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Junction Improvement Planning and Design A Case Study for Whitefield in Mahadevpura Traffic Zone-Bangalore

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Abstract *The growth of traffic in the road network of large cities in developing countries like India is a serious concern from the traffic engineer's point of view. The congestion at the intersection is most crucial because the performance of intersection affects the performance and productivity of the whole road network most significantly. To reduce conflicts and ensure orderly movement of traffic at the urban intersections, it is common practice to introduce fixed time traffic signals at uncontrolled or priority controlled or traffic police controlled intersections if the conditions warrant its choice. Due to the growth in economic activities, the city is attracting migrants. To serve this influx of population, residential layouts are being developed. But adequate transport infrastructure facilities such as roads, grade separators, subways, mass transit system, etc. To match this demands are conspicuously absent. The additional demand is to be catered by the already saturated road network. Due to the inherent road network in Bangalore, there are on the average 2 major and 2 minor junctions per kilometer of road length. This has resulted in increase in travel time due to frequent bottlenecks and breakdowns.*

The number of motor vehicles registered in Bangalore increased from 2, 36,000 in 1983 to 6, 84,497 by 1992 and 35 lakhs by December 2009. Out of the total 35 lakhs registered vehicles in Bangalore, 26 lakh vehicles account for two wheelers and 6 lakh vehicles account for car, which means 91.43% of total vehicles are personal vehicles.[1] This does not include floating vehicle population. In a recent study done by CRRI, it has been reported that annual traffic growth rates vary in the range of 2 – 4% in the central zone, 5 – 7% in the intermediate zone and 8 – 9% on the regional roads in Bangalore city. CRRI study also reported delays of 26.8 sec per km of travel and 9.9 seconds per minute of travel.

Major problem in Bangalore city is delay in time and congestion due to longest queues during signal. The number of vehicular conflicts at the point of intersections is being eliminated by traffic signals calculated from PCU's. Due to lack of adjacent land width to increase the capacity of roads the peak hourly traffic volume is increasing. Traffic related problems have become regular phenomena on Bangalore roads, due to the vast developments. This fact is substantiated by the traffic study results at various road networks and intersections of the city. Most of the major junctions of the core city have crossed the mark of 10,000 pcu's in the peak hour. Though number of grade separators have been constructed and are being constructed, most of them are located in the developed part of the city and causing a trigger of congestion at adjacent junctions.

Keywords: *Unsignalised intersections, Intersections,congestion, optimization*

1. Introduction

A junction is the general area where two or more roads join or cross. The importance of design of junction stems from the fact that efficiency of operation, safety, speed cost of operation and capacity are directly governed by the design. Since a

junction involves conflict between traffic moving in different directions, its scientific design can control accidents and can lead to orderly movement of traffic reducing delays. Junctions represent potentially dangerous location from point of view of traffic safety. It is believed that well over half of the fatal and serious road accidents in built up area occur at junctions [2].

Junction is a major bottleneck and the planned improvements will reduce traffic congestion considerably. The scheme is the result of a number of years of planning and design to find the best possible solution to reducing congestion and improving safety. The improvements will mean that car drivers, public transport users, cyclists and pedestrians will all find their journeys quicker, easier and safer[3].

Traffic signal control is a multi-objective optimization encompassing delay, queuing, pollution, fuel consumption, and continuous traffic, combined into a network performance index. It can be either stage based or group based. Signal optimization applies to several decision variables, such as green time, cycle length, stage sequence and offset. The optimization of signal timing for an isolated junction is relatively straight forward, but optimizing the timing in dense networks where the distances between the intersections are too small to dissipate the platoons of traffic is a difficult task. The difficulty comes from the complexity of the signal coordination. Optimization of signal timings is well established at individual junctions, but optimization of timings in coordinated signalized network requires further research due to the offsets and common network cycle time requirements [4].

1.2 Growth of Bangalore

1.2.1 Growth in area:

The urban agglomeration is spread between North and South Taluks of Bangalore covering an area of about 1306 sq.kms with an average population density of 43,354 individual per sq.kms. This area is formed by attaching 110 villages, 6 CMC and 1 TMC and termed as BBMP. The policy issues are taken not to expand further more.Table 1.1 shows the spatial growth of Bangalore in Sq.kms as per BBMP vision document 2020 [5]. Fig 1.1 represents the growth in pictorial form.

Table 1.1 Year wise growth of Bangalore area

Year	Area in sq.kms	Increase	% Increase
2001	451.08	-	-
2004	494.00	42.92	9.51
2005	494.00	0.00	0.00
2006	636.00	142	28.74
2007	1309.00*	673	105.82
2008	1309.00	0.00	0.00
2009	1309.00	0.00	0.00
2010	1309.00	0.00	0.00

Source: BBMP vision document 2020.

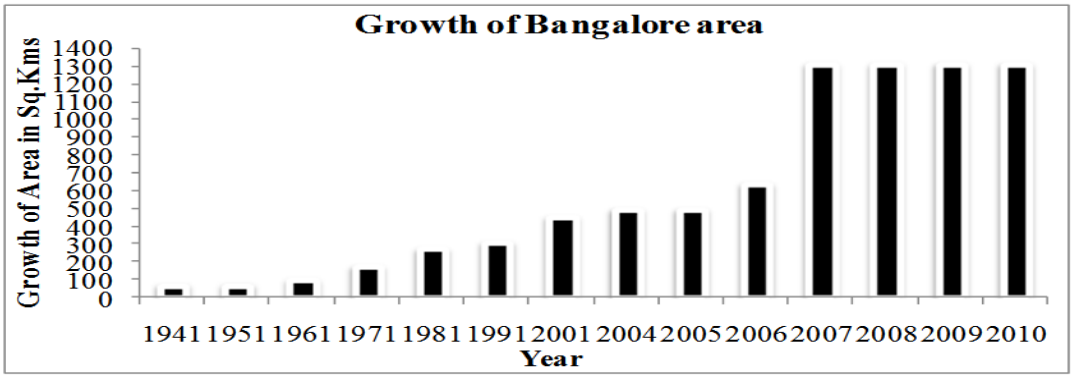


Figure 1.1 Year wise growth of Bangalore area

The reason for spatial growth in Bangalore is due to spatial & commercial activities & its centers, residential arcades, educational, scientific & research institution, industrial complexes.

1.2.2 Growth of population:

The population has increased drastically from the last few decades due to the exponential growth of software industry. Other reasons for the increase in population are

1. Migrants from other states in search of work
2. Attracted to good weather conditions
3. Growth of IT industry giving rise to employment opportunities
4. Presence of educational and scientific institutions
5. Presence of industrial complexes

Average population density of Bangalore in 2011 was 43,354 individual per Sq.kms.

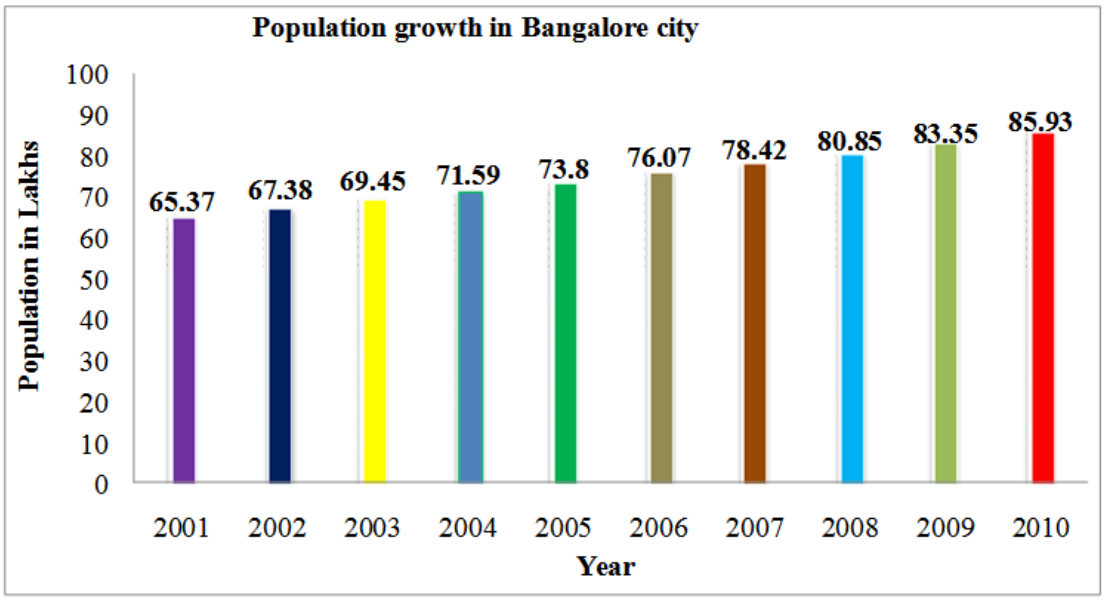


Figure: 1.2 Population growths in Bangalore city.

1.2.3 Growth of vehicles:

Rapid population growth because of IT and other associated industries in Bangalore led to an increase in the vehicular population to about 1.5 million, with an annual growth rate of 7-10%.

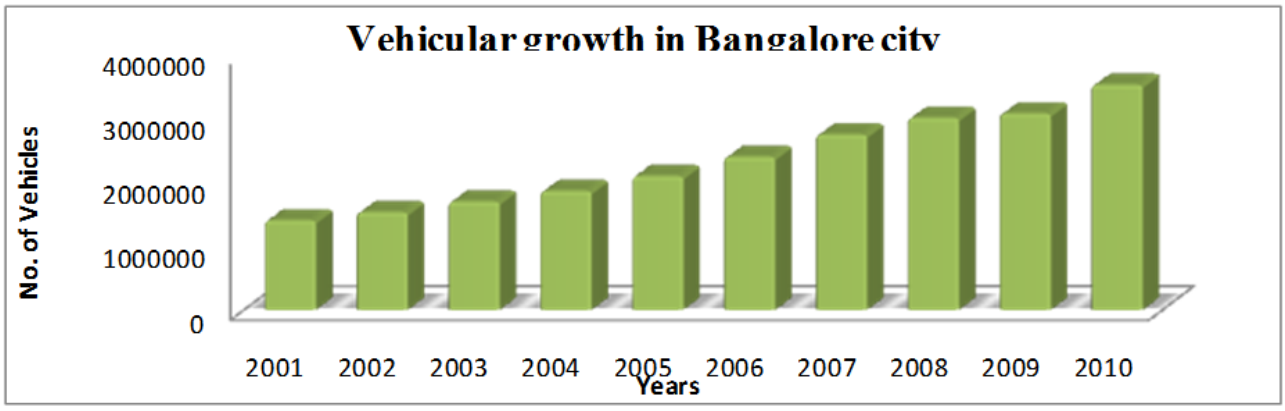


Figure: 1.3 Vehicular growths in Bangalore city from 2001 to 2010.

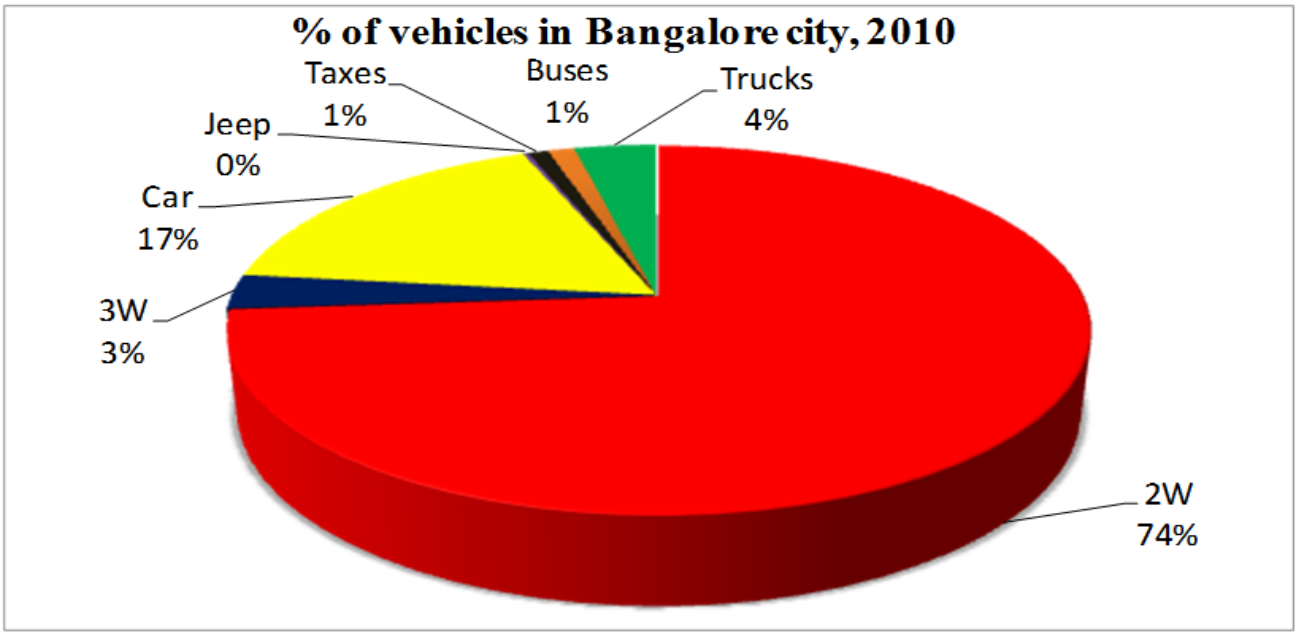


Figure 1.4 Percentage of Vehicles in Bangalore city in the year 2010.

1.3 Impact of traffic growth in Bangalore city

I. Most of the roads in the city are operating above their capacity and the volume: capacity ranges from 1:2, 1:3 and 1:5.

II. Travel speed has dropped to 15 kmph during the peak hours.

III. Insufficient or no parking spaces for vehicles.

IV. Public transport vehicles vying for road space with private modes.

Table 1.2 Shows the V/C ratio for main roads of the Bangalore City.

Table 1.2 V/C ratios for main roads in Bangalore City

SL No.	Name of Road	V/C Ratio
1	Nrupatunga Road	3.62
2	District Office Road	2.51
3	K.G. Road	2.51
4	Lalbagh Fort Road	2.67
5	PuttannaChetty Road	2.45
6	Richmond Road	2.26
7	M.G. Road	2.26
8	Chord Road	2.51
9	Tumkur Road	2.62
10	Sankey Road	1.52

Source: Bangalore traffic management cell (2010).

Sl.No	Years	Two Wheelers	Three Wheelers	Cars	Jeeps	Taxes	Buses	Trucks	Total
1	2001	1067430	61424	201052	6827	6299	20656	41887	1405575
2	2002	1162111	64001	221508	6934	7062	22841	47683	1532140
3	2003	1292228	67778	245893	7091	7974	24989	53424	1699377
4	2004	1419396	72107	269648	7434	9444	28262	59150	1865441
5	2005	1586397	74357	314931	7991	13132	34271	68186	2099265
6	2006	1811361	80432	359580	11012	16484	36888	84571	2400328
7	2007	2074306	90934	426394	7587	20025	39162	91699	2750107
8	2008	2232271	95029	490982	7609	28223	48159	109761	3012034
9	2009	2263552	95859	515109	7272	30940	48605	119051	3080388
10	2010	2607536	105630	606427	8188	31879	42164	129312	3531136

Table 1.3 Vehicular growths in Bangalore city

1.4 Objectives and Scope of the study

This project mainly attempts to study parameters that influence the design, performance of intersections and to suggest modification with respect to non-lane based traffic condition. The main objectives of the proposed study are summarized as follows:

1) To establish volume-capacity ratio for the given stretch of the approach which may leads to improvements required for the study roads.
2) To develop saturation flow model based on width of the approach road.
3) To find out saturation flow using different models based width, hourly traffic volume and ratio between numbers of vehicles to their equivalent PCUs.
4) Pedestrian safety studies and intervention.
5) To study applicability of delay as a level of service parameter and to redefine LOS parameter for non-lane based traffic condition.
6) To propose grade separators at the intersection if the traffic volume of the junction exceeds 10,000 pcu's/hr. (IRC-92).

It is expected that the outcome of this research will be able to develop analytical tools for the design and evaluation of performance of new and existing isolated signalized intersections in urban areas under non-lane based traffic conditions.

2. STUDY METHODOLOGY, DATA COLLECTION AND ANALYSIS

2.1 Methodology

A methodology based on technically sound information will have to be formulated before collecting the data and its analysis. The various stages are presented below.

Stage 1 Reconnaissance survey.

Stage 2 Road inventory survey.

Stage 3 Turning movement surveys of vehicles at junctions.

Stage 4 Delay Survey.

Stage 5 Pedestrian Survey

2.2 Selection of study area

The study area selected for the analysis is Whitefield in Mahadevapura Zone-Bangalore, Because of its wide spread commercial, industrial, government, private and other activities; Whitefield has become one of the most densely populated area in Bangalore. The road traffic facilities of the area have not improved to cope with this population boom.

As a consequence, the road network and especially the intersections remain congested for significant period of time, which makes the road users the ultimate victim.

Whitefield in Mahadevpura Zone was used for the imprisonment of prisoners of war. This slowly became a settlement area sought after by retired officials. Life in the past used to depend largely on Bangalore, as people had to go to the city for their livelihood. As time passed, this stretch became industrialized and in the 1960s and 1970s, it became one of the fastest developing industrial areas, with several medium and large-scale industries setting up shop here.

Public sectors giants such as HAL, BEML, ITI and NGEF became instrumental for massive private investment in the area. Consequently, Krishnarajapuram, Mahadevpura, Whitefield Road and Old Madras Road, upto Hoskote, became the industrial belt of Bangalore, which attracted capital investment from many industrialists.The Whitefield Industrial estate is the only place having two roads connecting Bangalore, encompassing the entire industrial complexes. It is one of the best connected places from Old airport and also new airport and Krishnarajapuram Railway Station.

Roads are the backbones of any industrial set up, but unfortunately, the roads leading to Whitefield are in a bad state. Several representations were made to the authorities, but only recently small measures were taken to mitigate the hardship to the travelling public. The main road linking Krishnarajapuram to Hope Farm is one of the main links and is in a state of disarray. Because of resource limitation, the only remedial option is to implement proper traffic management techniques. One of these techniques is the optimization of traffic signals and improves the junctions.

The following are the junctions selected for the study and improvement measures have been taken.

1. Hope Farm Junction.
2. Graphite India Junction.
3. Varthur Kodi Junction.
4. Hodi Junction.
5. Kundala Halli Junction.
6. K.R.Puram Junction.

Figure 2.1 Bangalore city

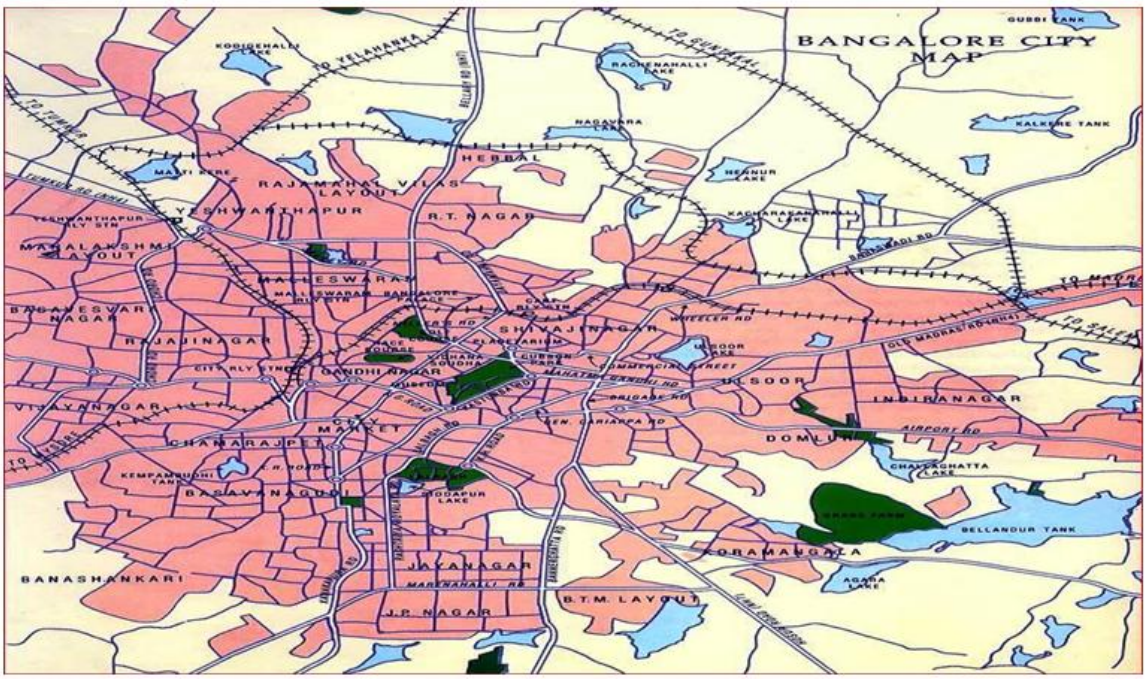


Figure 2.2 Whitefield area Map. the selected intersections in the Whitefield area map.

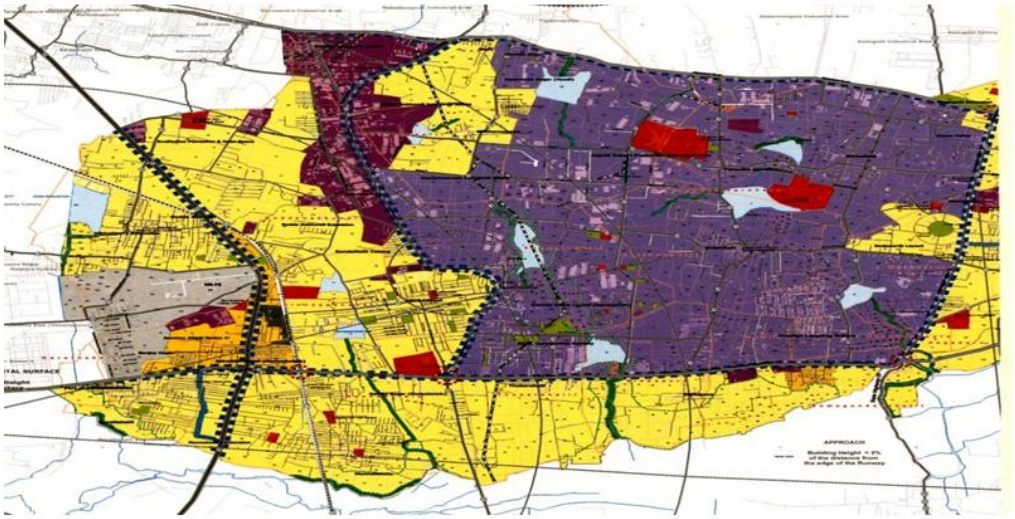


Figure 2.3 The selected intersections in the Whitefield area map.

2.2 Data collection

Data from study area were collected during the period of January 2011 until March 2011. Numbers of intersections are selected in Whitefield area for the analysis. The following data have been collected for improvement of Junction.

Traffic volume survey: Turning movement at the junction.

1. Pedestrian count at zebra crossing and pedestrian timing at the junction.
2. Queue length.
3. Saturation flow of the approach roads of the junctions.
4. Signal timings of the junction.
5. Delay timing at the junction (signalized and unsignalized)
6. Distance b/w other intersection.

Road Geometric Data

1. Width of carriageway and type and condition.
2. Width of median.
3. Width of footpath/shoulders.
4. Road features and markings(central and ends)
5. Utilities such as tree, transformer, well, electric pole, telephone, temple, drainage and availability of power and lighting.
6. Details of on-going road improvements, junction improvements, grade separator schemes, footpath improvement schemes and metro rail alignment along the project stretch.

2.3.1 HOPE FARM JUNCTION

Figure 2.4 Hope Farm Junction from Google Map (Hybrid).

This is four-legged four phase intersection connecting with Kadugodi, Channasandra, Whitefield, and ITPL in North, East, South and West directions respectively. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity). The road surface condition at study approaches is not good, affecting the speed of vehicles. Traffic consists of Trucks, MAV, LCV, Minibus, Van, Tempo, Buses, Car, Motor Cycle, Auto, Bicycle and Tractors.

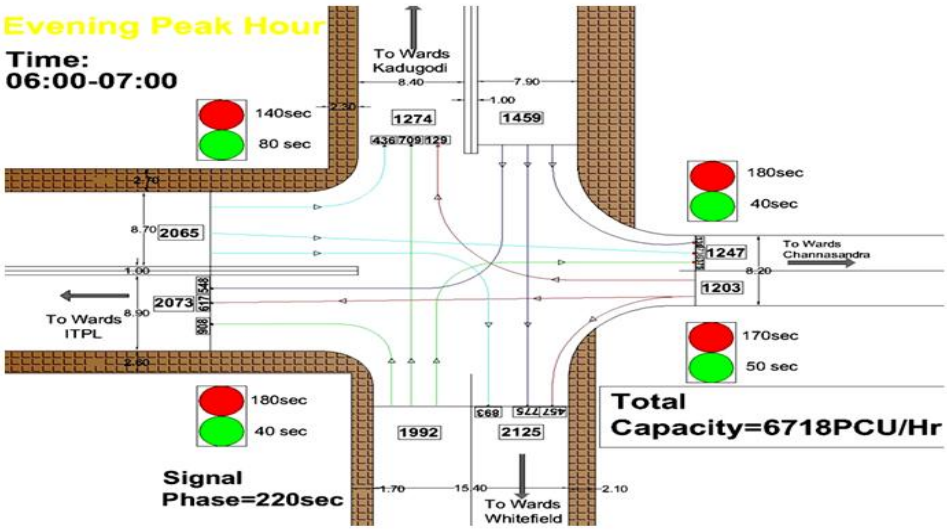


Figure 2.5 Shows the Hope farm Junction with PCU's and Road Geometric

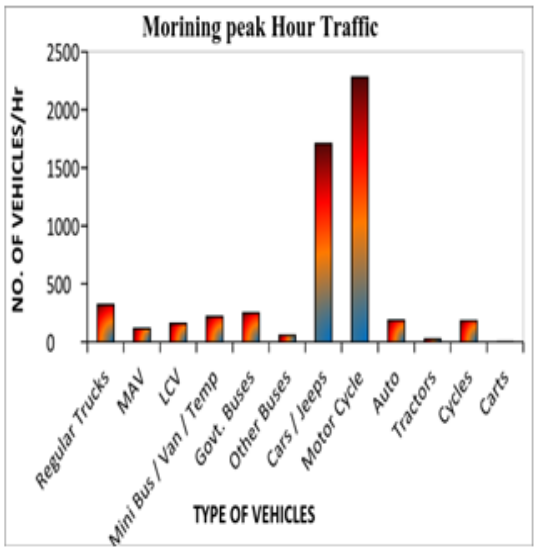


Figure 2.6 Morning peak hour traffic

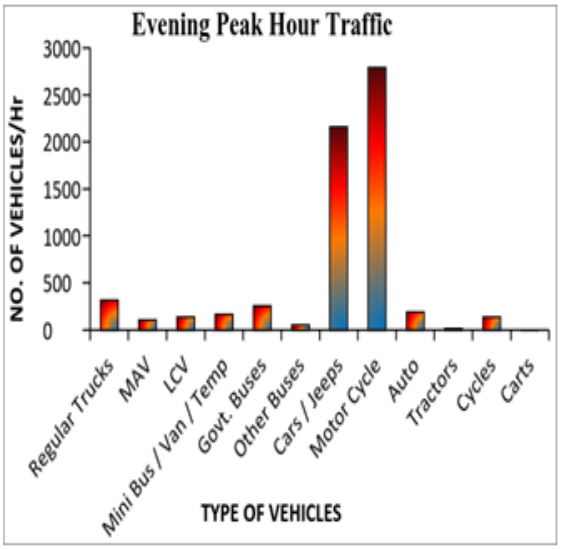


Figure 2.7 Evening peak hour traffic

2.3.2 GRAPHITE INDIA JUNCTION

Figure 2.8 Graphite India Junction from Google Map (Hybrid).

This is Three-legged three phase intersection connecting with Hudi, ITPL and Marthahalli in North, East, and South directions respectively. This is one of the most congested intersections in Whitefield. The surface Condition and platoon speed at both study approaches of the intersection is not good. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity). Traffic consists of Trucks, MAV, LCV, Minibus, Van, Tempo, Buses, Car, Motor Cycle, Auto, Bicycle and Tractors. Figure 2.8 Shows the Graphite India Junction Google Map and Figure 2.9 shows the Graphite India Junction with PCU's & Road Geometric.

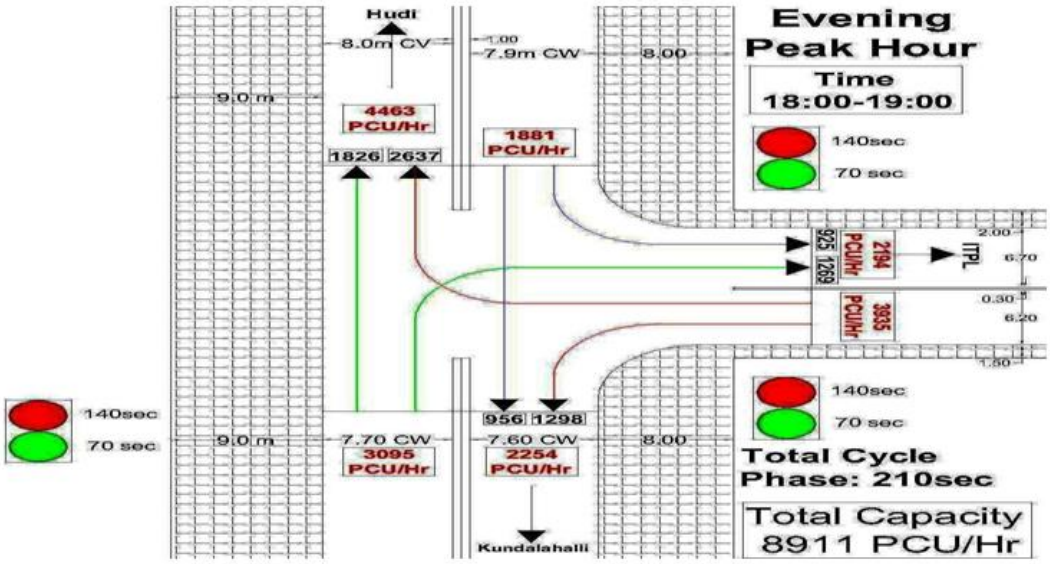
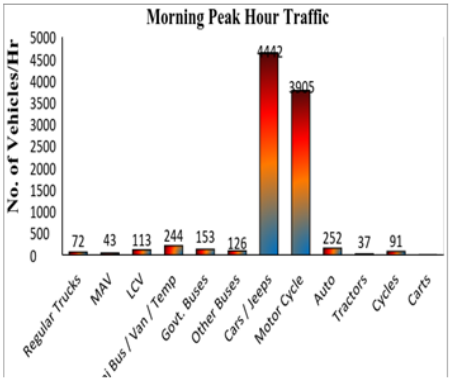


Figure 2.9 Shows the Graphite India Junction with PCU's and Road Geometric.



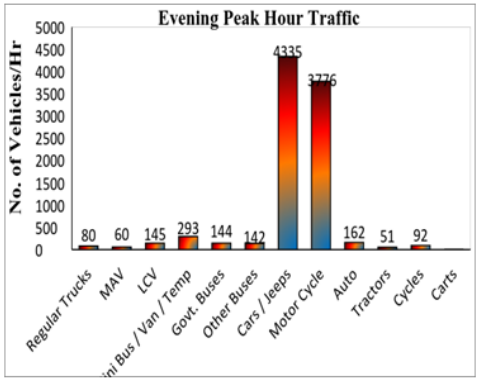


Figure 2.10 Morning peak hour traffic Figure 2.11Evening peak hour traffic

2.3.3 KUNDALA HALLI JUNCTION

Figure 2.12 Kundalahalli Gate junction

This is Four-legged four phase intersection connecting with ITPL, Varthur Kodi, Sai Layout and Marthahalli in North, East, South and West directions respectively. This is also one of the most congested intersection in Whitefield. The surface Condition and platoon speed at both study approaches of the intersection is not good. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity). Traffic consists of Trucks, MAV, LCV, Minibus, Van, Tempo, Buses, Car, Motor Cycle, Auto, Bicycle and Tractors. Figure 2.12 Shows the Kundalahalli Junction Google Map.

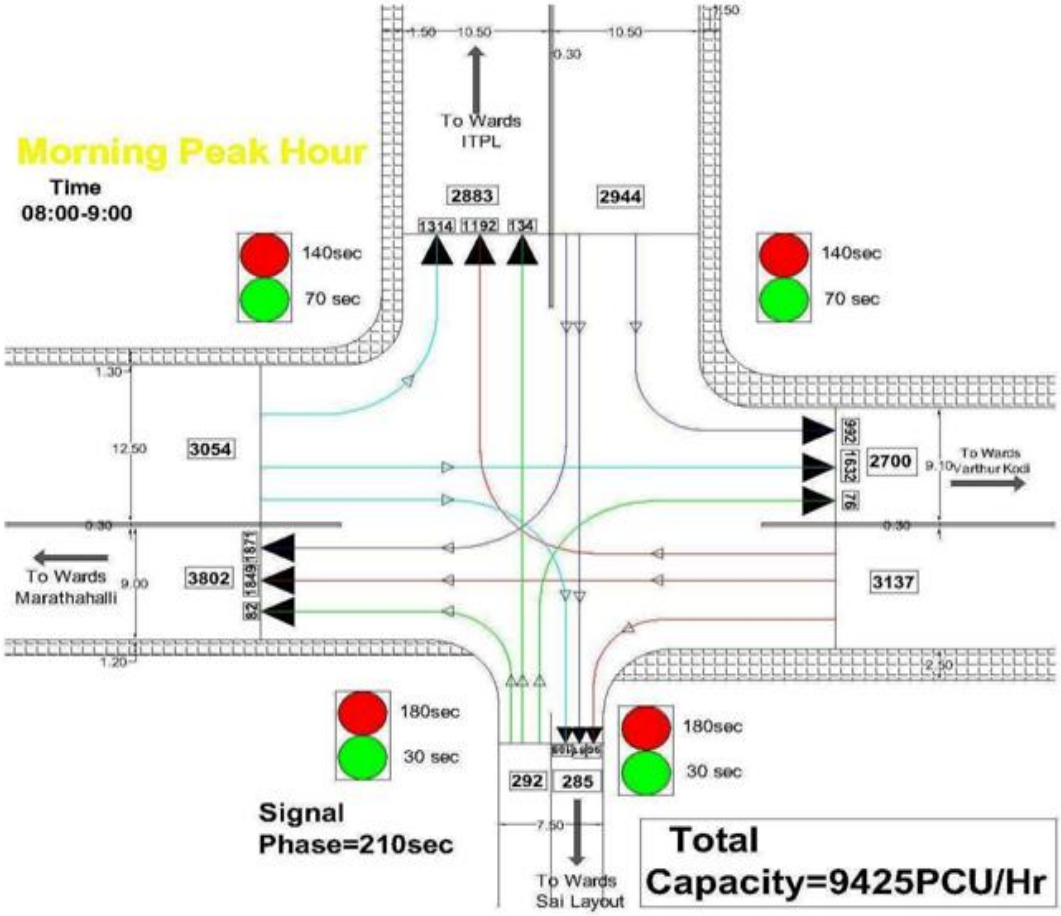


Figure 2.13 Shows the Kundalahalli Junction with PCU's and Road Geometric

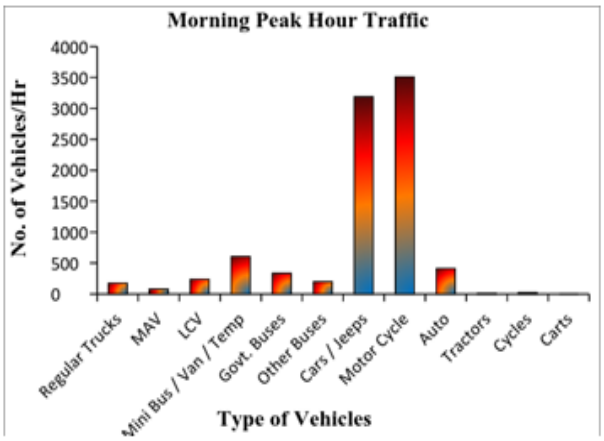


Figure 2.14 Morning peak hour traffic

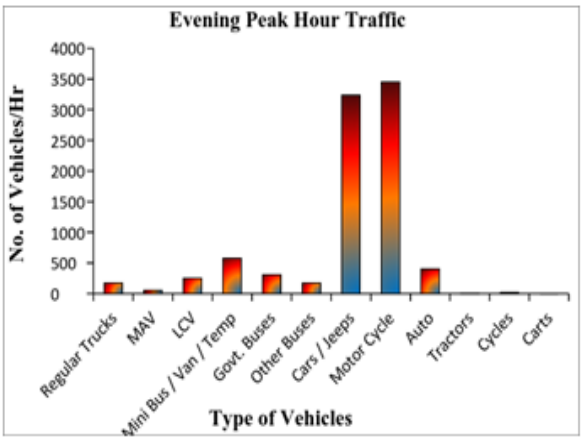


Figure 2.15Evening peak hour traffic

2.3.4 HUDI JUNCTION

Figure 2.16 Hudi Junction

This is also Four-legged four phase intersection connecting with Hudi Main Road, Hope Farm, Graphite India and K.R.Puram in North, East, South and West directions respectively. This is also one of the most congested intersections in Whitefield. The surface Condition and platoon speed at both study approaches of the intersection is not good. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity). Traffic consists of Trucks, MAV, LCV, Minibus, Van, Tempo, Buses, Car, Motor Cycle, Auto, Bicycle and Tractors. Figure 2.16 Shows the Hudi Junction Google Map.

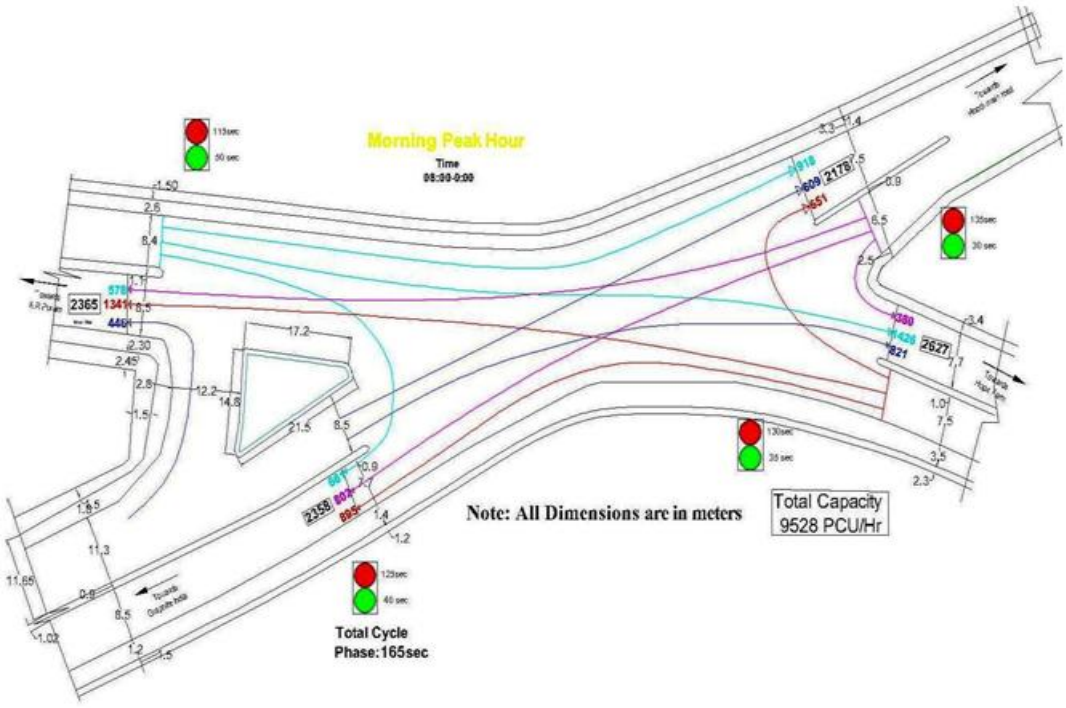


Figure 2.17 Shows the Hudi Junction with PCU's & Road Geometric

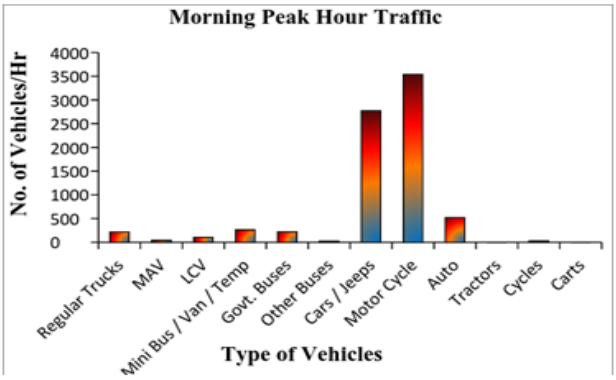


Figure 2.18 Morning peak hour traffic

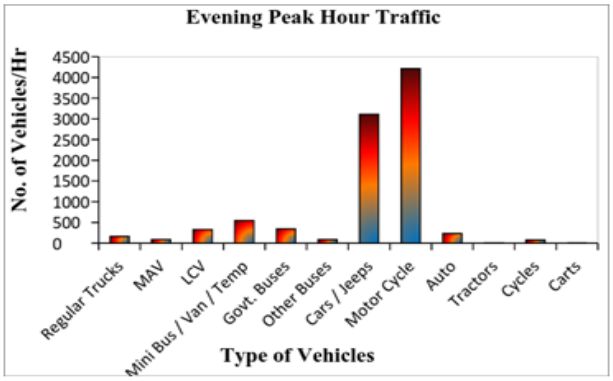


Figure 2.19 Evening peak hour traffic

2.3.5 K.R.PURAM JUNCTION

Figure 2.20 K.R.Puram Junction

This is Three-legged unsignalized intersection connecting with Whitefield, B-Narayanpura and Majestic in East, South and West directions respectively. This is one of the most congested intersections in K.R.Puram. The surface Condition and platoon speed at both study approaches of the intersection is not good. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity). Traffic consists of Trucks, MAV, LCV, Minibus, Van, Tempo, Buses, Car, Motor Cycle, Auto, Bicycle and Tractors.

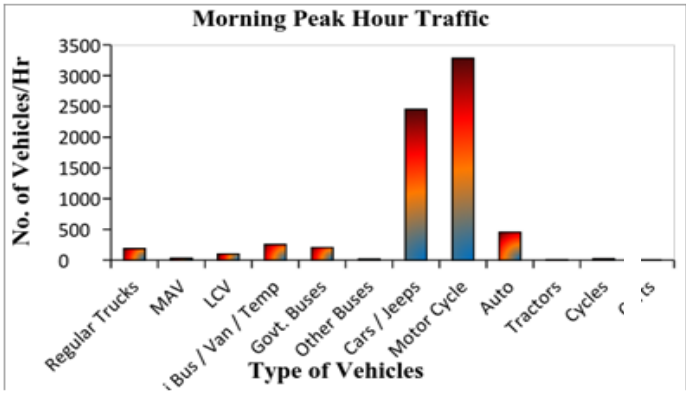


Figure 2.21 Morning peak hour traffic

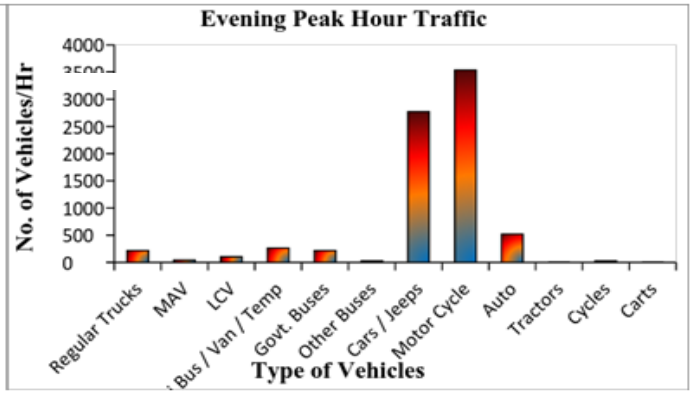


Figure 2.22 Evening peak hour traffic

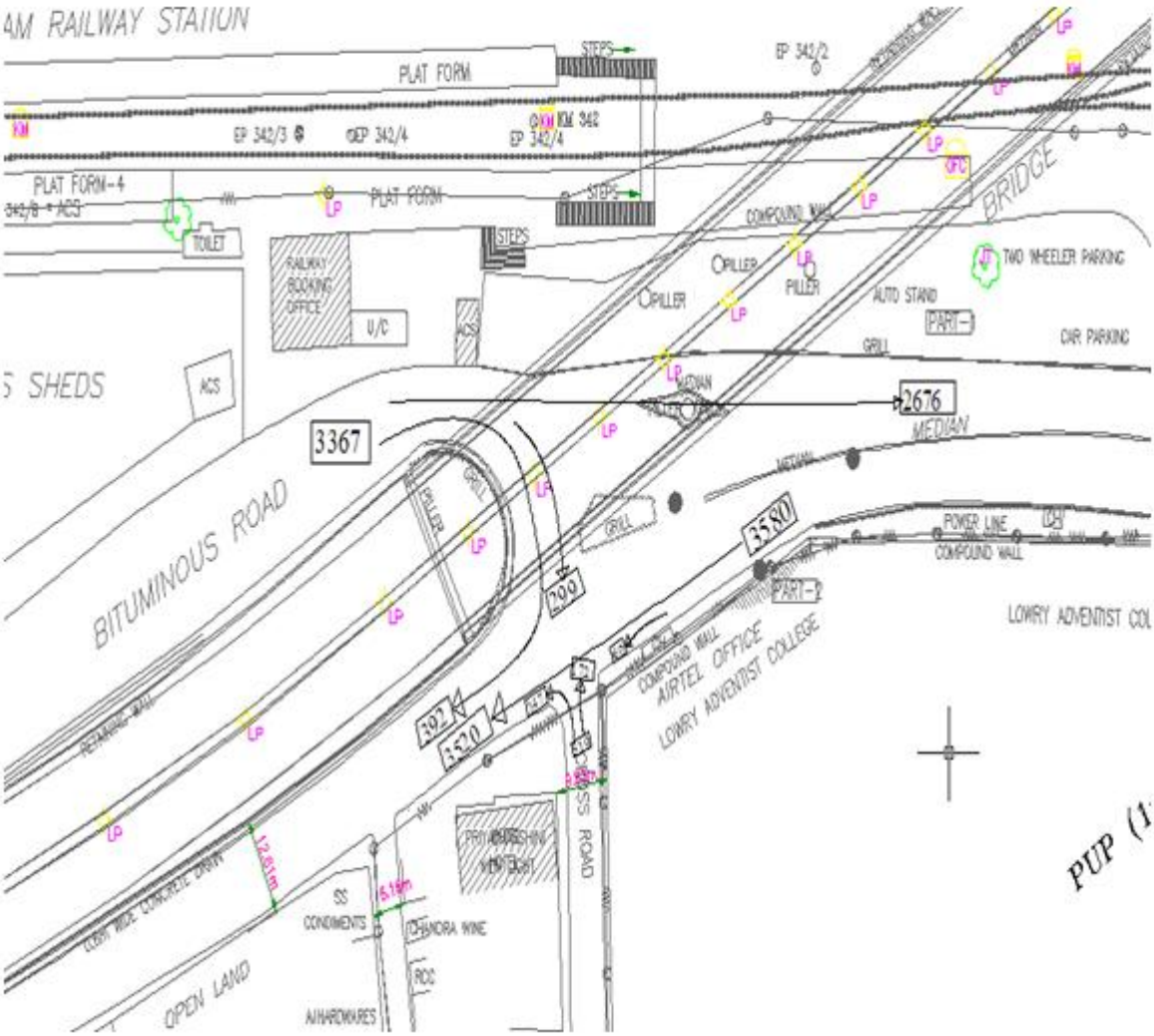


Figure 2.23 Shows the K.R.Puram Junction with PCU's & Road Geometric.

2.3.6 VARTHUR KODI JUNCTION

Figure 2.24 Varthur Kodi Junction

This is Three-legged unsignalized intersection connecting with Whitefield, Sarjapur and Marthahalli in North, South and West directions respectively. The surface Condition and platoon speed at both study approaches of the intersection is not good. During peak hours (morning peak and evening peak), the intersection gets over saturate (Demand more than capacity).

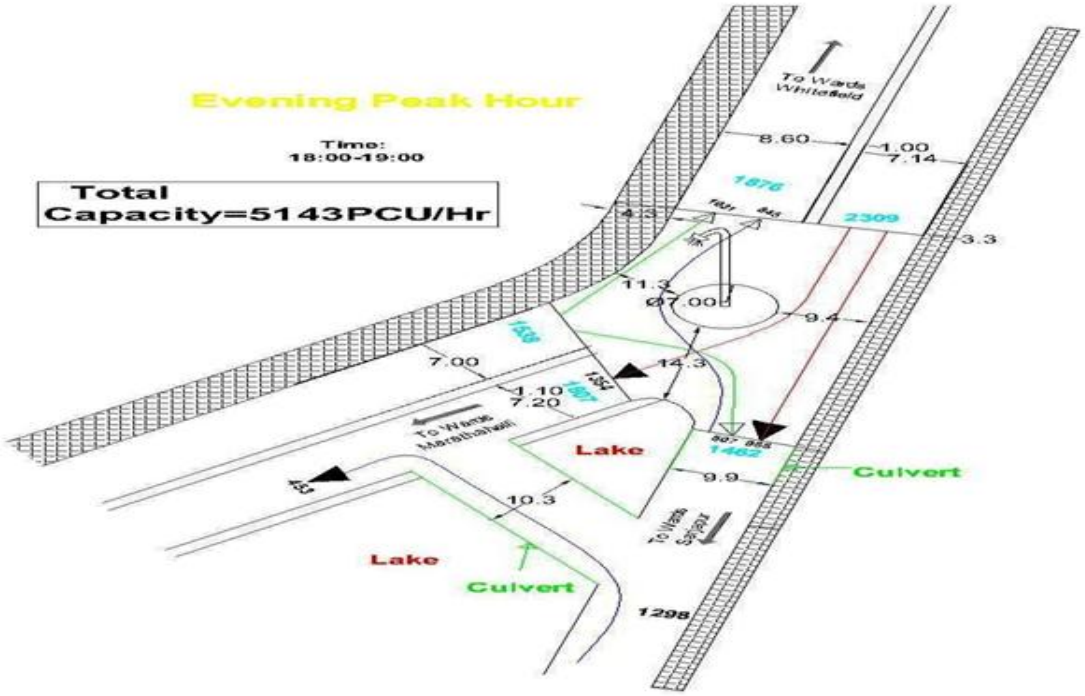


Figure 2.25 Shows the Varthur Kodi Junction with PCU's and Road Geometric.

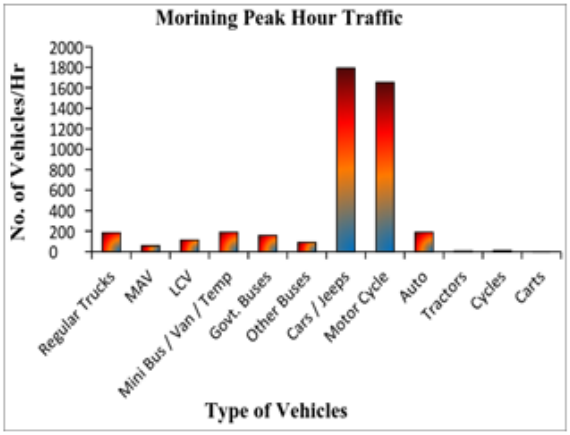


Figure 2.26 Morning peak hour traffic

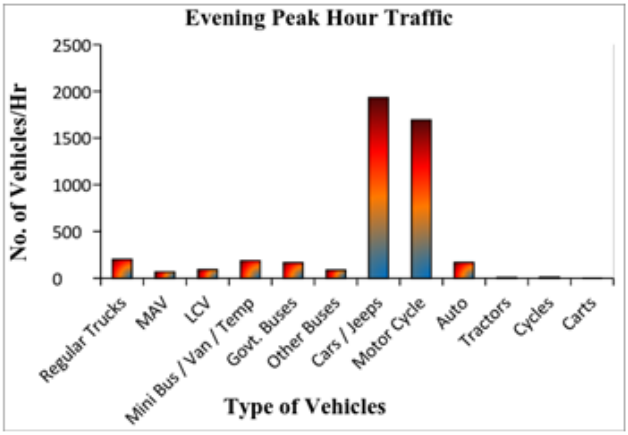


Figure 2.27 Evening peak hour traffic

2.4 Data Analysis

2.4.1 Projection of Traffic

Projected traffic Individual vehicular growth modeling is considered for next thirty years based on individual vehicular growth as per IRC: 108-1996.

2.4.1.1 Determination of past trends

Past trend of traffic growth is a valuable guide in determining the future trend. Past trend can be established from a variety of traffic growth indicators such as

1. Traffic flow from census
2. Vehicle registration
3. Fuel sales

A comparison of the growth rates for each of the above will be useful. For establishing reliable growth rates, the data should be for a number of years. The analysis can then be done for the entire period, and also for blocks of 5 years.

The growth rate of individual vehicles is calculated from Table 1.3. Motor Cycle is 10.51%. Cars, Minibus, Van, LCV are 13.29% and Bus, Trucks, MAV are considered as 12%.

The best way to arrive at the rate of growth is through a regression analysis. The formula expressing the compound rate of growth of traffic is

$$P_n = P_0 (1+r)^n$$

Where P_n= Traffic in the n^{th} year

P_0= Traffic flow in the base year

n= Number of years

r= Annual rate of growth of rate of traffic, expressed in decimals.

2.4.1.2 Traffic projection at selected intersections

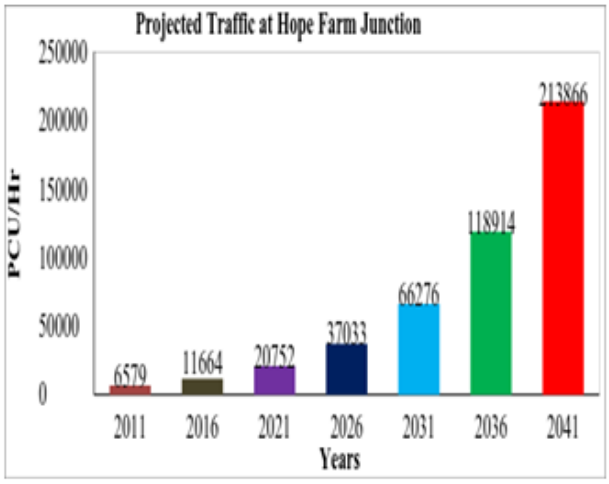


Fig 2.28 Traffic Growths at Hope Farm Junction

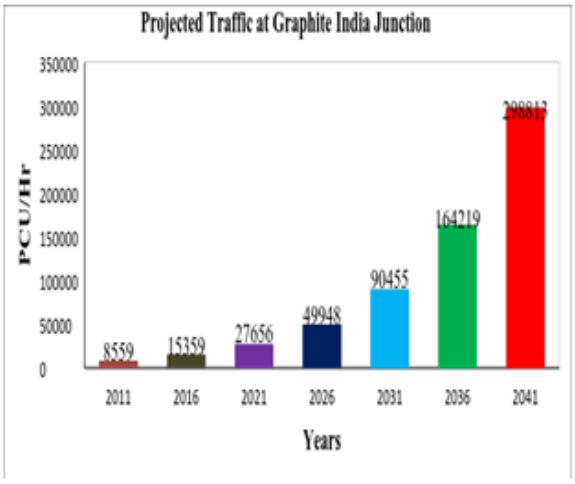


Fig2.29 Traffic Growths at Graphite India Junction

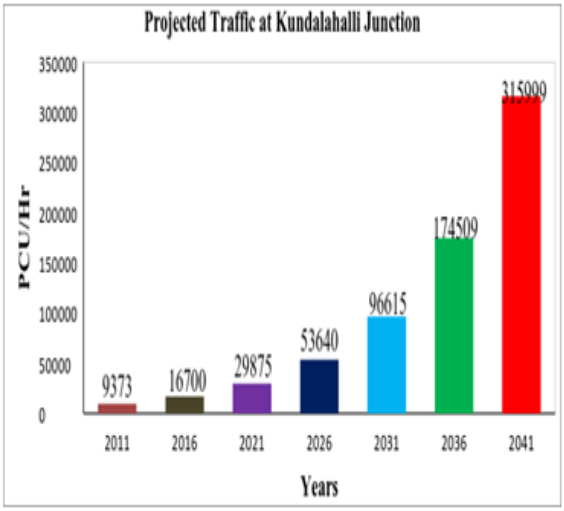


Fig 2.30 Traffic Growths at Kundalahalli Junction

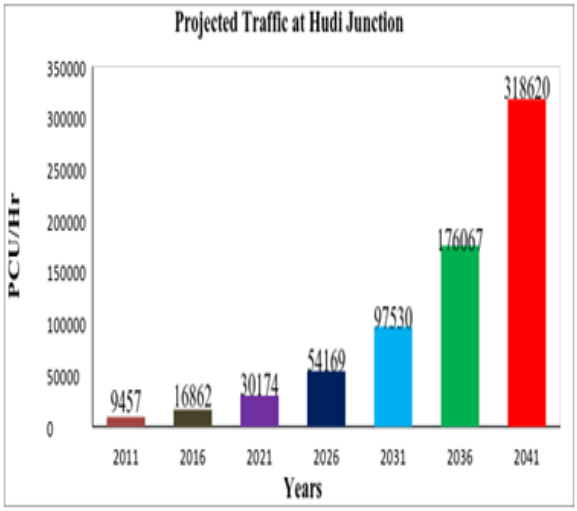


Fig 2.31 Traffic Growths at Hodi Junction

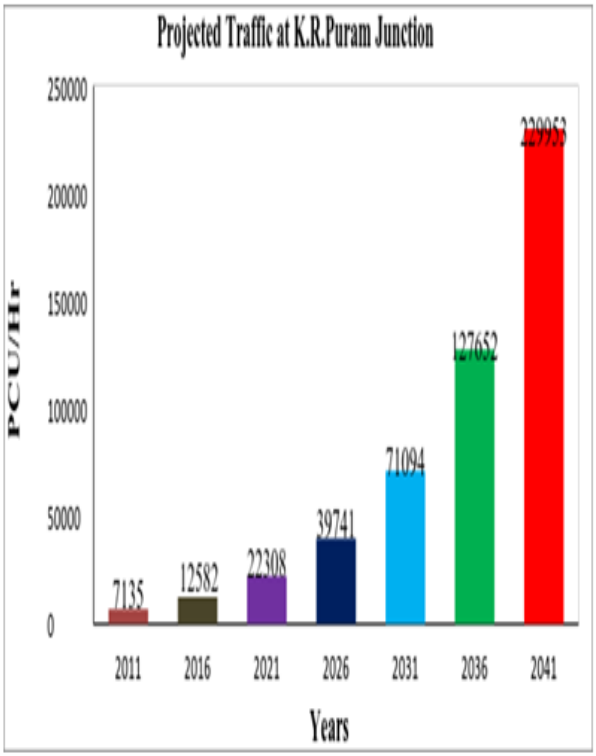


Fig 2.32 Projected Traffic Growths at K.R.Puram Junction

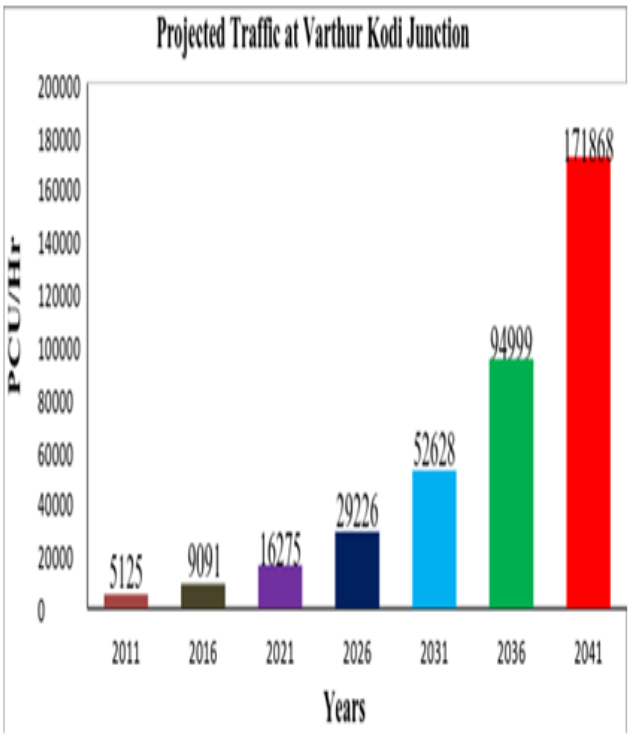


Fig 2.33 Projected Traffic Growths at Varthur Kodi Junction

2.4..1.3 Pedestrians projection at selected intersections

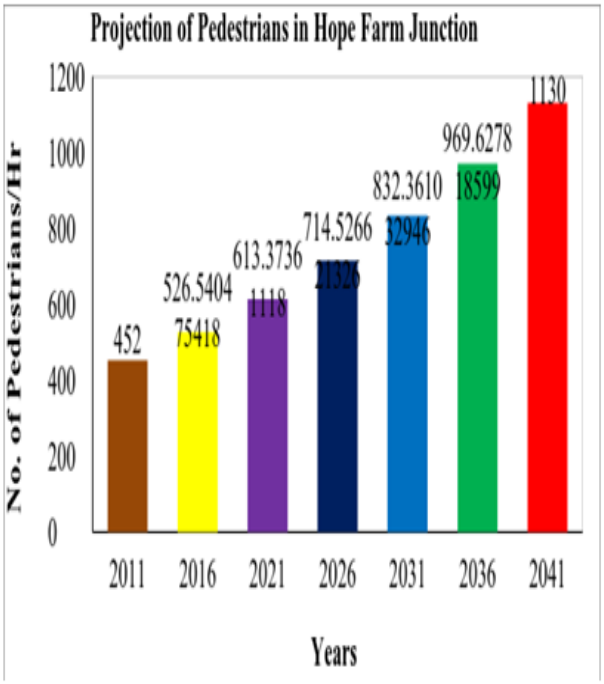


Fig 2.34 Projection of pedestrians in Hope farm junction

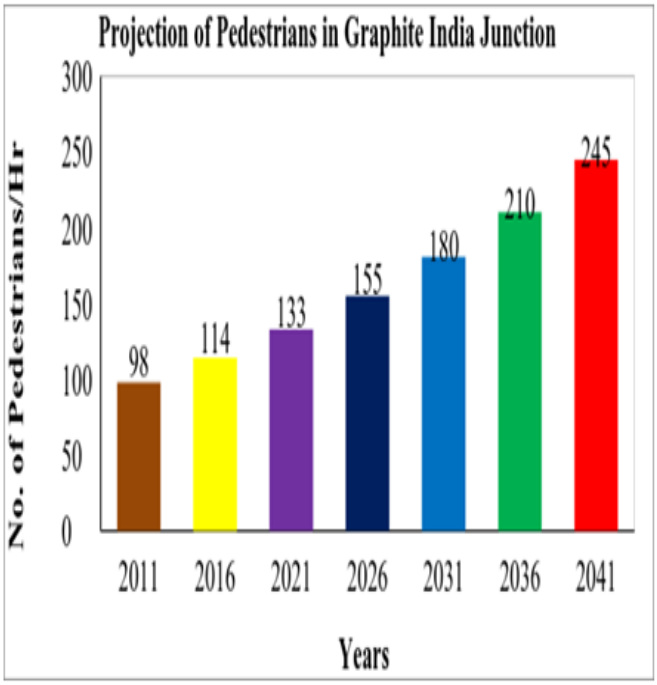


Fig 2.35 Projection of pedestrians in Graphite India Junction

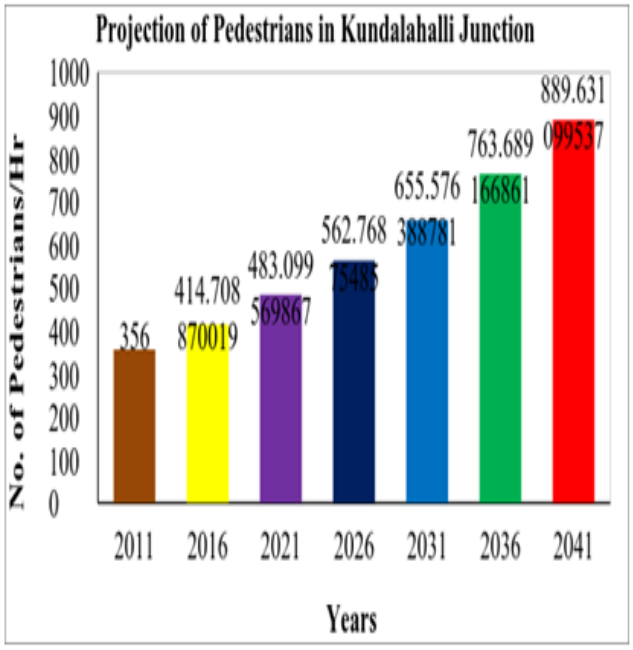


Fig 2.36 Projection of Pedestrians in Kundalahalli

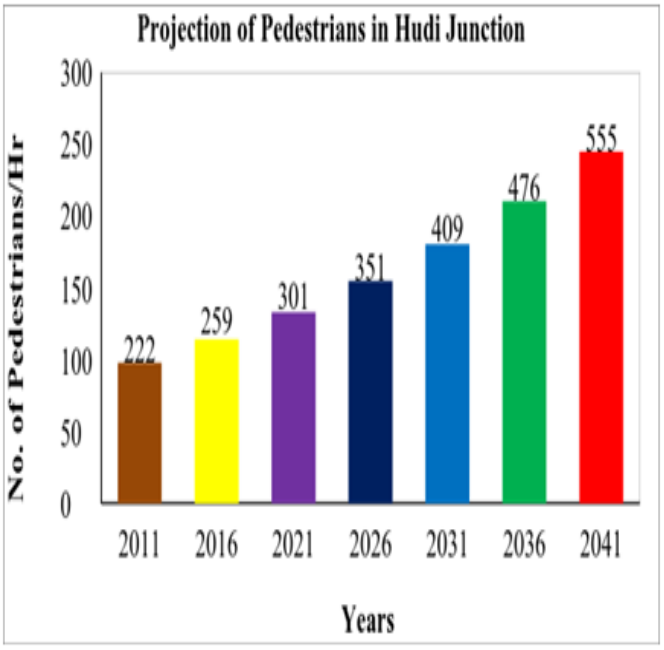


Fig 2.37 Projection of Pedestrians in Hudi junction

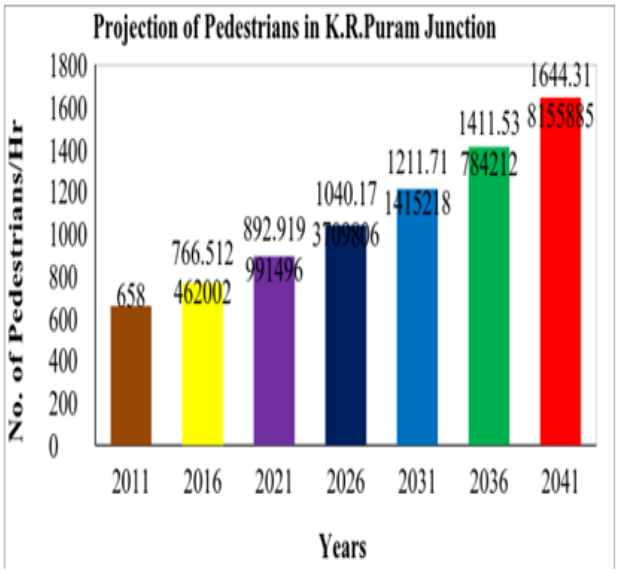


Fig 2.38 Projection of Pedestrians in K.R.Puram junction

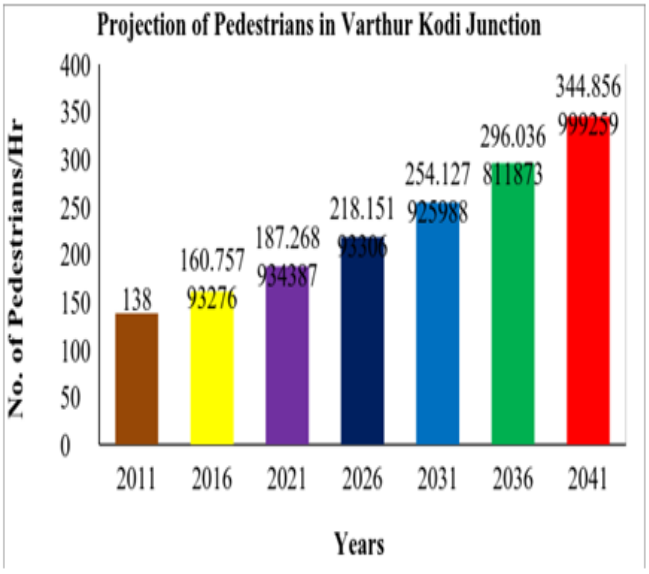


Fig 2.39 Projection of Pedestrians in Varthur Kodi

2.4.2. Capacity and Level of Service for selected intersections

The amount of traffic that can pass through a signal control intersection from a given approach depends on the green time available to the traffic and on the maximum flow of vehicles past the stop time during the green periods. The capacity and service volume that a signalized intersection can handle depends upon geometric, signal operation and traffic factors.

Table 2.1 Capacity and Level of Service of selected intersections as per IRC: SP-41

SI NO	Junction Name	Type	Name of the Road	Lane Width in mts	Total Volume PCU/Hr	Green time in sec(g)	Cycle Length in sec©	Capacity =(s*g)/c	V/C	LOS	Junction LOS
1	Hope Farm	4 Arms +	Kadugodi	7.9	1459	40	220	754	1.93	F	F
			Channasandra	4.1	1203	50		489	2.46	F	
			Whitefield	7.7	1992	40		735	2.71	F	
			ITPL	8.7	2064	80		1661	1.24	F	
2	Hudi	4 Arms x	K.R.Puram	8.4	3005	50	165	1336	2.25	F	
			Hope Farm	7.5	2887	35		835	3.46	F	
			Graphite India	11.3	1876	40		1438	1.30	F	
			Hudi Road	6.5	1759	30		620	2.84	F	
3	K.R.Puram	3 Arms Y	Whitefield	7.8	3579	-	-	2400	1.49	F	
			Majestic	12.5	3314	-		2400	1.38	F	
			Narayanpura	3.1	319	-		1200	0.27	B	
4	Varthur Kodi	3 Arms Y	Whitefield	7.2	2308	-	-	2400	0.96	E	D
			Sarjapur	9.9	1298	-		2400	0.54	C	
			Marthahalli	7	1538	-		2400	0.64	D	

Table 2.2 Capacity and level of service of selected intersection as per IRC-106-1990

SI NO	Junction Name	Type	Name of the Road	Directions	Total Volume PCU/Hr	Std. Capacity/Hr	V/C	LOS	Junction LOS
1	Hope Farm	4 Arms +	Kadugodi	Towards Hope Farm	1459	2400	0.61	D	F
				Towards Kadugodi	1274	2400	0.53	C	
			Channasandra	Both side	2372	1200	1.98	F	
			Whitefield	Both side	4027	3000	1.34	F	
			ITPL	Towards Hope Farm	2065	2400	0.86	E	
				Towards ITPL	2073	2400	0.86	E	
2	Hudi	4 Arms x	K.R.Puram	Towards Hudi	2005	2400	0.84	E	F
				Towards K.R.Puram	2635	2400	1.10	F	
			Hope Farm	Towards Hudi	2887	2400	1.20	F	
				Towards Hope Farm	2627	2400	1.09	F	
			Graphite India	Towards Hudi	2358	2400	0.98	E	
				Towards Graphite	1876	2400	0.78	D	
			Hudi Road	Towards Hudi	2523	2400	1.05	F	
				Towards Hudi road	2178	2400	0.91	E	
3	K.R.Puram	3 Arms Y	Whitefield	Towards K.R.Puram	3579	2400	1.49	F	F
				Towards Whitefield	2795	2400	1.16	F	
			Majestic	Towards K.R.Puram	3314	2400	1.38	F	
				Towards Majestic	4058	2400	1.69	F	
			Narayanpura	Both side	677	1200	0.56	C	
4	Varthur Kodi	3 Arms Y	Whitefield	Towards Varthur Kodi	2309	2400	0.96	E	F
				Towards Whitefield	1876	2400	0.78	D	
			Sarjapur	Both side	2397	1200	2.00	F	
			Marthahalli	Towards	1538	2400	0.64	D	

				Varthur Kodi					
				Towards Marthahalli	1807	2400	0.75	D	
5	Graphite India	3 Arms T	ITPL	Towards Graphite	3935	2400	1.64	F	F
				Towards ITPL	2194	2400	0.91	E	
			Kundalahalli	Towards Graphite	3095	2400	1.29	F	
				Towards Kundalahalli	2254	2400	0.94	E	
			Hudi	Towards Graphite	1881	2400	0.78	F	
				Towards Hudi	4463	2400	1.86	F	
6	Kundalahalli Gate	4 Arms +	Marthahalli	Towards Kundalahalli	3054	2400	1.27	F	F
				Towards Marthahalli	3802	2400	1.58	F	
			Sai Layout	Both side	570	1200	0.48	C	
			Varthur Kodi	Towards Kundalahalli	3137	2400	1.31	F	
				Towards Varthur Kodi	2700	2400	1.13	F	
			ITPL	Towards Kundalahalli	2254	2400	0.94	E	
				Towards ITPL	3095	2400	1.29	F	

2.5 Saturation flow for selected intersections

The saturation flow is estimated with the help of average rates at an interval of 6 sec excluding the discharge rates of the 1st and last interval for each approach of the study junctions. The saturation flow is estimated in pcu's/6 sec of green and hence converted into pcu's/hour of green.

SI NO	Junction Name	Name of the Road	Total Volume in PCU/Hr./Lane	Mashkur Eqn. S=1.25*Q+644 (PCU/Hr/Lane	Sarna, Malhotra Eqn. S=882+0.83Q (PCU/Hr/Lane)
1	Hope Farm	Kadugodi	730	1556	1487
		Channasandra	1203	2148	1880
		Whitefield	996	1889	1709
		ITPL	1032	1934	1739
2	Hodi	K.R.Puram	1503	2522	2129
		Hope Farm	1444	2448	2080
		Graphite India	938	1817	1661
		Hodi Main Road	880	1743	1612

3	K.R.Puram	Whitefield	1790	2881	2367
		Majestic	1657	2715	2257
		B-Narayanpura	319	1043	1147
4	Varthur Kodi	Whitefield	1154	2087	1840
		Sarjapur	1298	2267	1959
		Marthahalli	769	1605	1520
5	Graphite India	ITPL	1968	3103	2515
		Kundalahalli	1548	2578	2166
		Hodi	940	1819	1662
6	Kundalahalli Gate	Marthahalli	1527	2553	2149
		Sai Layout	291	1008	1124
		Varthur Kodi	1568	2604	2183
		ITPL	1472	2484	2104

Table 2.3 comparative assessment of saturation flow based on approach volume

As may be seen, saturation flow values calculated from the above relation developed in the present study are greater than those calculated from relationships by other researches. On the approaches, vehicles try to utilize every gap available to them. It results in more efficient movement of vehicles, and therefore, more discharge per unit width of the approaches.Table 2.3 shows the comparative assessment of saturation flow based on approach volume for different studies, as it has been seen from the studies that the saturation flow increases with the increase in approach volume. Table 2.4 shows the comparative assessment of saturation flow based on ratio of number of vehicles to equivalent pcu's in different studies, as it has been seen earlier that the saturation flow increases with the increase in ratio of number of vehicles to equivalent pcu's. However, there is a decrease in ratio of number of vehicles to equivalent pcu's for the same approach of the study intersections due to comparative lesser share of bicycle/cycle rickshaws in the traffic stream.

SI NO	Junction Name	Name of the Road	Total Volume in Vehicles/Hr/Lane	Total Volume in PCU/Hr /Lane	No. of veh. To equiv. PCU ratio (R)	Mashkur Eqn. S=1055 R+62 (PCU/Hr /Lane)	Sarna, Malhotra Eqn. S=1210+ 78.6 R (per 10')
1	Hope Farm	Kadugodi	579	730	0.794	899	1272
		Channasandra	1034	1203	0.860	969	1278
		Whitefield	1018	996	1.022	1140	1290
		ITPL	1042	1032	1.010	1127	1289
2	Hodi	K.R.Puram	1441	1503	0.959	1074	1285
		Hope Farm	1434	1444	0.993	1110	1288
		Graphite India	942	938	1.004	1121	1289
		Main Road	847	880	0.963	1078	1286
3	K.R.Puram	Whitefield	1901	1790	1.062	1183	1293
		Majestic	1762	1657	1.063	1184	1294
		B-Narayanpura	395	319	1.238	1368	1307

4	Varthur Kodi	Whitefield	1015	1154	0.880	990	1279
		Sarjapur	978	1298	0.753	857	1269
		Marthahalli	804	769	1.046	1165	1292
5	Graphite India	ITPL	2083	1968	1.059	1179	1293
		Kundalahalli	1576	1548	1.018	1136	1290
		Hodi	982	940	1.045	1164	1292
6	Kundalahalli Gate	Marthahalli	1473	1527	0.965	1080	1286
		Sai Layout	378	291	1.299	1432	1312
		Varthur Kodi	1401	1568	0.893	1005	1280
		ITPL	1353	1472	0.919	1032	1282

Table 2.4 Comparative assessment of saturation flow based on ratio of number of vehicles to equivalent pcu's

2.5.1 Analysis of Delay for selected intersections.

Field measurement of delay was done at five intersection approaches. The number of vehicles in queue is recorded at regular interval of 10 to 20 seconds. The regular interval should not be an integral divisor of the cycle length, to eliminate potential survey bias caused by queue buildup in a regular cyclic pattern. This number is then multiplied by the interval length, resulting in total vehicle seconds of delay on the approach over the analysis period. This total is then divided by the total volumes of vehicles passed through the approach over the analysis period, resulting in the delay per vehicles at an approach. This value is then multiplied by the correction factor of 0.9 to account for the overestimation of delay by this method.

The resultant number is time-in-queue per vehicle. Estimated acceleration/deceleration delay is added to time-in-queue. The resultant delay is control delay for particular approach, which is also Level of Service criterion for signalized intersections as per HCM 2000. Survey period of about 15-20 minutes is taken for delay measurement as per convenience. Table 2.50 gives the field measured delay.

Junction Name	Name of the Road	Total Volume in Vehicles/Hr	Red Time Signal	Time in queue (Sec)	Acc/Dec Delay (Sec)	Total Delay (Sec)	LOS
Hope Farm	Kadugodi	1157	180	121.56	5.25	126.81	F
	Channasandra	1034	170	49.534	5.25	54.78	E
	Whitefield	2035	180	164.25	5.25	169.50	F
	ITPL	2084	140	155.48	5.25	160.73	F
Hodi	K.R.Puram	2881	115	180.1	5.25	185.35	F
	Hope Farm	2868	130	174.32	5.25	179.57	F
	Graphite India	1884	125	159.77	5.25	165.02	F
	Hodi Main Road	1693	135	125.33	5.25	130.58	F
K.R.Puram	Whitefield	3801	-	92.74	5.25	97.99	F
	Majestic	3524	-	104.09	5.25	109.34	F
	B-Narayanpura	395	-	55.28	5.25	60.53	E
Varthur Kodi	Whitefield	2030	-	85.88	5.25	91.13	F
	Sarjapur	978	-	38.25	5.25	43.50	D
	Marthahalli	1607	-	67.19	5.25	72.44	E
Graphite India	ITPL	4165	90	167.84	5.25	173.09	F

	Kundalahalli	3152	120	152.02	5.25	157.27	F
	Hodi	1963	100	94.136	5.25	99.386	F
Kundalahalli Gate	Marthahalli	2947	140	156.38	5.25	161.63	F
	Sai Layout	378	180	44.8	5.25	50.05	D
	Varthur Kodi	2802	180	110.55	5.25	115.80	F
	ITPL	2705	140	106.81	5.25	112.06	F

Table 2.50 Observed delay at selected intersections.

3. Conclusions

The growth in vehicular traffic and industrial activity in Whitefield area and associated activities necessitates the improvement of the project road to a good riding quality and of adequate width which enhances the level of service, driving comfort and safety.

The road inventory and traffic survey of the existing road section has been carried out. Some part of the existing road is in very poor condition, due to playing large number of vehicles. At many locations the road is severely distressed with severe raveling and deep potholes. The volume of the all selected intersection is almost reached to 10,000 pcu's/hr, hence widening of the all the approaches of the intersections and Grade separators are needed.

The volume capacity ratio and level of service is determined for all the intersections and it's found to be more than 1.0 in all the approach roads of the junctions and level of service is obtained as F. The saturation flow model is developed based on the field data of saturation flow and width of the approach roads of the all the junctions.

The underpass and redesign of signal has been proposed in Hope farm junction, Graphite India junction, Hudi junction and Kundalahalli junction. The design of signal has been proposed in Varthur Kodi junction, the design of signal is done by using Webster's method.

Adequate road furniture comparing of road signs, delineators, guard posts, crash barriers and zebra range have been proposed at appropriate locations and at junctions for the safety of road users. For the safety of pedestrians, footpaths and raised footpath have been proposed.

The road improvements proposed will ensure better level of service, improved riding quality and enhanced safety for the commuting passengers and specially, freight traffic. As the entire region is mainly dependent on industrial activities, an efficient and economical road network ensures optimal and quicker transportation of materials. Improvement of these intersections provides a better level of service for movement of vehicles in different places. This induces growth in transportation and related industry, in addition to automatically spur the growth of economy of the region as a whole. Improvement to project junctions ensures integrated development of various road systems with associated socio economic growth. The potential growth of different industries due to the improved road connectivity is expected to be very high and in fact it could attract more investment and economy will grow. The associated revenue to state's exchequer will improve. This intern will enhance the traffic also.

Construction period for the project road is suggested as twelve months using modern construction equipment's and methodology.

4. Scope for further studies

1. The saturation flow model is developed based on traffic condition of Bangalore city, which is assumed to be similar to other parts of India. This developed model may be applied in other cities of India and checked for its usefulness.
2. Saturation flow depends on various factors. In the present study all intersections were selected having almost flat surface. Saturation flow also gets affected by parking facility near intersection. All these factors needs to studied and develop new model taking into account maximum possible variables.

3. The offset optimization can be done by minimizing the offset by graphical superimposition of the service curve on the demand curve and by minimizing the area between the curves.
4. The performance index can be made more realistic by including the effect of queuing, number of vehicle stops, fuel consumptions etc.
5. The effect of varying speed on different approaches of the intersection can be taken into account.
6. Design of signals by using SCOOT (Split Cycle Offset Optimization Technique) method. To develop algorithms using optimization techniques.

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1. IRC-SP-41-1994: Guidelines for Design of At Grade Intersection in Rural and Urban Areas.
2. IRC-92-1985: Guidelines for Design of Interchanges in Urban Areas.
3. IRC-93-1985: Guidelines on Design and Installation of Road Traffic Signals.
4. IRC-106-1990: Guidelines for Capacity of Urban Roads in Plan Area.
5. IRC-108-1996: Guidelines for Traffic Prediction on Rural Highways.
6. IRC-54-1974: Lateral and Vertical Clearances at Underpasses for Vehicular Traffic.
7. IRC-09-1972: Traffic Census on Non-Urban Roads.
8. IRC-103-1988: Guidelines for Pedestrian Facilities.
9. IRC-86-1983: Geometric Design Standards for Urban Roads in Plains.
10. IRC-70-1977: Guidelines on Regulation and Control of Mixed Traffic in Urban Areas.
11. IRC-SP-55-2001: Guidelines for Safety in Construction Zones.

