Carrying Capacity of Urban Transportation Networks: A Case Study of Designed Ideal City

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Abstract. With the rapid growth of urbanization, the population coupled with economy of most cities not only in India but globally is going through significant changes. One of the significant changes is relating to the fast development of transportation infrastructures in these areas which gives rise to a quick change on the travel behaviours. Changing life style along with the city's expansion, increasing population growth in urban areas and vehicular growth demand the design of new transportation system which is capable of meeting the free flow of traffic by assessing the carrying capacities of road network to accommodate increasing growth of vehicles on a time scale. Carrying capacity is a commonly used concept to represent the maximum flows that can pass through the roads without traffic congestion in transportation system. The authors of the present paper have designed a hypothetical ideal city having population of 10000 people with projected population up to year 2051 and corresponding estimation of increased vehicles through well-defined methods. The authors have also designed the road network to accommodate estimated vehicles to ensure free flow of traffic without any congestion by assessing the carrying capacity of such road network through compatible simulation models.

Index Terms: Transportation Networks, Roads carrying capacity, Ideal City

I. INTRODUCTION

A gradual rise in the population triggering urban sprawl. In oxford dictionary, it is defined as "the disorganized and unattractive expansion of an urban in an adjoining countryside." A unorganised expansion of the urban area and the unevenly distributed road networks have become more congested. Urban sprawl is due to the migration from the countryside in search of work and the movement of people from one city to another. It has forcedan increase in the population of the surrounding areas of the city and, at the same time the number of vehicles has also increased.

Today, 55% of the world's population stay in urban areas and expected to increase 68% of the world's population by 2050 according to the United Nations. In developing countries, the urban population has increased from 446 million to 903 million (United Nations, 2000).Therefore,as the urban population increases, the number ofvehicle per 1000 population also increases. According to records, the average number of motor vehicles per 1,000 people in India's urban population in 2011-15 was 402 vehicles per 1,000 people, an increase of 44% from 1960-65 (9 vehicles per 1,000 people).

The increase in the number of vehicles will increase the traffic congestion, pollution, more fuel consumption and energy losses, mainly in developing countries. Therefore, the construction of urban roads should be able to accommodate the maximum numbers of vehicles. In this research paper, we willdevelop a circular city setup with a good road network system. The maximum carrying capacity of road is sufficient to accommodate the number of vehicles and reduce the carbon footprint and energy loss.

An imaginary urban setting capable of accommodating an increased population within 30 years will be created. The area of the urban area will be calculated with the help of the optimal area per capita of 50 meters specified by WHO. And use the population size increase in four wheelers and two wheelers.Plan the road network accordingto the number of vehicles.In additional, wewill show how many houses are needed for each family with five members and green open spaces to meet the population size.

This imaginary urban area is going to be planned in such a way that can easily solve the problem of uneven urban sprawl. The setting of road, buildings and urban areas with the maximum carrying capacity. People living in the city get open space as well as build-up space. Our planning is to develop a city that can meet the requirements of Sustainable Development Goal 11 (Sustainable cities and communities) and make cities a sustainable means by providing safe and affordable housing, public transportation and green public spaces. This can increase employment opportunities and build social and economic resilience.

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Urban Sprawl Effect on Road Networks

Rapid urbanization has caused population growth to exceed the capacity of the city, and local communities have begun to expand into rural areas far from the city center. These people will start to use their cars more frequently, which lead to more road traffic, more pollution and accidents [1]. Increased dependence on automobiles, worsening air pollution have led to more sedentary lives and unhealthy community development [8]. According David Suzuki Foundation urban sprawl is also wounding precious farm and wildlands, leaving less greenspace and wildlands, putting precious wildlife habitat and species at risk.

Traffic appear in two form: recurring congestion and non-recurring congestion.Recurring congestion occurs in the peak flow period, when vehicle's lane on the road, bridge, or tunnel increases more than the capacity of roads. The occurrence of non-recurring congestion is unpredictable, and occurs due to traffic accidents, work areas, weather or other activities. The traffic congestion leads to energy loss and pollution. According to a 2014 report, traffic congestion caused American people loss a total of 160 billon US dollarsdue to an additional 3.1 billion gallons of fuel and 6.9 billion hours of travel. It releases so much pollution in the air.

However, congestion is the inevitable result of the scarcity of traffic facilities such as road space, parking lots, road signals, and good traffic management. Up to 80 % of the traffic on urban roads comes from cars, two wheelers and three wheelers [3]. The frequency of collisions and traffic speed are the main reason for the severity of collisions. Due to urban expansion, the volume and speed of traffic will cause the frequency and severity of collisions [2].

Congestion affects society, economy and environment. The increasing traffic congestion has increased fuel consumption and the release of greenhouse gas emissions. Transportation also reduces the productivity in urban areas, which leads to economic losses and affects society. An effective transportation system is very important for economic growth, and it provides connection between localities. It connects to work, delivers products to the customers, supports trade and helps supply. In order to avoid traffic jams, we need to plan our roads and parking lots and their management.

Taragin and Eckhardt [6] found that the shoulder of a road affect speed and lateral positioning of motor vehicles, they also found that the shoulder should be constructed with at least 1.2 m of stabilized material when lane pavement on the main highway is 6 m in width or less, plus additional width of grass and gravel. A wide road easily enables free flow of traffic without congestion. The green cover along the roads absorbs the harmful greenhouse gases and also please the mind of the riders. A good road network can keep traffic flowing, reduces air pollution, support trading and connect people.

The Indian Roads Congress [7] guidelines on the capacity of urban roads in plain areas gave some measures for improve the roads capacity of urban roads. Such measures are developing off street parking areas, central verge, separate right off way for slow vehicles, restriction in the movement of heavy and slow vehicles on busy arterial and sub-arterial during some period of a day, no roadside commercial business, separate way for cycles, controlling cross traffic, improving traffic discipline and banning certain conflict movement. The result is reduced traffic, reduced air pollution and noise. These guild lines would improve the transportation network.

Other Effects of Urban Sprawl

More population move from rural to urban, which affects housing capacity. Some people live in a house or in a small apartment with high rent. People from areas outside the city came to settle in the periphery, not in the planned structure. They build houses on the land, forest, swamps, leaving no empty space. Urban Sprawl's negative impacts of unsustainable housing cause global warming and environment quality increase. S. Kolte [9] state that the design of the house should have a durable and timeless spaces and reduce the need to replace it every few years. We should use materials with low emission of volatile organic compounds and other air pollutants. These materialshave moisture-proof properties and can adsorb harmful compounds to create a healthy living space.

How Cities Should Be Planned?

Cities are the engines of national economic growth. It is a virtuous cycle of growth and development. A well-planned city can improve the quality of life and attract people and investor to the City. Smart cities promote the mixed use of land, everyone has house, creates walkability, preserves open spaces, provides real transportation options, has a good and citizen friendly government, and has better smart solutions.

The core infrastructure elements a smart city include adequate water and electricity supply, solid waste management, efficient transportation facilities and public transport, affordable housing for each income group, IT connectivity and digitalization, good governance, sustainable environment, safety and security of citizens, health and education facilities. Smart solutions applytechnology, information and data to promote cities to improve infrastructure and services. It makes cities more inclusive by providing quality of life for all people (especially the poor), creating jobs and increase income.

Turcotte [8] stated that a modern form new urbanism will produce positive social, economic and environmental changes, but complainedthat such changes are limited.

In Curitiba, Brazil, the road system is designed in the trinary system, the central road has two exclusive bus lanes in the center connected by two local roads, both the sides of the central road there are one way roads with high capacity free flowing, one road is for flowing in the city and other is for out of the city. The land attached to each axis is used for high-density occupation [10].

Self-reliant cities are organized by local economies, and these economies are more self-reliant in meeting local needs through local businesses and cooperatives. A self-reliant economy requires more use of local environmental resources, and efforts to reduce and redirect waste streams so that we can be absorbed efficiently or with minimal ecosystem disturbance [18]. The self-reliant city has a considerable political agenda, to change moral values away from anthropocentric views of nature and toward more decentralised and cooperative forms of human endeavour [11].

According to G. Haughton [12] in the eco-city, nature should be restored to bioregions of the urban area, with more open spaces, roof gardens, and good habitat. Ravetz, White and Whitney [15] argued that non-sustainable urban development includes external exchanges, the external areas such as resources and waste streams are taken away by people without any compensation. Approximately 90% of people spend most of their time in buildings. Therefore, in the past ten years, indoors shouldbe comfortable, healthy, efficient, productive and satisfactory, with less energy consumption and carbon dioxide emissions [13].

II. METHODOLOGY

This paper conducts an action research to solve the problem of road carrying capacity and urban unsustainably. By establishing an imaginary urban settlement with population of 10,000. The population increases exponentially every year, increasing the transfer and migration population. Vehicles will increase exponentially according to the number of people, and will be divided into a car and a two-wheeler in each house. This setting will be multiplied in three decades, in which the road diameter and building area are developed based on imaginedmeasurements. The city area will be estimated by per capita open space and 60% build-up area and shownin a quadrangle shape. The calculated urban area has a large carrying capacity that can hold the population in future. Further, more detailing is done with the households' division as per income group, each house five members. Using the households number vehicles number and parking area is calculated.

III. CASE STUDY

The Ideal City is planned according to the following design salient features:

a) Population forecast
b) Area estimation to accommodate population
c) Houses of different income groups
d) Estimation of number of vehicles
e) Parking area
f) Road network planning
g) Overall ideal city planning

3.1 Population forecast:

An imaginary urban setting is designed that capable of accommodating an increased population in 30 years is created. Here 10,000 populations of the city are taken for the base year 2021. Which increases per year with 25% of growth rate of population, 70% of transfer of population, 40% migrate workers. After adding each year, the population will increase approximately 12 lakhs or 1.2 million by 2051.The calculation of population is shown in the table 1. The table shows the imaginary population of years 2021, 2013,2014,2051. Total 12 lakhs population include Super-high income group of 2 lakhs, High Income Group of 4 lakhs, Middle Income Group of 3 lakhs and Lower Income group of 3 lakhs.

Table 1: Projected population during different decades

SL No.	Decadal year	Projected population as per growth rate of 25 percent year	Transfer of population to extent assumed as 70 per cent	Migrant workers of assumed 40 percent	Total projected population
1	2021	10000 (base population)	NIL	NIL	10000
2	2031	12500	21250	17500	51250
3	2041	64062.5	108906.25	89687.5	262656.25
4	2051	328320.3125	558144.531	328320.7125	1214785.556

Therefore, designed population for 2051 is 12 Lakhs.

3.2 Area estimation to accommodate population:

The optimal are is calculated according to World Health Organization recommendation. The green space per individual is minimum 9 square meters and ideal is 50 square meters. The open space is calculated and check in all aspect from9 to 50 square meters per capita for 12 lakhs population, and 60 % of build-up area. Finally, the calculation for 50 square meters per capita gave out the estimated area of 15,00,00,000 meters square or 150 square Kms. Thus the urban area is of 15,00,00,000 square meters with Open space of 6,00,00,000 square meters and 9,00,00,000 square meters. Calculation of open, build-up and total area as per different square meters for 12 lakhs population is given in the Table 2. Urban area is quadrangle in shape, surrounded by and divided into four equal parts by four lane roads and in between everything is connected with two lane roads.

Well covered with greenery,15 storey residence towers and bun

galows, separate commercial area and proper parking areas for four and two wheelers etc.

table 3 show the total towers and bungalows that can accommodate 12 lakhs population.

Table 2: Designed Open and Built-up space in $m^2$for the city having population of 12 lakhs in 2051					
SL No.	**open space requirement criteria in m^2/ person**	**Population in 2051**	**Open space (m^2)**	**Built-up area (m^2) (50% of open area)**	**Total area (m^2)**
1	9	12,00,000	1,08,00,000	1,62,00,000	2,70,00,000
2	15	12,00,000	1,80,00,000	2,70,00,000	4,50,00,000
3	20	12,00,000	2,40,00,000	3,60,00,000	6,00,00,000
4	25	12,00,000	3,00,00,000	4,50,00,000	7,50,00,000
5	30	12,00,000	3,60,00,000	5,40,00,000	9,00,00,000
6	35	12,00,000	4,20,00,000	6,30,00,000	10,50,00,000
7	40	12,00,000	4,80,00,000	7,20,00,000	12,00,00,000
8	45	12,00,000	5,40,00,000	8,10,00,000	13,50,00,000
9	50	12,00,000	6,00,00,000	9,00,00,000	15,00,00,000
Total area of town to accommodate population of 12 lakhs in the 2051 is 15,00,00,000 m^2 or 150 sq. KMs					

3.3 Houses of Different Income Group:

The quadrilateral urban area has well developed settlements. The hoses are divided according to four different income groups. Each houses have average family member of five. For Super-High Income group there are one storey bungalows with beautiful big lawn. For High-Income group there are 15 floor towers, each floor has six flats of triple bedrooms. For Middle Income group there are also 15 floor towers, each floor has eight flats of double bedrooms. For Lower income group there are 15 floor towers with 24 rooms with a kitchen and common bathrooms per floor. Each room can have accommodated three people. This tower is mainly for migrate workers. The towers are of 5 meters high. Below

3.4 Estimation of number of Vehicles:

Number of vehicles is taken as each house of Super-High Income Group, High Income Group and Middle Income Group, one 4 wheelers and one 2 wheelers. Thus the four and two wheelers for high-income houses (8,1000) is 3,24,000 vehicles each wheeler. The city also has 50 City Buses running with biogas. (Table 4).

3.5 Parking Area:

The parking area is calculated according the number of vehicles. For two wheelers six square metres each parking area and for four wheelers 20 square meters each parking area is taken. Whereas for city buses 70 square meters per vehicles is taken. Table 5 shows the total area of parking in square meters.

Table 3: Total Towers/Bungalows								
SL No.	**Income-Group**	**Population**	**Member can live**	**Storey**	**Flats in one floor**	**Total Flats**	**one tower occupied by**	**Total Tower/ Bungalow**
1	**Supper High Income Group**	2,00,000	5	0	0	0	5	40000
2	**High Income Group**	4,00,000	5	15	6	19	450	900
3	**Middle Income Group**	3,00,000	5	15	8	120	600	500
4	**Lower Income Group**	3,00,000	3	15	24	360	1080	278

Table 4: Vehicles				
Sl No.	**Groups**	**Houses**	**4 wheelers**	**2 wheelers**
1	**High-Income**	81,000	3,24,000	3,24,000
2	**Super High-Income**	40,000	40,000	40,000
3	**Middle-Income**	60,000	4,24,000	4,24,000

Table 5: Parking Space				
Sl No.	**Wheelers**	**Area in Sq. meters**	**Vehicles numbers**	**Total area in Sq. meters**
1	**2 Wheelers**	6	7,88,000	47,28,000
2	**4 wheelers**	20	7,88,000	1,57,60,000
3	**City Buses**	70	50	3500

3.6 Road Network:

Road networks are calculated on the basis of Basic Road Statistics (BRS) of India state listed below [17]:

- Standard Single Lane: carriageway width between 3.75 M to below 7.0 M.
- Standard Double Lane: carriageway width between 7.0 and below 10.5 M.
- Standard Multi Lane: carriageway width of 10.5 M. and above.

APPENDIX B of Traffic Level of Service Calculation Methods shows Free Flow Speed range from 35 to 30 mph (miles per hour), when there is minimal signal per mile and parking permit [16]. Therefore, using the standard measurements and speed flow range, the four and two lane roads are designed. The area between two tower is 150 m which include two lane roads, pedestrian pathway, green dividers, green space, children parks, gym, open-gym etc. For four lane roads on the border of the city include two ways up and two ways down roads, pedestrian pathway, green dividers and plants& trees along it. The roads are designed for the Free flow of traffic 40 km/h.

The roads planning is taken care that there is less traffic congestion so that there would be less energy loss and pollution. It will also tackle the problem of fuel shortage. The width of two lane roads is 4.5 meters of one lane with 1.5 meters' green divider and 2.5 meters' pedestrian pathway whereas the four lane roads width is of 3.5 meters one lane with 1.5 green divider and 2.5 meters' pedestrian pathway.

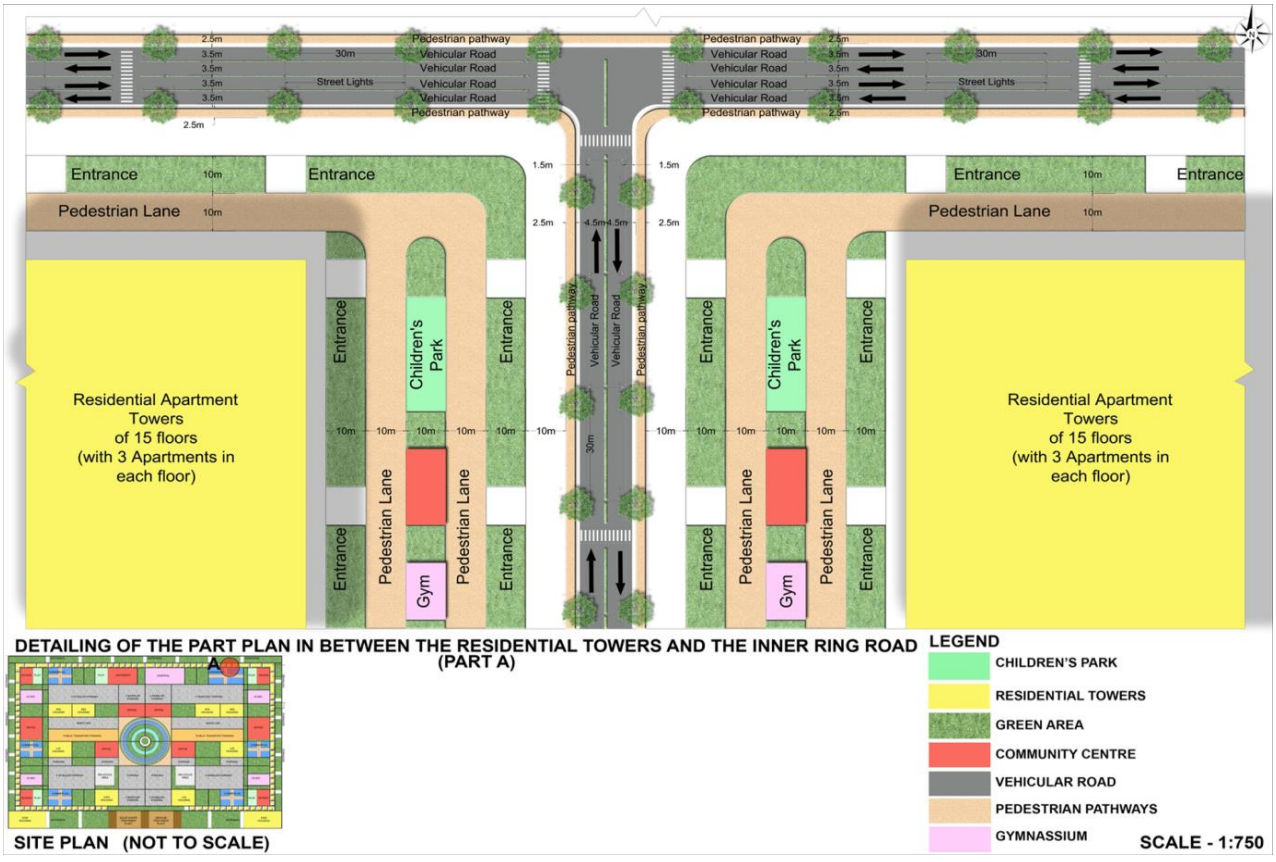

Figure 1 Road Network Planning

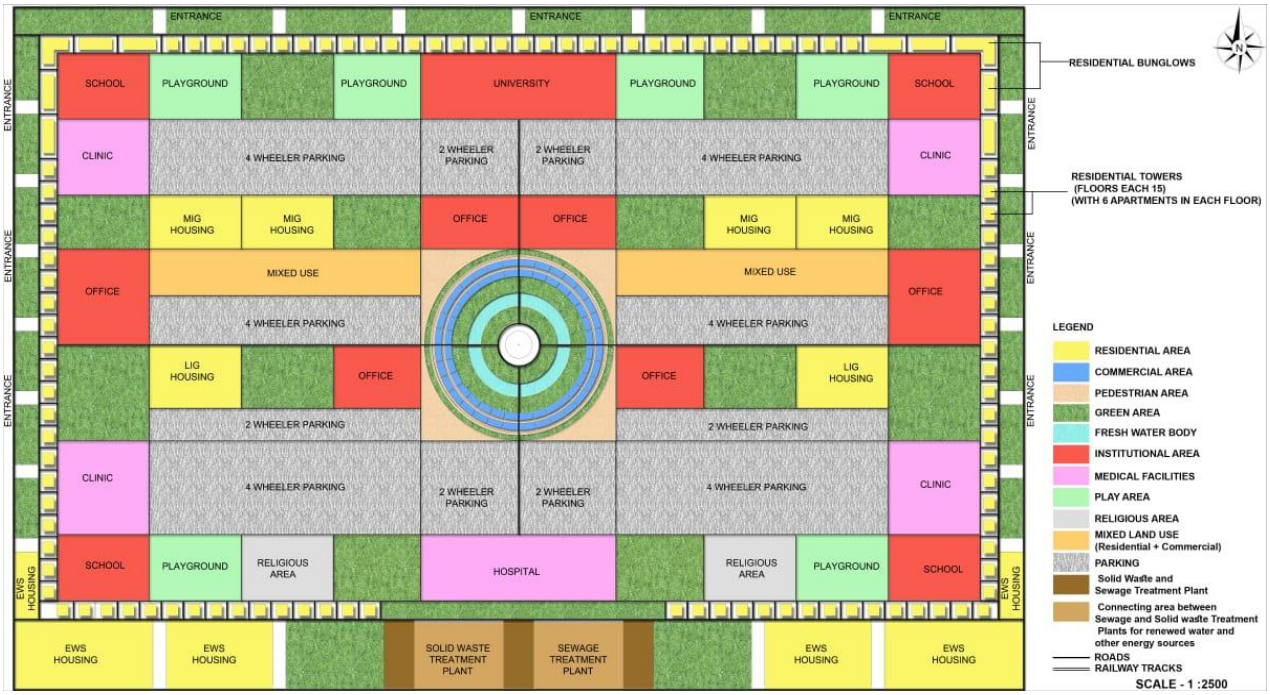

Figure 2: Ideal City Map

3.7 Overall Ideal City Mapping:

The urban map is designed in keeping in mind the needs of future generation. It can tackle the problem of rise in population, carrying capacity, traffic, energy loss, pollution, green space, efficient building, waste management and economic. The above map is divided the resident area and commercial area and both of them are well connected with fee flow roads. In the centre there is a circular commercial area which is connected with four lane roads delated as thick black line. The residence area is marked in yellow MIG housing is for middle income group and LIG housing for lower income group and yellow small boxes are for super high and high income group. Each residence areas are connected with commercial roads through two lane roads marked are thine black line. As defined above the roads are well covers with greenery and residence areas have good refreshment areas. There are also separate parking areas for four and two wheelers. All the green colour showing open area which is very essential for free flow of air and water percolation to maintain water table. The city also has E-waste management house denote as EWS housing and Solid waste treatment Plant marked in brown colour. The biogas generates from the waste use to run city buses in the city and e–waste will use to generate electricity. All the characteristics of the ideal city can attract many stakeholders such as investors, workers and other people which will help in economic development.

IV. CONCLUSION

Urban sectors are going to be hard pressed in terms of environmental pollution, mainly air, water, noise, solid waste etc. Increasing population growth coupled with demand and changing life style accelerate the problems on a time scale. Transport sector in urban areas is posing significant threat to the quality of urban environment. Traffic congestion is a normal offshoot of increasing automobiles having limited road network which leads to increasing air pollution, longer time to reach destination and discomfort. Such an alarming situation is being witnessed everywhere in the urban areas of the world and need to be addressed. The present paper demonstrates the need of carrying capacity based road network of an urban area with a case study to address such issues. Urban planners and regulating authorities should scientifically carryout carrying capacity of road network having regard to emerging trends of vehicular growth of urban areas in order to ensure free flow traffic as has been demonstrated and planned in the present paper.

REFERENCES

1. What is Urban Sprawl (Migration of a Population)?, Conserve Energy Future, (n.d.)
2. R. Ewing, S. Hamidi, J.B. Grace, Urban sprawl as a risk factor in motor vehicle crashes, US Geological survey, Vol. 53, No.2, 247-266, 2016
3. R. Gajjar, D. Mohandas, Critical Assessment of Road Capacities on Urban Roads – AMumbai Case-Study, Science Direction, Vol. 17, 685-692, 2016
4. H. Samaniego, M. E. Moses, Cities as organisms: Allometric scaling of urban road networks, Journal of Transport and Land use, 21-39, (2008)
5. Batty, Longley, Fractal Cities: A Geometry of form and function, Research gate, 1994
6. Taragin, Eckhardt, A study on the lateral placement of automobiles due to restriction on two-lane rural highways restrictions two-lane rural highway, Scholars' Mine, 1953

7. The guidelines for capacity of Urban Roads in plain areas, The Indian Roads Congress,1990.
8. D. A. Turcotte, Developing Sustainable Housing: Moving Beyond Green, Planers Network,2007
9. S. Kolte, Sustainable Housing: A better way of living, Business World, 2020
10. J. Rabinovitch, Curitiba: towards sustainable urban development. Environment and Urbanization, Vol. 4, No. 2, 1992
11. M. Bookchin, The Limits of the City, Harper Colophon, New York, 1974
12. G. Haughton, Developing sustainable urban development models, Pergamon, Vol. 14, No. 4 189-195, 1997
13. P.H. Shaikh, N.B.M. Nor, P. Nallagownden, I. Elamvazuthi, T. Ibrahim, A review on optimized control systems for building energy and comfort management of smart sustainable buildings, Elsevier, 2014
14. J. Ravetz, Manchester 2020 - a sustainable city region project, Town and Country Planning, Vol. 63, 181-185, 1994
15. R. White, J. Whitney, Cities and environment: an overview. In Sustainable Cities: urbanization and the environment in international perspective, (1992)
16. Appendex B Taffic level of service calculation Methods, (n.d.)
17. Chapter 21 Roads, (n.d.)
18. Andruss, Van, C. Plant, J. Plant, E. Wright, Home! A bioregional reader, Philadelphia: New Society,1990