the CO_2 from commuters and inform the study approach for the two case study cities.

2.1 Transportation CO_2 emission calculations

Transportation CO_2 emissions are produced at various stages of the transportation development process, such as vehicle manufacturing, infrastructure construction and operations, traffic operations, and infrastructure maintenance. For road transportation, the fuel consumption during the traffic operation stage accounts for 95–98 % of the total fuel consumed in the infrastructure construction, operations, maintenance, and traffic operation stages (Araújo et al. 2014). For metro operating at design occupancy level, the CO_2 emissions of the metro operation account for 98 % of the total CO_2 emissions during the metro infrastructure and facility construction and metro operation (Zhang et al. 2014b). For buses operating at design occupancy level, the CO_2 emissions of the buses during the traffic account for 99 % of the total CO_2 emissions in the stage of the bus facility construction and operations and bus vehicle operations (Zhang et al. 2014b). Currently, very few studies have been conducted with regards to the CO_2 emissions at the vehicle or metro train manufacturing stage. CO_2 emissions during the traffic and metro operating stage account for most of the emissions in the transportation. Hence, this study mainly considers the emissions during the traffic and metro operation stages.

The common method for calculating transportation emissions was recommended in 1996 (IPCC 1997); the transportation CO_2 emissions are equal to the amount of the energy consumed or the distance travelled for a given mobile source activity multiplied by the emission factor for a given fuel type, vehicle type, and the emission control. Since vehicle fuel consumption depends on transport level, operating characteristics (vehicle occupancy, travel speed, and engine size), emission control, maintenance procedures, and vehicle age (Redsell et al. 1988; Gover et al. 1994; Potter 1997; Anable et al. 1997), researchers have conducted tests to investigate the range of fuel consumption and emissions for real-world operations (Liu and Hou 2009; Huo et al. 2011; Zhang et al. 2014a).

2.2 Socio-economic characteristics and transportation CO_2 emissions

A number of studies have been conducted to examine the relationship between socio-economic characteristics and transportation CO_2 emissions in different cities and countries. It was found that people with higher income produced more transportation CO_2 emissions (Carlsson-Kanyama and Lindén 1999; Brand and Boardman 2008; Weber and Matthews 2008; Susilo and Stead 2009; Brand and Preston 2010; Ko et al. 2011; Brand et al. 2013; Büchs and Schnepf 2013), people with full-time jobs produced more transportation CO_2 emissions than

those with part-time jobs (Carlsson-Kanyama and Lindén 1999; Susilo and Stead 2009; Ko et al. 2011; Brand et al. 2013) and the unemployed (Brand and Boardman 2008), households with at least one car produced more transportation CO_2 emissions than those without any cars (Ko et al. 2011; Brand et al. 2013), households with two or more cars produced more than twice transportation CO_2 emissions of the households with only one car (Brand and Boardman 2008; Brand and Preston 2010), people with age of 36–65 produced more transportation CO_2 emissions than those in other ages (Brand and Boardman 2008; Brand and Preston 2010; Brand et al. 2013), and people with higher education levels produced more transportation CO_2 emissions than those with lower education levels (Büchs and Schnepf 2013).

2.3 Household locations and transportation CO_2 emissions

The relationship between transportation CO_2 emissions and household location has also been studied in the recent years. It was found that people located in the peri-urban areas produced the largest transportation CO_2 emissions with 1000 kg/year/individual for daily travel and 700–800 kg/year/individual for long-distance travel (Nicolas and David 2009). In Seoul metropolitan area, people located at the edge of the metropolis produce more transportation CO_2 emissions than those located in other parts of Seoul (Ko et al. 2011). It was also found that the transportation CO_2 emissions produced by the neighborhoods located in the central district were less than those in the suburbs (Xiao et al. 2011; Liu et al. 2012), and whether the district was classed as a suburb or not was a strong indicator of the transportation CO_2 emissions (Xiao et al. 2011). Büchs and Schnepf (2013) found that rural places were strongly associated with higher transportation CO_2 emissions than urban households in UK. The straight line distance from the zone to the central business district (CBD) has been found to be the most important factor in VKT per worker in the Greater Toronto Area. It can be interpreted as a measure of the effect of *sprawl* or *decentralization*. The VKT per worker increases by 0.25 km on average as a worker lives 1 km farther away from the CBD (Miller and Ibrahim 1998).

2.4 Urban form and transportation CO_2 emissions

Low-density suburban development is more energy and GHG intensive than high-density urban development on a per capita basis (Norman et al. 2006). Increasing residential density can lead to a significant reduction in transportation emissions (Hong and Shen 2013). VKT declines as the compactness of subdivisions increases, and vehicles tend to be driven at lower average speed in more compact subdivision. The lower speed is not significant enough to offset the reduced VKT; therefore, total gasoline consumption and the associated CO_2 emissions still tend to be lower in more compact developments (Emrath and Liu 2008). There exists a significant inverse relationship between the land use density, street connectivity (block density), and vehicle emissions while controlling for the effects of household size, vehicle ownership, and income (Frank et al. 2000). The type of the neighborhood is correlated with transportation CO_2 emissions (Guo et al. 2014). For four types of neighborhoods (traditional, grid, enclave, and superblock) in Jinan of China, the superblock neighborhoods produce the highest emissions, which are related to the higher household annual income, whereas traditional neighborhoods produce the lowest emissions. It is also found that mixed land use and convenient accessibility to public transportation can reduce transportation CO_2 emissions. In the study of Hong and Shen (2013), a Bayesian multilevel model with spatial

random effects and instrumental variables was employed to control for spatial autocorrelation and self-selection. The results indicate that the effect of residential density on transportation emissions is influenced by spatial correlation and self-selection. Also, they found that increasing residential density led to a significant reduction in transportation emissions.

3 Methodology

This section will present the study methodology. First, the household sampling and characteristics of the samples in the two cities will be discussed. Then, the calculation method of the transportation CO_2 emission and its sensitivity analysis will be presented. Next, the Tobit models will be developed to investigate factors of the commuting CO_2 emissions. Also, we will present the method of using the spatial join module in ArcGIS to show the spatial distribution of the home-based commuting CO_2 emission by zone in the entire urban area of Xi'an and Bangalore.

3.1 Data collection

Household surveys were carried out in the urban area of Xi'an and Bangalore to collect data of commuting CO_2 emissions. The statistical method from Meyer and Miller (2001) was used to determine the sample size as shown in Eq. (1). At least 1476 and 756 commuting trip observations in Xi'an and Bangalore are needed, respectively, to achieve the precision within ±5 % ($r = 0.05$) of the real value at 95 % of the time ($\alpha = 0.05$).

$$n = \frac{\left[Z_{1-(1/2)\alpha}\right]^2 (1-p)}{r^2 p} \tag{1}$$

where r is the margin of error or precision and is assumed to be 0.05 (assuming an estimate of the sample size within ±5 % of the real value at 95 % of the time), p is the observed value of the proportion of the commuting trips in the urban passenger transportation, and $Z_{1-(1/2)\alpha}$ is the standard normal statistic corresponding to the (1-α) confidence level.

In Xi'an, simple random sampling was implemented in each zone in 2012. On average, 9 to 10 households were surveyed in each zone and a total of 1501 households were surveyed. In Bangalore, the survey was carried out on the basis of a stratified (economic status) random selection procedure during 2011–2012. The validation of the sampled data was conducted during 2012–2013. The survey covered 1967 households representing heterogeneous population belonging to different income, education, and social aspects. The distributions of the sampled households and the areas, population, and densities between the ring roads in Xi'an and Bangalore are shown in Table 1.

Commuting mode, trip distance, commuting frequency, household location, and workplace were included in the questionnaire. Furthermore, socio-economic characteristics of the households and individuals, including household annual income, household tenure, car availability, age, work unit type, and education level of the household members, were also surveyed. Table 2 presents the levels of each characteristic in the survey. It is found that some common characteristics exist in both Xi'an and Bangalore: (1) most commuters have good education level (65.9 and 62.2 % commuters in Xi'an and Bangalore have college degrees or above, respectively); (2) there is a high percent of commuters working in private enterprises (41.7 %

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Table 1 Area, population, density, and sample distributions by ring roads in Xi'an and Bangalore

Xi'an	1st Ring Road	1st–2nd Ring Road	2nd–3rd Ring Road	Outside 3rd Ring Road
Area (km^2)	10.78	64.51	271.57	
Population (million people)	0.396	1.324	1.791	
Population density (thousand people/km^2)	36	20	6.5	
Sample size (household/%)	93/6.2 %	469/31.2 %	848/56.5 %	91/6.1 %
Bangalore	CBD	CBD-Outer Ring Road	Outer Ring Road-Peripheral Ring Road	Outside Peripheral Ring Road
Area (km^2)	15.65	203.35	493.97	
Population (million people)	0.193	4.036	1.610	
Population density (thousand people/km^2)	12.3	19.8	3.2	
Sample size (household/%)	12/0.6 %	962/48.9 %	993/50.5 %	

in Xi'an and 25.4 % in Bangalore); and (3) a high percentage of commuters have their own houses/apartments (81.2 % in Xi'an and 58.2 % in Bangalore). However, (1) Xi'an has higher household annual incomes (72.1 % more than $10,000), a higher rate of car availability (54.4 %), and a higher percentage of commuting by car (28.56 %) than Bangalore has. (2) Bangalore has more household members (averagely 4.53 per person in one household) and a higher two-wheeler ownership rate (55.4 %).

3.2 Calculation of commuting CO_2 emissions and sensitivity analysis

The commuting CO_2 emissions were calculated as the emission factor (by mode, fuel type, and occupancy) multiplied by trip distance (IPCC 1997), as shown in Eq. (2).

$$C = \text{EF} \times L \tag{2}$$

where C is the CO_2 emission (kg/passenger/km), EF is the emission factor (by mode, fuel type, and occupancy), and L is the trip distance (km).

Well-to-wheel (WTW) CO_2 emission intensity by fuel types suggested by Huo et al. (2012) was applied in this study. The fuel consumed (e.g., liter of gasoline consumed per 100 km) by vehicles is associated with uncertainty because it is affected by several factors such as driving speed. For instance, during commuting hours, driving may become less fuel efficient due to congestions (Huo et al. 2011). The actual vehicle occupancy is not a fixed value either. Hence, we collected local data on the range of these values in Xi'an and Bangalore through surveys and the related literatures to calculate the ranges of the CO_2 emission factors by mode, fuel type, and occupancy, as shown in Eq. (3).

$$\text{EF}_{\text{max,min}} = \frac{\text{CI} \times \text{FC}_{\text{max,min}}}{\text{VO}_{\text{min,max}}} \tag{3}$$

where CI is the WTW CO_2 emission intensity by fuel type, FC is the fuel consumption, and VO is the vehicle occupancy.

Table 2 Socio-economic characteristics and sample distributions by ring roads in Xi'an and Bangalore

	Levels	Xi'an		Bangalore	
		Number	Percent	Number	Percent
Age	<35 years old	1378	47.9 %	547	13.9 %
	35–55 years old	1364	47.4 %	3119	79.3 %
	>55 years old	137	4.8 %	268	6.8 %
Work unit type	Government	113	4.2 %	593	19.9 %
	Public institution	511	19.0 %	234	7.8 %
	Foreign company	32	1.2 %	152	5.1 %
	Private enterprise/local company	1120	41.7 %	758	25.4 %
	State-owned company	453	16.9 %	83	2.8 %
	Others	454	16.9 %	1166	39.0 %
Education level	Middle school graduate	307	10.7 %	322	8.5 %
	Graduated from the high school or technical secondary school	671	23.4 %	1106	29.3 %
	Graduated from college	664	23.1 %	413	10.9 %
	Bachelor's degree	1029	35.9 %	1391	36.8 %
	Master's degree	167	5.8 %	426	11.3 %
	Ph.D. degree	31	1.1 %	119	3.2 %
Household members	Average number of household members	3.22		4.53	
Household traffic vehicles	Household car availability	817[a]	54.4%[a]	1415[b]	71.9%[b]
Household annual income	<US$2,000	9	0.6 %	197	10.0 %
	US$2,000–6,000	77	5.2 %	839	42.7 %
	US$6,000–10,000	326	22.1 %	381	19.4 %
	US$10,000–16,000	580	39.3 %	306	15.6 %
	US$16,000–20,000	311	21.1 %	64	3.3 %
	US$20,000–40,000	139	9.4 %	125	6.4 %
	>US$40,000	34	2.3 %	55	2.8 %
Housing tenure	House owner occupied	1158	81.2 %	1136	58.2 %
	House is rented	268	18.8 %	817	41.8 %
Household location	Inside the 1st Ring Road/CBD	93	6.20 %	12	0.6 %
	1st–2nd Ring Road/CBD-Outer Ring Road	469	31.25 %	962	48.9 %
	2nd–3rd Ring Road/Outer-Peripheral Ring Road	848	56.50 %	993	50.5 %
	Outside the 3rd Ring Road/Peripheral Ring Road	91	6.1 %		

[a] In Xi'an, household car availability refers to people owning car or willing to buy car

[b] The car availability of the household in Bangalore's questionnaires includes both cars and two-wheelers; two-wheelers account for 77.1 % of these two types of vehicles (BT 2015)

The calculation results of CO_2 emission factors are presented in Table 3. The average value of each CO_2 emission factor was used in the calculation of commuting CO_2 emissions for Xi'an and Bangalore.

Considering the rapid growth of motorization in Chinese and Indian cities, it is necessary to investigate the impact of the reduction in vehicle occupancy and the increase in traffic congestions on commuting CO_2 emissions. Thus, the sensitivity of CO_2 emission factor

Table 3 Well-to-wheel CO_2 emission factors by fuel type, travel mode, and occupancy in Xi'an and Bangalore

Travel mode	Fuel type	WTW CO_2 intensity (t CO_2 eq./unit of fuel)[a]	Fuel consumptions per 100 km[b]	Occupancy (passengers/vehicle)[h]	WTW CO_2 emission factor (kg/passenger/km)	Average WTW CO_2 emission factor (kg/passenger/km)
Xi'an						
Car	Gasoline	3.87/t	7.80–10.45 (L)	1~3	0.073–0.295	0.184
Normal coach	Diesel	3.94/t	39.12–42.38 (L)	20~50	0.027–0.072	0.050
Taxi	Compressed natural gas (CNG)	2.76/1000 m³	8~10 (m³)	2~5	0.044–0.138	0.091
Bus	CNG	2.76/1000 m³	52~58 (m³)	60~100	0.014–0.027	0.021
Metro	Electricity	0.83/1000 kWh	3340~3350 (kWh)[c]	1100~1600/train	0.017–0.025	0.021
Electric bicycle[d]	Electricity	0.83/1000 kWh	1.1~1.25 (kWh)[e]	1~2	0.005–0.010	0.008
Electric motor[f]	Electricity	0.83/1000 kWh	1.6~1.7 (kWh)[g]	1~2	0.007–0.014	0.011
Bangalore						
Car or two-wheeler[i]	Gasoline	3.87/t	1.23–10.45 (L)	1~3	0.032–0.184	0.067
Taxi	Gasoline	3.87/t	7.80–10.45 (L)	2~5	0.044–0.148	0.096
Bus	Diesel	3.94/t	36–39 (L)	30~50	0.024–0.044	0.034

m^3 cubic meter, *kWh* kilowatt hour, *L* liter

[a] Data was from Huo et al. (2012)

[b] Data was from Liu and Hou (2009), Huo et al. (2011), Zhang et al. (2014a), and Ramachandra et al. (2015); the fuel consumptions considered the factor of vehicle speed in the peak hours

[c] Data was collected from the survey of Xi'an Metro Co., Ltd

[d] The highest speed of the electric bicycle is 20 km/h

[e] Data was from National Standard of the People's Republic of China, GB17761-1999, Electric bicycles—general technical requirements, issued by China State Bureau of Quality and Technical Supervision

[f] The highest speed of the electric motor is more than 20 km/h

[g] Data was collected from the questionnaire surveys of the electric motor users in Xi'an

[h] Data came from Xi'an Transport Development Annual Report in 2012 and field surveys in Bangalore in 2012

[i] In the Bangalore's questionnaires of the travel mode, car and two-wheeler were combined in one choice option; thus, the CO_2 emission factor of car or two-wheeler is weighted by proportions of car and two-wheeler, which are 22.9 % for cars and 77.1 % for two-wheelers (BT 2015). The average value of CO_2 emission factor for car and two-wheeler is 0.067 kg/passenger/km

to vehicle occupancy and fuel consumption was analyzed. That is, the change of CO_2 emission factor due to the changes of vehicle occupancy and fuel consumption was calculated using Eq. (4).

$$\Delta_{EF} = \frac{CI \times FC_{average} \times (1 + \Delta_{FC})}{VO_{average} \times (1 + \Delta_{VO})} \tag{4}$$

where Δ_{EF} is the change of CO_2 emission factor due to the changes of vehicle occupancy and fuel consumption, Δ_{FC} is the change of fuel consumption, and Δ_{VO} is the change of vehicle occupancy.

In the future, in both China and India, if the total number of vehicles increases, the vehicle occupancy decreases, and the traffic congestions increase, the CO_2 emissions will increase significantly. Therefore, to estimate this tendency, the CO_2 emissions in the future from major transportation modes (electric motors, buses, and cars) in Chinese and Indian cities were also calculated based on the past increasing trend on CO_2 emissions.

3.3 Spatial distribution of CO_2 emissions by commuters

The spatial join module in the ArcGIS software was used to explore the characteristics of spatial distributions of the household and individual commuting CO_2 emissions by zone in the urban area of Xi'an and Bangalore and to find where the high commuting CO_2 emissions are from.

3.4 Tobit modeling

To explore the impact factors of the emissions and the characteristics of the high and low emitters in the urban areas of the two cities, the relationships were modeled between the household/individual commuting CO_2 emissions and the urban spatial and household/individual socio-economic characteristics. The distributions of the household and individual commuting CO_2 emissions were analyzed. The significance levels for the normality test are all smaller than 0.05 as shown in Table 4, which means that it is hard to say these distributions follow normal distributions. Also, it is observed that the household and individual commuting CO_2 emissions are left censored at zero. Therefore, the Tobit model was established to analyze the relationships between the CO_2 emissions by commuters and their factors.

Table 4 Normality test for CO_2 emissions by commuters in Xi'an and Bangalore

	Kolmogorov-Smirnov		Shapiro-Wilk	
	Statistic	Significance	Statistic	Significance
Individual emissions (Bangalore)	0.181	0.000	0.827	0.000
Household emissions (Bangalore)	0.165	0.000	0.843	0.000
Individual emissions (Xi'an)	0.272	0.000	0.665	0.000
Household emissions (Xi'an)	0.245	0.000	0.709	0.000

The Tobit model presented in Eq. (5) was used.

$$y_i = \begin{cases} x_i'\beta + \varepsilon_i & \text{if} \quad y_i^* = x_i'\beta + \varepsilon_i > 0, \\ 0 & \text{if} \quad y_i^* = x_i'\beta + \varepsilon_i \leq 0. \quad i = 1, 2, \cdots, N \end{cases} \tag{5}$$

where y_i is the dependent variable, y_i^* is the latent variable, x_i' is a vector of independent variables, β is a vector of estimable parameters, N is the number of observations, and ε_i is a random term. In the Tobit model for household CO_2 emission by commuters, the dependent variable is the household commuting CO_2 emissions; the potential independent variables are household car availability, household annual income, housing tenure, household location separated by the ring roads, straight-line distance from the household to the city center, and distance to the nearest bus stop/metro station. Similarly, in the Tobit model for individual CO_2 emissions by commuters, the dependent variable is the individual commuting CO_2 emissions; the potential independent variables are household car availability, age, work unit type, education level, household locations separated by the ring roads, straight-line distance from the household to the city center, and distance to the nearest bus stop/metro station.

In the process of Tobit modeling, all the potential independent variables were considered. Then, based on the interim modeling results, less significant independent variables were removed. The best Tobit models of household and individual commuting CO_2 emissions were established with all significant variables.

4 Trends of commuting CO_2 emissions in Chinese and Indian cities and their global impacts

4.1 Overview of Xi'an and Bangalore

The basic information of Xi'an and Bangalore is shown in Table 5.

4.1.1 Rapid growth in the economic, urbanization, and motorization

In Xi'an, the GDP increased from US\$ 10.55 billion in 2000 to US\$ 71.29 billion in 2012. Now, Xi'an ranks the 13th among Chinese cities (JLL 2015). In Bangalore, from 2000 to 2013, the GDP continued increasing except in 2009 (Glastris 2013). In 2011, the GDP of Bangalore was US\$ 83 billion, and now, Bangalore ranks the sixth among Indian cities (Indiancn 2013). Xi'an's leading industries are cultural activities, high technology, and equipment manufacturing. Bangalore's economy is prospering on the information technology (IT) industry, which contributes ca. 74 % to the city's revenues in the year 2000 to 2001 (Parthasarathy 2004). Bangalore has been economically and socially fragmented due to the gap in income between the workers of IT sectors and local industries (Sabapathy et al. 2012).

In 2010, the built-up area in Xi'an reached 522.28 km^2, 37 times of the area in 1949 (Xu 2012). The city area of Bangalore is now 741 km^2, grown about 10 times since 1949 (Ramachandra et al. 2012). In Xi'an urban central area, the population was 3.09 million in 2003 and increased to 4.48 million in 2014. Similarly, the population of Bangalore increased from 4.13 million in 1991, 5.68 million in 2001, to about 9.58 million in 2014 (Ramachandra et al. 2012).

Table 5 Basic information of Xi'an and Bangalore

	Urban area (km^2)	Population (million)	GDP (US$ billion)	Per capita income (US$)
Xi'an[a]	522	4.48	71	10,905
Bangalore[b]	741	9.58	83	10,247
	City ranking[c]	Commuters by bus (million person times/day)	Metro passengers (million person times/day)	Number of buses
Xi'an	13th	2.47	0.16	7695
Bangalore	6th	3.50		4203
	Average vehicle speed in CBD (km/h)	Average volume/ capacity (V/C) in CBD	Cars/LMV[b] (million)	Two-wheelers (million)
Xi'an	5–15	0.9	1.044 (car)	0.440[d]
Bangalore	4–13	3.5[h]	1.102 (LMV)[b]	3.725
	Urban form			
Xi'an	Three ring roads and radial roads, leading industries mostly located outside the 2nd Ring Road, historical and cultural protection inside 1st Ring Road			
Bangalore	Two ring roads and radial roads, leading industries mostly located outside the Outer Ring Road, building and market maintain traditional in CBD			

Sources: (Mamatha and Madhu 2007; Sudhira et al. 2007; Ramachandra et al. 2012; XCTMCCU 2012; Indiancn 2013; Sudhakara and Balachandra 2013; XBS and NBSXIT 2013; BT 2015)

[a] In Xi'an, the data of urban central area is for the year of 2010 and the data of resident population in the urban central area is for the year of 2014; other data of Xi'an in the table is for the year of 2012

[b] In Bangalore, the data of the urban area is for the year of 2009; the data of the population is for the year of 2014; the data of the GDP and per capita income is for the year of 2011; the data of average V/C in CBD and number of light motor vehicle (LMV) and two-wheeler is for the year of 2014 and comes from the Department of Transportation in Bangalore (BT 2015); and the data of the commuters by bus and number of buses is for the year of 2007

[c] City ranking data of Xi'an comes from the study of JLL (2015), and city ranking data of Bangalore comes from the reports of the ten richest cities rankings in India (Indiancn 2013)

[d] In Xi'an, there is prohibition of two-wheelers inside the 2nd Ring Road

In Xi'an, the number of the motor vehicles increased from 0.46 million in 2005 to 1.47 million in 2012, with an average annual growth rate of 18 %. Among these vehicles, the number of cars increased from 0.18 million in 2005 to 1.04 million in 2012, with an average annual growth rate of 28.1 %, and the car ownership was 159 cars per 1000 people in 2012 (XCTMCCU 2012). In Bangalore, the average annual growth rate of the vehicles was 20.22 % per year from 1980 to 2005, and the car ownership rate is 47 per 1000 population (Sudhakara and Balachandra 2013). Additionally, there is a sharp increase of two-wheeler ownership (3.72 million, 69.1 % of all traffic vehicles in 2014).

Both cities are facing severely increasing motorized traffic, especially for the car trips (28.56 % of the mode share in Xi'an in 2012) and two-wheeler trips (42 % of the mode shares in Bangalore in 2007) during the commuting, and walking and cycling trips decreased. In Xi'an, the bus ridership (37.94 % of the mode share) was 4.8 million per day on 243 routes with a fleet of 7695 buses in 2012. The passenger volume of Xi'an Metro Line 2 that began operations in September 2011 has reached 0.16 million people per day (XCTMCCU 2012). In Bangalore, the buses (20 % of the mode share in 2007) served about 3.5 million commuters per day with a fleet of 4203 buses (Mamatha and Madhu 2007). The metro in Bangalore is still

under construction. Quick motorization, inconvenient bus services, and increasing commuting distances have led to a large amount of travels by cars or two-wheelers in both cities.

4.1.2 Similar industry distribution and quick urban sprawl

Xi'an and Bangalore have similar urban forms regarding ring roads, radial roads, and industry distributions. Within the 1st Ring Road in Xi'an, it is the city center with large malls, entertainment venues, government offices, and famous historic scenic spots. In the late 1990s, a government-led initiative created several economic zones that focused on new high-technology industry, ecological and cultural tourism industries between the 2nd Ring Road and the 3rd Ring Road. The economic zones in the south, southwest, and southeast outside the 2nd Ring Road developed more quickly than those in the northern part. Similarly, in Bangalore, there exist the government offices, commercial sites of retail and wholesale, cultural institutions, and transport hubs in the CBD area. Bangalore's IT industry and the concentration of small and medium enterprises clustered mostly along or outside the Outer Ring Road (Sudhira et al. 2007).

Also, both cities sprawl by ring roads and radial roads quickly. In Xi'an, the newly developed suburbs in 1990s have now become part of the city sprawl as the urban area gradually spread out. Similarly, in Bangalore, as the city gradually sprawled, industrial estates at the periphery of the city along or beyond the Outer Ring Road have become part of the sprawl.

Compared with Xi'an, Bangalore has a less dense and more extensive urban sprawl in the outer areas, outskirts, and peri-urban regions of the city. At the urban fringe of Bangalore, the sprawl is haphazard and unplanned (Pucher et al. 2005; Mamatha and Madhu 2007; Ramachandra et al. 2012). In Xi'an, there is denser and more compact urban sprawl. Bangalore's haphazard and unplanned urban sprawl pattern is due to the land privatization, highly market-oriented economic development, and government's lack of urban and transportation planning control and land use control, while Chinese governments have the ability to control the urban and transportation planning and land use.

4.1.3 Congested CBD

In the CBD of Xi'an, there are severe congestions during peak hours. The reasons include many large malls, entertainment venues, and government offices have attracted a huge amount of traffic; there exist some through traffic between the northern and the southern districts; and the famous historic scenic spots and old streets in the CBD attract tourists to this area. These all lead to more traffic volumes and congestions in the CBD area. The average volume/capacity (V/C) is as high as 0.9 in the CBD area; on other roads, it ranges from 0.4 to 0.8 (XCTMCCU 2012).

Bangalore's transportation is even worse in its CBD (Mamatha and Madhu 2007). The Outer Ring Road is 8 km away from the CBD. If people want to use this ring road for travelling, the detour is a burden in terms of time and cost. Therefore, people tend to use the CBD as a thoroughfare, which is one of the reasons for the congestions in the CBD area. Besides, the government offices, commercial sites, cultural institutions, and transport hubs are all located in the CBD area. These attracted lots of traffic in the CBD. In peak hours, the average travel speed in the CBD is 13 km/h. In the core area of the CBD, the average travel speed in the peak hours is as low as 4 to 7 km/h. And, the V/C is as high as 3.5 in CBD area; on other roads, it ranges from 2.34 to 2.96 (Mamatha and Madhu 2007). (Due to a large number of two-wheelers in India, India uses a special method to calculate traffic capacity, which is different from normal method.)

4.2 The ranges and trends of urban commuting CO_2 emissions in Chinese and Indian cities

The average commuting CO_2 emission per person per kilometer varies with fuel consumption and vehicle occupancy. The sensitivity analysis of CO_2 emission factor by mode and fuel type is shown in Fig. 1, and the maximum changes of CO_2 emission factors are shown in Table 6. It is found that the occupancy has a significant impact on the CO_2 emission factor (kg/passenger/km). The variation of the occupancy can cause -50 to $+66.67$ % variations on the CO_2 emission factors of car, normal coach, and taxi. If vehicles travel smoothly and do not have frequent idling, the CO_2 emission factors of cars and two-wheelers can be reduced by 14 %. If the road is congested with poor road conditions, the CO_2 emissions of cars and two-wheelers can be increased by 14 %. From the perspective of the global CO_2 emission reductions, increasing vehicle occupancy in China and India has the largest impact on controlling the increase of commuting CO_2 emission and the global climate change mitigations. In addition, traffic congestion reduction, pavement condition improvement, and reduction of frequent driving speed changes are also important for CO_2 emission reduction.

4.3 Trends of CO_2 emissions for major travel modes in Chinese and Indian cities

In 2008, the trips by electric motors, buses, and cars in Xi'an were 0.89, 5.34, and 2.42 million, respectively, and the average trip distance was 5.4 km. In 2012, the trips by electric motors, buses, and cars in Xi'an increased to 1.48 million (with an annual increase rate of 13.64 %), 5.89 million (with an annual increase rate of 2.47 %), and 3.39 million (with an annual increase rate of 8.82 %), respectively, and the average trip distance reached 5.81 km (with an annual increase rate of 1.85 %). In 2012, the CO_2 emission factors for electric motors, buses, and cars are 0.011, 0.021, and 0.184 kg/passenger/km. Using the same annual increase rates of the trips of electric motors, buses, and cars and the average trip distance from 2008 to 2012, it is estimated that, by 2030, the trips by electric motors, buses, and cars in Xi'an will reach 14.88, 9.13, and 15.55 million, respectively, and the average trip distance will increase to 8.08 km. Based on the calculation in Sect. 4.2, under the worst situation where the vehicle occupancy decreases and the traffic congestions increase, the CO_2 emission factors for electric motors, buses, and cars will be increased to 0.015, 0.031, and 0.295 kg/passenger/km. Then, by 2030, the total CO_2 emissions from the above three travel modes in Xi'an will reach 15×10^6 t, about 7.8 times of current CO_2 emissions; the annual average CO_2 emissions per person will reach 1.6 t, about 7.1 times of current level.

Based on the estimated CO_2 emissions in 2030 of Xi'an and the population of Xi'an and other major Chinese cities, by 2030, it is estimated that the total CO_2 emissions from electric motors, buses, and cars in major Chinese cites (Beijing, Shanghai, Shenzhen, and Guangzhou excluded) will reach 480×10^6 t. If India has the similar increasing tendency in CO_2 emissions as China has, the annual average CO_2 emissions per person in both China and India will reach 1.6 t in 2030, increased from 0.22 t in 2012; the total CO_2 emissions from the above three travel mode in China and India will be increased from 135×10^6 t in 2012 to 961×10^6 t in 2030 (accounting for 0.37 to 2.67 % of the total global CO_2 emissions of 2013), which will affect the global climate change significantly. Hence, to mitigate global change, it is important to explore the characteristics of the commuting trips and to find strategies to reduce commuting CO_2 emissions in China and India.
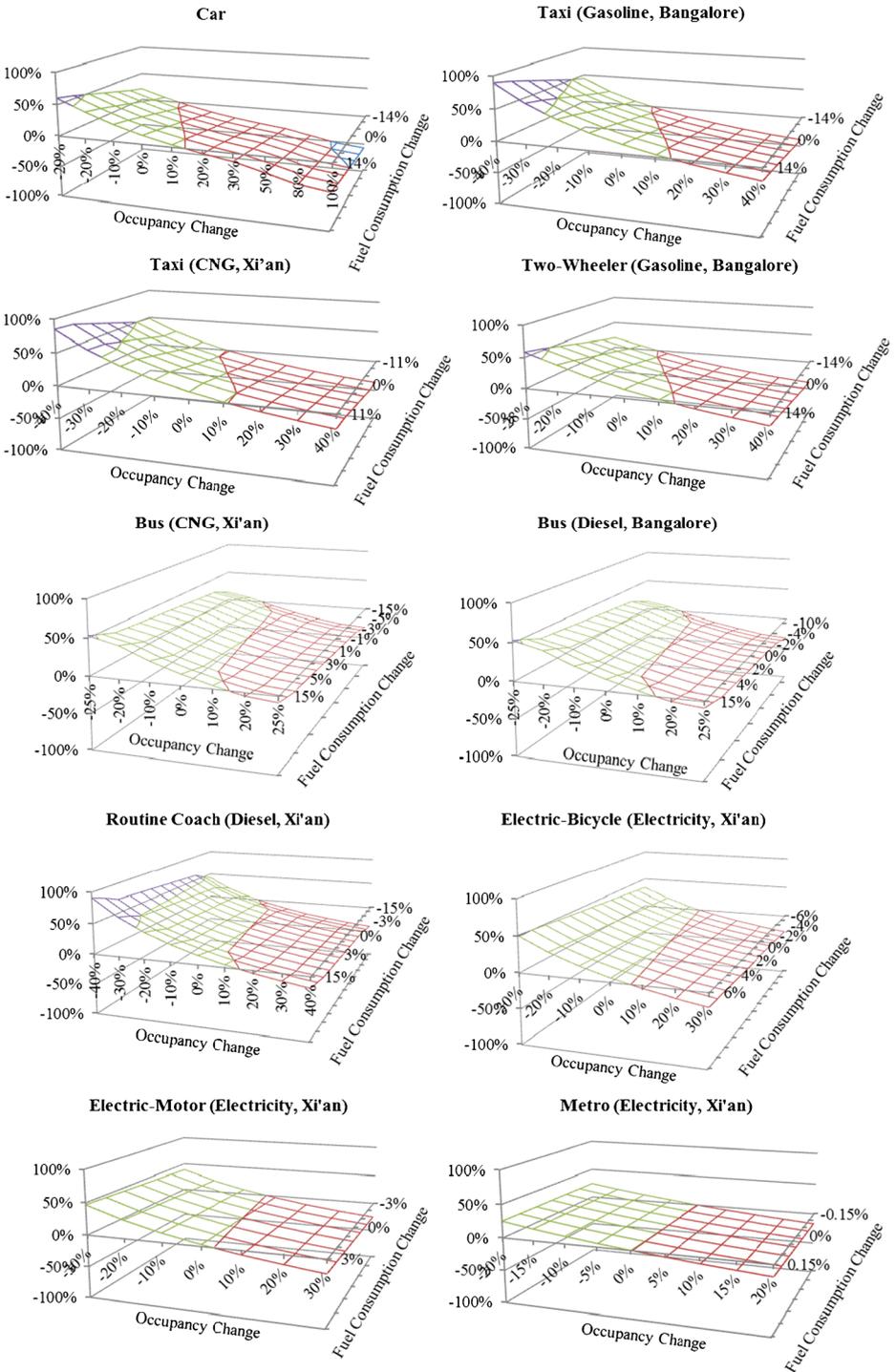
Fig. 1 Sensitivity analysis of the well-to-wheel CO_2 emission factor to fuel consumption and vehicle occupancy in Xi'an and Bangalore by mode

Table 6 Maximum changing extents of well-to-wheel CO_2 emission factors with the changes of fuel consumption and the occupancy in Xi'an and Bangalore

Travel mode	Fuel type	Only fuel consumption change percent		Only occupancy change percent		Both fuel consumption and occupancy change percent	
		Decrease	Increase	Decrease	Increase	Decrease	Increase
Car/two-wheeler[a]	Gasoline	−14.00/−14.00 %	14.00/14.00 %	−50.00/−28.57 %	40.85/38.39 %	−57.00/−38.57 %	60.56/58.33 %
Taxi	CNG/gasoline[a]	−11.00/−14.00 %	11.00/14.00 %	−28.57/−28.57 %	66.67/66.67 %	−36.43/−38.57 %	85.00/90.00 %
Bus	CNG/diesel[a]	−15.00/−15.00 %	15.00/15.00 %	−20.00/−20.00 %	33.33/33.33 %	−32.00/−32.00 %	53.33/53.33 %
Normal coach[b]	Diesel	−15.00 %	15.00 %	−28.57 %	66.67 %	−39.29 %	91.67 %
Metro[b]	Electricity	−0.15 %	0.15 %	−16.67 %	25.00 %	−16.79 %	25.19 %
Electric bicycle[b]	Electricity	−6.00 %	6.00 %	−23.08 %	42.86 %	−27.69 %	51.43 %
Electric motor[b]	Electricity	−3.00 %	3.00 %	−23.08 %	42.86 %	−25.38 %	47.14 %

[a] Two-wheelers and taxis use gasoline and buses use diesel according to the data of Bangalore

[b] Only Xi'an has this travel mode information

5 Commuting CO_2 emission distribution, model results, and countermeasure analysis

5.1 Key challenges revealed from distribution of commuting CO_2 emissions

The percentiles of the individuals and households commuting CO_2 emissions in Xi'an and Bangalore are shown in Fig. 2. It is seen that the emissions in Xi'an are lower than those in Bangalore except the highest 10 % households. The average and median values of the individual and household emissions in Table 7 also show that the emissions in Bangalore are higher than those in Xi'an. The average individual CO_2 emissions by modes in Table 7 and emission factor by modes in Table 3 indicate that longer commuting distance is a major factor for higher CO_2 emissions in Bangalore. The average commuting distance in Bangalore (7.09 km) is twice of that in Xi'an (3.8 km). The longer distance in Bangalore is due to its haphazard and dispersed urban growth, and the shorter distances in Xi'an can be attributed to its compact and high-density pattern. Thus, one key challenge for Indian cities is to develop the compact and high-density urban pattern so as to reduce their commuting distances and improve their public transit operation efficiency.

It is found that, in Xi'an, 20 % of the commuters produced 78 % the total emissions; in Bangalore, 20 % of the commuters produced 56 % the total emissions. Also, 20 % of the households produced 73 % the total emissions in Xi'an; 20 % of the households produced 53 % the total emissions in Bangalore. Therefore, generally, "70-20" and "50-20" emission patterns exist in Xi'an and Bangalore, respectively. This result is different from the "60-20" emission rule in UK (Brand and Preston 2010; Susilo and Stead 2009), the "50-10" emission rule in Dutch (Susilo and Stead 2009), and the "60-10" emission rule in Seoul (Ko et al. 2011), which indicates that the high emitters produce a disproportionate fraction of the total emissions. It also indicates that the high emitters produced higher proportion of CO_2 emissions in Chinese cities. Thus, another key challenge for Chinese and Indian cities, especially for Chinese cities, lies in that they should focus on reducing CO_2 emissions from the high emitters. Other global cities' experiences of reducing the transportation CO_2 emissions may also be applied to Indian cities.

Fig. 2 Percentiles of CO_2 emissions by commuters

Legend:
- – –□– – Individual commuting CO2 emission in Bangalore
- —■— Individual commuting CO2 emission in Xi'an
- – –○– – Household commuting CO2 emissions in Bangalore
- —●— household commuting CO2 emissions in Xi'an

Y-axis: Commuting CO2 emission (kg/trip, kg/household trips)

X-axis: Percentiles of the individuals and households sorted by the emision
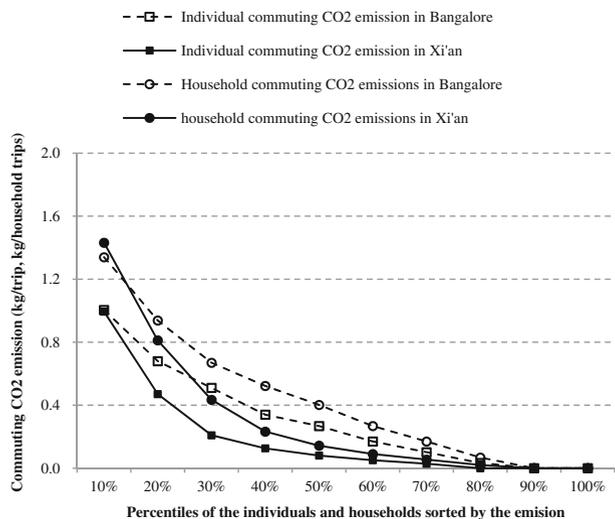
Table 7 Summary of commuting CO_2 emissions, population, and vehicles in Xi'an and Bangalore

| | Household and individual commuting CO_2 emissions | | | |
| | Household CO_2 emissions | | Individual CO_2 emissions | |
	(kg/household)		(kg/trip)	
City	Xi'an	Bangalore	Xi'an	Bangalore
Minimum	0.00	0.00	0.00	0.00
Maximum	3.96	3.6	2.33	2.4
Average	0.45	0.55	0.28	0.41
Median	0.14	0.39	0.08	0.27
	Average commuting CO_2 emissions by modes (kg/trip)			
City	Xi'an		Bangalore	
Bus	0.087		0.347	
Metro	0.134			
Normal coach	0.293			
Taxi	0.382		0.986	
Car	0.838		0.569[a]	
Motor/electric motor/electric bicycle	0.055			
	Population and vehicles			
City	Xi'an		Bangalore	
Population (million)	4.48[b]		9.58	
Car/LMV (million)	1.044 (car)		1.102 (LMV)[c]	
Bus	7695		4203	
Two-wheeler (million)	0.440[d]		3.725	

[a] In Bangalore, the average commuting CO_2 emissions by car include both car and two-wheelers

[b] The data refers to the population in the Xi'an urban central area

[c] In Bangalore, LMV refers to the light motor vehicle

[d] In Xi'an, there is prohibition of two-wheelers inside the 2nd Ring Road

Figures 3 and 4 present the spatial distributions of household and individual commuting CO_2 emissions in Xi'an and Bangalore, respectively. It is seen that Bangalore has higher emissions than Xi'an in general, and households and individuals located in the outer areas produce much more emissions than those in the inner areas and CBDs. The highest emissions scattered along/outside the 2nd Ring Road in Xi'an and the Outer Ring Road in Bangalore, respectively. These indicate that, from the urban spatial perspective, the key challenge of low-carbon development is to reduce higher emissions along the ring roads and in the outer areas.

5.2 Tobit models for CO_2 emissions by commuters and corresponding countermeasures

5.2.1 Tobit model results

The Tobit models for commuting CO_2 emissions are shown in Table 8 below. The results show that the car availability is the key factor of both household and individual commuting CO_2 emissions in the two cities. The coefficients of the car availability in Xi'an models are bigger
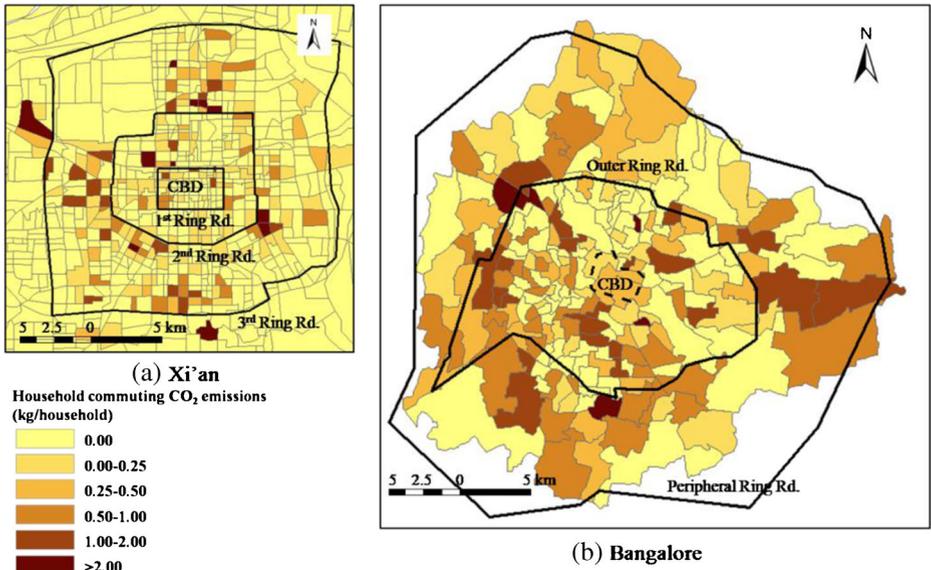
Fig. 3 Distributions of average household commuting CO$_2$ emissions by zone (kg/household, sum of commuting CO$_2$ emissions of each commuter in the household)

than those in the corresponding Bangalore models. This is because there are more cars in Xi'an than in Bangalore and because the two wheelers account for 77.1 % of the car and two-wheeler in Bangalore. It is the first time that our method found that household locations separated by the ring roads have a great impact on both household and individual commuting CO$_2$ emissions in all the four models. Households and individuals located outside the 2nd or
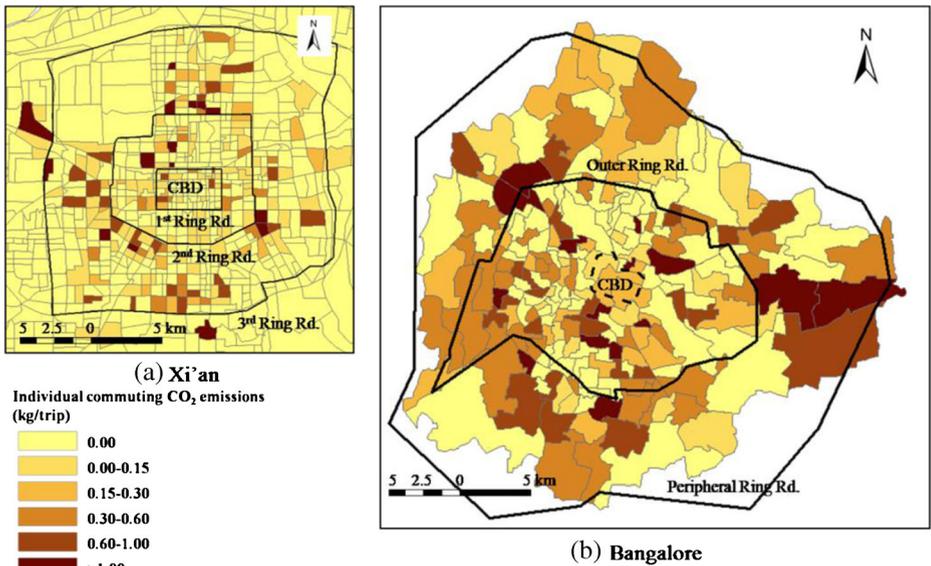
Fig. 4 Distributions of average individual commuting CO$_2$ emission by zone (kg/trip)

Table 8 Tobit models for commuting CO_2 emissions

Independent variables	Household		Individual	
	Xi'an	Bangalore	Xi'an	Bangalore
Car availability	0.572 (0.000)	0.256 (0.000)	0.407 (0.000)	0.303 (0.000)
Household location by ring roads				
Inside the 1st Ring Road/CBD	−0.248 (0.000)		−0.135 (0.001)	
1st–2nd Ring Road/CBD-Outer Ring Road	−0.178 (0.000)	0.195 (0.000)	−0.075 (0.000)	
2nd–3rd Ring Road/Outer-Peripheral Ring Road		0.298 (0.000)	0.020 (0.150)	0.072 (0.000)
Household annual income				
US$6,000–10,000		0.186 (0.000)		
US$10,000–16,000	0.135 (0.000)	0.419 (0.000)		
US$16,000–20,000	0.159 (0.001)	0.357 (0.001)		
US$20,000–40,000	0.233 (0.006)	0.236 (0.021)		
>US$40,000	0.556 (0.001)			
Work unit type				
Work in the government				0.207 (0.000)
Work in the foreign enterprise				0.333 (0.000)
Work in the local company				0.173 (0.000)
Work in the state-owned company				0.150 (0.006)
Distance to the nearest bus stop (km)				0.107 (0.046)
F value	77.74	219.96	135.14	221.19
Probability > *F*	0.000	0.000	0.000	0.000
Log pseudolikelihood	−1181.364	−1659.755	−1397.139	−1834.1607
Observations	1240	1835	1952	2433

The numbers in the brackets refer to significance levels. In Bangalore, car availability includes both cars and two-wheelers. In Xi'an, car availability refers to people owning car or willing to buy car

Outer Ring Road produced larger CO_2 emissions than those located in the inner areas. This indicates that geographic location separated by the ring roads is a good indicator of the commuting CO_2 emissions. It is related to mode supply, mixed level of land use, and the commuting distances in the areas separated by the ring roads, and it has great values in the urban planning and management practice. The average commuting distance is 5.51 km inside the CBD of Bangalore and increases sharply to 7.32 km outside the CBD and to 8.44 km outside the Outer Ring Road. The average commuting distance is 2.88 km inside the 1st Ring Road of Xi'an and increases to 3.22, 4.03, and 5.09 km between the 1st and 2nd Ring Roads, between the 2nd and 3rd Ring Roads, and outside the 3rd Ring Road, respectively, as shown in Fig. 5a. By analyzing Figs. 3, 4, and 5a, we can find that there are longer average commuting distance, higher average and total commuting CO_2 emissions, and more average emission distributions among the individuals and households in Bangalore than in Xi'an. Considering the future rapid economic growth, urbanization, and motorization in Bangalore, there is a need to reduce the possible sharp increase of the commuting CO_2 emissions in Indian cities. In addition, the percentages of the car availability in different household locations separated by the ring roads are also different. There is a higher percentage of car availability in the outer area
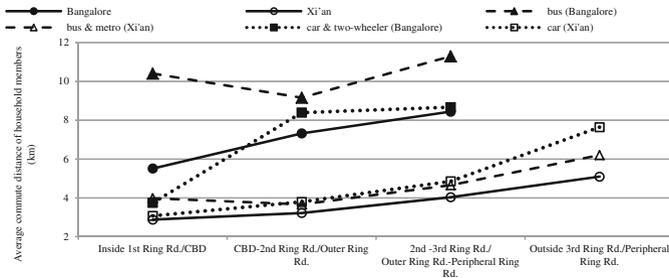
(a) Average commute distance of household members by household location and by travel mode
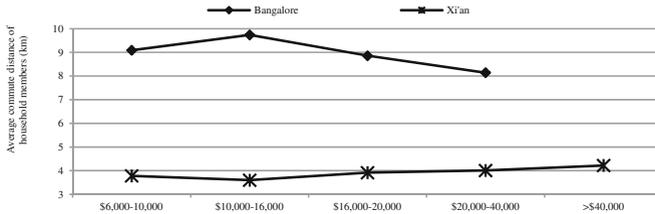
(b) Average commute distance of household members by household annual income
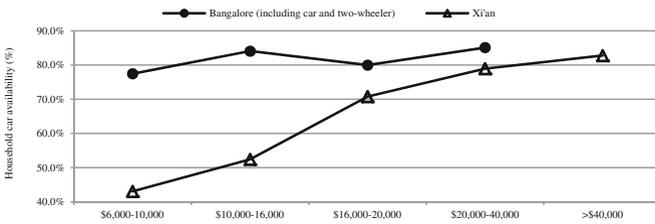
(c) Percentage of household car availability by household annual income
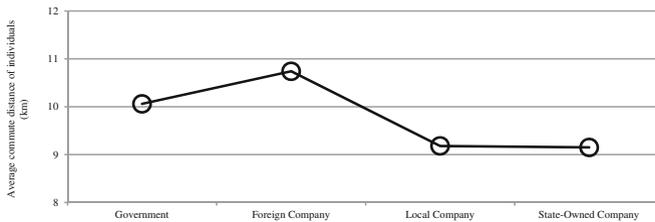
(d) Average commute distances of individuals by work unit type in Bangalore
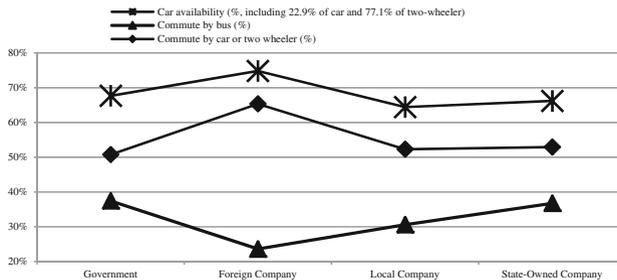
(e) Car availability and car/bus shares by work unit type in Bangalore

Fig. 5 Average commuting distances, car availability, and car/bus shares

than that in the inner area. According to the statistical results, in Xi'an, the percentages of car availability are 36.8, 52.4, and 61.6 %, respectively, for the sampled households inside the 1st Ring Road, between the 1st and 2nd Ring Roads, and between the 2nd and 3rd Ring Roads. In Bangalore, the percentages of sampled households with car availability between the CBD and Outer Ring Roads and between the Outer and Peripheral Ring Roads are 71.5 and 73.2 %, respectively.

Apart from the household location separated by the ring roads and car availability, household annual incomes have been proven to be another key factor of the household commuting CO_2 emissions in Xi'an and Bangalore. The result of Xi'an model shows that household commuting CO_2 emissions increase with the household annual income's increase. It could be because the households with higher income tend to have longer commuting distance and higher percentage of car availability. Details are shown in Fig. 4b, c. The impact of household annual income on the household CO_2 emission in Bangalore model is different from that in Xi'an model. It is found that, in Bangalore model, household commuting CO_2 emissions are not linearly increasing with the household annual income's increase as in Xi'an model. Also, the households with middle-level income of US\$ 10,000–16,000 tend to produce the highest commuting CO_2 emissions; correspondingly, these households have the longest commuting distances and the highest percentage of the car and two-wheeler's availability, as shown in Fig. 4b, c.

Previous studies found that full-time workers produced more transportation CO_2 emissions than part-time workers (Carlsson-Kanyama and Lindén 1999; Susilo and Stead 2009; Ko et al. 2011; Brand et al. 2013) and unemployed (Brand and Boardman 2008). While in this study, for the first time, we found that the type of work unit for the full-time worker is a key factor for the commuting CO_2 emissions in Bangalore's model, even though this factor is not significant in the Xi'an model. In Bangalore, foreign company workers produce higher CO_2 emissions than the government staff and the workers in local and state-owned companies. This is mainly due to the long commuting distance, high percentages of the car and two-wheeler's availability, and the high percentage of car uses among the foreign company workers, as shown in Fig. 4d, e. In addition, this is also because the household annual income of foreign company workers in Bangalore is 22 % higher than the overall average level.

Distance to the nearest bus stop is another factor of the individual commuting CO_2 emissions in Bangalore. The model results show that 0.107 kg more individual CO_2 emissions can be produced if the commuters live 1 km farther away from the nearest bus stop. However, in Xi'an models, this factor is not significant.

In summary, there are two common factors which affected the commuting CO_2 emissions in the all models of Xi'an and Bangalore, car availability and household location separated by the ring roads. For household CO_2 emission models of Xi'an and Bangalore, household annual income is a significant factor. The difference between the models lies in that work unit type and distance to the nearest bus stop are only significant in Bangalore's individual emission model.

5.2.2 Countermeasures based on the model results

The results of the Tobit models show that the positive factors for the commuting CO_2 emissions in Bangalore include car availability, high household income, working in foreign company, living in the outer areas of city, and distance to the nearest bus stop. The positive factors for the commuting CO_2 emissions in Xi'an include car availability, high household income, and living in the outer areas of city. Among these factors, car availability has the

largest impact on the commuting CO_2 emissions, followed by household income, working in foreign company, living in the outer areas, and distance to the nearest bus stop. Consequently, the key countermeasure to reduce the high CO_2 emissions is to encourage the emitters to take public transit instead of driving cars. As there is a high requirement on the comfort and convenience for trips by high emitters, the high emitters will not use public transit if the bus service is poor or the bus is inconvenient. Therefore, only by providing good public transit service and high bus stop coverage rate, mixed with the car demand management policy at the same time, the high emitters with car availability can take public transit.

In Xi'an and Bangalore, the closer to the city center, the higher the population density is and the severer the traffic congestions are. In contrary, the farther to the city center, the better the road conditions are and the higher the car availability is. Since the public transit typically costs passengers more travel time than self-driving, the residents with car availability, far away from the bus stop, and living in the outer areas or along the ring roads are more likely to commute by driving. As the city sprawls, the commuting distance of the residents living in the outer area of the city will be longer and longer. Consequently, the traffic congestion will be easily formed in a large scale with commuting CO_2 emissions increasing sharply in the central urban area. Therefore, there is a need to develop rapid transit system from the outer area to the inner area in the cities of China and India, such as rail transit and bus rapid transit (BRT). Due to the reason that there is no link between the land development revenue and the transportation investment in the early stage of urban development in both Xi'an and Bangalore, metro- or BRT-oriented development is hard to be implemented now. In other words, fund shortage for the transit-oriented development (TOD) in new developing areas in the early stage of urban development can further cause the shortage of the land for public transit terminal, transfer, and facilities and finally leads to the high commuting CO_2 emissions. In addition, it is necessary to implement parking demand control in the industrial development area, especially in the area with foreign companies and government in Indian cities; at the same time, the good transit service should be developed.

6 Discussion

From the analyses in this study, it is seen that the resident samples in the two case cities have good education level and thus are more open to strategies for global climate change mitigation. Most commuters working in the private companies are sensitive to the cost of commuting. It is also found that a high percentage of commuters own houses/apartments; therefore, the probability of changing their house locations is low, especially in the short term. The increase in CO_2 emissions by commuters during the fast development period of a city is mainly due to travel mode changes and commuting from newly developed areas. Avoiding the sharp increase of car use, implementing TOD pattern at the early stage of the land development, and providing outstanding public transport service are important to reduce the commuting CO_2 emissions.

It is also seen that the vehicle occupancy is an important factor of commuting CO_2 emission in both China and India. Maximizing the vehicle occupancy of cars, normal coach, and taxis could reduce commuting CO_2 emissions by as much as 50 %; decreasing the vehicle occupancy could increase commuting CO_2 emission by as much as 66.67 %. Therefore, avoiding smaller vehicle occupancy is critical to control the increase of commuting CO_2 emissions.

The analyses show that the characteristics of the high emitters are car availability, high income, working in the foreign company, and living in the outer areas/along the ring roads or far away from the bus stop. Reducing their emissions is important in both China and India. The outer areas of a city usually have better road conditions, lower service level of public transport, limited rail transit, or bus rapid transit to the central area of the city; it is hard for commuters to use travel modes other than self-driving, which leads to high commuting CO_2 emissions. Therefore, the adjustment in urban planning, construction of rail transit, or rapid bus routes in the outer-inner area directions, as well as cycling and walking system, public transport service level improvement, and avoiding fast increase of car uses are the keys to low-carbon urban transportation development. In Chinese and Indian cities, the implementation of transportation pricing, transportation management, and public transit priority policies can guide commuters with high income to use public transportation and make them less car-dependent.

Traffic congestions already exist in the central areas of the cities in both China and India. How to increase the mode share of public transport and to reduce travels by car is a challenge for city leaders. There is a need to balance the overall efficient development of the city and the ability to drive in the central area of the city.

The larger emissions and longer commuting distances in Bangalore indicate that Indian cities should focus on high density and compact development, which can reduce average commuting distance, and can also improve public transport operations and service levels since the lower density, sprawled, and decentralized urban form has caused inefficiencies for the public transport. The use of clean energy vehicles in Xi'an is another reason for the lower commuting CO_2 emissions. In Xi'an, buses and taxis are driven by compressed natural gas (CNG); metros and two-wheelers are powered by electricity. These can help reducing the commuting CO_2 emissions to some extent, which can be learned by Indian cities.

In addition, even though Xi'an is a good example of compact urban development pattern compared with Bangalore at present, if Xi'an continues to develop under this pattern in the future, the central area will suffer from increasing traffic pressures and increasing transportation CO_2 emissions. An alternative strategy is to control the development intensity in the central urban area and try to apply a multicenter strategy for the urban development.

7 Conclusions

The increase of transportation CO_2 emissions in Chinese and Indian cities in the future will significantly impact the global climate change. By 2030, the total CO_2 emissions from major travel modes (electric motors, buses, and cars) in major Chinese cites (Beijing, Shanghai, Shenzhen, and Guangzhou excluded) will reach 480×10^6 t. The annual average CO_2 emissions per person will be increased to 1.6 t in 2030 from 0.22 t in 2012. It is estimated that the total CO_2 emissions from the above three travel modes in major China and India cities will be increased from 135×10^6 t in 2012 (0.37 % of the total global CO_2 emissions) to 961×10^6 t in 2030 (2.67 % of the total global CO_2 emissions), which will affect the global climate change significantly. Hence, to mitigate global change, it is important to explore the characters of the commuting trips and to find strategies to reduce commuting CO_2 emissions in China and India.

From the analysis in this paper, several common characteristics in both Xi'an and Bangalore can be found, including (1) both cities are under fast urbanization and quick motorization; (2) the residents have good education level; (3) a high percentage of commuters work in private companies; (4) a high percentage of commuters own houses/apartments; (5)

both cities sprawl by radial and ring roads and leading industries are located outside or along the 2nd Ring Road in Xi'an and Outer Ring Road in Bangalore; (6) traffic congestions exist in central areas of the city; (7) commuters with car availability, high income, or living in the outer areas/along the ring roads are high CO_2 emitters and a small percent of commuters produce the majority of the CO_2 emissions; and (8) the vehicle occupancy and traffic congestion have large impacts on reducing CO_2 emissions. It is found that the changes on vehicle occupancy of car, normal coach, taxi, and bus could reduce CO_2 emissions by as much as 20 to 50 % or increase CO_2 emissions by as much as 33.33 to 66.67 %, and the changes on traffic congestions could reduce or increase CO_2 emissions by as much as 11 to 15 %. The differences between the two cities include (1) Xi'an has higher population density and compact urban form; (2) the sprawl in the outer areas of Bangalore is large, haphazard, and unplanned; (3) the household income, car ownership rate, commuting by car, and commuting share of public transport in Xi'an are higher than those in Bangalore; (4) the average commuting distance in Xi'an is shorter than that in Bangalore; (5) the average individual or household CO_2 emissions in Xi'an are lower than those in Bangalore; and (6) Bangalore has more household members (averagely 4.53 per person in one household) and a higher two-wheeler ownership rate (55.4 %).

The reasons of these findings are (1) better road conditions, longer commuting distance in the outer areas, and weak public transport service have caused more car uses and high CO_2 emissions in both cities; (2) Bangalore's lower density and more dispersed urban growth has caused even longer commuting distances, poor transit service, prevalence of the two-wheelers fueled by gasoline, and thus higher emissions than those in Xi'an; and (3) the buses and taxis driven by CNG and metro and electric motors driven by electricity also helped in reducing the transportation CO_2 emissions in Xi'an.

A number of countermeasures can be proposed from this study for the global low-carbon transportation development and climate change mitigation. Firstly, it is important for Chinese and Indian cities, especially for Chinese cities, to focus on reducing the commuting CO_2 emissions and controlling the potential increase of commuting CO_2 emissions produced by the high emitters and individuals located in the outer areas, with car availability, or high income during the rapid economic growth, urbanization, and motorization, and to provide the substitute travel modes for self-driving. Secondly, the keys to reduce the commuting CO_2 emissions in Chinese and Indian cities are increasing vehicle occupancy, ensuring the priority of public transit and its outstanding service, controlling the car uses, and implementing parking demand management in the area of the industry zone. Furthermore important, in the early stage of the land development in Chinese and Indian cities, investment in public transit must be guaranteed to support TOD. Thirdly, radial rail transit and rapid bus routes in the inner-outer directions should be developed with outstanding service levels so that high emitters with car availability, high income, and living in the outer areas will use public transit instead of car for commuting. Fourthly, Indian cities need more compact and high-density urban development patterns to reduce the travel distance. Fifthly, the use of clean energy vehicles can also help in reducing the transportation CO_2 emissions in Chinese and Indian cities. These strategies are significant for reducing CO_2 emissions in Chinese and Indian cities and other similar cities in the developing countries. Thus, they are important for the global climate change mitigations.

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ANNEXURE-R9

A STUDY ON AIR POLLUTION BY AUTOMOBILES IN BANGALORE CITY

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Abstract

This Paper has made an attempt to study on urban air pollution in Bangalore city by emission of gases by vehicles which emit from them. The present day environment crisis demands a change in attitude, which initiatives can be taken to rescue environment from destruction in the city of Bangalore. But the urban areas have a big share in the present day environmental problems from the automobiles throughout the world. This will finally focus on the attempt on the effects due to increase in the vehicle ratio in the city. Based on the facts and data obtained, the scenarios regarding future vehicle growth and their impact for travel is discussed to over come emissions problems. The main objective is based on the emission of vehicles and their problems. In future vehicle-based emissions testing should be conducted for at least once in three months in Bangalore to gain a more accurate picture of the emissions that Occur from the specific vehicles in this city. The results posed by important issues on transport and facts of existing situation will be used for the recommendations.

Keywords*: Ambient ,Dependency , Emissions , Processes, Scenario

1. INTRODUCTION

At the global level, the rapid growth in motor vehicle activity has serious energy security and climate change implications. The transport sector already consumes nearly half of the world's oil. But in urban areas – both developing and developed countries, it is predominately mobile or vehicular pollution that contributes to air quality problem.

The sources of pollutants includes emissions from the combustion of fossil fuels in motor vehicles and for industrial processes, energy production, domestic cooking and heating, and high dust levels due to local construction, smoking, unpaved roads, sweeping, hotels, restaurants and long-range transport. By this the quality of air has become so poor that, Bangalore is the result of both high emissions from the vehicles and unfavorable conditions.

The rapid growth in motor vehicle activity is the challenges to overcome in urban areas in Bangalore during the last and this decade. This has brought a serious range of socio-economic, environmental, health, and welfare impacts on environmental degradation. The rapid growth in motor vehicles in Bangalore is important not only because of their locally harmful air pollution effects, but also because of their regional and global impacts So the paper deals with the study of air pollution caused by the automobiles in the city of Bangalore

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The problem:

One of the main problems that is overlooked across the globe is pollution. The Pollution is evident in many different forms, such as, water, sound, light, radioactive, land, and air. The only way is to reduce the problem of air pollution is the elimination or reduction of fossil fuels used by vehicles.

Thus, the increases in population, migration, uncontrolled urban expansion, income, economic growth, energy consumption and mobility have created a serious for air pollution problems, in cities throughout the world. The study is to find the emissions from the vehicles and their impact on the environment. This deals with the present scenario of air pollution and the effects on environment in Bangalore city. The worst thing about vehicular pollution is that it cannot be avoided as the vehicular emissions are emitted at the near-ground level where we breathe. The problem of vehicular air pollution especially relates to Bangalore. This paper depends on the data of registered vehicles and the emission factors of vehicles.

Objectives:

1. To identify the number of vehicles in Bangalore city.

2. To identify the types of pollutants released from vehicles in Bangalore city.

3. To forecast and suggestion for controlling measures of air pollution in Bangalore.

The Study Area:

 Bangalore is a rapid development in urban area either in demography, migration, transportation, or industrial sector since last two decades. The Bangalore has the highest demography and the only metropolitan city, of Karnataka, which it has 94 lacks of population as per the 2011 census. The intensity, quantity, and frequency of both urban, suburban and movement with other cities are same factor of increasing transportation problem in the Bangalore area; particularly in transportation utility development could not comply with the demand. The dependency of urban population on transportation systems on fossil fuels is quite high.

The Bangalore is one of the cities having 41 lacks registered vehicles apart from other vehicles of neighboring city and towns. The vehicle with poor environmental quality continues to grow in multiple ratios.. There is an urgent need to address the interrelated problems and obstacles experienced by the people of Bangalore regarding air pollution through the vehicles.

The traffic congestion resulting from transportation changes contributes even greater to deteriorating environment in urban communities. In the last few years, about 70% of ambient-air quality degradation in Bangalore is affected by transportation activities.

Based on Statistics of the department of road transport offices in Bangalore (2010) the increasing of motor vehicle in Bangalore has gone up by 18 per cent every year. While the transportation activities could effect on positive impact like the increasing on Bangalore economic activity, or negative impact like the increasing of street capacity in surrounding downtown area. This could effect in decreasing ambient air quality and also decreasing on public health quality either pedestrian or local communities.

2. AIR POLLUTION FROM TRANSPORT SOURCES

Air pollution is addition of any harmful gaseous, liquid or solid particles or substances to the atmosphere, which causes the damaging of the environment, human health on quality of life in urban area that can endanger the health of human beings, plants animals, or damage materials reduce visibility or release undesirable odors. By this one of the great problems faced in urban areas throughout the world is the increase in vehicles due to imbalance between the public transport and the increase in population, mobility and last mile connectivity. This increase in the number of vehicles has lead to increase in congestion and the increase in pollution by the private vehicles

Polluting such a natural resource by various human activities will substantially change the composition of air. This may lead to many short term and long term implications on the life of plants and animals. Besides the change in composition, the pollution may directly add some poisonous and harmful gases - which may cause series of health complications.

Transportation is one of the important of economic activity and beneficial social interactions. While the transportation sector is also a major source of air pollution in Bangalore, estimated to account for nearly all of carbon monoxide (CO), more than 80% of nitrogen oxides (NOx), 40% of volatile organic compounds (VOC), 20% of sulfur dioxide (SO2), and 35% of PM10 in 1998. The growing problems related to traffic are congestion, accidents, pollution and lacks of security are also very worrisome. The key question is how to reduce the adverse environmental impacts and other negative effects of transportation without giving up the benefits of transportation.

This is due to increase in the automobiles and the mobility of people, rapid urban growth, which is likely to increase travel demand significantly in Bangalore city. Given current trends, by 2020 the Bangalore city will have a 1.3 crore population will reach 2 largest city including the nearby cities of other states capital such as, Hyderabad, Chennai, Tiruvananthapuram in south India by 2030.

The increase in the number of vehicles from transportation sector presents a wide range of issues viz. air pollution, noise, congestion, accidents and increased travel time and delays. It was evident from the existing information that air pollution controls are not only important and a current priority in the local context, but also can present a significant potential to control greenhouse gas emissions. Thus, with an ultimate goal of

greenhouse gas reduction, the present study has chosen air pollution control as a strategic target from the transport sector due to its high greenhouse gas co-benefits.
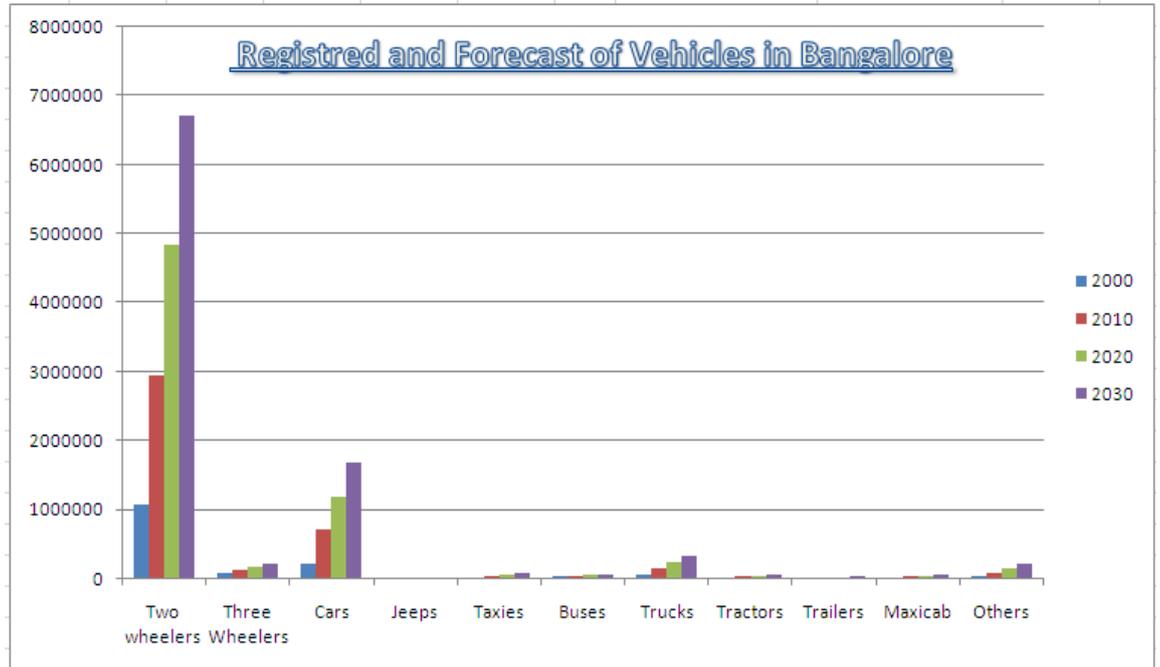
FIGURE 1 - SHOWS THE DATA OF REGISTERED VEHICLES IN BANGALORE IN 2010.

3. MOBILITY AND AIR POLLUTION

In recent years due to increase in the number of vehicles has shown drastically in, levels of air, noise, and sight pollution were much higher in all urban centers today. Due to increase in automobiles on the road today we experience higher levels of pollution than before. The automobile is one of the major sources, probably the leading contributor pollution in the cities. The transportation is of the major source for the economic activity and redistribution of resources among people. But transportation sector is a major source of air pollution in Bangalore, it is estimated that the account for nearly all of carbon monoxide (CO), more than 80% of nitrogen oxides (NOx), 40% of volatile organic compounds (VOC), 20% of sulfur dioxide (SO2), and 35% of PM10 in 1998. The growing automobiles have lead to problems of congestion, accidents, and lack of security due to automobiles are worrisome. Therefore to reduce adverse environmental impacts and other negative effects of transportation without giving up the benefits of mobility. As the increasing geographic dispersion of Bangalore population is also likely to increase aggregate transportation demand, since the greater number of trips will also be longer and public transport will be less efficient and universal.

As the population increased in residential areas where decentralized, patterns of passenger trip mode choice in Bangalore have also shifted dramatically by using private vehicles: The number of private vehicles increased drastically, due to decentralization, globalization, economic development, standardization by most

estimates at a rate of 18 percent annually in recent years. This could mean a higher number of vehicles in Bangalore, a higher ratio of vehicles per persons, possibility of trips and the distances traveled will increase even more for coming years.

TABLE1 - DATA OF REGISTERED VEHICLES FROM RTO'S, AND DISTRICT CENSUS HAND BOOK. BANGALORE REGISTERED VEHICLES AND THEIR FORECAST

Type of Vehicles	1980	1990	2000	2010	2020	2030
Two Wheelers	111750	458860	1067430	2951520	4835610	6719700
Three wheelers	10044	17379	61424	115401	169378	223355
Cars	31738	82205	201052	697745	1194438	1691131
Jeeps	3554	6376	6827	9104	11381	13658
Taxi	1120	2511	6299	32818	59337	85856
Buses	4671	4516	20656	35723	50790	65857
Trucks	8236	19149	41887	139573	237259	334945
Tractors	1929	1993	6158	20555	34952	49349
Trailers	1734	1723	5544	12487	19430	26373
Maxi cab	*	*	4238	23153	42068	60983
Others	549	3574	16542	84018	151494	218970
Total	**175325**	**598286**	**1438057**	**4122097**	**6806137**	**9490177**

The data shows the number of registered and share of different modes of vehicles in Bangalore city for the year 2011 (projected and estimated). The share of percentage of vehicles is shown with a pie diagram shown below; but the number of vehicles data is shown in numbers in the form of tables in the left side below.
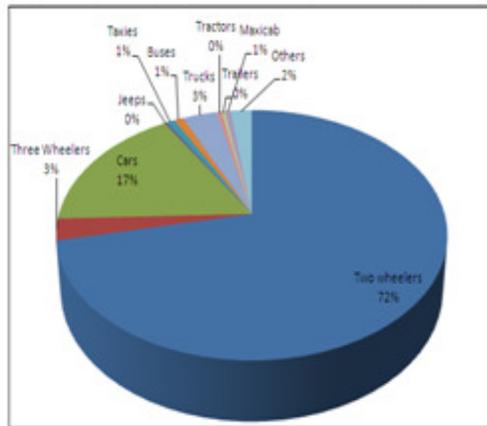
Type of Vehicles	Year-2010
Two Wheelers	2951520
Three Wheelers	115401
Cars	697745
Jeeps	9104
Taxis	32818
Buses	35723
Trucks	139573
Tractors	20555
Trailers	12487
Maxi cab	23153
Others	84018
Total	**4122097**

Source: Praia website

FIGURE 2 - SHOWS THE MODAL SPLIT AND SHARE OF VEHICLES IN BANGALORE CITY IN 2010

4. SOURCES OF POLLUTION

Pollution from 2-wheelers: Two-wheelers account for about 72 percent of the total vehicular population in Bangalore. Because of inherent drawbacks in the design of 2- stroke engines, 2-wheelers emit about 20-40% of the fuel un-burnt/partially burnt. Presently, two-wheelers account for more than 65% of the hydrocarbons and nearly 50% of the carbon monoxide in Bangalore. As these emissions are less visible, the general public is not aware of the role of 2-wheelers in the deteriorating air quality in the city. The 2-stroke engine, in spite of

R&D efforts towards improving its design, will continue to be a high emitter of hydrocarbons and carbon monoxide. While the absence of a technological breakthrough on the conventional 2-stroke engine and its high pollution potential, it is for consideration that Government considers the phasing out of two-stroke two and three wheelers.

Pollution from 3-wheelers: Of the 1, 15,401 three-wheelers in Bangalore nearly 3 percent of the total population of vehicles, they are petrol-driven, powered by 2-stroke engines. These vehicles are also high emitters of carbon monoxide and hydrocarbons. A pollution check conducted by Regional Transport Department has revealed that in some instances the levels are so high that they go beyond the measurable scale of test instruments. In addition, it is widely believed that petrol is adulterated with kerosene which results in emissions of thick black smoke.

Pollution from 4-wheelers: The Bangalore city is having 7, 39,667 vehicles on the roads (Jeep-9104, Taxi-32818 and Cars-697745) as it consist of both petrol and diesel driven vehicles. It excludes the floating vehicles in the city area. These vehicles are also high emitters of carbon monoxide and hydrocarbons which pollutes the air. These consist of old as well as new vehicles in the city. The city is having 18 percent of 4 wheelers which occupies maximum space on the road, it is one of the air pollutants in the city. it is widely believed that petrol is adulterated with kerosene which results in emissions of thick black smoke.

Pollution from BMTC and other privately operated buses: There are about 3,500 privately operated BMTC buses of about 6077 buses in Bangalore Metropolitan transport Corporation consists of 1 percent of the total population. About two thirds of the BMTC fleet is beyond the recommended age of 4-5 years, some even beyond 8-10 years. Most of these buses require phasing out as their condition is beyond normal maintenance measures. Their continued use has resulted in emissions of very high levels of smoke and particulates from this the KSRTC, NWKSRTC, other State owned buses, and the private and industrial busses. If such vehicles continue to function beyond the recommended age and carry more than the permitted load of passengers.

Overloading at peak hours: The buses, particularly during peak hours, carry more than recommended load of passengers. These buses will stops near the junctions and signal lights due to congestion of vehicles. This results in higher smoke emissions during the peak hours. While high capacity buses require to be inducted for carrying more passengers. The worst polluters should be taken off the heavy traffic corridors and high density areas. Similarly, for trucks, enforcement of laws related to overloading requires to be enforced vigorously to BMTC and other state owned buses etc.

Pollution from diesel trucks: The diesel trucks consists of 3 percent in population, similar to buses, emit high levels of smoke and particulate matter. An age limit needs to be specified for all commercial diesel trucks 15 years but still it had remained in the paper. But still so many BBMP, BESCOM and other Government

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vehicles is running on the streets. Renewal of permits must be done only if the vehicle conforms to satisfactory inspection and maintenance measures for pollution control for the state owned and private buses.

Impact of air Pollution on Health Human health is the major concern over air pollution in the urban areas. However, the Bangalore City Study considers effects of air pollution in and its impact on ecosystems, and with the linkage with global warming. The Bangalore city like other countries in the world, contributes to global warming and is likely to be affected by it. In this paper, we will discuss only the impact on health.

Air pollution caused by the automobiles has impacts on health and imposes potentially substantial economic costs to society. Most of the health effects from air pollution come from respiratory symptoms in the levels of pollution in Bangalore City and other cities throughout the world. The time-series have revealed the effects of various pollutants (generally PM10= particulate matter smaller than 10 µm in diameter, ozone, CO=Carbon Monoxide, NO2=Nitrogen dioxide, and SO2=Sulpher dioxide.).The Harvard school of public health has assessed health risks found in current and anticipated levels of air pollution Mexico city Metropolitan Area implications of air quality focused on pollutants, mainly by PM10 (particulate matter smaller than 10 µm in diameter) and ozone. The Studies in various cities around the world, including Bangalore City, shows that there is a daily fluctuations in air pollution levels in different parts of the world. It is estimated that for each 10 µg/m3 increase in daily levels 4 of PM10. So, due to increase in particulate matter of air cardiovascular, coronary heart diseases and even premature deaths among the infants will take place. This can be done by reducing 10 percent reduction in PM10   may reduce the death of infants. Several studies revealed that the effect could be several times larger if one considers longer-term responses to particulate matter exposure PM10 concentrations have also been associated with health outcomes including increased cases of chronic bronchitis, respiratory or cardiovascular problems, asthma attacks, symptoms etc.

The ozone has significant effects on respiratory function and on respiratory conditions such as asthma. So for this recent research suggests that important factor for human health involves the presence of fine particles (PM2.5). So for the monitoring PM2.5   and to develop an emission in inventory should be given more importance.

 So for this the government or the pollution control board has to set up 8 to 10 air pollution monitoring centers in and around the Bangalore. The collected data will be useful for control of pollutant in a spatial manner. The corporation or Karnataka Government and other agencies has to contribute to the understanding of the air quality problem in Bangalore by conducting measurements and modeling studies of atmospheric pollutants within the city. Such an understanding will helps to provide a scientific base for devising effective emissions control strategies to reduce exposure to harmful pollutants in Bangalore and also provide insights to air pollution science in other cities in Karnataka.

5. MEASURES FOR EMISSION CONTROL

1. Use of Remote Sensing Technology: Remote sensing technology measures the pollutant level during the vehicle's exhaust while vehicle is traveling down the road. Unlike the conventional methods, the remote sensing devices are not physically connected to the vehicle. The paper highlights how to achieve almost zero percent pollution and prevent the environment from vehicle emission.

2. Modification on cost effective: Due to today's strict emissions and fuel economy standards to which manufacturers have to conform, most new cars bought these days are actually capable of performing far better than they are advertised. Cost effective depends on these factors

   a. Turbo Charger: The turbo Charger works as compresses air which is driven through the exhaust system,

   b. Nitrous helps in cooling effect as it rapidly changes from a liquid to a Gas.

   c. Sway bars and control arms: It works components of car suspensions that work to counteract body roll and keep the car firmly planted in turns. Adding stronger sway bars and control arms to a car stiffens the suspension, minimizing body roll and allowing it to take corners at higher speeds.

   d. Ceramic brakes: is used instead of mottled brakes as they get very hot and when brakes get hot, they lose a lot of their stopping power. One way around this is to switch to ceramic disc brakes.

   e. Spoiler: is the addition of air rushing overhead to push down on the car, stabilizing it and making sure that more of the engine's power hits the road. And for even more grip a splitter can be added which has much the same effect but at the front of the vehicle,

   f. Chipping and ECU remapping: Chipping is basically the same as ECU remapping but instead of re-programming the unit you're bypassing it completely. This is often less effective than remapping because every engine runs slightly differently, and mass produced pre-programmed chips don't take into account an engines subtle differences.,

   g. Reboring the engine: it's important to check that you can get a gasket, piston with rings and other components to match your chosen bore capacity. A rebore is irreversible and you'll certainly not want to have to do it again. Another thing to consider is that after reboring your engine, it will be necessary to run the engine in again.

h.   Additional cylinder heads: A good way to get more power out of your car is to upgrade your cylinder heads to a set that has four valves per cylinder. The additional intake valve allows more air to enter the cylinder, resulting in stronger combustion, while the extra exhaust valve clears out the engine's waste faster.

i.   Exhaust: A good way to get more power out of your car is to let more air into the engine which results in stronger combustion. An often-overlooked way to improve performance is to help the exhaust gasses get out of the engine. The exhaust is an engine's way of exhaling.

3.   Curtile use of private Vehicles: Reducing vehicles use across the globe can cut carbon dioxide emissions by thousands of tones. As mention before, efficiency is unquestionably the largest, cheapest, and cleanest wedge among the many we need to rid carbon from our energy economy. Avoiding unnecessary driving is the most effective way to reduce vehicle emissions; however, traffic trends indicate more vehicles are being driven more frequently due to urban sprawl. The options we have available to reduce the number of vehicles being driven on our roads.

4.   Day without car/ 2 wheeler: This is a new idea which has been accepted in different countries and to accept and implement ideas such as a car-free day in order to ensure less traffic congestion, stem pollution and contribute our small bit in solving the environmental problems that confront us today.

5.   Car Pooling: The employers, or groups of employers, find it convenient to have one or more cars or vans that are readily available for business use by a number of employees. The cars or vans are not allocated to any one employee and are only available for genuine business use. Such cars and vans are usually known as pooled cars and vans. As it has to be started in the corporations ex: BEML, Vikrant, Universities, Institutions and corporate sectors such as Infosys, L&T etc.

6.   Staged Working Scheme: will be different times for the people employed state Government, Central Government, Corporate, Banks and Financial institutions, Educational institutions, and Public sector etc. This should be introduced in the developed and developing countries based on the congestion and the level of pollution. This will help the citizens or employer will be healthy and can drive his vehicle during their office timings within the city based on their convenience as per the city.

7.   Commitment: The citizens should have commitment for the society as it helps in solving the problems related to pollution and the human health in Mysore. The people has to think in a manner that, the pollution is a problem of our house rather than the society which effects mankind and poisoning the environment by unwanted emissions from vehicles and make them unhealthy.

8. Traffic Management side: The present day traffic has to be maintained and planned in such as way that the junctions, intersections, should be made as a traffic free corridor as it emits smoke in these places which will effects the human health and harms the environment.

9. Emission test by RTO: To mitigate transport emissions, stringent emission norms are being introduced for new vehicles. However, this effort would be futile without an improvement in the emissions performance of the large number of in use vehicles. Hence, an effective inspection and maintenance program for in use vehicles is essential for mitigating transport emissions the Regional Transport offices with environment experts.

10. Ban of 2 stroke vehicles: Emissions from 2-stroke engines can be reduced by rigorous inspection and maintenance programs and used of lubricating oil of correct quality and quantity. But the best option is to ban the use of 2-stroke engines in new motorcycles in favour of 4-stroke engines. The 4-stroke engines may be slightly more expensive, but are cheaper to run as they are more fuel efficient and last longer

11. Ban of vehicles more than 15 years of age: The Supreme court has banned the Commercial vehicles of 15 years of age, but we should think of banning all the vehicles of same age .The law should be made that imports of heavy vehicles (Trucks etc) older than seven years from the date of manufacture and light vehicles (Cars, Pickups) older than five years from the date of manufacture should also be banned. While the transfer of ownership of a vehicle over 10 years old should also be illegal, in other words you cannot sell the vehicle on. This leaves two options scrap the vehicle or export it to another, more lenient, country.

12. Celebration of Bus Day: This has been introduced BMTC on 4th of every month should use public transport. As an individual we should not use our cars for the day, and only use public transport as it reduces the traffic. The Bus Day will be success if the roads are not congested, polluted. If we can see a change in the traffic around us like smoke rings or fog around street lights in the night, winter fog instead of pollution fog, in the night sky.

Urban Planning: Studies of advanced urban-engineering concepts for cities to evaluate alternatives to urban sprawl. Such engineering analysis would consider the co-location of activities with complementary needs for energy, water, and other resources and would enable evaluation of alternative configurations that could significantly reduce vehicle-miles travelled and GHG emissions. The city transport systems has to provide faster and cheaper movement of passengers than the urban automobile such as (ELRTS) elevated rail system, Bus route priority system, (BRTS) Metro rail, Mono rail, commuter rail, Sky Bus etc. for the public transport modes.

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Freight Transport: Strategies and technologies are needed to address congestion in urban areas and freight gateways by increasing freight transfer and movement efficiency among ships, trucks, rail and ports

6. CONCLUDING REMARKS

The rapid population growth of vehicles in multiple ratios continues to be a matter of concern for the Bangalore city as it has manifold effects since the last decade, one of the most important being environment degradation. The unprecedented speed of urbanization of Bangalore has resulted in enormous pressure on the environment with severe adverse impacts in terms of pollution, and today city is considered as one of the most polluted city in the country.

While the projected rate of population increase may be reduced, even moderate population growth is likely to lead to substantial increases due to passenger and freight travel demand in the city, due to introduction of Metro, Monorail, BRTS, fuel price etc. The increasing geographic dispersion of metropolitan population is also likely to increase aggregate transportation demand, since the greater number of trips will also be longer and public transport will be less efficient and universal.

So to improve the quality of air and water there is a need of strict enforcement and monitoring program by the Karnataka Pollution Control Board. There is also a need traffic regulations; efficient public transportation system in the city and heavy penalties and seizure of vehicles during violation of rules should be imposed on public. For the protection of environment more emphasis should be laid on compulsory environmental education at school level for the awareness to people know about how and why we need to save environment.

Our Future

For this carbon wedge era we should work together in reducing global warming and other efficiencies by reducing vehicle use across all transport sectors .

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KARNATAKA ROAD DEVELOPMENT CORPORATION LIMITED

Consultancy Services for Preparation of **Detailed Feasibility Report (DFR)** for the Construction of **Proposed Elevated Corridors** within Bengaluru Metropolitan Region, Bengaluru

KEYMAP FOR BENGALURU ELEVATED CORRIDORS
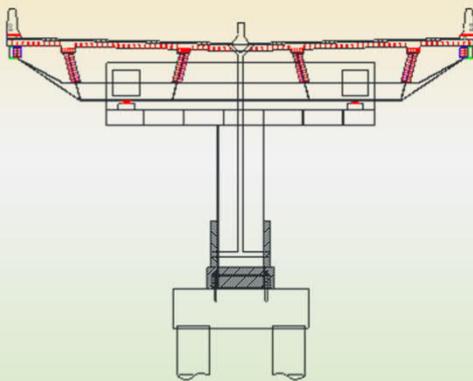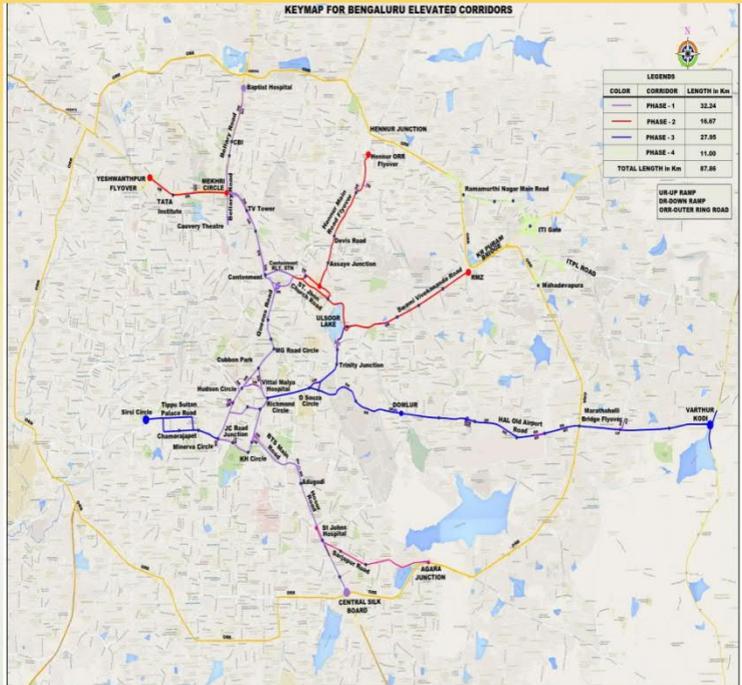
FINAL FEASIBILITY REPORT

VOLUME-I : MAIN REPORT

FEBRUARY, 2019

AECOM Asia Co. Ltd.

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Consultancy Services for Preparation of Detailed Feasibility Report for the Construction of Proposed Elevated Corridors within Bengaluru Metropolitan Region, Bengaluru

Final Feasibility Report   *VOL- I Main Report*

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E. EXECUTIVE SUMMARY

E 1 PROJECT BACKGROUND

Bengaluru (Earlier called "Bangalore") city is the capital of Karnataka State and is the IT capital of India. The city is distinct in its nature because of its climate, terrain and peace loving people, the city attracts enormous people from all corners of India and hence has sizeable population originating from other states making it the most cosmopolitan city in India. The city is the third most populous city & fifth largest Metropolis in India as well as 18th most populous City in the World making it the most sought after cities in India by people, companies and multinationals. The massive growth that the city has witnessed in the last two decades has brought the city to fame but also to chaos due to grossly inadequate infrastructure in all fronts.

Due to large scale initiative and support by Govt of Karnataka for establishment of IT & BT industries during 1990-2000, Bangalore attracted large scale investments in IT / BT sector from many global / MNCs thus triggering exponential growth of Real estate industry and many other service related industries. It resulted in rapid increase of population from 4.10 million in 1991 to 8.4 Million in 2011 census and 115.50million in 2016 thus the city is 3rd most populous city in the country. With the exponential growth of IT/ BT and service sectors, the population has increased from 7-8 % per annum during 2011-2016 as against 0.5% per annum during 1991 – 2001 and the vehicle population has also grown at a rate of over 10% per annum during 2011-2016. With this, the projected population by 2020 will be 13 million.

Bengaluru is endowed with a radial pattern of road network converging in the core area of the city. As per CTTP report-2011, the total road network of the city is over 4000 km of which arterial/sub-arterial roads account for about 350 km. The road network in the central parts of the city has developed organically over last century and has inadequate Right-of- Way. There are also Ring Roads (IRR-30 kms, ORR-62 Km) which cuts across the various radial roads creating vast number of bottle necks. Also, a fractured Intermediate Ring Road has been constructed in fragments at south-east of the city between Koramangala and Old Airport Road. Keeping in view of the narrow ROW and heavy developments along the arterial roads the widening of existing arterial roads is not feasible. As such the necessity of going in for elevated corridor with minimal land acquisition for widening / at grade improvement for ramps and provision of grade separators at all major intersections is the best alternative to improve the traffic condition in Bangalore.

Government of Karnataka (GOK), through Karnataka Road Development Corporation Limited (KRDCL) vide letter KRDCL/CE-EE2/EC/LOA/2015-16/- 3024 dated 30jan2016 has appointed M/s AECOM joint venture (JV) with M/s Deloitte and M/s Infra Support Engineering Consultants Pvt. Ltd as technical consultant for "Consultancy Services for Preparation of Detailed Feasibility Report for the Construction of Proposed Elevated Corridors within Bengaluru Metropolitan Region, Bengaluru".

Final Feasibility Report   *VOL- I Main Report*

The main objective of the Consultancy is aimed to alleviate congestion and provide unhindered travel along the Proposed Corridors that will contribute to savings in travel time, vehicle operating cost, improve road safety and minimize carbon emissions resulting in overall economic growth of Bangalore.

The overall objective of the Consultancy assignment is to assist KRDCL in developing Feasibility Study, recommend financing mechanisms, identify preferred procurement route.

The Feasibility Study and Preliminary Engineering Design that will demonstrate the bankable feasibility of the project from traffic, technical, economic, social, environmental and financial angles leading to preparation of detailed engineering design, tender documentation and project procurement plan.

E 2   PRESENT TRAFFIC SCENARIO

Various relevant traffic surveys have been conducted on project roads viz. mid-block classified traffic volume count survey at 11 locations, Origin & Destination surveys at 11 locations and Intersection volume count survey at 54 locations.

NS, EW I and EW II corridor stretches have an average traffic of 200,000 PCU, 180,000 PCU and 150,000 PCU respectively during week days as shown in below Table E-1:

Table E-1:- Present Traffic in PCU

| SI.No | Location | Name | Vehicles | | | Total PCU | Average PCU/hr | Capacity (PCU/hr) as per IRC: 106-1990 |
			Motorised	Non-motorised	Total			
1	Hebbal	Hebbal- Airport	2,29,429	245	2,29,674	2,38,599	9,942	5400
2	Kasturba Road	Corporation Circle- MG Road	83,259	469	83,728	89,782	3,741	3000
3	Silk Board Flyover	Electronic City-Madiwala	1,74,441	730	1,75,171	1,88,377	7,849	5400
4	K R Puram	Bangalore-Hoskote	1,15,997	276	1,16,273	1,27,376	5,307	3000
5	Jayamahal Road	Armane Nagar-Bangalore Cantonment	76,923	624	77,548	81,918	3,413	1200
6	CPRI Road	Bangalore Cantonment-TATA Institute	91,056	398	91,453	94,869	3,953	3000
7	Ramgundanhalli	Marathahalli-Varthur Kodi	65,823	663	66,486	66,905	2,788	3000
8	HAL Kalyana Mantap Bus stop	Marathahalli- HAL	1,06,579	865	1,07,444	1,08,999	4,542	3000
9	Sirsi	Bangalore- Mysore	1,47,246	179	1,47,425	1,64,387	6,849	3000

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| SI.No | Location | Name | Vehicles | | | Total PCU | Average PCU/hr | Capacity (PCU/hr) as per IRC: 106-1990 |
			Motorised	Non-motorised	Total			
10	Jakkasandra	Madiwala-Sarjapur	1,21,603	878	1,22,481	1,27,858	5,327	3000

∗ Major Observations and Recommendation based on Traffic Analysis:

- Maximum traffic volume was observed on the Section I – Jayamahal Road along the NS corridor accounting for 1,33,358 PCUs of traffic followed by Section - VII Hosur Road - Sarjapur Junction accounting 1,25,422 PCUs of traffic thereby exceeding the capacity in 2023.
- For EW II corridor, Section IV – Richmond Road - Hal Airport Road section accounts for 1,14,588 PCUs of traffic followed by Section-V Hal Airport Road - Domlur Flyover accounts for 1,06,077 thereby exceeding the capacity in the base year, i.e. 2023.
- CC-II D'souza Circle - Bhaskaran Road section accounts for 95,051 PCUs of traffic thereby exceeding the capacity in the base year, i.e. 2023.
- Section II and Section VII (Hosur Road – Sarjapur Junction section) of NS corridor is expected to exceed the 6-lane capacity by 2023.
- The capacity of the EW II corridor sections being 60,000 PCUs, Section IV and V of EW II corridor is expected to exceed the capacity by 2023.
- Major share traffic being diverted to elevated corridors are two wheelers, followed by private cars and commercial cabs.
- The CC-I i.e. Sarjapur road section is expected to have a maximum volume of 64,252 PCUs in the year 2037.
- CC-II i.e. Bhaskaran Road-Dsouza circle section is expected to have a maximum volume of 96,335 PCUs in 2037.

The very Objective of the elevated corridors in Bangalore will only be achieved if the proposal is integrated with development of Peripheral Ring Road (PRR) to avoid the through traffic from entering the City Core central area, development of Mass transit system including new Metro and Mono rail feeder corridors. The existing MRT System of Bangalore city can be strategically expanded using Metro rail and Mono rail combinations to connect all the arterial and sub arterial roads with the potential Production and Attraction zones to meet the growing travel demand of the city. Policy level interventions are required to integrate the upcoming metro corridors / Mono rail corridors with the proposed elevated corridors so as to provide last mile connectivity and generate substantial shift of passengers from private to public modes. Access to MRTS is needed to be optimized in both central as well as peripheral areas of the city of Bangalore to maximize its utility. Promoting public transit and strengthening mass transit network in the city can be a holistic way forward to solve the growing congestion impacts on the streets of Bangalore and improve the degrading quality of urban life as a whole.

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E 3   PROPOSALS:

In order to design the proposed elevated corridors, the road capacity requirements have been ascertained. The Traffic Assignment Model for the study corridor has been developed using VISUM-13 software. The details of proposed Elevated corridor including length of one ways/Loops, No. of Ramps are furnished in below Table E-2:

<center>Table E-2: Proposed Corridor Details</center>

SI No.	Name of the Corridor	Lane Configuration	Corridor Length (Km)	Entry/ Exit ramps (Nos.)	Total Length (Km)
1	NS-1: North-South Corridor-1 connecting Baptist Hospital, Mekhri Circle to Central Silk Board (i.e., NH-7 towards Bellary to NH-7 towards Hosur)	6 Lane/4 Lane	27.79	17	27.79
2	EW-1: East-West Corridor-1 connecting K.R. Puram to Yeshwanthpura Flyover (i.e., NH-4 towards Old Madras and NH-4 towards Tumkur Road)	4 Lane	9.67	14	9.67
3	EW-2: East-West Corridor-2 connecting Varthur Kodi to Sirsi Circle (Old Airport Road, SH-35 to Mysore Road, SH-17)	4 Lane	27.95	13	27.95
4	CC-1: Connecting Corridor-1 Connecting North-South corridor at St. John's Hospital Junction to Agara on Outer Ring Road	4 Lane	4.45	0	4.450
5	CC-2: Connecting Corridor-2 Connecting East-West Corridor-1 at Ulsoor to East-West Corridor-2 at D'souza circle.	4 Lane	2.8	4	2.80
6	CC-3: Connecting Corridor-3 Connecting East-West Corridor-1 at Wheeler's road jn.to Hennur Flyover at Outer Ring Road	4 Lane	4.20	5	4.2
7	EW-1 Additional Corridor from Rammurthy Nagar (Ring road) to ITPL Stretch	4 Lane	11.00		11
TOTAL LENGTH			87.86	53	87.86

The Proposed Composite Elevated Corridors will have Prefabricated Steel super structure with RCC Concrete deck to make the best use of its advantages such as being sleeker in sections, lighter by weight, faster in construction, aesthetically good, occupying lesser space during construction and being ecofriendly when compared to regular Concrete structures. The substructure consists of Concrete filled Steel piers. The high strength of composite pier results in sleeker sections with minimum impact on the existing road. As per the Geotechnical

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investigation pile foundation has been recommended which ease the construction in an urban location compared to open foundation with minimum hindrances to existing traffic.

E 4   DESCRIPTION OF PROJECT CORRIDORS:

A Key plan of the corridors is presented in below Figure.
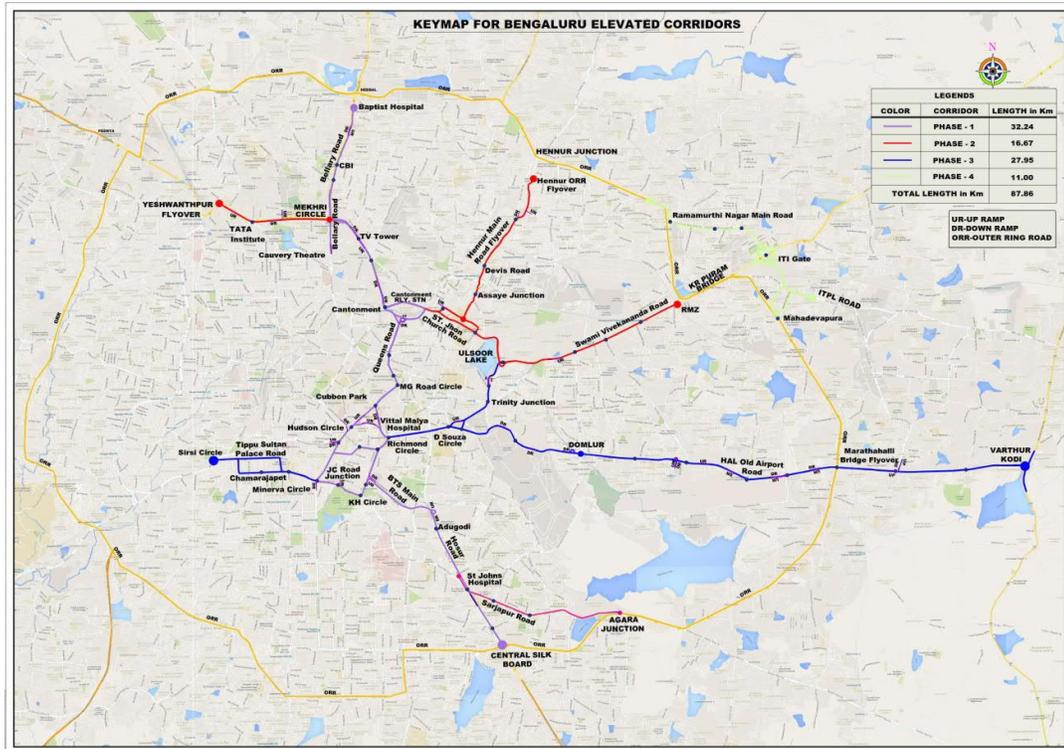
Figure E-1: Key plan of the corridors

- North - South Corridor: Connecting Baptist Hospital and Silk Board Junction

  The corridor starts from Baptist Hospital and ends at Silk Board flyover via. Jayamahal main road - Queen's Road-Indian Express Junction - Infantry Road Junction - Minsk Square - Kasturba Road - Hudson Circle – Shanthinagar Bus Stand – BTS Road - Audugodi main road.

- East - West Corridor -1: Connecting NH48 (earlier NH-4) at RMZ and Yeshwanthpura Flyover

  The project corridor starts at RMZ on Old Madras Road and ends at Yeshwanthpura Flyover on Tumkur road via. Suranjandas Road Junction - 80 Feet Road junction - 100 feet Indiranagar road Junction - D Bhaskaran Road Junction - Kensington Road Junction (Philips buildings) – Ulsoor lake - St. John's Road – Millars road - Jayamahal Main Road – Mekri circle - CV raman road.

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- East - West Corridor -2: Connecting SH-35, Varthur Kodi to Sirsi Circle on Mysore road

  The corridor takes off at Varthur kodi junction on SH-35 – ends at NICE link road on Mysore road via. Kundala halli gate junction – Marathahalli underpass - Suranjandas Road Junction - Old Airport road – Wind tunnel road junction - Domlur Junction - Trinity Church Junction - D'Souza circle - General K S Thimayya Road - Vellara Junction - Richmond Circle - K.H.Road - Lalbagh Main Road – Minerva junction - Chamarajpet 5th Main Road - 9th Cross Road - 1st Main Road Junction - Alur Venkata Rao Road

- Connecting Corridor-1 : This corridor creates connectivity between North-South corridor and Sarjapura road, corridor starts at St. John's Hospital and ends at Agara on ORR via Jakkasandra - Madiwala Market Junction - Koramangala 100 Feet Road Junction

- Connecting Corridor-2 : This corridor creates connectivity between East-West Corridor-1 and East-West Corridor-2, corridor starts from D'souza circle on Richmond road Junction and ends at Ulsoor Lake via General KS Thimayya Road - Trinity Junction & Ulsoor Lake Junction (connecting East West Corridor-1)

- Connecting Corridor-3: This corridor creates connectivity between St. Johns Church Road and Outer Ring Road (ORR) at Hennur Flyover on ORR. via. Wheeler Road - Lingarajapuram

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E 5   COST ESTIMATE

The project cost estimates have been prepared based on various items of works
required for the construction of the Proposed Elevated Corridors within Bengaluru
Metropolitan Region, Bengaluru for different lane configuration.

The Major items rates for like Steel, Cement, Bitumen, M-Sand, Aggregates, labour and
other items are from PWP IWTD SoR 2018-19, Bangalore Circle, Govt. of India.

E 6   SOCIAL IMPACT OF PROJECT

A social impact assessment (SIA) is a proactive and anticipatory tool used to help, understand
the potential impacts that a proposed project may have on a community. Social Impact
Assessment (SIA) alerts the planners as to the likely benefits and costs of a proposed project,
which may be social and/or economic. The knowledge of these likely impacts in advance will
help decision-makers in deciding whether the project should proceed, or proceed with some
changes, or dropped completely. The most useful outcome of a SIA is to develop mitigation
plans to overcome the potential negative impacts on individuals and communities. As shown
in below Table E-5 & Table E-6.

Table E-3: Additional land requirement

Phase	Length of Project	Land to be acquired in (Ha)				
Nos.	Corridor (km)	Private	State Government	Central Government	Defence	Total
I	32.24	3.56	1.69	0.86	0.00	6.10
II	16.67	3.77	5.81	0.02	0.00	9.59
III	27.95	2.94	0.07	0.70	0.53	4.25
IV	11	2.35	0.00	19.71	0.00	22.06
Total	87.86	12.62	7.57	21.28	0.53	42.01

Table E-4: Affected Buildings

Sl. No.	Phase No.	LHS	RHS	Total
1	Phase 1	13	20	33
2	Phase 2	138	142	280
3	Phase 3	6	6	12
4	Phase 4	8	15	23
5	Phase 5	17	17	34
	Total	182	200	382

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E 7   ENVIRONMENTAL ASPECTS OF PROJECT

Bengaluru's vehicle population has been growing day by day and there has been an uncontrolled growth in number of vehicles leading to choking of city roads with frequent traffic jams. This increase in number of vehicles is adding to the problems of congestion, accidents, noise pollution and air pollution ultimately resulting in loss of productivity, reduced quality of life, and increase in costs for services and goods. As the widening of Bengaluru city roads is not possible due to unavailable right of way, we are only left with the option of going vertical in the form of elevated roads. This concept of elevated roads may provide solution for many of the traffic related problems, separating the cross-city traffic and the neighborhood traffic and providing easy access to different parts of the city. The project is planned based on two traffic directions of the city - North-South and East-West, with interconnecting and loop elevated corridors.

In this context, Government of Karnataka has planned for six elevated corridors to ensure safe, fast and congestion free connectivity to different parts of city. The project constitutes total of six corridors for a length of 92.20 km which includes three major corridors North South Corridor (from Baptist Hospital to Central Silk Board); East-west Corridor - 1 (from Krishna Raj Puram to Yeshwanthpura Flyover); East West Corridor - 2 (from Varthur Kodi to Sirsi Circle) and Connecting Corridors - 1 (St. John's Hospital to Agara on Outer Ring Road), Connecting Corridor - 2 (from Ulsoor to East-West Corridor-2 at D'souza circle) Connecting Corridor – 3 (from East-West Corridor-1 at Wheeler's road Jn. to Hennur Flyover at Outer Ring Road) which are considered as major traffic corridors in the city. The proposed project will be implemented in three phases.

The main objective of the Environmental Impact Assessment is to identify the impact of the elevated corridor project on environment, and to ensure these environmental factors are considered in decision making. The assessment helps to alleviate the impacts either by avoiding the development proposals or by proposing mitigation and management measures.

Elevated corridors do not have mention in the list of projects qualifying for environmental clearance as per EIA Notification and its amendments. Considering elevated corridors as a part of national and state highways which do have mention in the schedule of Notification, neither total length of the elevated corridor do not exceed 100 km nor involve additional right of way or land acquisition greater than 40 m on the existing alignments. On the other hand, buildings and construction projects which are open to sky and has activity area spread equal to or more area than 20,000 sqm are qualified to be considered for environmental clearance and there is a possibility for considering elevated corridor projects under construction projects as per schedule 8A of EIA Notification.

The proposed elevated corridor project will have both negative and positive impacts on the environment. Significant adverse impact will be on avenue trees along the proposed corridor alignment. It is estimated that approximately 3800 trees are to be cut and around 2000 are to be trimmed. The other significant adverse impacts from the proposed project will be deterioration of air quality from construction activities and its impact on air sensitive receptors; increase in noise levels and its impact on noise sensitive receptors like schools, colleges, hospitals due to construction equipment and activities, disturbances to city traffic due to traffic diversions; land use changes by land acquisition to accommodate the traffic lanes along the corridor, at ramps and proposed grade separators; impact on nearby water bodies

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during construction; transportation and disposal of unserviceable debris generated from excavations and structure demolition and impact on the livelihood, public services, health and safety of community in the vicinity and labourers during construction of the project.

Most of identified adverse impacts of the project are temporary in nature and can be mitigated through specific engineering solutions incorporated into the project design; construction methodology during project implementation and the remedial measures. All the identified significant impacts have been addressed in the form of Environmental Management Plan with a budgetary provision of 56.32 crores for impact mitigation and environmental enhancement measures.

Proposed project will have advantages like the connectivity to major arterial roads like Bellari road, Hosur road, Hoskote road, Tumkur road, Mysore road, Sarjapura road; help segregating the fast moving long distance traffic without interrupting the slow moving neighbourhood traffic; elevated roads will decongest most of the major junctions and make way for traffic movement without hindrance thus emitting less air pollutants and facilitate pedestrians to use at grade roads more safely.

Further, with the current phenomenal growing rate of vehicle population and the absence of adequate public transport system, which is ultimately leading to traffic chaos, Bengaluru city surely needs a comprehensive, integrated and sustainable transportation infrastructure which gives a boost to productivity, improved quality of life.

CHAPTER – 1

PROJECT BACKGROUND

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CHAPTER 1 : PROJECT BACKGROUND

1.1 INTRODUCTION

Bengaluru (Earlier called "Bangalore") city is the capital of Karnataka State and is the IT capital of India. The city is distinct in its nature because of its climate, terrain and peace loving people, the city attracts enormous people from all corners of India making it the most cosmopolitan city in India. The city is the third most populous city & fifth largest Metropolis in India as well as 18th most populous City in the World making it the most sought after cities in India by people, companies and multinationals. The massive growth that the city has witnessed in the last two decades has brought the city to fame but also caused severe strain due to grossly inadequate infrastructure in all fronts.

The growth of city has resulted in rapid increase of population, at 8.4 Million in 2011 census; the city is 3rd most populous city in the country. The population has grown at a rate of over 48% in the last decade. With that rate, the population at present (year 2017) is around 11.98 Million and projected to 13 Million by 2020.

Bengaluru is endowed with a radial pattern of road network converging in the core area of the city. As per CTTP report-2011, the total road network of the city is over 4000 km of which arterial/sub-arterial roads account for about 350 km. The road network in the central parts of the city has developed organically over the last few centuries and has inadequate Right-of-Way. The existing Ring Roads (CRR-30 kms, ORR-62 Km) which cuts across the various radial roads creating vast number of bottle necks. Also, a fractured Intermediate Ring Road has been constructed in fragments at south-eastern part of the city between Koramangala and Old Airport Road.

Following are the National Highways & State Highways (which traverse through Bengaluru city and have since become major arterial roads of the city.

    a. Tumkur Road (NH 48)

    b. Bellary Road (NH 44)

    c. Old Madras Road (NH 48)

    d. Sarjapur Main Road (SH 35)

    e. Hosur Road / Electronic City Road (NH 44)

    f. Bannerghatta Road (SH-87)

    g. Old Kanakapura Main Road (NH 209)

    h. Mysore Road (NH-275)

    i. Magadi Road (SH 85)

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The above listed nine arterial roads are the lifelines for through traffic as well as intra city movement of traffic. With ever increasing traffic in the city, these roads have reached beyond their capacities and suffer heavy traffic congestion and traffic jam conditions most part of the day.

Since terrain of Bengaluru is plain and accessible at all sides, the city has developed laterally and spread on all directions. This spread has resulted in taking longer commuting distances to cross city from one side to other. At present, the city has spread to about 40 km of radius with International airport located at Devanahalli, which is on the north Bengaluru and 60 kms away from electronic city situated in Southern most part of Bangalore and similarly 40Kms away from IT Park & Export promotion Industrial Park (EPIP) in White field in Eastern part of Bangalore where the maximum concentration of IT firms and supporting service industries are located inducing crisscross movement of traffic across the City throughout the day and night.

High volumes of traffic and congested roads have resulted in very high ratio of Volume to capacity of Roads (V/C ratio), which is as high as 4 in most of the roads. As per IRC, the V/C ratio shall be 0.6 for city roads and more than 1 means the roads are in worst level of service.

The Comprehensive Traffic and Transportation Plan (CTTP) for Bengaluru city, prepared in year 2011 have found the following among many other issues.

— Road network capacity is grossly inadequate. Most of the major roads are with four lanes or less with little scope of their widening. This indicates the need for judicious use of available road space.

— V/C ratios on most of the roads are more than 1. Overall average traffic speed is about 13.5 Kmph in peak hours. This not only indicates the need of widening of the roads but the also the need to plan high capacity mass transport systems on many corridors.

— Outer cordon surveys indicate high through traffic to the city. These points to the need of road bypasses not only for BMA but also for BMRDA area. High volume goods traffic also indicates the need of truck terminals at the periphery of the city.

— 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 is likely to have a major impact on traffic demand. Taking into consideration the huge potential for further development of Bangalore, The Integrated transport network including Grade separated Intersections at all major road intersections, Elevated corridors, Mass transport system like Metro rails along all arterial roads / Ring Roads connected with feeder Mono rails along Sub arterial roads needs to be planned .

CH-1: Project Background   1-2

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The solution to the problems mentioned above is to reduce the traffic on roads either by policy implementation on restriction of usage of vehicles, providing mass transport facilities, feeder line connectivity and last mile connectivity which encourage people to shift from private mode to public transport, encourage usage of walking and also by capacity augmentation by building wider roads and Elevated corridors that are fast, efficient and safe.

Reducing vehicles on roads by policy or through encouragement is possible only when the cities are built though long term planning and have a ceiling on population. Since our cities are neither planned on long term nor have a ceiling limit on population, it's not possible to save cities without going for a massive capacity augmentation by adding wider, fast & safe roads which are sustainable for longer durations. Since widening of roads is not possible due to non-availability of road right of way (ROW) widths, the next inevitable solution is to build road over roads, i.e., elevated roads on existing major roads as part of capacity augmentation.

In view of the above, the Govt. of Karnataka (GoK) has planned to construct elevated corridors connecting North-South and East-West parts of the city to ensure smooth and hassle free connectivity within the city and outskirts of the city. The project was announced by GoK in year 2015 and further included in the budged speech of Ho. CM for the year 2016-17.

Further to this, The Government of Karnataka (GOK), through Karnataka Road Development Corporation Limited (KRDCL) vide their letter no: KRDCL/CE-EE2/EC/LOA//2015-16/-3024 dated 30 Jan2016 has appointed M/s AECOM Asia Company Limited in Association with M/s Deloitte Touché Tohmatcu India private limited and M/s Infra Support Engineering Consultants Pvt. Ltd as technical consultant for "Consultancy Services for Preparation of Detailed Feasibility Report for the Construction of Proposed Elevated Corridors within Bengaluru Metropolitan Region, Bengaluru" aimed to alleviate congestion and provide unhindered travel along the Proposed Corridors that will contribute to savings in travel time, vehicle operating cost, improve road safety and minimize carbon emissions resulting in overall economic growth. Following road sections in Table 1-1 are proposed to be developed with Elevated Corridors.

Table 1-1: List of Project Corridors (as per ToR)

Name of the Corridor	Approx. Length (in Km)
NS-1: North-South Corridor-1 connecting Hebbal to Central Silk Board (i.e., NH-7 towards Bellary to NH-7 towards Hosur)	18.10
EW-1: East-West Corridor-1 connecting K.R. Puram to Gorguntepalya (i.e., NH-4 towards Old Madras and NH-4 towards Tumkur Road)	19.70
EW-2: East-West Corridor-2 connecting Varthur Kodi to Jnanabharathi (Old Airport Road, SH-35 to Mysore Road, SH-17)	27.70
CC-1: Connecting Corridor-1 Connecting East-West Corridor-2 at Kalasipalya to Agara on Outer Ring Road	9.20
CC-2: Connecting Corridor-2 Connecting East-West Corridor-1 at Ulsoor to East-West Corridor-2 at D'souza circle.	2.30
CC-3: Connecting Corridor-3 Connecting East-West Corridor-1 at Wheeler's road jn.to Kalyan Nagar at Outer Ring Road	5.70
Total length	82.70

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1.2   Design length

Consultants have studied the project corridors as given in ToR, traffic movement along these corridors and the influence area of the project corridors assigned for the development and other planned /ongoing projects within the BMRDA region. Based on the study, consultants have proposed few changes in alignment, additional links for effective traffic movement, better connectivity between project corridors and CBD area, important commercial employment generation areas, interstate public transport origin, destination points and other important places. Based on the above mentioned study the revised road network proposed for development of Elevated corridors is furnished in Table 1-2 below:

Table 1-2: List of Revised Project Corridors

SI No.	Name of the Corridor	Lane Configuration	Length (Km)
1	NS-1: North-South Corridor-1 connecting Baptist Hospital to Central Silk Board (i.e., NH-44 towards Bellary to NH-44 towards Hosur)	6 Lane	27.79
2	EW-1: East-West Corridor-1 connecting RMZ to Yeshwanthpura Flyover (i.e., NH-48 towards Old Madras and NH-48 towards Tumkur Road)	4 Lane with paved shoulder	12.47
3	EW-2: East-West Corridor-2 connecting Varthur Kodi to Sirsi Circle (Old Airport Road, SH-35 to Mysore Road, NH-275)	4 Lane	24.80
4	CC-1: Connecting Corridor-1 Connecting North-South at St. John's Hospital Junction to Agara on Outer Ring Road	4 Lane	4.45
5	CC-2: Connecting Corridor-2 Connecting East-West Corridor-1 at Ulsoor to East-West Corridor-2 at D'souza circle.	4 Lane	3.15
6	CC-3: Connecting Corridor-3 Connecting East-West Corridor-1 at Wheeler's road jn.to Hennur Flyover at Outer Ring Road	4 Lane	4.2
7	EW-1 Additional Corridor from Rammurthy Nagar (Ring road) to ITPL Stretch	4 Lane	11
TOTAL LENGTH			87.86

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1.3   OBJECTIVE OF THE PROJECT

The objective of this consultancy Services is to assist KRDCL in developing Feasibility Study along with commercial analysis to identify preferred procurement route, establish financing mechanisms keeping in mind fiscal constraints, etc. The project is aimed to alleviate congestion and provide unhindered travel along the Proposed Corridors that will contribute to savings in travel time, vehicle operating cost, improve road safety and minimize carbon emissions resulting in overall economic growth.

The specific objective, however, is to prepare Feasibility Study and Preliminary Engineering Design that will demonstrate the bankable feasibility of the project from traffic, technical, economic, social, environmental and financial angles leading to preparation of detailed engineering design, tender documentation and project procurement plan. Also the assignment is expected to provide the required technical services to KRDCL in project implementation and contract execution during construction of the elevated highway corridor:

1.4   SCOPE OF THE PROJECT

The broad scope of work encompasses (a) Feasibility Study and (b) Preliminary Engineering Design. Following is the brief scope of work as extracted from the RFP Document.

1.4.1   Feasibility Study

1.   The aim of the Feasibility Study is to prepare an implementable report relating to technical, economic, social, environmental and financial appraisal of the proposed development of elevated highway corridor. The Feasibility Study should evaluate if there is any need to propose alternate alignment with clear justifications, particularly in light of the existing establishments in the area.

2.   While studying the alignment, the Consultant should examine the Master Plan and Comprehensive Transport Plan, if any, prepared in order to integrate the alignment with future transport network development. In this regard, special attention shall be given to the possibility of developing monorail and or metro along the Corridor. The Consultant shall also explore the possibility of developing multi-level highways or provisioning thereof, particularly for meeting future expansion needs.

3.   Another aspect that requires special consideration is to propose multilevel grade separators at intersections where multi-modal development will have impact on the traffic flow along the Corridor, keeping in view the adjacent land use.

4.   At the feasibility stage traffic and transport planning shall assume significance. Therefore, all required traffic and travel surveys shall be carried out to establish the base year traffic flow characteristics. Based on the flow pattern and socio-economic conditions, future

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traffic demand shall be estimated by using appropriate transport demand models. Similarly, various engineering surveys will have to be conducted to generate all required design values for engineering design.

5. Environmental Impact Assessment and Mitigation measures shall be carefully studied by consultant to apply and obtain all necessary clearance for the project which aims at decongestion of traffic in the metro city and minimize pollution levels with ease and safe movement of traffic.

6. Using VOC sub-model of HDM-IV economic evaluation should be carried out. The financial analysis should not only establish the financial feasibility but also the most optimal funding mechanism. While evaluating the economic and financial feasibility, the impact of competing corridors should be kept in view as there may be proposals to widen competing corridors, which might reduce the through traffic potential of the proposed elevated highway.

1.4.2   Feasibility Study cum Preliminary Engineering Design

1. The Feasibility Study will contain results of all the surveys envisaged along with design, cost, etc in conclusive manner. Thus Feasibility Study cum Preliminary Design is a comprehensive document in all respect based on which the next stage of detailed engineering design and tender documentation can be carried out. Feasibility Study will also contain project implementation mechanism, time schedules and proposed tendering procedure under project procurement plan, which shall also include proposals for contract packages.

2. As a part of Final Feasibility Report, the Consultant will conduct Preliminary Engineering Design of all aspects of the project as per relevant design code of practice as applicable in India and adopt international design standards if necessary. The preliminary engineering drawings will be prepared for all geometric, both horizontal and vertical of the elevated highway. It should be noted that proposals for drainage and utility shall be integrated with the existing facilities.

1.5   DETAILED TASKS

- General Scope of Services shall cover but shall not be limited to the following major tasks:

- Review of all available reports and published information about the project road and the project influence area.

- Environmental and social impact assessment, including impact on cultural properties, natural habitats, involuntary resettlement etc.

- Public consultation, including consultation with Communities located along the road, NGOs working in the area, other stake-holders and relevant Govt. departments at all the

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different stages of assignment (such as inception stage, feasibility stage, preliminary design stage and once final designs are concretized).

- Detailed reconnaissance; Identification of possible improvements in the existing alignment and bypassing congested locations with alternatives, evaluation of different alternatives comparison on techno-economic and other considerations and recommendations regarding most appropriate option;

- Traffic studies including traffic surveys and demand forecasting for next thirty years;

- Inventory and condition surveys for existing roads along the project corridors;

- Inventory and condition surveys for bridges, cross-drainage structures and drainage provisions;

- Detailed topographic surveys using Total Stations and GPS;

- Pavement investigations;

- Sub-grade characteristics and strength: investigation of required sub-grade and sub-soil characteristics and strength for road design and sub soil investigation;

- Identification of sources of construction materials;

- Preliminary design of Elevated road, its x-sections, horizontal and vertical alignment. Preliminary design of Elevated Road Structure including preparation of GAD and cross-drainage structures including rehabilitation of existing bridges and underpasses etc

- Identification of the type and the design of interchanges;

- Design of complete drainage system and disposal point for storm water

- Value analysis / value engineering and project costing;

- Economic and financial analyses;

- Contract packaging and implementation schedule. Strip plan indicating proposed improvement proposal, location of all existing utility services (both over- and underground) and the scheme for their relocation, trees to be felled and planted and land acquisition requirements including schedule for LA: reports documents and drawings arrangement of estimates for cutting of trees and shifting of utilities from the concerned department;

- Financial viability of project

- Procurement option analysis and recommendations for the project

- Financing study with detailed options of financing available to develop the project keeping due consideration to public finance constraints.

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- Preparation of Detailed Feasibility Report, Preliminary Engineering Design, rate analysis and Preliminary cost estimate as per current applicable PWD SoR; for the items not available in PWD SoR rates as per NHSR may be adopted.

- Design of toll plaza (if any) and identification of their numbers and location and office cum residential complex including working drawings.

- Due to proposed improvement proposal in congested urban location, for the kind of traffic to be treated, if tolling option not feasible, alternative revenue generation to be studied and proposed backed up with necessary financial analysis

- Any other user oriented facility enroute toll facility.

- Tie-in of on-going/sanctioned works of State Highways/other agencies.

1.6   STRUCTURE OF THE REPORT

The Final Feasibility Report has been structured as follows.

Volume I: Main Report

Volume I – Main Report
Executive Summary
Chapter 1   : Project back ground
Chapter 2   : Social analysis of the project
Chapter 3   : Surveys and investigations carried out and Interpretation of data
Chapter 4   : Traffic studies and demand forecast
Chapter 5   : Designs Proposals (Geometric, Pavement and Structure)
Chapter 6   : Environmental Aspects
Chapter 7   : Social Impact and RAP
Chapter 8   : Cost Estimation
Volume II - Design Report
Chapter 1   : Design standards
Chapter 2   : Geometric design
Chapter 3   : Pavement design
Chapter 4   : Elevated structure design
Volume III –Material Report
Volume IV – EIA & EMP, SIA & RAP
Volume V   – Technical Specifications
Volume VI – Drawings

CHAPTER – 2

SOCIAL ANALYSIS OF PROJECT

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CHAPTER 2 : SOCIAL ANALYSIS OF PROJECT

2.1   BACKGROUND

This chapter contains the socio-economic profile of Bangalore city along with profile of the State of Karnataka as well as the project-impacted district for the purpose of providing a contextual background to understand the social impacts of the proposed project. The remaining information has been provided as a supplement for the contextual background.

2.2   DELINEATION OF PROJECT INFLUENCE AREA (PIA)

As it is experienced, Development of any infrastructure project always influences the major part of influence area through which it passes, brings in multidimensional growth, prosperity due to increased economic activities through safer and faster accessibility of the corridor.

The project connects six important locations of the Bengaluru City; NS-1 : North-South Corridor-1 connecting Baptist Hospital to Central Silk Board (i.e., NH-7 towards Bellary to NH-7 towards Hosur), EW-1 : East-West Corridor-1 connecting RMZ to Yeshwanthpura Flyover (i.e., NH-4 towards Old Madras Road and NH-4 Tumkur Road), EW-2 : East-West Corridor-2 connecting Varthur Kodi on SH-35 to Sirsi Circle on Mysore road , CC-1 : Connecting Corridor-1 Connecting North-South Corridor at St. John's Hospital Junction to Agara on Outer Ring Road, CC-2 : Connecting Corridor-2 Connecting East-West Corridor-1 at Ulsoor to East-West Corridor-2 at D 'Souza Circle and CC-3 : Connecting Corridor-3 Connecting East-West Corridor-1 at Wheeler's Road Junction to Hennur Flyover on Outer Ring Road and EW-1 Additional Corridor from Rammurthy Nagar(Ring road) to ITPL Stretch.

The existing routes along which the elevated corridors are envisaged to be built are the major arterial roads in the city which are connecting the Central Business District (CBD) areas in the city.

From the Socio –Economic point of view, the project influence area covers the entire Bengaluru City.

2.3   PROJECT STATE

The State of Karnataka is located within 11.5 degree North and 18.5 degree North latitudes and 74 degree East and 78.5 degree east longitude. It is situated on a table land where the Western and Eastern Ghat ranges converge into the Nilgiri hill complex, in the Western part of the Deccan Peninsular region of India. The

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Karnataka State is bounded by Maharashtra and Goa States in the North; by the Arabian Sea in the West; by Kerala and Tamilnadu States in the South and by the States of Telangana and Andhra Pradesh in the East. Karnataka extends to about 750 km from North to South and about 400 km from East to West. The State has a total land area of 1,91,791 sq.km, accounting for 5.83% of the total area of the country (32.88 lakh sq. km) and ranks eighth among major States in terms of size. Karnataka State has been divided into four Revenue divisions, 49 sub-divisions, 30 districts, 177 taluks for administrative purposes: Bengaluru Division, Mysore Division, Belgaum Division and Gulbarga Division. Bengaluru, the capital of the State and is the sixth largest urban agglomeration out of 23 metropolis, urban agglomerations and cities in India.

2.3.1   Demographic Profile of Karnataka State

Karnataka, India's eighth largest state in terms of geographical area (191791 sq.km) is home to 6.11 crore people (2011 Census) accounting for 5.05% of India's population. The state's population has grown by 15.7% during the last decade, while its population density has risen from 276 in 2001 to 319 in 2011, indicating an increase of about 15.6%. Sex Ratio in urban regions of Karnataka was 963 females per 1000 males. For child (0-6) sex ratio the figure for urban region stood at 946 girls per 1000 boys. Total children (0-6 age) living in urban areas of Karnataka were 2,643,388. Of total population in urban region, 11.19 % were children (0-6). Out of total population of Karnataka, 38.67% people live in urban regions. The total figure of population living in urban areas is 23,625,962 of which 12,037,303 are males and while remaining 11,588,659 are females. The urban population in the last 10 years has increased by 38.67 percent. Salient demographic features of the state of Karnataka are presented in Table 2-1 and Table 2-2.

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Table 2-1: Demographic Profile of Karnataka State

Sl.No.	Particulars	Details
1	Area (2011 census)	1,91,791 sq. km.
2	Population (2011 census)	61,095,297
3	Decadal Growth (Census 2011)	15.60
4	Male	30,966,657
5	Female	30,128,640
6	Sex Ratio (Census 2011)	973
7	Population density per sq. km. (2011)	319
8	Literacy (in %)	75.36
9	No. of Districts	30
10	No. of Talukas	177
11	No. Towns	347
12	Inhabited Villages	27397
13	Uninhabited Villages	1943
14	Municipal Corporations	219
15	Scheduled Caste Population (in %)	17.15
16	Scheduled Tribe Population (in %)	6.95
17	Urban Population	23,625,962
18	Rural Population	37,469,335

*As per Census 2011.

Table 2-2: Social and Economic Indicators in Karnataka State

Sl. No	Particulars	Details Sample survey-2006
1	Literacy rates	75.36%
2	Literacy rates Males	82.47
3	Female Literacy Rate	68.08
4	Crude Birth Rate	18.3
5	Crude Death Rate	7.0
6	Total fertility rate	1.9
7	Infant Mortality rate	31.0
8	Maternal Mortality Ratio	144
9	HDI	0.508

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The Literacy rate of Karnataka is 75.36% which is higher than the India average of 74.04%. There are 60,913 Elementary schools of which 26,118 are Lower Primary schools, 34,795 are Upper Primary schools. The State has a total of 15140 secondary schools of which 4659 schools are run by the DoE, 566 SW and LB schools, 3818 by aided managements, and 6013 by private unaided managements and 84 by others.

2.3.2   Employment Pattern

According to Census 2011, the Work Participation Rate (WPR) is defined as the proportion of total workers (i.e. main and marginal workers) to total population. In the State, 2,78,72,597 persons constituting 45.62% of the total population have enumerated themselves as workers. Among them, 1,82,70,116 are males and 96,02,481 are females. Of the total 2,78,72,597 workers in the State, 2,33,97,181 persons, constituting 83.94% of the total workers, are main workers and 44,75,416 persons, constituting 16.06% are marginal workers. The proportion of main workers has marginally increased from 82.28% in 2001 to 83.94% in 2011.

A major proportion of workers in the state, 47.44%, belongs to "Other" category, which is higher than the national average (37.6%) Compared to the national average of 31.6%, only 23.61% workers are involved in cultivation in Karnataka has decreased from 2001, where it was 29.25%. (*As per Census 2011)

Government has guaranteed unskilled employment in rural areas subject to certain conditions. Under UPSS approach, UR of Karnataka is 1.7% for all persons i.e., urban and rural put together which is very less compared to India's rate of 3.4%. In Karnataka, in rural areas unemployment rate is 1.3% for males and 2% for females. Whereas, in urban areas, for males it is 1.5% and for females, it is 3.1%. At all India level, for males in rural areas it is 2.7% and for females 3.4%.

2.3.3   Economy

The economic uncertainty in agriculture and allied activities sector continued during the current year as the south-west monsoon was delayed and was below average. The main driving forces of the economy viz. manufacturing and service sectors were badly affected by the global economic slowdown. Horticulture sector has emerged as an important component of the economy of our State and has contributed more than one third share to the economy of agriculture and allied sectors.

The Gross State Domestic Product (State Income) Estimates have undergone a facelift with regard to the shift in their base year from 2004-05 to 2011-12 following the method adopted by the Central Statistics Office which too has released the new series at Market Prices. GSDP, with 2004-05 as base was being complied at "factor-cost". However, in the new series i.e. 2011-12 as base year, the GSDP estimates are

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being prepared at Market Prices. As such, statistical comparisons between the old and new base year cannot be drawn for GSDP from 2011-12 onwards. A brief introduction about the changes insources and methodology to compute the GSDP in the revised new base year is presented in this chapter.

Per Capita State Income (i.e. per capita NSDP) of Karnataka at current prices is estimated at Rs.145799 during 2015-16 as against Rs.130897 in 2014-15 with an increase of 11.4%. The Per Capita National Income is expected to reachRs.93231 during 2015-16 from Rs.86879 during 2014-15 with an increase of 7.3%. The level of per capita income at constant (2011-12) prices for the year 2015-16 is estimated to reach Rs.110624 as compared to Rs.105350 achieved in 2014-15.

The estimates of Net State Domestic Product (NSDP) are derived from the Gross State Domestic Product (GSDP) by deducting Consumption of Fixed Capital (CFC) or Depreciation. The estimated NSDP at constant (2011-12) prices is Rs.710215 crore in 2015-16 compared to Rs.669078 crore in 2014-15, showing a growth of 6.1% in 2015-16 against 7.8% during 2014-15. Agriculture & allied activities, industry and service sectors are expected to register a growth of -5.6%, 4.5% and 9.1% respectively in 2015-16.
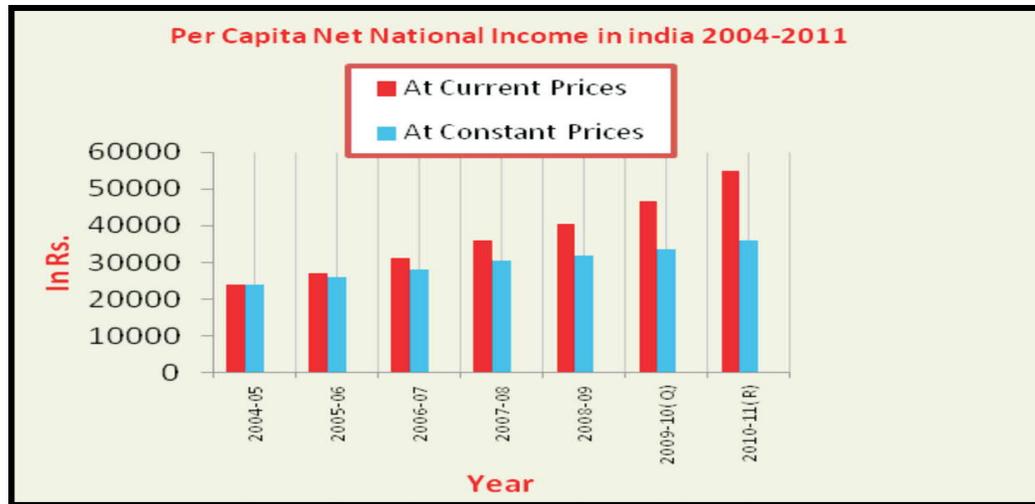
Figure 2-1: Per Capita Net National Income

The Gross State Domestic Product (GSDP) Estimates of Karnataka State with 2011-12 as new base year, replacing 2004-05, will be released during this year. In the earlier series (with 2004-05 as base year), the GSDP estimates were presented at factor cost only. However, in the new series, with 2011-12 as base year, the GSDP estimates are at market prices. Advance estimates show that Karnataka's GSDP at constant (2011-12) prices is expected to grow at 6.2% and reach Rs.780805 crore in 2015-16.

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The growth of agriculture and allied sector is expected to show a decline of 4.7% in 2015- 16 as against a growth of 1.6 % during 2014- 15. This is due to the fall in production of food grains from 122.6 lakh tonne during 2014-15 to 110 lakh tonne (expected) during 2015-16 because of drought conditions in 136 taluks in Kharif and 62 taluks in Rabi. The industry sector (comprising mining & quarrying, manufacturing, construction and electricity, gas & water supply) is expected to grow by 4.5% in 2015-16 as against a growth of 4.7 % during 2014-15.

(Source: Karnataka Economic Survey)

2.3.4 Sectoral Composition of the State Income

A perceptible decrease is evident in the composition of GSDP of agriculture & allied activities and industry sector from 13.4% and 24.8% in 2014-15 to 12.3% and 23.6% in 2015-16 respectively. At the same time, a small but significant increase in the composition of the service sector from 61.8% to 64.1% is apparent. During the last few years, the services sector has been the largest component of GSDP. The composition of 'Real estate, Professional Services & Ownership of Dwellings' is highest with 32.8% in 2015-16. This is followed by Manufacturing (14.6%), Trade and Repair Services (9.2%) and Crops (8.7%).

The GSVA growth under Agriculture and allied sector is expected to fall to -4.7% during 2015-16 as compared to the growth of 1.6% during 2014-15. Industry sector (comprising Mining & Quarrying, Manufacturing, Construction and Electricity, Gas, Water Supply and Remediation Services) is estimated to decrease marginally to reach 4.5% during 2015-16, compared to a growth of 4.7% during 2014-15.

2.3.5 Agriculture

As per the land utilization statistics for 2013-14, out of the total 190.50 lakh hectare geographical area of the State, the net cropped area was 99.23 lakh hectare accounting to 52% of the total geographical area. Gross cropped area was 122.67 lakh hectare including 23.44 lakh hectare area sown more than once, this works out to 124% cropping intensity. Around 16% of the area was covered under forests, 8% area was under non-agricultural uses, 4% land was barren and uncultivable land and 2% land was cultivable waste. Permanent pastures, grazing land and miscellaneous tree crops constituted 6% of the total geographical area. About 12% of the total area falls under current fallow and other fallow land. The decrease in current fallow over the previous year was on account of better rainfall distribution.

2010-11 Agriculture Census shows 78.32 lakh farm holdings operating 121.61 lakh hectares. Small and marginal holdings account for 76.44% of total holdings and operate only 40.05% of the total operated area, while semi-medium, medium and

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large holdings account for 23.57% of the total holdings and their operational land holding is 59.95% out of the total operational area. Karnataka State falls in Zone X (Southern Plateau and Hilly region) and Zone XII (West Coast Plains and Ghats region) as per the Agro-climatic Regional Planning of Planning Commission. The State is divided into 10 Agro-climatic zones on the basis of distribution and percentage of Rain fall, soil quality, height from the sea and on the basis of major crops.

On account of this varied agro-climatic features almost all cereals, pulses, oilseeds and commercial crops are cultivated in different parts of the State. Farmers in Karnataka are very innovative and take lead in diversification as per the market trends. The average area under agricultural crops grown in three seasons viz. Kharif (69.20 lakh ha.), Rabi (30.30 lakh ha.) & summer (5.90 lakh ha.) is 105.40 lakh hectares. Cereals, Pulses, Oilseeds, Cotton, Sugarcane and Tobacco account for 49%, 24%, 15%, 6%, 5% and 1% respectively of the total agricultural cropped area.

Karnataka has a potential and plenty of scope to grow various horticulture crops. Horticulture sector has emerged as an important component of the economy of our State and has contributed more than one third share to the economy of agriculture and allied sectors. In many dry regions of the State, Horticultural crops have evolved as an alternative crop to agricultural crops. Currently, Horticulture crops covers an area of 19.22 lakh Hectares and the annual production is 162.57 lakh Metric Tons. The average Productivity of Horticultural crops in the state is 8.46 Metric Tons per Hectare. The annual value of Horticultural products produced in the state is Rs.35307.00 crores and constitutes 40.25% of the total income from entire agriculture sector. The share of Horticultural produces in total GSDP of the state is 5.74%.

(Source: Karnataka Economic Survey)

2.3.6 Industries

Industries play an important role in the economic development of the state. Karnataka has been driving force in the growth of Indian industry, particularly in terms of high-technology industries in the areas of electrical and electronics, information & communication technology (ICT), biotechnology and, more recently, nanotechnology. The industrial structure of Karnataka presents a blend of modern high-tech capital goods and knowledge intensive industries on the one hand and traditional consumer goods industries on the other.

The general index of industrial production (IIP) of Karnataka covering mining, manufacturing and electricity sectors for 2014-15 stood at 181.15. The overall organized industrial sector of Karnataka has registered 2.06% growth in 2014-15 as

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compared to 2013-14. Within the organized industrial sector, Manufacturing sector recorded highest growth of 2.93% followed by the electricity sector (1.91%) and mining sector registered negative growth of (-26.16%). Contraction in mining activities and deceleration in manufacturing output moderate growth was observed in industrial sector.

2.4 BANGALURU DISTRICT PROFILE

2.4.1 Geographical Location

Bengaluru District is located in the South-Eastern part of Karnataka State. Spanning a Geographical area of 2,196 sq km, the district lies stretched between the latitudinal parallels of 12º39′ N and 13º18′ N on the one hand and the longitudinal meridians of 77º22′ E and 77º52′ E on the other. It is surrounded by the Bengaluru Rural district on the east and north, the Ramanagara district on the west and the Krishnagiri district of Tamil Nadu on the south. Bangalore Urban district came into being in 1986, with the partition of the erstwhile Bangalore into Bangalore Urban and Bangalore Rural districts.

Bengaluru is the Capital city of Karnataka State, Country's leading IT exporter it is the 4th largest technological hub in the world and largest in Asia. World Economic Forum identified Bengaluru as the Innovation Cluster and as the fastest growing major metropolis in the country with an economic growth of 10.3%. Located on Deccan Plateau in the South Eastern part of Karnataka, Bengaluru possesses world class infrastructure in housing, education & research. Bengaluru is teeming with restaurants, clubs, pubs, health spas, amusement parks, supermarkets, theatres, cinemas, shopping malls, discotheques and other necessities of a modern-day metropolitan lifestyle.

Currently in Bengaluru Urban district, there are 2 divisions, 4 Talukas, 17 hoblies, 699 revenue villages, 1 Nagar Nigam, 19 Nagar Palika and 86 Gram Panchayats. Proximity to Bengaluru city will have its own impact on the district, with sizable daily commuting population as the taluks are well connected by road and rail.

In 2011, Bengaluru had population of 9,621,551 of which male and female were 5,022,661 and 4,598,890 respectively. Sex Ratio in Bengaluru, stood at 916 per 1000 male compared to 2001 census figure of 908. Bengaluru District population constituted 15.75 percent of total Karnataka population. Population density has risen by 47.18 percent as compared to the population as per 2001. Details shown in below Table 2-3.

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Table 2-3: Bengaluru District at a Glance

Description	2011
Actual Population	9,621,551
Male	5,022,661
Female	4,598,890
Population Growth	47.18%
Area Sq. Km	2,196
Density/km2	4,381
Sex Ratio (Per 1000)	916
Child Sex Ratio (0-6 Age)	944
Average Literacy	87.67%
Male Literacy	91.01%
Female Literacy	84.01%
Total Child Population (0-6 Age)	1,052,837
Male Population (0-6 Age)	541,656
Female Population (0-6 Age)	511,181
Literates	7,512,276
Male Literates	4,078,041
Female Literates	3,434,235

2.4.2 Transport and Trade Linkages

The Benguluru city is well connected with the capital of country and surrounding
district headquarters through road and rail linkages. The road network consists of
Express Highways, National Highways, State Highways and Major District Roads.
The rail network consists of both broad gauge and meter gauge.

2.4.3 Road network

Bengaluru's road network exceeds 3,000 km (1,800 mi) and consists of ring roads,
arterial roads, sub-arterial roads and residential streets. The city road network is
mainly radial, converging in the centre. The main roads of Bengaluru coming into the
city include Bellary Road in the North, Tumkur Road and Mysore Road in the West,
Kanakpura Road, Bannerghatta Road and Hosur Road in the South and Old Airport
Road and Old Madras Road in the East. Many of Bengaluru's erstwhile colonial and
town streets were developed into commercial and entertainment areas after
Independence. The B.V.K Iyengar Road became the retail hub of Bengaluru, while
MG Road, Commercial Street and Brigade Road became important shopping,
recreation and corporate areas.

The project connects six important locations of the Bengaluru City; NS-1 : North-
South Corridor-1 connecting Baptist Hospital to Central Silk Board (i.e., NH-7

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towards Bellary to NH-7 towards Hosur), EW-1 : East-West Corridor-1 connecting RMZ to Yeshwanthpura Flyover (i.e., NH-4 towards Old Madras Road and NH-4 Tumkur Road), EW-2 : East-West Corridor-2 connecting Varthur Kodi on SH-35 to Sirsi Circle on Mysore road , CC-1 : Connecting Corridor-1 Connecting North-South Corridor at St. John's Hospital Junction to Agara on Outer Ring Road, CC-2 : Connecting Corridor-2 Connecting East-West Corridor-1 at Ulsoor to East-West Corridor-2 at D 'Souza Circle and CC-3 : Connecting Corridor-3 Connecting East-West Corridor-1 at Wheeler's Road Junction to Hennur Flyover on Outer Ring Road and EW-1 Additional Corridor from Rammurthy Nagar(Ring road) to ITPL Stretch.

2.4.4   Rail network

The total railway track length in the district is 148 km. Bengaluru is a divisional headquarters in the South Western Railway zone of the Indian Railways. There are four major railway stations in the city: Kranti veera Sangolli Rayanna Railway Station / Bangalore City Railway station, Bengaluru Cantonment railway station, Yeshwantapur junction and Krishnarajapuram railway station, with railway lines towards Jolarpettai in the east, Chikballapur in the north-east, Guntakal in the north, Tumkur in the northwest, Nelamangala in the west, Mysore in the southwest and Salem in the south.

The Rail Wheel Factory is Asia's second largest manufacturer of wheel and axle for railways and is headquartered in Yelahanka, Bengaluru.

2.4.5   Per Capita Income

The Per Capita Net State Income (i.e. Per Capita NSDP) was estimated at 2,02,340 during 2012-13. The latest Economic Survey (2015–16) of the State government indicates that Bengaluru Urban district contributes 33.6 per cent to the Gross State Domestic Product (GSDP) followed by Dakshina Kannada (5.8 per cent) and Belagavi (4.4 per cent). At the same time, Yadgir (1.04 per cent) and Kodagu (0.89 per cent) occupy the last two places in terms of the district's contribution to the GSDP.

2.4.6   Forest Area

Bengaluru district covers 50.55 km^2 of forests as per Karnataka Forest Dept. Total forest area of the Karnataka state is 38720 km^2. The percentage of Karnataka's forest area in comparison to its geographical area is slightly lower than the all-India average of around 23%. The percentage recommended by the National Forest Policy is 33%.

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2.4.7   Economic Profile of Project Influenced District

Bengaluru is the second fastest-growing major metropolis in India and is also the country's fourth largest fast-moving consumer goods (FMCG) market. Forbes considers Bengaluru one of "The Next Decade's Fastest-Growing Cities". District income is also a measure of the level and growth of economic development at the district level. It is a useful policy indicator to monitor the nature and degree of inter district variations as well as, disparities in the process of economic growth at the State level. A simple statistical indicator of inter-district variations in the levels of district income is coefficient of variation. Figure 2.1 shows these computed values across the four divisions and at the State level.
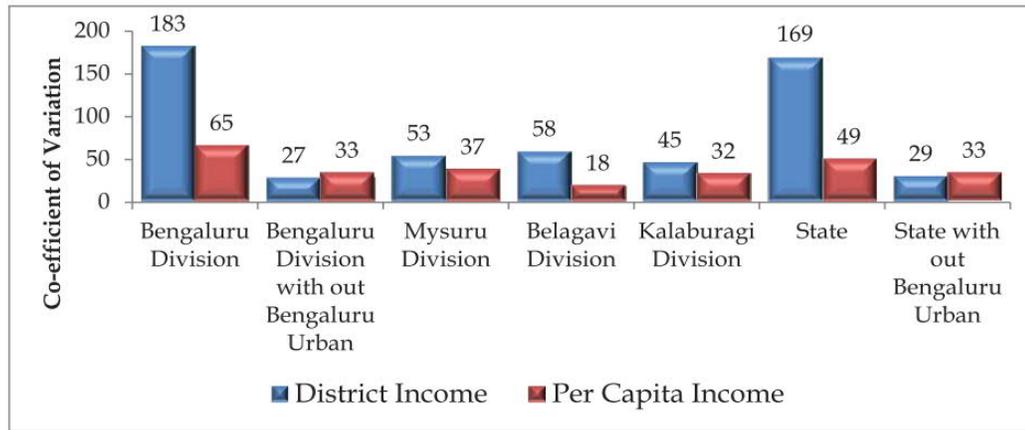
Figure 2-2: Inter-district variations of Gross District Income and Per Capita Income by Divisions in Karnataka for 2012-13

The highest variation is evident with respect to Bengaluru division, if Bengaluru Urban District also included. Excluding Bengaluru Urban, inter-district variations in district income and per capita district income gets remarkably reduced at the division and State level. The growing inter-district variation is an important indicator and source of broader inter-regional disparities in the process of State's economic development. However, a low coefficient of variation as such does not necessarily imply either a higher or lower district economic growth or regional disparity. The major industries in the district are given in Table 2.4 below:

Table 2-4: Industries in Bengaluru District

District	Major Industries
Bengaluru	IT, Bio Technology, Agro based, Cotton textile, silk & artificial Thread based clothes, Wood/wooden based furniture, Paper & Paper products, Leather based, Rubber, Plastic & petro based, Mineral based.

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2.4.8   Tourist Destination in Project Influenced Districts

Table 2-5 indicates the tourist destinations of the district playing a major part in the district economy.

Table 2-5: Places of Interest

Karnataka	Bengaluru
Hampi, Coorg, Gokarna, Anthargange, Nrityagram, Madikeri, Nandi hills, Kudremukh, Bijapur, Mysore, Nagarhole, Shivanasamundram, Davanagere, Kemmanagundi etc.	Bengaluru Palace, Lal Bagh, Bannerghatta National Park, Cubbon Park, Wonder La Water Park, Ulsoor Lake, ISKCON Temple, Jawaharlal Nehru Planetarium

2.5   JUSTIFICATION OF PROJECT IMPACTS AND BENEFITS

The proposed project can be viewed as boosting economic growth and poverty reduction which will bring substantial social and economic development in the region. More importantly the Project improves the mobility of the commuters' in the Benguluru city. The possible direct and indirect positive impacts are listed below. To enhance project benefits for roadside communities and road users, the project design has incorporated the following:

- Provision of Elevated road.
- Separate provision of footpaths Atgrade;
- Provision of anti-crash barriers;
- Effective surface drainage system to ensure that there shall be no pooling of water on the Elevated corridor and Atgrade road;
- Safety measures such as pedestrian rails, barriers, highway signs, pavement marking, traffic signals, landscaping, illumination and road furniture
- Saving in vehicle operating cost
- Time saving freight and passenger movement
- Employment potential – direct employment in road construction and allied activities and greater mobility
- Lower accidents, quick access to services like hospitals, markets, offices etc.

Although various positive impacts and benefits are expected from the proposed project as mentioned above, there will be some negative impacts on title holders and non-title holders such as encroachers and squatters who are living near to the immediate corridor of impacts in terms of loss of land, structures and fresh land acquisition. The project proposal has been made with the criteria of minimum negative social impacts.

CHAPTER – 3

SURVEYS AND INVESTIGATIONS

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CHAPTER 3 :   SURVEYS AND INVESTIGATIONS

3.1   INTRODUCTION

This chapter deals with various surveys and Investigations carried out as per the Terms of Reference and required for quality compliance of the Project design and report preparation.

Various surveys and Investigations carried out are as follows:

- Inventory and condition survey
- Traffic surveys
- Topographic surveys
- Material and Geotechnical Investigations

3.2   INVENTORY AND CONDITION SURVEYS

As per ToR, Road Inventory and Bridges / Flyover structures / CD structures inventory surveys have been conducted. Surveys are conducted as per the standard methodology / IRC guidelines. However brief methodology is given below:

As per the ToR consultants have to propose improvement proposals for the existing roads together with Elevated corridors along the project corridors. Hence, The road and bridge inventory and condition surveys were conducted accordingly.

The road inventory survey involves making visual estimates and actual measurements of geometric and cross sectional elements of the road and its deficiencies. This survey involves the collection of the data pertaining to the existing road such as the width of the road, type of the shoulder and its width, type of terrain, longitudinal and vertical curves, number of CD structures, retaining walls, available land widths, nearby water bodies if any, number of trees, utility services etc. Road inventory has been recorded in a standard format.

The team has travelled and walked along all the alignments and adjacent roads collected first-hand information on the width and type of carriage way, length between consecutive junctions, traffic intensity, width of footpath cum drain and relevant details of Grade separators, Metro Rail crossings and skywalks comprising in the proposed elevated corridor are noted.

The Details of Inventory has been presented in ANNEXURE – 3.01

3.3   TRAFFIC SURVEYS

Traffic surveys are an integral component of any transport study where appreciation of existing traffic and travel characteristics of the study area are extremely important.

Traffic surveys provide information on number and type of vehicles travel on each of the corridor and cross major intersections. Hence, traffic surveys are the very basis of

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assessing the existing traffic, projecting for future and to decide what kind of transportation solutions are to be proposed to meet the future traffic requirements.

At the outset, AECOM has collated available secondary data and data collected from various primary surveys and studies to establish the base line data for the study. The baseline data, apart from helping in understanding the existing traffic and transportation situation along with its problems and constraints, would help in development, calibration and validation of the travel demand forecasting models.

A number of traffic & transportation surveys were conducted as part of the study in order to assess the passenger movement pattern and travel characteristics in the study and adjoining areas.

3.3.1   Secondary Data Collection

Review of previously conducted studies help in understanding the past trend of traffic growth and travel pattern in the region. Some of the major studies carried out in the past and reviewed by the Consultants are:

- Comprehensive Traffic and Transportation Plan For Bangalore, June 2011.
- Detail Project Report Bangalore Metro, March 2003.

3.3.2   Primary Data Collection

As part of data collection, following primary traffic surveys were conducted to appreciate the existing traffic & travel characteristics and to estimate the future traffic demand:

- Classified Traffic Volume Counts (7-day, 24-hours count at stations along the Project Roads; 7-days / 1-day count on other selected links of the network)
- Origin & Destination Survey (1-day, 24-hours)
- Turning Movement Count Survey
- Willingness to Pay Survey

3.3.3   Type and Details of Survey Locations

The type of traffic surveys and methodology of collection and analysis of data has been as per applicable IRC guidelines. The locations where traffic surveys were carried out are shown in the Table 3-1 below.

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Table 3-1: Traffic Surveys and Durations

Sl.No.	Traffic survey	Number of Survey Stations	Survey Extent and Duration
1	Traffic volume Counts (TVC)	11	At mid blocks Continuously for 24 hours x 7 days
2	Turning Movement Counts (TMC)	54	At major intersections Continuously for 24 hours x 1 day
3	Origin and Destination Survey	11	Along mid blocks/ TMC Locations/ 6 Corridors Continuously for 24 hours x 7 days
4	Willingness to Pay Survey	10	200 samples of total interviews at the different O-D survey locations along the corridors.

3.3.4 Classified Traffic Volume Count Survey

The classified traffic volume count surveys were carried out for 7 days (continuous, direction-wise) at the selected survey stations. A total of 11 locations were selected for conducting this survey. The survey was carried out on all the major corridors and outer cordons of the city. The list of the survey locations and schedule is mentioned in Table 3-2.

Table 3-2: Traffic Survey Locations for TVC

Sl. No	Location	Survey	Type of Junction	Date
North - South Corridor (Hebbal to Silk Board)				
1	Near Esteem mall, Hebbal	TVC 01	7 Days TVC	28/04/2016 - 05/05/2016
2	Kasturba Road	TVC 02	7 Days TVC	18/04/2016 - 25/04/2016
3	Before Silk board flyover	TVC 03	7 Days TVC	12/4/2016 - 19/04/2016
East - West Corridor-1 (K R Puram-Yeshwanthpura)				
4	ITC Colony	TVC 01	7 Days TVC	11/4/2016 - 18/04/2016
5	Jayamahal Road	TVC 03	7 Days TVC	18/04/2016 - 25/04/2016
6	CPRI Bus Stop	TVC 04	7 Days TVC	12/4/2016 - 19/04/2016
East - West Corridor-2 (Varthur to Jnanabharathi)				
7	Ramagondanahalli Bus Stop	TVC 01	7 Days TVC	12/4/2016 - 19/04/2016
8	HAL Kalyana Mantap Bus Stop	TVC 02	7 Days TVC	28/04/2016 - 05/05/2016
9	Sirsi circle	TVC 03	7 Days TVC	18/04/2016 - 25/04/2016
Connecting Corridor - 01 (Agara to St. John's Hospital Junction)				
10	Jakkasandra Bus Stop	TVC 01	7 Days TVC	12/4/2016 -

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Sl. No	Location	Survey	Type of Junction	Date
				19/04/2016
Connecting Corridor - 03 (Wheeler's Road to ORR)				
11	Lingarajapuram road			

Average Annual Daily Traffic (AADT) at each of the count station will be presented by total number of vehicles and PCUs.

The following outputs were obtained from the Classified Traffic Volume surveys:

- Average Annual Daily Traffic (AADT)
- Hourly and daily variation of traffic, and peak hour share
- Traffic composition & Traffic intensity on links
- Directional distribution of traffic

Results from the classified volume count surveys has been used for checking the validity of the traffic models in predicting the quantum of traffic along various corridors and highway routes in future. The data has been used further to evaluate prevailing level of service on the network and also for validating the assignment model. The model calibrated will be used for future traffic projections. Details as shown in below Figure 3-1.
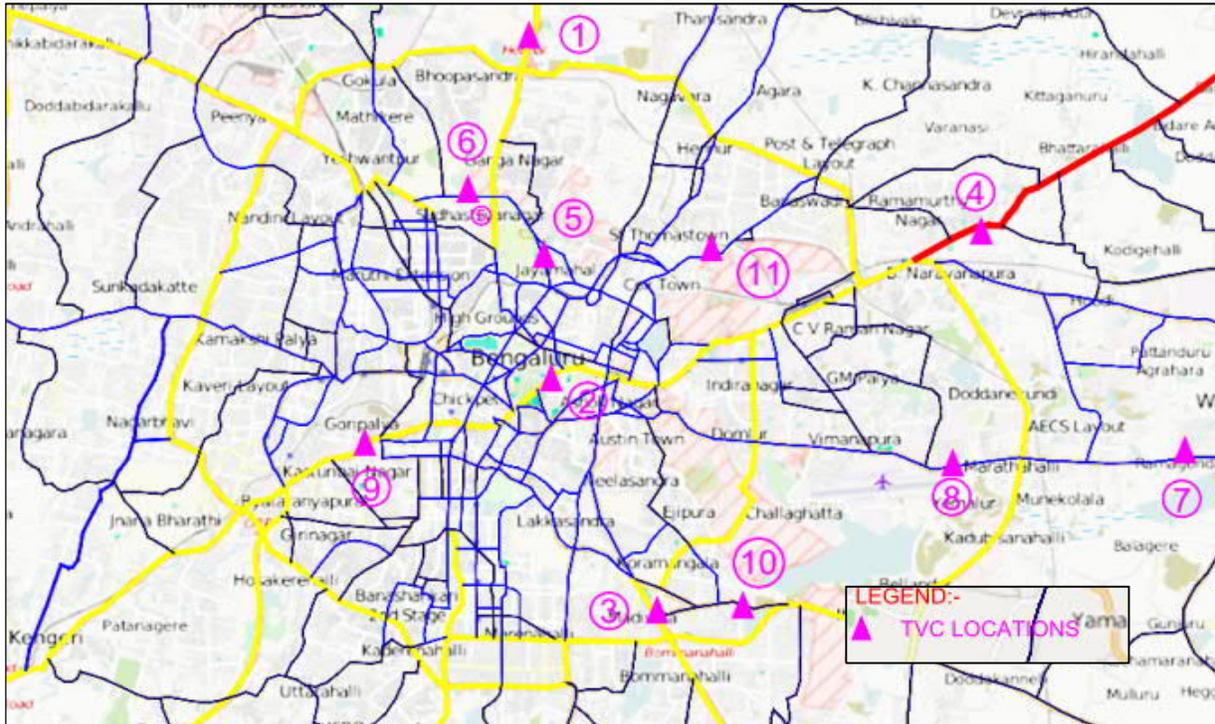
Figure 3-1: TVC Survey Locations

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3.3.5   Origin-Destination (O-D) and Commodity Movements Surveys

Origin – Destination (OD) surveys were conducted to obtain information of travel pattern of passenger and goods vehicles in terms start and end of the journey, purpose of travel, commodity carried and route followed.

OD surveys were conducted along with 7 day TVC surveys and TMC surveys by roadside interview method for a duration of 24 hours, where the enumerator has to stop the vehicle and record the information regarding the type of vehicle, its registration number, origin, destination, frequency of visit, purpose of trips, and occupancy of vehicle etc. by interviewing the users. Separate enumerators were kept for interviewing the goods and passenger vehicles. The questions regarding the type of commodity carried, weight were also asked apart from the other question from the driver of goods vehicle. Table 3.3 and Figure 3.2 present the OD survey locations.

Table 3-3: Traffic Survey Locations for OD Surveys

OD + TVC				
SI. No	Location	Survey	Type of Junction	Date
1	Near Agara Lake	OD + 1 day TVC	Mid-block	05-04-2016
2	Near HAL	OD + 1 day TVC	Mid-block	05-04-2016
3	Mid of Suranjandas road	OD + 1 day TVC	Mid-block	05-04-2016
4	Beyond KR puram	OD + 1 day TVC	Mid-block	05-05-2016
5	Bt. Yeswantapur and Gorguntapalya	OD + 1 day TVC	Mid-block	05-06-2016
6	Bt. Chord rd. and ORR on EW-2	OD + 1 day TVC	Mid-block	05-06-2016
OD + TMC				
SI. No	Location	Survey	Type of Junction	Status
7	Adugudi	OD +TMC	3-leg	05-05-2016
8	Trinity circle	OD +TMC	5-leg	05-02-2016
9	MG road junction	OD +TMC	4-leg	05-02-2016
10	KR Rly bridge	OD +TMC	4-leg	05-05-2016
11	Mekri circle	OD +TMC	4-leg	05-03-2016

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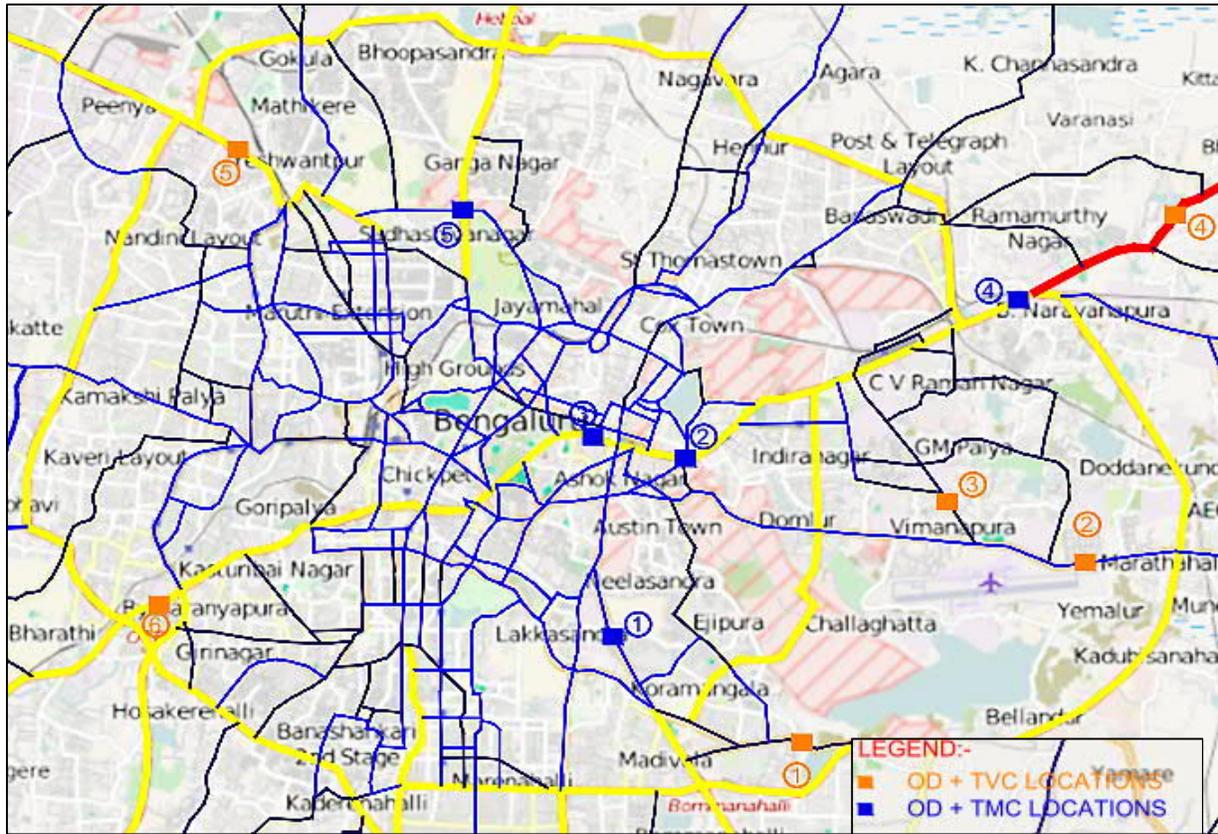
Figure 3-2: OD Survey Locations

3.3.6   Turning Movement Count (TMC) Surveys

The turning movement surveys for estimation of peak hour traffic for the design of
intersections and interchanges have also been carried out for the study. Turning
movements Count (TMC) survey was carried out at 54 major intersections inside
Bangalore city. The survey was conducted for 24 hours on a normal working day to
capture the peak hour traffic flow and also to understand the directional distribution of
traffic. Locations covered under TMC survey are mentioned in the Figure 3.3 Presents
the TMC survey locations.

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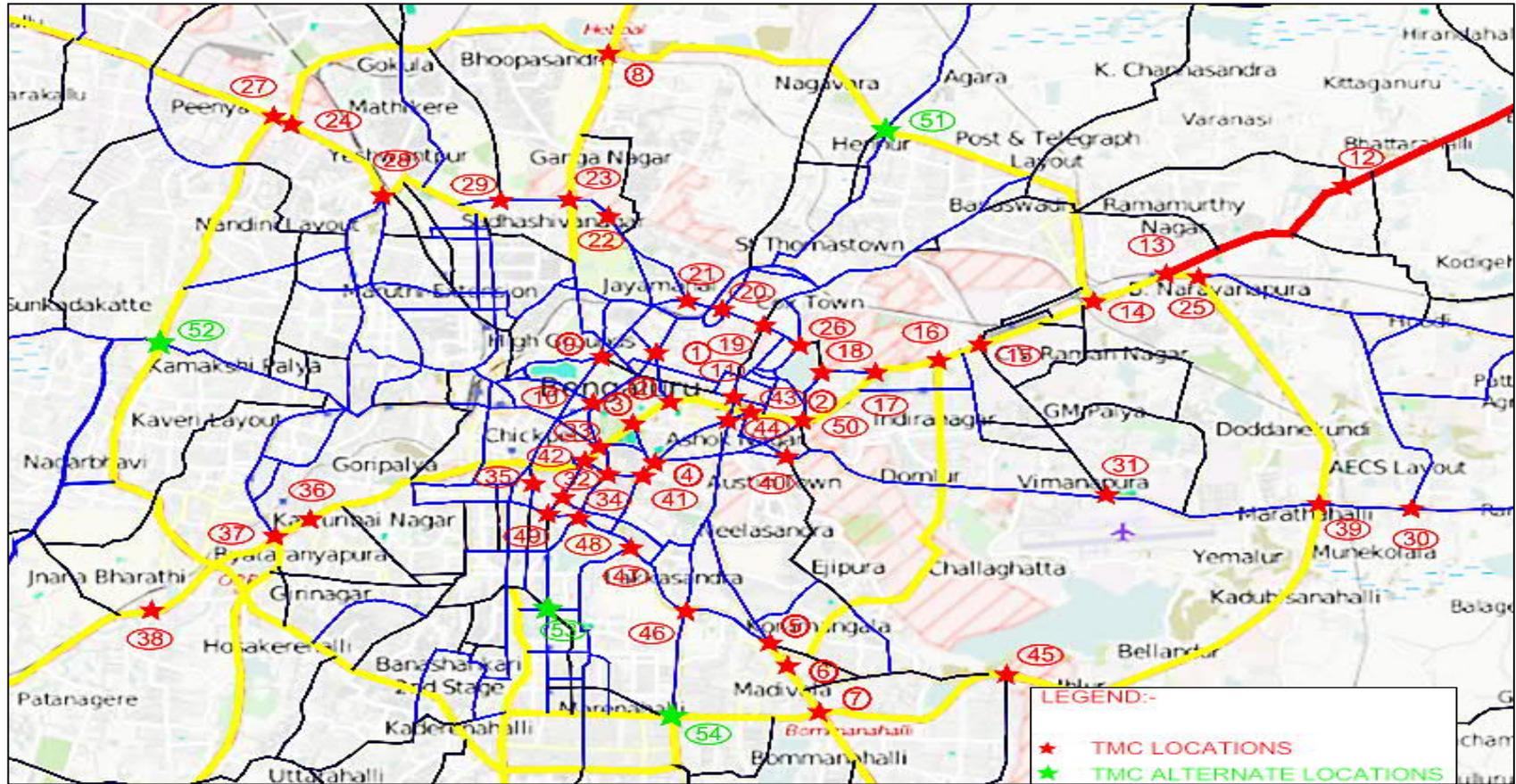
Figure 3-3: TMC Survey Location

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Table 3-4: Location for TMC Surveys

S. No	Location	Survey	Type of Junction	Date
North - South Corridor (Cantonment to Silk Board)				
1	Indian Express Junction	TMC 02	5 Leg	29/04/2016
2	M G Road Junction	TMC 04	5 Leg	02/05/2016
3	Siddalingaiah Junction	TMC 05	5 Leg	28/04/2016
4	Richmond Circle	TMC 06	4 Leg (+ Type)	27/04/2016
5	Madiwala Check Post	TMC 8	3 Leg (Y Type) staggered	22/04/2016
6	St. John's Hospital Road Junction			22/04/2016
7	Silk Board Junction	TMC 9	4 Leg (X Type)	25/04/2016
8	Hebbal jn.	TMC-NS-A1		23/04/2016
9	Chalukya jn.	TMC-NS-A2		05-03-2016
10	KR circle jn.	TMC-NS-A3		28/04/2016
11	Cubbon Road - Kamaraj road jn.	TMC-NS-A4		29/04/2016
East - West Corridor-1 (NH - 04 to K R Puram)				
12	T C Palya Junction	TMC 01	3 Leg (T Type)	20/04/2016
13	K R Puram Bridge Junction	TMC 02	3 Leg (Y Type)	20/04/2016
14	Hebbal Road Flyover Junction	TMC 03	3 Leg (T Type)	19/04/2016
15	Suranjandas Road Junction	TMC 04	4 Leg (X Type)	19/04/2016
16	100 Feet Road Junction	TMC 05	3 Leg (T Type)	19/04/2016
17	Ulsoor Road Junction	TMC 06	3 Leg (Y Type)	19/04/2016

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S. No	Location	Survey	Type of Junction	Date
18	Phillips Junction	TMC 07	3 Leg (Y Type)	18/04/2016
19	Wheelers Road Junction	TMC 08	4 Leg (+ Type)	18/04/2016
20	Haines Road Junction	TMC 09	5 Leg	21/04/2016
21	Nandi Durga Road Junction	TMC 10	3 Leg (Y Type)	18/04/2016
22	CIL Road Junction	TMC 11	3 Leg (T Type)	18/04/2016
23	Mekri Circle	TMC 12	4 Leg (+ Type)	21/04/2016
24	Goraguntepalya Junction	TMC 13	3 Leg (T Type)	21/04/2016
25	Cable stayed Br.-Whitefield-Marathahalli jn.	TMC-EW-1-A1		20/04/2016
26	Ulsoor lake krishna bhagavan jn.	TMC-EW-1-A2		20/04/2016
27	ORR jn.	TMC-EW-1-A3		21/04/2016
28	Karle jn.	TMC-EW-1-A4		22/04/2016
29	New BEL jn.	TMC-EW-1-A5		21/04/2016
East - West Corridor-2 (Varthur to Jnanabharathi)				
30	Kundalahalli Gate	TMC 02	3 Leg (T Type)	25/04/2016
31	Suranjandas Road Junction	TMC 04	3 Leg (T Type)	25/04/2016
32	Subbaiah Circle	TMC 07	3 Leg (Y Type)	13/04/2016 and 27/04/2016
33	Hudson Circle	TMC 08	Multi Leg	05-05-2016
34	J C Road Junction	TMC 09	4 Leg (+ Type)	13/04/2016
35	Kalasipalyam Bus Stop	TMC 10	4 Leg (+ Type)	13/04/2016
36	Bapuji Nagar Junction	TMC 11	3 Leg (Y Type)	04-12-2016

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S. No	Location	Survey	Type of Junction	Date
37	Deepanjali Nagar Junction	TMC 12	3 Leg (T Type)	04-12-2016
38	R Nagar Junction	TMC 13	3 Leg (T Type)	04-12-2016
39	Marthahalli jn.	TMC-EW-2-A1		25/04/2016
40	Lower Agaram jn.	TMC-EW-2-A2		29/04/2016
41	Double road jun.	TMC-EW-2-A3		27/04/2016
42	Town hall jn.	TMC-EW-2-A4		13/04/2016
43	Brigade rd. - Residency rd. jn.	TMC-EW-2-A5		13/04/2016
44	Museum rd.-Residency rd. jun.	TMC-EW-2-A6		13/04/2016
Connecting Corridor - 01 (Agara to St. John's Hospital Junction)				
45	HSR Layout Junction	TMC 01	Staggered	26/04/2016
46	Dairy Circle	TMC 03	4 Leg (+ Type)	26/04/2016
47	Siddapura Road Junction	TMC 04	3 Leg (T Type)	04-11-2016
48	Lalbagh Main Gate	TMC 05	3 Leg (T Type)	04-11-2016
49	Minerva Circle	TMC 06	5 Leg	27/04/2016
Connecting Corridor - 02 (Richmond Road to Ulsoor)				
50	Trinity Junction	TMC 01	4 Leg (+ Type)	done along with OD on 02/05/2016
Additional TMC Locations				
51	Hennur road Jn. on ORR	TMC-AL1	Multi Leg	05-04-2016
52	Magadi road Jn. on ORR	TMC-AL3	Multi Leg	23/04/2016
53	South End Circle Jn.	TMC-AL4	Multi Leg	05-03-2016

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S. No	Location	Survey	Type of Junction	Date
54	Marenahalli Jn. on ORR	TMC-AL5	Multi Leg	05-02-2016

3.3.7 Willingness to Pay Surveys

The willingness to pay survey was carried out at major commercial, workplaces, recreational centres along the proposed corridor stretches corresponding to the O-D locations. The objective of the study is to identify the probability of shift, willingness to pay tolls and the users' perception about the new facility.

This survey was carried out by interviewing the commuters about their willingness to shift to the new facility. This survey was carried out at places like shopping complex, workplaces, marketplaces, bus stops, food joints where commuters stop for daily activities.

This survey was conducted to achieve the following outputs:

- Socio-economic parameters of road users.
- User's opinion on imposition of tolls.
- User's desire to pay tolls.
- User's concept of savings in VOC and travel time.

Traffic survey data punched in the format provided in QAP is presented in engineering survey and Investigation report as part of Stage 2 submissions.

3.4 TOPOGRAPHIC SURVEY

As per ToR, topographic survey has to be conducted along all project stretches. As detailed in QAP, due to traffic congestion in urban area and huge number of features to be surveyed, total station survey would have been a mammoth task and hence topo survey conducted with latest technology i.e. with LiDAR scanner (Mobile Mapper). Initially DGPS survey carried out and reference points established at every 100m on ground. LiDAR scanner mounted on vehicle has been run along all project corridors to pick all the topographical features. There after AutoCAD drawing showing all existing features is prepared.

3.5 MOBILE LIDAR MAPPING

Mobile Mapper is the world's most accurate Mobile LiDAR Scanning System. At the core of this lies the proven Street Mapper technology to collect Engineering Grade LiDAR data for Indian road. Mobile Mapper is capable of collecting 11, 00,000 3D coordinates per

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second and has the range of 800m. Mobile Mapper has proven its technical capability by achieving the accuracy upto 1cm for engineering solution.

Mobile Mapper is a Mobile Mapping System designed to collect engineering grade LiDAR data over large areas. At the core of this lies the proven Street Mapper technology. Mobile Mapper can collect 10 to 100 times more data points when compared with other LiDAR technology that hugely improves the resolution and data density. Moving even at highway speeds, Mobile Mapper can obtain a remarkable, three-dimensional view of the nearby terrain. Details as shown in below Table 3-5 and Figure 3-4.

Table 3-5: Mobile Street Mapper Specifications

Manufacturer	3D Laser Mapping, England
Model	Street mapper 360°
Range (80% reflectivity)	800m
Laser Repetition Rate	Up to 550Khz per scanner
Field of View	Up to 360° full circle without any gaps
Average Raw Range Accuracy	8mm
Laser Wavelength	1,535nm
Laser Beam Divergence	0.3µrad
IMU drift	0.03 deg/h

Figure 3-4: Mobile LiDAR Survey

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3.5.1   Street Mapper

In the past decade, because of the advantages of LiDAR, it has largely displaced Photogrammetry as the process for development of large scale topographic maps. LiDAR sensors can be operated in any weather. LiDAR can actually operate at night. More hours of useful flying per day means LiDAR offers greater efficiency, faster results, and can cover more ground than photogrammetry.

Key Benefits

Aerial LiDAR Pre-Processing report	Detailed Project Report
Raw and Processed Ortho Photo	Infrastructure Planning
Topographical Map	Design and Planning
0.5m Contour Map	Encroachment Identification DEM

3.5.2   Cross sections of topography

The Road corridor was scanned using the Mobile LiDAR technology and the Topographic area using static Terrestrial LiDAR technology with the horizontal accuracy of 5cm and spot level accuracy of 0.5 cm.

Figure 3-5: Few Pictures taken during demo of Mobile LiDAR Mapper to KRDCL Officials

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3.5.3 DGPS survey

DGPS survey carried out using latest Leica instrument. LiDAR Survey is an amalgamation of DGPS, Leveling Digital and Total Station techniques aimed at providing cost-effective, efficient and quality solutions to the client. The survey methods adopted stand on solid bedrock of Surveying Knowledge and extensive field experience and aim at providing international standard survey solutions. This service can be used for topographic survey, structural deformation survey etc.

The Primary task in a topographic survey is to establish control network in the area and transfer the Bench Mark from nearby location using Auto-Level followed by traversing to collect the field details. High precise Dual frequency geodetic receivers were employed to establish the horizontal control points. The Remote Sensing data and the Toposheets were collected and a maps with village boundary, land use and utilities were prepared with the WGS 84 coordinate system. Accurate positions of the GCPs were collected to geo-reference the map, followed by image interpretation and digitization. Then a detailed LiDAR survey was carried out using the Terrestrial and Mobile LiDAR technology to obtain a continuous

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point cloud data. These Point Cloud data were processed using software and finally topographical map was prepared.

Figure 3-6: Few Pictures taken during DGPS Survey

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3.5.4   Topo survey using Drone (UAV)

Along the project corridor many busy junctions exists. At these junctions to have free flow of traffic interchanges proposed. For this purpose huge land beyond existing road required. Surveying these big land parcels much away from existing road cannot be scanned/mapped with vehicle mounted LiDAR. Hence using Drone technology these huge lands have been surveyed. For carrying out drone survey with the help of KRDCL we could get the police permission. We humbly extend our sincere thanks to the police department for their cooperation for carrying out drone survey.

An unmanned aerial vehicle (UAV), colloquially known as a drone, is an aircraft without a human pilot on board. Its flight is controlled either autonomously by computers in the vehicle or under the remote control of a pilot on the ground or in another vehicle

- Portable solution
- Faster and accurate data capture
- Higher resolution imagery
- Highly accurate survey results Free from weather conditions

3.5.5   Detailed Topographic Survey

The information obtained from Survey of India about existing Bench Marks has been used as reference stations. The data from the topographic survey is available in (x, y, z) co-ordinates for use in a digital terrain model (DTM) based road design software (mx-road suite).

Detailed topographical survey within ROW has been carried out with LiDAR scanner, by picking all features including roads, buildings, fencing, trees (with girth greater than 0.3 meter), structures (bridges culverts etc) utilities, electric and telephone installation,

spot levels, road center, road edges, shoulder edges, embankment top and bottom, OFC, hectometer & kilometer stones, ponds etc. and any other feature within ROW. Detailed topographical survey for junction improvement by picking all features and extending the survey limits to 100m length of cross road.

Detailed topographical survey for existing bridges by picking all existing features of bridge including, shape and dimensions of abutments and piers, Drain Top & bottom and taking cross-sections of stream at centre of proposed carriageway, 50m, 100m and 250m upstream & downstream from proposed centreline.

Carryings out detailed topographical survey for ROB/Flyovers by picking all features such as existing ROB details (if any), railway track, signals, traction pole etc.

Base plan covering existing features of all 6 corridors is presented in Engineering survey and Investigation report as part of Stage 2 submissions.

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Figure 3-7: Pictures taken during Drone Survey

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Table 3-6: NS - DGPS POINTS

Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS-33	12°59' 24.681"	77°35' 57.6797"	915.966	781976.264	1437489.281	913.655
GPS-33A	12°59' 21.7137"	77°35' 57.2641"	913.503	781964.666	1437397.918	911.235
GPS-34	12°58' 36.52"	77°35' 58.2091"	915.342	782007.333	1436008.637	913.101
GPS-34A	12°58' 33.0878"	77°35' 53.7497"	912.426	781873.941	1435901.737	910.183
GPS-35	12°58' 18.7672"	77°35' 38.6254"	904.631	781422.368	1435456.779	902.365
GPS-35A	12°58' 20.8108"	77°35' 39.7375"	904.801	781455.264	1435519.957	902.532
GPS-36	12°57' 54.2095"	77°35' 49.7073"	906.136	781764.218	1434705.108	903.915
GPS-36A	12°57' 53.8212"	77°35' 45.9462"	904.942	781650.925	1434692.013	902.730
GPS-37	12°58' 3.118"	77°35' 21.7092"	904.581	780917.163	1434970.434	902.344
GPS-37A	12°58' 3.1738"	77°35' 19.0375"	906.157	780836.582	1434971.333	903.921
GPS-38	12°57' 45.0476"	77°35' 41.0843"	896.967	781507.057	1434420.762	894.777
GPS-38A	12°57' 42.4736"	77°35' 40.2995"	895.167	781484.195	1434341.381	892.947
GPS39	12°57' 21.4076"	77°35' 32.3759"	890.319	781251.834	1433691.240	888.154
GPS39A	12°57' 19.0759"	77°35' 31.382"	888.999	781222.592	1433619.243	886.787
GPS-40	12°57' 23.1935"	77°34' 39.1905"	901.022	779647.439	1433729.916	898.841
GPS-40A	12°57' 22.8115"	77°34' 36.644"	902.431	779570.766	1433717.396	900.195
GPS-41	12°57' 25.6143"	77°33' 47.913"	891.398	778100.403	1433788.782	889.199
GPS-41A	12°57' 25.0423"	77°33' 45.0764"	894.984	778015.042	1433770.338	892.702
GPS-42				777659.228	1434141.413	887.620
GPS-42A			892.712	777642.522	1434266.748	890.531
GPS-56	12°57' 44.3685"	77°35' 22.1218"	898.978	780935.455	1434394.076	896.752
GPS-56A	12°57' 44.9321"	77°35' 24.3223"	897.734	781001.636	1434412.078	895.521
GPS-57	12°57' 41.1251"	77°35' 3.1687"	893.222	780364.933	1434288.561	892.600
GPS-57A	12°57' 43.5892"	77°35' 3.6486"	894.850	780378.638	1434364.470	891.016

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Table 3-7: EW-1 DGPS Points

Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS1	12°59' 41.2108"	77°36' 14.2906"	923.699	782471.918	1438002.640	921.451
GPS1A	12°59' 39.8286"	77°36' 18.6245"	916.359	782603.026	1437961.478	914.114
GPS2	12°59' 37.8236"	77°35' 44.2192"	916.388	781566.288	1437889.237	914.136
GPS2A	12°59' 39.7655"	77°35' 44.7794"	916.889	781582.571	1437949.117	914.636
GPS3	13°0' 18.5946"	77°35' 35.855"	932.982	781301.326	1439140.247	930.729
GPS3A	13°0' 21.2426"	77°35' 34.9944"	933.453	781274.548	1439221.400	931.181
GPS4	13°0' 52.0116"	77°35' 3.088"	941.426	780302.965	1440157.659	939.224
GPS4A	13°0' 52.015"	77°34' 59.9908"	941.344	780209.588	1440156.814	939.134
GPS5	13°0' 50.9738"	77°34' 2.5972"	943.292	778479.588	1440107.273	941.073
GPS5A	13°0' 50.7008"	77°33' 59.1965"	945.361	778377.147	1440097.846	943.145
GPS6	13°1' 12.393"	77°33' 9.2112"	915.962	776863.488	1440749.624	913.794
GPS6A	13°1' 15.2238"	77°33' 7.6825"	916.955	776816.527	1440836.198	914.738
GPS7	13°1' 50.9656"	77°32' 9.8257"	922.113	775061.351	1441917.645	919.944
GPS7A	13°1' 53.3384"	77°32' 6.2794"	922.377	774953.717	1441989.530	920.167
GPS10	12°59' 37.4393"	77°36' 25.5246"	913.780	782811.828	1437890.142	911.524
GPS11	12°59' 27.2972"	77°36' 48.4258"	909.481	783505.538	1437585.378	907.210
GPS11A	12°59' 25.579"	77°36' 50.3667"	908.402	783564.602	1437533.149	906.112
GPS12	12°59' 18.5268"	77°37' 1.7385"	901.221	783909.713	1437319.835	898.977
GPS12A	12°59' 17.2765"	77°37' 3.4095"	899.870	783960.495	1437281.908	897.614
GPS13	12°58' 54.7929"	77°37' 22.1019"	896.633	784531.233	1436596.391	894.397
GPS13A	12°58' 54.4089"	77°37' 27.042"	896.455	784680.315	1436586.116	
GPS14	12°59' 1.4676"	77°38' 21.6732"	895.838	786325.395	1436820.166	893.563
GPS14A	12°59' 1.8509"	77°38' 24.3237"	897.278	786405.193	1436832.779	895.035
GPS15	12°59' 27.4086"	77°39' 24.7322"	908.241	788218.539	1437637.567	906.001
GPS15A	12°59' 29.7279"	77°39' 26.9145"	906.558	788283.597	1437709.568	904.320
GPS16	12°59' 46.1803"	77°40' 3.71"	894.141	789387.795	1438227.053	891.909
GPS16A	12°59' 47.8825"	77°40' 5.8939"	894.711	789453.095	1438280.084	892.464
GPS17	13°0' 19.4881"	77°41' 6.411"	898.279	791267.601	1439271.108	896.121
GPS17A	13°0' 21.0563"	77°41' 11.8196"	898.659	791430.172	1439321.053	896.507
GPS-17-NEW	13°0' 19.1285"	77°41' 8.3651"	898.249	791326.638	1439260.675	
GPS-18	13°0' 42.8432"	77°41' 54.7632"	882.587	792717.900	1440004.687	879.837
GPS-18A	13°0' 47.3282"	77°41' 58.5275"	881.911	792829.934	1440143.802	880.54
GPS-19	13°1' 19.9912"	77°42' 45.9578"	874.826	794249.31	1441163.397	872.762
GPS-19A	13°1' 17.5937"	77°42' 41.8459"	876.134	794126.118	1441088.354	874.111

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Table 3-8: EW-1 DGPS Points

Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS23	12°58' 3.3132"	77°36' 41.524"	898.202	783323.886	1435000.966	895.942
GPS23A	12°58' 1.335"	77°36' 40.1004"	897.938	783281.58	1434939.702	895.706
GPS24	12°57' 56.8149"	77°37' 30.4157"	901.799	784800.271	1434816.29	899.553
GPS24A	12°57' 54.9317"	77°37' 32.106"	902.387	784851.84	1434758.91	900.123
GPS25	12°57' 39.1618"	77°38' 25.5987"	883.996	786469.962	1434290.662	881.764
GPS25A	12°57' 38.2195"	77°38' 28.9906"	885.498	786572.548	1434262.748	883.243
GPS26	12°57' 33.3597"	77°39' 30.1853"	887.484	788419.525	1434132.472	885.244
GPS26A	12°57' 33.1526"	77°39' 32.9081"	887.43	788501.702	1434126.96	885.194
GPS27	12°57' 17.7742"	77°40' 45.34"	893.583	790691.002	1433676.931	891.374
GPS27A	12°57' 16.631"	77°40' 48.0934"	893.15	790774.409	1433642.651	890.919
GPS28	12°57' 23.2062"	77°41' 41.2413"	879.239	792375.115	1433861.698	876.950
GPS28A	12°57' 23.3035"	77°41' 45.2015"	880.873	792494.513	1433865.951	878.623
GPS29	12°57' 22.1455"	77°42' 47.6978"	884.272	794379.673	1433850.305	881.979
GPS29A	12°57' 21.159"	77°42' 50.3995"	885.546	794461.474	1433820.837	883.250
GPS30	12°57' 22.2963"	77°43' 54.4716"	877.232	796393.433	1433876.415	874.974
GPS30A	12°57' 23.3783"	77°43' 56.7076"	877.803	796460.514	1433910.408	875.516
GPS31	12°57' 25.336"	77°44' 43.6831"	863.474	797876.602	1433985.803	861.172
GPS31A	12°57' 28.8924"	77°44' 45.1146"	863.842	797918.597	1434095.627	861.516
GPS32	12°57' 56.6376"	77°36' 14.0807"	904.159	782498.434	1434787.254	901.922
GPS-36	12°57' 54.2095"	77°35' 49.7073"	906.136	781764.218	1434705.108	903.915
GPS-36A	12°57' 53.8212"	77°35' 45.9462"	904.942	781650.925	1434692.013	902.730
GPS-37B	12°57' 35.1909"	77°34' 29.6477"	905.932	779355.952	1434095.889	903.710
GPS-37C	12°57' 34.2606"	77°34' 32.8316"	904.267	779452.251	1434068.254	902.067
GPS-42				777659.228	1434141.413	887.620
GPS-42A			892.712	777642.522	1434266.748	890.531

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Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS-43	12°57' 17.6282"	77°32' 41.4806"	854.513	776099.586	1433523.207	852.338
GPS-43A	12°57' 15.3302"	77°32' 38.9308"	852.803	776023.401	1433451.789	850.647
GPS-44	12°56' 46.3015"	77°31' 48.725"	816.174	774518.291	1432544.249	814.003
GPS-44A	12°56' 44.808"	77°31' 45.4277"	816.969	774419.314	1432497.346	814.811
GPS-45	12°57' 2.0874"	77°32' 16.8235"	837.515	775360.802	1433037.997	835.334
GPS-45A	12°57' 3.8865"	77°32' 21.2565"	839.113	775493.933	1433094.64	836.947
GPS-46	12°56' 10.3185"	77°30' 58.7328"	802.553	773021.637	1431423.065	800.398
GPS-46A	12°56' 10.6966"	77°30' 55.6278"	802.017	772927.887	1431433.767	799.870
GPS-47	12°55' 32.0794"	77°30' 6.8198"	795.852	771467.619	1430232.052	793.726
GPS-47A	12°55' 29.7939"	77°30' 10.1218"	796.056	771567.886	1430162.76	793.936
GPS-48	12°55' 22.5726"	77°29' 44.4711"	791.618	770796.487	1429933.192	789.463
GPS-48A	12°55' 23.5656"	77°29' 47.4664"	793.514	770886.52	1429964.6	791.366
GPS-49	12°54' 41.3911"	77°29' 20.8792"	784.435	770097.314	1428660.16	782.312
GPS-49A	12°54' 43.9841"	77°29' 24.9499"	789.550	770219.306	1428741.075	787.395
GPS-50	12°54' 17.5737"	77°28' 15.2293"	774.433	768124.446	1427908.755	772.396
GPS-50A	12°54' 13.8946"	77°28' 13.5562"	771.762	768075.077	1427795.159	769.715
GPS-57	12°57' 41.1251"	77°35' 3.1687"	893.222	780364.933	1434288.561	891.016
GPS-57A	12°57' 43.5892"	77°35' 3.6486"	894.85	780378.638	1434364.47	892.600

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Table 3-9: CC1 – DGPS Points

Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS-52	12°55' 48.0728"	77°36' 53.8628"	900.903	783738.52	1430846.503	898.706
GPS-52A	12°55' 50.0144"	77°36' 51.4948"	901.643	783666.49	1430905.472	899.457
GPS-54				785348.615	1430249.203	893.573
GPS-54A			895.607	785466.871	1430270.241	893.353
GPS-55	12°55' 28.5139"	77°38' 53.3364"	879.856	787348.045	1430282.167	877.610
GPS-55A	12°55' 28.7697"	77°38' 56.6503"	879.589	787447.914	1430291.064	877.344

Table 3-10: CC-2 DGPS Points

Point ID	Geographic Co-Ordinates System			UTM Co-Ordinates		
	Latitude	Longitude	Ortho Ht (EGM 96)	Easting	Northing	Elevation
GPS13	12°58' 54.7929"	77°37' 22.1019"	896.633	784531.233	1436596.391	894.397
GPS13A	12°58' 54.4089"	77°37' 27.042"	896.455	784680.315	1436586.116	894.211
GPS13B	12°58' 20.3152"	77°37' 9.7917"	905.793	784170.930	1435532.473	903.542
GPS13C	12°58' 17.45"	77°37' 10.6789"	905.635	784198.588	1435444.649	903.362
GPS23	12°58' 3.3132"	77°36' 41.524"	898.202	783323.886	1435000.966	895.942
GPS23A	12°58' 1.335"	77°36' 40.1004"	897.938	783281.580	1434939.702	895.706

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3.6   MATERIAL AND GEOTECHNICAL INVESTIGATIONS

3.6.1   Material Investigations

Pavement and material investigations involve the determination of the adequacy and effectiveness of the in-service pavement to accommodate the traffic loading, and identifying potential sources of construction material in the near vicinity of the project corridor. These investigations involve collecting data on existing pavement crust, sub grade, embankment, and locally available material for construction, and examining their suitability.

3.6.2   Pavement Structures

The bituminous layers contribute the major part of the strength of the flexible pavement structure. Hence pavement investigation is carried out to know the Existing Bituminous Thickness without disturbing the surrounding area of test pit, the existing bituminous layer thickness is measured by cutting a bituminous core cutting equipment. The core samples are taken on all the project roads at different identical sections recognized at site. The photographs taken during core cutting in project stretch are given in following paragraphs.

A detail investigation has been presented in Chapter 5 of Survey and Investigation Report.

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Figure 3-8 : Bituminous Crust Evaluation by Core Cutter

Figure 3-9: Bituminous Crust Evaluation by Core Cutter

3.6.3   Pavement Condition Survey

The tasks involved are visual estimation of the various distresses, digging test pits, measurement of in-situ CBR using DCP test apparatus, field density and field moisture content, carrying out laboratory tests for soil classification and strength characteristics, and clear recommendations in respect of their suitability for pavement structures.

Equipment used in the tests was checked for proper functioning before they are put to use, and recalibrated when it is found necessary. Test locations were marked in advance, referenced and logged. Arrangements were made for controlling traffic such that the field measurements are not affected by passing vehicles in the proximity.

The tests have been conducted in accordance with the applicable national or international codes and standards and as per ToR, where such codes do not exist, the tests have been performed according to international best practices.

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The pavement condition survey involves a visual assessment of various surface and structural distresses that affect the performance of the existing pavement. Various surface distresses identified in the condition survey are cracking, raveling, rutting, potholes, patching, edge failure etc. The engineers conducting condition surveys has make initial runs on selected stretches of roads, visually estimating the distresses and comparing their estimates with actual measurements and between themselves. After adjusting their perception in relation to these comparisons, actual measurements were conducted.

Standard practices for quantification of pavement distresses differ from agency to agency. The Pavement Material Engineer have carried out quality checks at regular intervals to estimate the consistency of the recordings. The pavement distresses have been measured or estimated for every 100 meters per kilometer and averaged for the kilometer. Pavement condition data were recorded using a standard format (which could be modified as per site condition). Rut depth measurements were carried out using the 2m Straight Edge.

Pavement condition surveys were carried out by visual observation of predominant distress on the existing pavement. The surveys have been done by walkover surveys all along the corridor. The percentage area of occurrence of each distress is noted for every 100m length of road and averaged for a kilometer.

A tabular representation of pavement condition is presented in Survey and Investigation report.

3.6.4   Pavement Strength Evaluation

Benkelman Beam Deflection (BBD) strength survey was carried out for pavement strength investigation in the month of Nov 2016. The beam was calibrated before commencement of field work, as per recommendation of IRC 81 - 1997.

The methodology adopted was the CGRA method as per IRC 81 - 1997. This method of test covers a procedure for the determination of the rebound deflection of pavement under static load of the rear axle of a standard truck. A truck with 8160 kg rear axle load equally distributed over two wheels, each with dual tyres inflated to a pressure of 5.6 kg/cm², is used for loading the pavement.

The deflection test was carried out in accordance with IRC: 81-1997. Readings were taken at 100m interval, on each lane of the project roads. Adjustments to reading locations were made in order to avoid culverts, bridge decks and locally damaged areas.

Special attention was for recording the dial gauge reading. The dial gauge readings were taken at intervals of 0.0m, 2.7m and 11.7m at each test point. The dial gauge least count was 0.01mm. Deflection readings were recorded on data sheet as per IRC guidelines. Also, the pavement surface temperature was measured and noted for making temperature correction.

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For the set of deflection readings on a km length, the average and standard deviation have been calculated and the characteristic deflection for that km length has been taken as the mean plus 2 times standard deviations for Arterial Roads and mean plus standard deviation for all other roads.

Figure 3-10: BBD Survey Photos

3.6.5   Axle Load Survey

The Axle Load Survey was carried out to compute loading pattern of the commercial traffic moving in the project road, for Pavement Design. The Axle Load Surveys were conducted as per the guidelines in IRC SP-19:2001. A set of two portable weigh pads (axle load pads) were used to conduct the survey for duration of 1 day. The site locations for axle load surveys were selected ensuring:

- The correct road section is surveyed;
- Traffic in both directions are to be surveyed;
- The traffic safety aspects are to be considered;
- The local police are informed of the survey location and duration.

The Axle load survey on both the directions was carried out on the project road stretch on a random sample basis for trucks, buses and LCV's (both empty and loaded) for 1 day (12 hours). The axle load survey is carried out using axle load pads. Axle load survey analysis has been performed as per IRC standards for the assessment of Axle load pattern as required for the white topping pavement design in accordance with IRC SP: 76 - 2015.

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Figure 3-11: Axle Load Survey Photos

3.6.6   Geo-Technical Investigations

Geotechnical investigations have been carried out as per the list of bore holes submitted along with Inception report with minor modification where the alignment has taken detour.

The investigation programme is for carrying out of boreholes at specified locations, up to a competent stratum as per IRC and BIS, recovering undisturbed and disturbed samples from the borehole, and carrying out the required in-situ tests on the soil in the borehole. The soil samples recovered have been properly packed, sealed, labeled and taken for testing of various soil properties, including index properties, grain-size distribution, shear and consolidation parameters, and other related tests. The depth of borehole has been fixed depending on the type of structure, type of soil or nature of stratum, taking into account the provisions of IRC-78: 2014. The Geo-technical Engineer has supervised the boring, sampling and testing operations. The agency carrying out the sub soil exploration was monitored in using the right equipment, in good condition, to recover the soil samples, using thin-walled samplers. Where rock is met with, proper core barrels have been used for recovery of rock cores. In cases of soft soils, undisturbed samples are recovered in thin-walled sampling tubes, to avoid sampling disturbance. The samples were sealed to preserve the natural moisture content and tests on shear strength and compressibility have been conducted. The soil a stratum was recorded during drilling on bore logs, as per the pro-forma given in IRC: 78-2014.

During the operations, proper drilling tools and drilling and sample recovery procedures have been adopted and monitored. Preserving of samples by sealing and waxing has been carried out. All tests have been conducted as per IRC and IS codes of practice. Some of the relevant codes which were used for investigation and testing are IS: 192 - Code of Practice for Site Investigations, IS: 1498 - Classification and Identification of Soils for General Engineering Purposes, IS: 2720 - Methods of Tests for Soils and IRC: 78 – 2014, Section VII - Standard Specifications and Code of Practice for Road Bridges, Foundation and Substructure.

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This report presents covers the details of 75 boreholes completed out of 149 boreholes at the proposed elevated corridor.

The report covers the details of boreholes drilled, sub-soil profile noticed and preliminary foundation recommendations. Details of Methodology of field investigation, Laboratory tests conducted on representative soil / rock samples collected from the boreholes, Sub soil profile analysis and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented in Volume – 3 Material and Subsoil Investigations Report.

3.6.6.1 Scope of Work

Brief scope of work includes of the following:

- Drilling of boreholes of 150 /76 mm diameter in all types of soil/rock by using Rotary Drilling rigs
- Performing Standard Penetration Test (SPT) in the boreholes at every 1.5 m intervals till refusal
- Collection of UDS Samples in cohesive / semi-cohesive soils at 3.0 m intervals alternatively with SPT, if possible.
- Recording of water table level in the boreholes after completion of boring.
- Collecting Rock core samples from boreholes and record the Rock Quality Designation (RQD) and Core Recovery (CR).
- Conducting laboratory tests on relevant Soil /Rock samples as per IS Code specifications.
- Preparation and Submission of Geotechnical Investigation report summarizing the details of soil / rock classifications, analysis of test data and recommending the type of foundations to be adopted for the proposed Elevated Corridor.

3.6.6.2 Location Details of East West Corridor - 1

This Corridor covers the details of 41boreholes at the proposed East West 1 elevated corridor. The report covers the details of boreholes drilled, sub-soil profile noticed and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented.

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The completed borehole details are as under below Table 3-12:

Table 3-11: Location Details of Boreholes

| BH No. | Location | Termination Depth of Borehole (m) | Layer at the Terminating depth | Reduced Level of Borehole | Co ordinates | | GWT below EGL (m) |
					Northing	Easting	
EW 1/BH – 6		20.0	MWR	890.055	1439620.625	792032.088	Not Met
EW 1/BH – 7		20.0	HWR	897.459	1439310.783	791293.834	Not Met
EW 1/BH -8		20.0	SDR	895.44	1439143.491	791160.738	Not Met
EW 1/BH-9		20.0	SDR	908.199	1438674.056	790368.617	Not Met
EW 1/BH - 10		20.0	SDR	899.927	1438496.979	789998.571	Not Met
EW 1/BH -11		20.0	SDR	892.99	1438248.715	789504.450	Not Met
EW 1/BH -12		20.0	SDR	894.579	1437968.986	788876.432	Not Met
EW 1/BH – 13		20.0	SDR	895.565	1437856.926	788579.355	Not Met
EW 1/BH - 14		20.0	SDR	905.521	1437646.923	788249.238	Not Met
EW 1/BH - 15		20.0	SDR	911.347	1437506.329	787984.265	Not Met
EW 1/BH - 16		20.0	SDR	910.906	1437190.833	787329.060	Not Met
EW 1/BH - 17		20.0	SDR	906.497	1437020.549	786929.831	Not Met
EW 1/BH - 18		20.0	SDR	895.722	1436831.55	786423.416	Not Met
EW 1/BH - 19		20.0	SDR	890.649	1436723.766	786140.778	Not Met
EW 1/BH - 20	East West Corridor 1	20.0	SDR	893.469	1436597.978	785474.097	Not Met
EW 1/BH - 21		20.0	SDR	895.016	1436579.781	785133.57	Not Met
EW 1/BH - 22		24.5	SDR	894.379	1436611.945	784608.843	Not Met
EW 1/BH - 23		20.0	SDR	894.201	1437190.354	784485.88	Not Met
EW 1/BH - 24		20.0	SDR	894.932	1437212.138	784116.592	Not Met
EW 1/BH - 25		24.0	SDR	899.503	1437358.627	783900.492	Not Met
EW 1/BH - 26		24.0	SDR	911.886	1437771.425	783125.362	Not Met
EW 1/BH - 27		15.5	HR	914.895	1437915.642	782690.53	Not Met
EW 1/BH - 28		20.0	SDR	927.801	1438077.819	782281.67	Not Met
EW 1/BH - 29		20.0	SDR	919.916	1438008.239	781702.08	Not Met
EW 1/BH - 30		13.0	HR	919.565	1438194.071	781583.928	Not Met
EW 1/BH - 31		20.0	SDR	927.335	1438805.845	781421.540	Not Met
EW 1/BH - 32		20.0	SDR	930.988	1439210.162	781279.632	Not Met

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BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
EW 1/BH - 33		20.0	SDR	932.828	1439715.896	780966.002	Not Met
EW 1/BH - 34		20.0	SDR	934.676	1440118.886	780678.168	Not Met
EW 1/BH - 35		20.0	SDR	937.675	1440157.22	780336.597	Not Met
EW 1/BH - 36		20.0	SDR	940.661	1440171.542	779836.405	Not Met
EW 1/BH - 37		20.0	SDR	931.073	1440159.516	779084.357	Not Met
EW 1/BH - 38		20.0	SDR	939.471	1440115.486	778527.765	Not Met
EW 1/BH - 39		20.0	SDR	942.608	1440073.885	778323.207	Not Met
EW 1/BH - 40		20.0	SDR	932.368	1440449.363	777723.091	Not Met
EW 1/BH - 41		20.0	SDR	922.421	1440411.300	777343.453	Not Met
EW 1/BH – 42	East West Corridor 1	20.0	SDR	913.893	1440727.605	776875.13	Not Met
EW 1/BH - 43		25.0	SDR	914.161	1440948.518	776743.97	Not Met
EW 1/BH - 44		20.0	SDR	911.668	1441215.817	776303.531	Not Met
EW 1/BH - 45		20.0	SDR	907.178	1441499.529	775803.129	Not Met
EW 1/BH - 46		20.0	SDR	917.449	1441842.78	775195.882	Not Met

Note: The coordinates and reduced level of the particular boreholes provided are tentative, the final coordinates and reduced level will be incorporated in the final report.

MWR – Moderately Weathered Rock

SDR – Soft Disintegrated Rock

HWR – Highly Weathered Rock

GWT – Ground Water Table

3.6.7   General Sub Soil Profile and Recommendation of East West Corridor - 1:

The boreholes drilled up to a minimum depth of 13.0m to a maximum depth of 25.0m in the proposed EW1 elevated corridor.

Generally Five (05) layer sub-soil profile was noticed out in the boreholes, described as under:

The top filled up layer / subgrade layer has been noticed in all the boreholes drilled in EW1 corridor. Soil encountered in this layer mainly comprises of filled up soil of waste

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materials with debris or with silty Sandy Subgrade material up to a minimum depth of 1.70m to maximum depth of 2.50m from the existing ground level. These are followed by silty SAND with few Gravel / Sandy SILT with Clay in medium dense to dense state from minimum depth of 1.70m to maximum depth of 20.0m in the majority of the boreholes drilled. These are underlined by Soft disintegrated rock in Very dense state from minimum depth of 4.50m to maximum depth of 25.0m depth explored in few boreholes. Three boreholes (BH-6, BH- 7 & BH – 30) shows a layer of highly to moderately weathered rock strata from 8.50m to 20.0m depth drilled in proposed EW1 corridor. Hard rock was encountered in one borehole (BH – 27) from 12.50m to 15.50m drilled.

The foundation recommendations provided in this report are for the completed borehole locations. Based on the sub-soil profile noticed and high intensity loads envisaged from the super structures, bored cast in-situ pile foundation is recommended at pier location.

The length of piles considering strata at pile termination at various borehole locations where hard strata is met at considerable depths for safe axial load of 550 tonnes and factor of safety of 3.0 is furnished below Table 3-13 and Table 3-14.

Table 3-12: Socketing for Pile Foundations

SI No	Pile Diameter (mm)	Min Termination Depth (m)	Max Termination Depth (m)	Safe axial load for piles socketed(T)
1	1000	12.0	18.0	550
2	1200	11.0	15.0	

Table 3-13: Socketing for Pile Foundations

Stratum at socket level	Depth of socketing (D = Pile diameter)
Soft Rock	2D
Hard Rock	1D

3.6.8 Location Details of East West Corridor - 2

This Corridor covers the details of 48 boreholes at the proposed East West 2 elevated corridor. The report covers the details of boreholes drilled, sub-soil profile noticed and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented.

The completed borehole details are as under below Table 3-15:

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Table 3-14: Location Details of Boreholes

BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
EW2 / BH - 1		20	SDR	862.542	1433948.931	797742.016	Not Met
EW2 / BH - 2		20	SDR	869.975	1433969.421	797250.970	Not Met
EW2 / BH - 3		20	SDR	875.048	1433917.515	796522.104	Not Met
EW2 / BH - 4		20	SDR	874.619	1433875.954	796194.973	Not Met
EW2 / BH - 5		20	HWR	868.046	1433847.985	795685.668	Not Met
EW2 / BH - 6		20	SDR	869.785	1433840.372	795458.192	Not Met
EW2 / BH - 7		20	SDR	884.556	1433805.770	794831.926	Not Met
EW2 / BH - 8		20	SDR	884.760	1433812.592	794578.477	Not Met
EW2 / BH - 9		20	SDR	874.573	1433863.935	793872.448	Not Met
EW2 / BH - 10	East West Corridor-2	20	SDR	890.052	1433880.238	793324.000	Not Met
EW2 / BH - 11		20	SDR	886.952	1433928.573	793025.630	Not Met
EW2 / BH - 12		20	MDR	876.281	1433833.545	792329.792	Not Met
EW2 / BH - 13		20	SDR	870.160	1433739.263	791711.366	Not Met
EW2 / BH - 14		20	SDR	867.805	1433611.061	791318.633	Not Met
EW2 / BH - 15		20	SDR	889.149	1433644.876	790924.119	Not Met
EW2 / BH - 16		20	SDR	888.372	1433743.676	790494.057	Not Met
EW2 / BH - 17		20	SDR	888.073	1433948.242	790067.480	Not Met
EW2 / BH - 18		20	SDR	898.060	1434011.972	789445.004	Not Met
EW2 / BH - 19		20	HWR	894.091	1434053.940	789143.810	Not Met
EW2 / BH - 20		20	SDR	885.441	1434129.482	788476.808	Not Met

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BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
EW2 / BH - 21		20	SDR	889.220	1434156.244	787990.466	Not Met
EW2 / BH - 22		20	SDR	892.955	1434189.792	787430.153	Not Met
EW2 / BH - 23		20	SDR	882.548	1434234.840	787011.831	Not Met
EW2 / BH - 24		20	HWR	881.721	1434279.264	786401.206	Not Met
EW2 / BH - 25		20	SDR	884.087	1434306.702	785951.680	Not Met
EW2 / BH - 26		20	SDR	897.145	1434327.523	785515.624	Not Met
EW2 / BH - 27		20	SDR	900.220	1434494.068	785040.374	Not Met
EW2 / BH - 28		20	SDR	899.295	1434873.412	784738.442	Not Met
EW2 / BH - 29		20	SDR	903.304	1434876.242	784266.929	Not Met
EW2 / BH - 30		20	SDR	895.048	1434778.062	783958.651	Not Met
EW2 / BH - 31		20	SDR	892.177	1434910.931	783445.362	Not Met
EW2 / BH - 32		20	SDR	908.314	1434842.459	782827.120	Not Met
EW2 / BH - 33		20	SDR	896.939	1434761.250	782236.808	Not Met
EW2 / BH - 34		20	HWR	903.722	1434674.272	781755.773	Not Met
EW2 / BH - 35		20	HWR	893.360	1434406.827	781461.252	Not Met
EW2 / BH - 36	East West Corridor-2	20	HWR	895.527	1434415.919	781023.546	Not Met
EW2 / BH - 37		20	HWR	892.638	1434266.165	780604.946	Not Met
EW2 / BH - 38		20	SDR	891.598	1433919.283	780149.309	Not Met
EW2 / BH - 39		20	SDR	892.814	1434026.648	779818.345	Not Met
EW2 / BH - 40		20	SDR	900.283	1434032.719	779608.850	Not Met

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BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
EW2 / BH - 41		20	SDR	901.167	1434167.639	778852.613	Not Met
EW2 / BH - 42		20	SDR	900.810	1434165.347	778247.626	Not Met
EW2 / BH - 43		13.5	MWR	901.327	1434137.211	777975.575	Not Met
EW2 / BH - 44		20	SDR	879.955	1433942.524	777230.746	Not Met
EW2 / BH - 45		13.5	MWR	871.728	1433777.315	776725.987	Not Met
EW2 / BH - 46		12.0	MWR	865.504	1433726.555	776452.678	Not Met
EW2 / BH - 47		8.0	MWR	850.563	1433474.847	776042.165	Not Met
EW2 / BH - 48		9.0	MWR	837.288	1433126.351	775552.278	Not Met

Note: The coordinates and reduced level of the particular boreholes provided are tentative, the final coordinates and   reduced level will be incorporated in the final report.

SDR   – Soft Disintegrated Rock
HWR – Highly Weathered Rock
MWR – Moderately Weathered Rock
HR   – Hard Rock

3.6.9   General Sub Soil Profile and Recommendation of East West Corridor - 2:

Generally, four (04) layer sub-soil profile was noticed out in the boreholes, described as under:

The boreholes drilled up to a minimum depth of 8.0m to a maximum depth of 25.0m in the proposed EW2 elevated corridor.

The top filled up layer / subgrade layer has been noticed in all the boreholes drilled in EW2 corridor. Soil encountered in this layer mainly comprises of filled up soil of waste materials with debris or with silty Sandy Subgrade material up to a minimum depth of 1.30m to maximum depth of 2.70m from the existing ground level. These are followed by silty SAND with few Gravel / Sandy SILT with Clay in medium dense to dense state from minimum depth of 5.0m to maximum depth of 19.0m in the majority of the boreholes drilled. These are underlined by Soft disintegrated rock in Very dense state from minimum depth of 8.0m to maximum depth of 25.0m depth explored in few boreholes.

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Few boreholes show a layer of highly to moderately weathered rock strata from 3.0m to 20.0m depth drilled in proposed EW2 corridor.

The foundation recommendations provided in this report are for the completed borehole locations. Based on the sub-soil profile noticed and high intensity loads envisaged from the super structures, bored cast in-situ pile foundation is recommended at pier location.

The length of piles considering strata at pile termination at various borehole locations where hard strata is met at considerable depths for safe axial load of 550 tonnes and factor of safety of 3.0 is furnished below Table 3-16.

Table 3-15: Socketing for Pile Foundations

Sl No	Pile Diameter (mm)	Min Termination Depth (m)	Max Termination Depth (m)	Safe axial load for piles socketed(T)
1	1000	11.0	18.0	550
2	1200	7.50	18.0	

Stratum at socket level	Depth of socketing (D = Pile diameter)
Soft Rock	2D
Hard Rock	1D

3.6.10 Location Details of North South Corridor

This Corridor covers the details of 19 boreholes at the proposed North South elevated corridor. The report covers the details of boreholes drilled, sub-soil profile noticed and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented.

The completed borehole details are as under below Table 3-17:

Table 3-16: Location of Details of Boreholes

BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
NS / BH - 1		20	SDR	918.388	1437893.225	781695.177	Not Met
NS / BH - 2		6.5	HR	914.248	1437486.39	781973.597	Not Met

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BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
NS / BH - 3		14	HR	909.781	1437226.798	781887.834	Not Met
NS / BH - 4		20	MWR	921.128	1436747.714	781731.898	Not Met
NS / BH - 5		6	HR	917.308	1436289.449	781833.772	Not Met
NS / BH - 6		20	SDR	909.142	1435882.708	781850.627	Not Met
NS / BH - 8		20	SDR	902.35	1434991.974	781509.072	Not Met
NS / BH - 9		20	SDR	888.495	1433917.425	781331.079	Not Met
NS / BH - 10		20	MWR	886.105	1433250.855	781708.667	Not Met
NS / BH - 11		9	HR	884.466	1433114.277	782471.424	Not Met
NS / BH - 12		20	MWR	884.41	1432912.069	782764.537	Not Met
NS / BH - 13	North South Corridor	12	HR	892.853	1432439.924	782893.427	Not Met
NS / BH - 14		20	SDR	903.613	1431674.607	783276.912	Not Met
NS / BH - 15		20	SDR	898.633	1431245.356	783501.655	Not Met
NS / BH - 16		20	SDR	900.456	1431083.189	783562.151	Not Met
NS / BH - 17		20	SDR	898.105	1430636.684	783865.899	Not Met
NS / BH - 18		20	SDR	887.06	1430259.394	784116.53	Not Met
NS / BH - 19		20	SDR	885.582	1429890.185	784389.843	Not Met
NS / BH - 20		20	SDR	881.111	1429488.908	784609.886	Not Met

Note: The coordinates and reduced level of the particular boreholes provided are tentative, the final coordinates and reduced level will be incorporated in the final report.

BH-7 Comes Under Tender Shore Road.

SDR – Soft Disintegrated Rock

MWR – Moderately Weathered Rock

HR   – Hard Rock

GWT – Ground Water Table

3.6.11 General Sub Soil Profile and Recommendation of North South Corridor:

The boreholes drilled up to a minimum depth of 6.0m to a maximum depth of 20.0m in the proposed North South elevated corridor.

The top filled up layer / subgrade layer has been noticed in all the boreholes drilled in NS corridor. Soil encountered in this layer mainly comprises of filled up soil of waste materials with debris or with silty Sandy Subgrade material up to a minimum depth of 1.30m to maximum depth of 2.20m from the existing ground level. These are followed by silty SAND with few Gravel / Sandy SILT with Clay in medium dense to dense state from minimum depth of 3.50m to maximum depth of 17.0m in the majority of the boreholes drilled. These are underlined by Soft disintegrated rock in Very dense state from

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minimum depth of 1.50m to maximum depth of 20.0m depth explored in majority of boreholes. Few boreholes show a layer of highly to moderately weathered rock strata from 14.0m to 20.0m depth drilled in proposed North South corridor. Hard rock was encountered in few boreholes from 3.0m to 14.0m drilled.

The foundation recommendations provided in this report are for the completed borehole locations. Based on the sub-soil profile noticed and high intensity loads envisaged from the super structures, bored cast in-situ pile foundation is recommended at pier location.

The length of piles considering strata at pile termination at various borehole locations where hard strata is met at considerable depths for safe axial load of 550 tonnes and factor of safety of 3.0 is furnished below Table 3-18.

Table 3-17: Socketing for Pile Foundations

Sr No	Pile Diameter (mm)	Min Termination Depth (m)	Max Termination Depth (m)	Safe axial load for piles socketed(T)
1	1000	7.0	17.0	550
2	1200	6.0	16.0	

Stratum at socket level	Depth of socketing (D = Pile diameter)
Soft Rock	2D
Hard Rock	1D

3.6.12 Location Details of Connecting Corridor 1

This Corridor covers the details of 9 boreholes at the proposed Connecting corridor 1. The report covers the details of boreholes drilled, sub-soil profile noticed and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented.

The completed borehole details are as under Table 3-19:

Table 3-18: Location Details of Boreholes

BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
CC1 / BH - 1		20	SDR	876.719	1430298.353	787548.248	Not Met

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BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates		GWT below EGL (m)
					Northing	Easting	
CC1 / BH - 2		20	SDR	877.168	1430270.911	786990.312	3.50
CC1 / BH - 3		20	SDR	877.417	1430150.523	786556.018	Not Met
CC1 / BH - 4	Connecting Corridor - 1	20	SDR	882.620	1430332.593	786077.294	Not Met
CC1 / BH - 5		20	SDR	890.981	1430289.807	785573.724	Not Met
CC1 / BH - 6		20	SDR	893.628	1430275.987	785179.249	Not Met
CC1 / BH - 7		20	SDR	895.551	1430398.163	784805.488	Not Met
CC1 / BH - 8		20	SDR	897.493	1430733.133	784055.768	Not Met
CC1 / BH - 9		20	SDR	898.736	1430826.060	783794.665	Not Met

Note: The coordinates and reduced level of the particular boreholes provided are tentative, the final coordinates and reduced level will be incorporated in the final report.

SDR – Soft Disintegrated Rock

MWR – Moderately Weathered Rock

HR – Hard Rock

GWT – Ground Water Table

3.6.13 General Sub Soil Profile and Recommendation of Connecting Corridor 1:

The boreholes drilled up to a minimum depth of 20.0m to a maximum depth of 25.0m in the proposed Connecting Corridor 1.

The top filled up layer / subgrade layer has been noticed in all the boreholes drilled in Connecting Corridor 1. Soil encountered in this layer mainly comprises of filled up soil of waste materials with debris or with silty Sandy Subgrade material up to a minimum depth of 1.80m to maximum depth of 2.10m from the existing ground level. These are followed by silty SAND with few Gravel / Sandy SILT with Clay in medium dense to dense state from minimum depth of 14.0m to maximum depth of 19.0m in the majority of the boreholes drilled. These are underlined by Soft disintegrated rock in Very dense state from minimum depth of 12.50m to maximum depth of 25.0m depth explored in all the boreholes drilled in Connecting Corridor 1.

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The foundation recommendations provided in this report are for the completed borehole locations. Based on the sub-soil profile noticed and high intensity loads envisaged from the super structures, bored cast in-situ pile foundation is recommended at pier location.

The length of piles considering strata at pile termination at various borehole locations where hard strata is met at considerable depths for safe axial load of 550 tonnes and factor of safety of 3.0 is furnished below Table 3-20.

Table 3-19: Socketing for Pile Foundations

Sl No	Pile Diameter (mm)	Min Termination Depth (m)	Max Termination Depth (m)	Safe axial load for piles socketed(T)
1	1000	16.5	19.0	550
2	1200	14.0	19.0	

Stratum at socket level	Depth of socketing (D = Pile diameter)
Soft Rock	2D
Hard Rock	1D

3.6.14 Location Details of Connecting Corridor 2

This Corridor covers the details of 4 boreholes at the proposed Connecting corridor 2. The report covers the details of boreholes drilled, sub-soil profile noticed and interpretation of the same for Safe Bearing Capacity (SBC) and Foundation recommendations will be presented.

The completed borehole details are as under below Table 3-21:

Table 3-20: Location Details of Boreholes

BH No.	Location	Termination Depth of Borehole (m)	Layer at the Terminating depth	Reduced Level of Borehole	Co ordinates Northing	Easting	GWT below EGL (m)
CC2/BH - 1	Connecting Corridor - 2	18	HR	897.09	1435113.886	783658.994	Not Met
CC2/BH - 2		20	SDR	903.715	1435422.248	784157.648	Not Met
CC2/BH - 3		4.5	HR	898.667	1435796.472	784254.505	Not Met
CC2/BH - 4		20	SDR	894.607	1436101.019	784273.418	Not Met

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Note: 1. The coordinates and reduced level of the particular boreholes provided are tentative, the final coordinates and   reduced level will be incorporated in the final report.

SDR – Soft Disintegrated Rock

MWR – Moderately Weathered Rock

HR   – Hard Rock

GWT – Ground Water Table

3.6.15 General Sub Soil Profile and Recommendation of Connecting Corridor 2:

The boreholes drilled up to a minimum depth of 4.50m to a maximum depth of 24.0m in the proposed Connecting Corridor 2.

The top filled up layer / subgrade layer has been noticed in all the boreholes drilled in Connecting Corridor 2. Soil encountered in this layer mainly comprises of filled up soil of waste materials with debris or with silty Sandy Subgrade material up to a minimum depth of 1.40m to maximum depth of 1.80m from the existing ground level. These are followed by silty SAND with few Gravel / Sandy SILT with Clay in medium dense to dense state from minimum depth of 11.0m to maximum depth of 18.5m in the majority of the boreholes drilled. These are underlined by Soft disintegrated rock in Very dense state from minimum depth of 15.0m to maximum depth of 24.0m depth explored in all the boreholes drilled in Connecting Corridor 2. Hard rock was encountered in two boreholes (BH – 1 & BH - 3) from Minimum depth of 1.50m to maximum depth of 18.0m drilled.

The foundation recommendations provided in this report are for the completed borehole locations. Based on the sub-soil profile noticed and high intensity loads envisaged from the super structures, bored cast in-situ pile foundation is recommended at pier location.

The length of piles considering strata at pile termination at various borehole locations where hard strata is met at considerable depths for safe axial load of 550 tonnes and factor of safety of 3.0 is furnished below.

Table 3-21: Socketing for Pile Foundations

Sr No	Pile Diameter (mm)	Min Termination Depth (m)	Max Termination Depth (m)	Safe axial load for piles socketed (T)
1	1000	5.0	18.5	550
2	1200	5.0	17.0	

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Stratum at socket level	Depth of socketing (D = Pile diameter)
Soft Rock	2D
Hard Rock	1D

Figure 3-12 : Geo tech Field Work Photographs

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Figure 3-13 : Geo tech Field Work Photographs

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CHAPTER – 4

TRAFFIC DEMAND FORECAST

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CHAPTER 4 :   TRAFFIC DEMAND FORECAST

4.1   INTRODUCTION

In order to design the proposed elevated corridors, the road capacity requirements have to be ascertained. The capacity requirements in terms of carriageway widths can only be analyzed by estimating the traffic that will potentially use the proposed elevated corridors once they are constructed.

The traffic which will use these corridors will comprise not only from the sections on which these corridors will be developed but will also be diverted from other sections of road network due to higher speeds and less travel time amongst the common Origin-Destination (OD) pairs. Therefore, in order to estimate the diverted traffic considering the impact of improved speeds, reduction in congestion, reduced travel time, application of toll rates 'Traffic Assignment Model' was developed. The model has been first validated for base year and then used further for estimating traffic on proposed elevated corridors for both cardinal and horizon years.

Traffic likely to be diverted to the proposed elevated corridors will be first estimated for the base year and then for subsequent cardinal years and horizon year considering the project phasing, impact of congestion due to increased traffic on surrounding network and other transport infrastructure upgradations projects proposed in the study area which are likely to be operational during the study horizon.

The section discusses in detail the preparation of base year traffic assignment model, its parameters and traffic forecast.

Detailed Traffic Report was submitted to Client KRDCL in the month of August 2016 wherein Detailed Toll Analysis was also carried out, however on further direction from Client, as the Client doesn't want to Toll the project Tolling proposal was dropped.

4.2   TRAFFIC ASSIGNMENT MODEL

The Traffic Assignment Model for the study corridor has been developed using VISUM-13 software. The model comprises of the major road network within the study area. The same will be used for traffic assignment and its evaluation & assessment. The traffic assignment process is initiated after data collection from the site. The various stages involved in traffic assignment are as follows:

- Stage 1: Data Collection, Analysis & Compilation;
- Stage 2: Base Year Traffic Assignment (Model Calibration & Validation)
- Stage 3: Horizon Year Traffic Assignment.

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Stage 1 of Data analysis & Compilation has been discussed in the previous chapters. The Steps involved in Stage 2 i.e. Base Year Data Calibration & Validation and Stage 3(Horizon year assignment) are discussed in subsequent sections.

The Transport model consists of various components like network, demand data/travel demand, traffic impact analysis. The traffic model that has been developed for the study utilizes the above mentioned components for arriving at the results. The same components are briefly discussed as follows:

Network Objects: The assignment model covers complete influence area of the project & major road network serving the city of Bangalore, which ensures a full assessment of demand potential. The network objects include nodes, links, zones, connectors etc. The capacity, speed & impedance of roads are fed into the network objects at this stage.

Demand Data: This component includes the volume that has been captured from ground surveys. The data is fed into the model in the form of OD (Origin & Destination).

Matrices which are further classified as mode-wise PCU matrices according to different vehicle categories.

Traffic Assignment: Traffic assignment has been done using Equilibrium assignment procedure, which is based on Wardrop's first principle, i.e. "Every road user selects his route in such a way that the travel time on all alternative routes is the same, and that switching to a different route would increase personal travel time."

Result Analysis: This step provides us the information related to the traffic assigned on the highway network, which can be in the form of PCUs, vehicles or Trips. The link wise details can also be obtained using link volumes. Further detailed analysis can also be done by using features such as Flow bundles, turn volumes etc.

4.3   ROAD NETWORK BUILDING

4.3.1   Highway Network – Business As Usual (BAU) Scenario

Highway networks provides the basis of estimating zone-to-zone travel times and costs for the trip distribution and mode choice models and for trip routing in the vehicle and transit assignments. As part of BAU scenario the entire study area network is required to be coded in VISUM environment for understanding and simulating the traffic flow pattern among various TAZs using various route choices depending attribute such as speed, length, capacity, etc of each road link. This coded network once validated will help in estimating likely traffic quantum which will use the proposed elevated corridors once they are developed.

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The study area road network comprises of substantial quantum of urban road network within Bangalore Municipal area. The primary road network within study area included all National Highways, State Highways, Outer Ring Roads, Inner Ring Roads, major arterial and sub-arterial roads within Bangalore Metropolitan Area. Attribute data like road lengths, widths, capacity, carriageway, ROW, vehicles that will use the network etc. were collected and coded for each link including speeds and travel time. Information related to intersection type such as flyovers, roundabouts, interchanges, etc was also included in link and node coding. The road network has been developed by interconnected links with each link having its own specific characteristics like speed, no of lanes, capacity etc. The description of road network characteristics also comprised of the distance and toll costs in addition to the speed, lanes, capacity etc. The factors like distance, toll, speed etc. are very important parameters that determine the route choice behavior of the road users.

After development of the network, the same was checked for its consistency & connectivity with all Zones that were developed as a part of OD analysis. All the principle roads in the influence area are included in the model as well as significant number of minor roads that are used as through routes and provide local access to the main commuters.

The major roads covered under base year network includes NH-7 Bellary Road, NH-7 Hosur Road, NH-4 Tumkur Road, NH-4 Old Madras Road, NH-209, SH-17 Mysore Road, SH-85 Magadi Road, SH-87, Outer Ring Road, Nice Road, Whitefield Road, Old Airport Road and other sub-arterial roads.

For purpose of the model, roadway capacities by functional classification have been set by utilizing recommendations of 'IRC-106 (Guidelines for Capacity of Urban Roads in Plain Areas)', 'IRC SP-84 Manual for 4 Laning of National Highways through PPP' & 'IRC 64 (Guidelines for Capacity of Roads in Rural Areas)'. Representative capacities for various urban and rural road links by type are listed in Table 4-1 and Table 4-2.

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Table 4-1: Capacity of Urban Roads

Carriageway Type	Design Service Volume (PCU/Hr)*		
2L-1 Way	2,400	1,900	1,400
2L-2 Way	1,500	1,200	900
3L-1 Way	3,600	2,900	2,200
4L-Undivided -2W	3,000	2,400	1,800
4L-Divided--2W	3,600	2,900	
6L-Undivided-2W	4,800	3,800	
6L-Divided-2W	5,400	4,300	
8L-Divided-2W	7,200		

</div>

*Source: IRC 106 (Guidelines for Capacity of Urban Roads in Plain Areas)

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Table 4-2: Capacity of Rural Roads

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Type of Carriageway (Rural)	Design Service Volume (at LOS C, PCU/day)	Capacity (PCU/hour) **
Two Lane	25,000*	2,000
Four Lane	60,000#	4,800
Six Lane	1,20,000	9,600
Six Lanes with Paved Shoulders	145,000	11,600

* Source: IRC 64 (Guidelines for Capacity of Roads in Rural Areas). IRC guidelines indicate that recommended design service volume is derived on the basis of peak hour factor of 8-10% of the AADT.

* Source: IRC SP-84-Manual for 4 laning of Highways through PPP

* Peak hour capacity is arrived using 8 % peak hour factor.

Links are coded to identify numerous link attributes including the following:

- Functional classification,
- Link type,
- Number of lanes,
- One or two-way traffic identifier,
- Capacity,
- Speed,
- Volume

The major road network considered for the present study which, has been developed in the VISUM network model is shown in Figure 4-1.
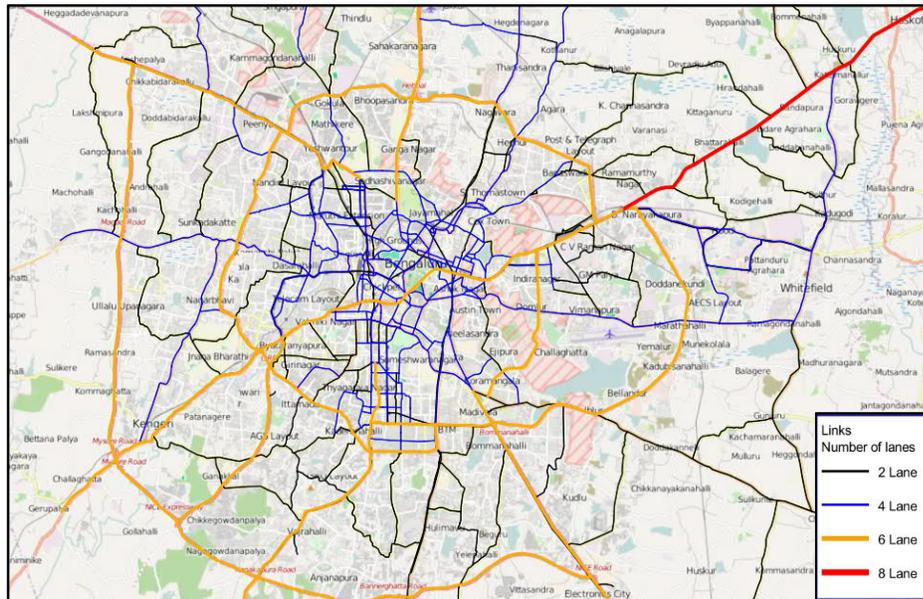

Figure 4-1: Coded Existing Highway Network- BAU Scenario

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4.3.2   Highway Network – Business Induced (BI) Scenario

As discussed above, the existing road network of study area is coded as part of BAU scenario. In order to estimate the likely traffic diversion, it is important to code the proposed elevated corridors. The attributes considered for coding will include corridor alignment, design speed, lane configuration, ramp locations, proposed intersection/ interchange arrangements, one-way circulation arrangements, vehicles that will use the network etc. coded network of proposed elevated corridors will be further added to the existing coded highway network to obtain Business Induced Highway Network for further modelling purposes.

For the present study, only cars, two –wheelers and buses have been coded as part of vehicles allowed on the proposed elevated corridors.

Carriageway configuration considered for proposed elevated corridors is presented in Table 4-3.

Table 4-3: Proposed Carriageway Configuration for Elevated Corridors

Sl. No.	Corridor	Extent	Length (Km)	Proposed Configuration
1	NS Corridor	Baptist Hospital to Silk Board	27.79	6-Lane Divided Carriageway
2	EW-1 Corridor	RMZ to Yeshwanthpura Flyover	12.47	4- Lane with paved shoulder Divided Carriageway
3	EW-2 Corridor	Varthur Kodi to Sirsi Circle	24.80	4- Lane Divided Carriageway
4	CC-1 Corridor	Agara to Outer Ring Road	4.45	4- Lane Divided Carriageway
5	CC-2 Corridor	Ulsoor to D' Souza Circle	3.15	4- Lane Divided Carriageway
6	CC-3 Corridor	Wheeler Road Jn to Hennur Flyover	4.20	4- Lane Divided Carriageway
7	EW-1 Additional Corridor	Rammurthy Nagar (Ring road) to ITPL Stretch	11	4- Lane Divided Carriageway

Figure 4-2 presents the alignment of proposed elevated corridors included as part of Business Induced (BI) Scenario.

4.4   TRAFFIC ANALYSIS ZONES

As discussed in Chapter 4, the study area was divided into 166 zones including both internal and external zones of traffic. The zones were derived in such a way to contain similar type areas in the same zone. The zones were then connected to various links by

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